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Tarek Sobh
Khaled Elleithy *Editors*

# Emerging Trends in Computing, Informatics, Systems Sciences, and Engineering

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Editors

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# Preface

This book includes the proceedings of the International Joint Conferences on Computer, Information, and Systems Sciences, and Engineering (CISSE 2010). The proceedings are a set of rigorously reviewed world-class manuscripts presenting the state of international practice in Innovative Algorithms and Techniques in Automation, Industrial Electronics and Telecommunications.

CISSE 2010 is a high-caliber research four research conferences that were conducted online. CISSE 2010 received 250 paper submissions and the final program included 99 accepted papers from more than 80 countries, representing the six continents. Each paper received at least two reviews, and authors were required to address review comments prior to presentation and publication.

Conducting CISSE 2010 online presented a number of unique advantages, as follows:

- All communications between the authors, reviewers, and conference organizing committee were done on line, which permitted a short six week period from the paper submission deadline to the beginning of the conference.
- PowerPoint presentations, final paper manuscripts were available to registrants for three weeks prior to the start of the conference
- The conference platform allowed live presentations by several presenters from different locations, with the audio and PowerPoint transmitted to attendees throughout the internet, even on dial up connections. Attendees were able to ask both audio and written questions in a chat room format, and presenters could mark up their slides as they deem fit
- The live audio presentations were also recorded and distributed to participants along with the power points presentations and paper manuscripts within the conference DVD.

The conference organizers and we are confident that you will find the papers included in this volume interesting and useful. We believe that technology will continue to infuse education thus enriching the educational experience of both students and teachers.

Bridgeport, CT, December 2011

Tarek Sobh Ph.D., P.E.
Khaled Elleithy Ph.D.

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The technical co-sponsorship provided by the Institute of Electrical and Electronics Engineers (IEEE) and the University of Bridgeport is gratefully appreciated. We would like to express our thanks to Prof. Toshio Fukuda, Chair of the International Advisory Committee and the members of Technical Program Committees.

The excellent contributions of the authors made this world-class document possible. Each paper received two to four reviews. The reviewers worked tirelessly under a tight schedule and their important work is gratefully appreciated. In particular, we want to acknowledge the contributions of the following individuals: Munther Abualkibash, Mohammed Abuhelalh, Tamer Abu-Khalil, Sumaya Abusaleh, Mohannad Abuzneid, Ibrahim Alkore Alshalabi, Laiali Almazaydeh, Muder Almi'ani, Amer Al-Rahayfeh, Ying-Ju Chen, Ayssam Elkady, Khaled Elleithy, Ali El-Rashidi, Ahmed ElSayed, Sarosh H. Patel, and Manan Joshi.

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# Contents

# Customized Opinion Mining using Intelligent Algorithms

**Pablo Cababie, Alvaro Zweig, Gabriel Barrera and Daniela Lopéz De Luise**

**Abstract** Since the INTERNET outburst, consumer perception turned into a complex issue to be measured. Non-traditional advertising methods and new product exhibition alternatives emerged. Forums and review sites allow end users to suggest, recommend or rate products according to their experiences. This gave raise to the study of such data collections. After analyze, store and process them properly, they are used to make reports used to assist in middle to high staff decision making. This research aims to implement concepts and approaches of artificial intelligence to this area. The framework proposed here (named GDARIM), is able to be parameterized and handled to other similar problems in different fields. To do that it first performs deep problem analysis to determine the specific domain variables and attributes. Then, it implements specific functionality for the current data collection and available storage. Next, data is analyzed and processed, using Genetic Algorithms to retro feed the keywords initially loaded. Finally, properly reports of the results are displayed to stakeholders.

## 1 Introduction

The paper represents the result of research carried out in the ITLab University of Palermo. Within this context, emerged the proposal for a system to collect and process information in a particular topic and to show the results in report form for analysis and decision making process. The problem arises from the need for a pharmaceutical company to obtain the perceptions of consumers available on the web about their products and competitors. Opinions are subjective expressions that reflect the perceptions or feelings of people about events or entities. When someone

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needs to make a decision, one factor that can cooperate to take it wisely is the opinion of others. Before the explosion of the Web, when an individual needed to make a decision, he used to consult with the family and alleges. When a company needed to know the opinion of the general public about a product or service, it used to send polls and interest groups. With the emergence of the Web, information started to appear online and available to everybody in public forums, discussion groups, or bogs. This new sites are defined as part of the concept called Web 2.0 user-generated content. The world wide web, having over 350 million pages, continues to grow rapidly at a million pages per day [1]. About 600 GB of text changes every month [2].

This available information becomes an essential tool for decision-making process based on a new paradigm called "crowdsourcing" [3]. Thus, these opinions and debates on the Web become highly relevant for companies or people to make decisions. However, it must be pointed that these views are sometimes not as easily identifiable and are hidden in different users' personal pages or forums. Therefore, the main challenge of the project is based on the collection, identification, processing and reporting of results of this "crawling". Throughout the work, covering topics such as background and previous and related research of the topic, the structure of the system, the process and analysis of the collected information and finally conclude with the future work proposed.

## 2 Background and Related Research

There are research papers relating to opinion mining. Most of them approach the problem from the point of view of semantic interpretation of the wording found on the Web [4–6]. For example, crawl a forum and analyzing the text for product reviews, recommendations and complaints [7–9]. Several papers focuses in the identification of opinion. If it is critical, comparation, complains, praise or sites directly sense devoted to the exchange of views [5, 10]. Also, there are studies that are based on a list of words classified as good or bad, used to catalog the mention of the view as positive, negative or neutral. The lists are defined with a lot of words dictionary as well, excellent, spectacular, bad, poor, etc. [11–15]. Also, to this list are incorporated opinion phrases such as "cost an arm and a leg" or "you need to rob a bank" or "is to pull the money." Related work can also be found in a research which it is proposed to differentiate the genuine opinion of the "opinion Spam" or "unwanted view" [16]. In this research it is analyzed opinion spam's factors and proposes methodologies to identify and isolate it. Among the background of the topic have found many works and established a theoretical framework on the subject quite extraction of opinions on the Web, Opinion mining and adjacent tracks, however, still have not been documented implementations of these concepts applied to any industry or a non-scientific or academic purpose. Existing studies focus upon the discovery and conceptualization of new terms and modeling of the new reality brought by the advent of the Internet and new communication technologies, but not in use for practical purposes.

Keep in mind that the work and research more relevant and committed to this issue are recent ones, since about 20 years ago, these concepts were unthinkable or difficult to conceive even with technologies that were unknown. Moreover, there was a published paper in which the objective is to detect trends in electoral campaigns using existing technology and information collected on social Web sites [17]. In the latter study it identifies different strategies for collecting information to analyze:

1. Comprehensive tracking: collecting all possible information in a given period of time.
2. Incremental Crawl: We revisit the pages already stored for changes and if changes, these are re-done.
3. Tracking focused: looking for information on a topic based on a ranking algorithm that filters the results that are not relevant.
4. Deep Tracking: Collect important information about a particular issue. Unlike the focused crawling, it has the ability to complete forms on the web to store and access the pages returned a completed form.

In addition, there were found research papers approaching crawling from different point of views. Crawlers and agent have grown more sophisticated [18]. Topical crawler have been studied extensively the last years [19–23].

Some interesting methods proposed in recent years are those of fish search [24] and focused crawling [25].

Focused crawling concept was implemented using a classifier that evaluates the relevance of hypertext document with respect to the focus topics and a distiller that identifies hypertext nodes that are great access points to many relevant sources [19]. There shouldn't be forgotten to analyze the linkage sociology, locating specialty sites and community culture [19]. The focused crawling is different in using a topic taxonomy, learning from example and using graph distillation to track topical hubs. After this research, it was found a lot of anecdotal evidence that bicycle pages are not refer a lot of other bicycle pages, but also refer more significantly more than one might expect to rd cross and first aid pages. Similarly, HIV/AIDS pages often do not directly refer to other HIV/AIDS pages but refer to hospital hoe pages.

AI implementations for crawling was proposed beginning with a basic exposure to search algorithms and then to be extended in a number of directions to include information retrieval, Bayesian learning, unsupervised learning, natural language processing, and knowledge representation [26].

## 3 Proposed Structure and Model

The system that supports the research consists on a set of three modules:

### *3.1 Crawler*

The crawler is in charge of Internet searching and text by storing in a database for further processing. This module has the following input components (input minimum):

- Parameter to search.
- Pages where to look.
- Deep level navigation links (if there is no limit would be sought through the Internet and never end this stage).
- Restrictions (e.g search only in a domain).
- Parameters to function as a filter (words that should not contain the text).

The operator enters the start point pages and then navigates the system for their "children" (linked) to the depth defined in the configuration. Is relevant to mention that the average number of outlinks on web pages is 7 [27]. This module basically follows the following behavior:

1. Loading a page.
2. Debug the code and convert it to plain ASCII text.
3. Read the HTML code in search of the parameter and if does not contain the filter words.
4. Search on the same code links to other pages (which must not exceed the maximum level of depth, no restrictions skip) to form a list of URLs to keep searching.
5. If step 3 was yes, the code goes to the analyzer.

The module generates text files with different information. Among them, there will be a metadata file, one with the title of the page, one with a header and the contents of the text in the body. In this way, can be isolated and properly process each part of the page separately.

### 3.1.1 Defined Directory Structure

It has been defined a structure to store the necessary files with information gathered after the sweep of the sites. The structure consists on a directory for each type of file stored. All those listed and indexed in a flat file. (Bd.txt). In this file each destination will have an ID followed by the URL. The other files will have the ID as a name and an extension that indicates their content, for example:

www.pagina.com —> 12345.
Then the files will emerge from this page:
12345.src (source).
12345.bdy (text body of the page).
12345.lin (links page).
12345.tit (title tag information).
122345.mta (information from meta data page).
12345.etc. (Additional information varies).
12345.ima (images listed on page).
12345.ifr (information contained in the Iframe tag).
12345.hrf (information inside the href tag).

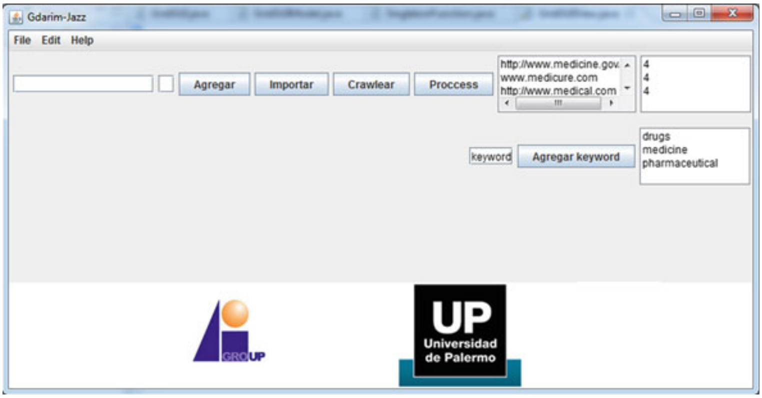



**Fig. 1** Gdarim application screenshot

It should be noted that for testing purposes, it was chosen to use ANMAT (National Administration of Drugs, Food and Medical Technology) as a start point. (http://www.anmat.gov.ar/). Later new URLs will be added to the scan list (Fig. 1).

The scanned websites are analyzed to make sure that they are written in Spanish. The procedure that we use to define their language is based on the amount of times the letter "e" appeared in the text.

As is illustrated in Fig. 2, the architecture was implemented using a standard model-view-controller. Figure 3 shows the defined scheme for the content of the module ''Model.''

In this module, it is implemented Genetic Algorithms to explore and expand the scope of the search criteria.

Basically the system analyzes word by word and associates it with an ID which later is linked to its frequency. The implementation use genetic algorithms operations such as mutation to infer and deduce new words to crawl and amplify the range of search, providing more opportunities to find the information needed.

### 3.1.2 Metrics

The system on each crawling operation estimates metrics about the amount of crawled web pages in every launch and crawling time to check the performance of the system. Also, it provides information about unreachable and rejected web pages.

Sometimes, the system found web pages referencing broken links, pages with forbidden access and or misspelled links.

Another metrics provided are the amount of links, hits and words contained in the web page. All of these properties will impact in the later ponderation of the webpage, making the scoring increase or decrease.

(i) Sub analyzer module. This sub module is part of the crawler or search engine.

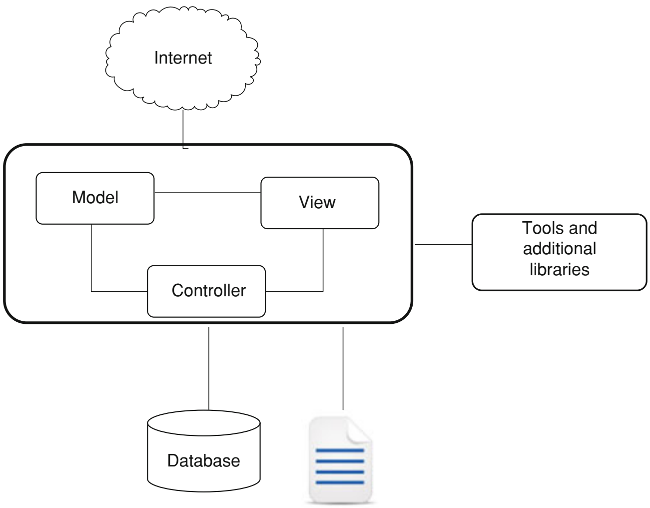



**Fig. 2** Architecture

**Fig. 3** Module "Model"

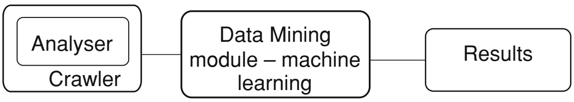
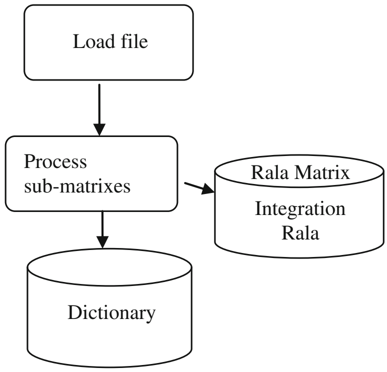



**Fig. 4** Sub module parser analyzer




The analyzer (see Fig. 4) was implemented using the Composite design pattern. It crawls the directory structure that hosts the pages provided by the Crawler.

The following is the description of the behavior of the algorithm to process the files:

For each plain text file:

1. Take the next line L in the text.
2. Apply Porter's algorithm, obtaining the root R of each word.

3. For each R:

   3.1 Save the dictionary Dictionary.dct.
   3.2 Save <file> matrix. MTRX.

4. If there are more lines in A, then go to 1.

After generating the dictionary and the array of frequencies for each file, proceed to the integration of all partial matrices to a single array called <integration>. MTRX. In this stage it was implemented the following algorithm: [18]. Generate sparse matrix <integration>. MTRX empty:

1. Take a matrix <file>. MTRX.
2. Integrate content in <integration>. MTRX.
3. If more <file>. MTRX then go to 1.

It should be noted that each word in the dictionary Dictionary.dct is unique and its records have the following format:

$$\text{WEIGHT} - \text{ON ID} + \text{APPEARANCES}$$

At the same time in the <file>. MTRX there are records with the following structure.

$$\text{ID} + \text{QTY} - \text{occurrence}$$

Where CANT-occurrence is a counter from 1 (indicating the first appearance of the word identification ID) to n (indicating the total number of times the same word that appears in row). Finally, in the matrix <integration>. MTRX records with the following structure.

$$\text{ID} - \text{FILE} + \text{ID} + \text{OCCURRENCE}$$

Where ID-Archive, is the unique identifier for each file processed (usually associated with a single URL) and can OCCURRENCE 1 (indicating the occurrence of the word with ID within the file A) or 0 (indicating the absence of such same word in A).

As an example, suppose the following ej.txt file with the contents:

> "The practices are complicated. There is a practice file.they claim that the situation is complicated".

The resulting matrix for ej.txt.mtrx file will contain:

1,1
2,1
3,1
4,1
5,1
1,1
6,1

7,1
8,1
9,1
3,1
1,1
10,1
11,1
12,1
13,1
14,1
15,1

Also, the generated entries in the dictionary Dictionary.dct are:

Afirm,10,0.0714285746216774,1
Las,2,0.0714285746216774,1
son,4,0.0714285746216774,1
Hay,6,0.0714285746216774,1
un,7,0.0714285746216774,1
de,9,0.0714285746216774,1
situ,13,0.0714285746216774,1
archiv,8,0.0714285746216774,1
practic,3,0.1428571492433548,2
la,12,0.0714285746216774,1
que,11,0.0714285746216774,1
complic,5,0.1428571492433548,2
es,14,0.0714285746216774,1

## 3.2 Data Mining Module

This module processes the views stored in the sparse matrix contained in text files using advanced techniques of "machine learning" [8, 28].

## 3.3 Presenter Module

This module is the last in the system and is responsible for exposing the user's search results completed and all information processed in the previous modules. The results are presented through pie charts and reports with all the needed information for analysis and decision making.

## 4 Scope

In the initial analysis of the research it was required to define the scope of the system developed to constrain the domain of the problem. This simplification provides the possibility of facilitating the conceptualization and development in a maintainable and orderly system. Moreover, these limitations on the system will let verify the results of the research and the application developed. The restrictions are:

1. The system will process only is Spanish pages.
2. The depth level is part of the system configuration.
3. The module only processes HTML, Excel, PDF and Word files.
4. The application uses a dictionary to identify opinions.

## 5 Conclusion and Future Work

The investigation as it progresses seems even more exciting and viable. The publications so far do not provide relevant information to solve the specific problem. The project will represent a significant improvement for the collection and administration of specific information in an efficient and automatic way. The next few months the project will focus on refining the relations in the database, model and improve the development and system design that enable collecting data wherever they are. After test this development deeply, will proceed to implement the concept of genetic algorithms to optimize the information search task. Tests will be required and adjustments on fitness functions to improve performance and to consider all the alternative answers. In particular, for the crawler module, the keywords must be defined to find the type of pages to go in case of multilingual sites. It will be added check boxes (checkboxes) to the user interface to setup the options such as learning threshold and histogram pruning.

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# Information Security Measurement Roles and Responsibilities

**Margareth Stoll and Ruth Breu**

**Abstract** An adequate information security management system (ISMS) to minimize business risks and maximize return on investments and business opportunities is recognized always more as key differentiator. Thus legal compliance, commercial image and competitive edge are sustainable maintained. Due to increasingly faster changing information security (IS) requirements (from market, customer, technology, law or regulations) the effectiveness and performance of the ISMS must be continually evaluated and improved. Data must be recorded, analyzed and if necessary appropriate corrective or preventive actions should be taken. For these measurement and improvement tasks we have to assign roles and responsibilities. Firstly we define different roles and their tasks for information security (IS) measurement and improvement. Starting from the approved organizational structure we assign the responsibilities for these roles to top and executive management. After we elaborate and document all relevant business processes with their supporting IT services and go on through all technical layers describing the relevant items with their dependencies and relationships. To entire processes, services and items are assigned responsibilities for the defined roles systematically, consistently and traceably. This innovative, systemic, strategic aligned approach has been implemented successfully by different medium sized organizations for several years. Based on our experiences IS awareness, IT alignment with business goals, service orientation, process and systems thinking, as well as the comprehension for the requirements of other organizational units were increased.

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# 1 Introduction

## *1.1 Starting Situation*

Due to globalization and ever stronger competition information management and supporting technologies have become key assets and differentiators for modern organizations. They are main performance driver for continual innovation and sustainable success. Organizations and their information and technologies are faced with security threats from a wide range of sources, including computer-assisted fraud, espionage, sabotage, vandalism, fire or flood. Causes of damage have become more common, further ambitious, and increasingly sophisticated [1]. 92 % of large enterprises had a security incident in the last year with an average cost of 280.000–690.000£ for the worst incident [2]. Mobile and cloud computing, off-shoring, social networks, as well as the increasing interconnected, flexible and virtualized business complexity and dependency are still great challenges for IS.

Organizations have to meet many different legal and regulatory requirements, such as data protection, sound and integer financial practices and internet crime. Most modern corporate governance guidelines, and always more laws, make the top management responsible for the well-being of the organization. Lack of security compliance may result in loss of confidence of customers, partners and shareholders, as well as severe civil and criminal penalties for the top management. In this respect availability of the essential assets, confidentiality, data integrity and legal and regulatory compliance are central for organizations' success and integral part of good IT and corporate governance [3–5].

More than 6,600 organizations worldwide [6] have implemented ISMS in accordance to ISO/IEC 27001. This international standard provides a model for establishing, operating, monitoring, maintaining and improving an ISMS to meet the specific security and business objectives of the organization and legal, statutory, regulatory and business obligations [1, 7]. Several best practices for IS management have been developed, such as Control Objectives for Information and related Technology (COBIT) [8], Information Technology Infrastructure Library (ITIL) [9] and national guidelines, such as NIST 800-53 [10].

## *1.2 Purpose and Structure of the Article*

An increasingly faster changing environment (market, customer, technology, law or regulations) requires continual adaption of business objectives, processes, controls and procedures. It is a widely accepted principle that an activity cannot be managed and overall not improved sustainably if it cannot be measured. Therefore the effectiveness and performance of the ISMS and the actual risk and compliance situation must be continually evaluated and improved [3–5, 8–12]. Effectively implemented security measurements demonstrate the value of IS to top management, face informed decision making, demonstrate compliance, improve security confidence and enable stakeholders to continual improve IS [8, 10, 12, 13]. It is a critical success factor for sustainable IS [1].

IS management, business management and on the other hand software security and network security engineering have been handled for a longer period as separate areas [12]. Measurement data are obtained at different levels within an organization. They are recorded and analyzed to detect errors and security events, to identify attempted and successful security breaches, incidents, threats and external events (such as changes to the legal or regulatory environment, changed contractual obligations, and changes in the physical environment) and to define effectiveness and performance of the implemented controls and the ISMS [7]. Based on this analysis appropriate corrective and/or preventive actions are elaborated, prioritized, approved, implemented and evaluated [1, 7, 10, 11].

It is axiomatic that those things for which no one is explicitly accountable are often ignored [14]. Thus we must define roles and responsibilities for all necessary tasks. According to COBIT 4.1 understanding the roles and responsibilities for each process is the key to effective governance [8].

How can we assign IS measurement and improvement roles and responsibilities efficiently, systematically, consistently and concretely? Are these assignments maintainable and traceable over a longer period?

Firstly we present the results of our literature research [II]. Based on these requirements we developed our hypothesis [III]. In Sect. 4 we explain our approach: firstly we establish the roles and describe their tasks [IV A]. In the second step we assign the IS measurement and improvement roles and responsibilities to the top and executive management [IV B]. After that we define and document all relevant IT services and their supporting items of all technical layers with their dependencies and relationships. To all these items we assign IS measurement and improvement roles and responsibilities [IV C]. Checks and quality assurance measures for the model [IV D] and the maintenance [IV E] are described next. This innovative approach is implemented successfully for several years by different medium sized organizations of distinct sectors (service, engineering and public). The obtained experiences are reflected in [V] with the project results [V A] and success factors [V B]. At the end we give an outlook and conclude [VI].

## 2 Research Framework

The field of defining security metrics systematically is young [12]. The problem behind the immaturity of security metrics is that the current practice of information security is still a highly diverse field. Holistic and widely accepted approaches are still missing [12].

A lot of papers are published about technical security metrics and scarcely holistic approaches. We find overall requirements for a holistic, systemic, managerial measurement approach [3, 8, 10, 11].

Measurement data must be extracted and reported to perform measurement and monitoring of the performance and effectiveness of the ISMS, to reflect the actual risk and compliance situation and to provide input for a continual improvement and for IS related management decisions [3–5, 7, 8, 10–12]. IS metrics support the detection of errors and security events and the identification of attempted security breaches, incidents and previously undetected or unknown IS issues [7, 11]. Based on this analysis appropriate corrective and/or preventive actions are elaborated, implemented and evaluated [1, 7, 10, 11]. The ISMS must be continually adapted to changing internal and external conditions to deliver sustainable business value to all stakeholders [1, 3–5, 7, 8]. Further the organization should maintain and improve the ISMS itself.

Since some years IS frameworks, standards, best practices, laws and regulations require that all stakeholders are responsible and collaborate for IS [1, 3, 4, 7, 8, 10, 11]. The management has to identify clear roles and assign responsibilities for the protection of assets and for all security processes and controls [1, 7, 8, 10, 11]. According to COBIT understanding the roles and responsibilities for each process is the key to effective governance [8]. Roles and responsibilities are required by ISO/IEC 27004 as one of the minimums of the measurement construct specification [11].

## *2.1 Roles and Responsibilities*

The literature defines a lot of different functional roles and responsibilities for IS.

ISO/IEC 27004 distinguishes following roles [11]:

- client for measurement: the management or other interested parties,
- reviewer: validates that the developed measurement constructs are appropriate for assessing the effectiveness,
- information owner: responsible for the measurement,
- information collector: responsible for collecting, recording and storing the data and
- information communicator: responsible for first data analysis and the communication of measurement results.

The relevant stakeholders may be internal or external to the organizational units, such as information system managers or IS decision makers. Reports of measurement results can be distributed also to external parties, such as customers, shareholders, regulatory authorities or suppliers [11].

The measurement program implementation plan of the NIST performance measurement guide includes [10]:

- responsibilities for data collection, analysis, and reporting,

- details of coordination within the office of the chief information officer, relating to areas such as risk assessment, certification and accreditation, and federal information security management act (FISMA) reporting activities,
- details of coordination between the senior agency information security officers (SAISO) and other functions within the agency (e.g., physical security, personnel security, and privacy) to ensure that measures data collection is streamlined and non-intrusive.

Key IS stakeholders are the agency head, chief information officer (CIO), senior agency information security officer (SAISO), program manager or information system owner, and the information system security officer (ISSO) [10].

COBIT categorize following roles [8]:

- chief executive officer (CEO),
- chief financial officer (CFO),
- business executives,
- chief information officer (CIO),
- business process owner,
- head operations,
- chief architect,
- head development,
- head IT administration,
- project management officer (PMO),
- compliance, audit, risk and security groups and
- eventual head of human resources, budgeting and/or internal control.

COBIT provides a RACI (responsible, accountable, consulted and informed) chart for each process. Accountable means “the buck stops here”. This is the person who provides direction and authorizes an activity. Responsibility is attributed to the person who gets the task done. The other two roles (consulted and informed) ensure that everyone who needs to be is involved and supports the process [8].

Different authors list the steering committee, board of directors/trustees, senior executives, business unit managers, collaborators from human resources, legal, compliance, audit, and risk management, chief information security officer or also a lot of more roles [1, 15, 16].

## *2.2 Further Requirements*

An appropriate assignment of measurement roles and responsibilities should ensure that the results are not influenced by information owners. Brotby writes that approximately 35 % of IS managers still report directly or indirectly to the chief information officer who is also responsible for the IT department. Based on his experience this creates conflicts of interest and the quest for greater IT performance at less cost is often made at expense of security [14]. Segregation of duties or independent checks can solve that problem [1, 3, 7, 8, 10, 11, 14].

The results of measurements need to be communicated to its intended audience in a way that is meaningful and useful. How they are represented and presented can make a huge difference to whether or not well-informed decision making can be achieved [13].

The relevant stakeholders should be identified. They should be involved in each step of IS measures development [11] to ensure organizational buy-in and promote a sense of ownership for IS measuring [10]. Each stakeholder requires specific, customized measures accordingly to his IS objectives and the IS requirements for his area of responsibility [10].

## 3 Hypothesis

Based on this research and requirements framework we developed an innovative, efficient and easy maintainable model to assign IS measurement and improvement roles and responsibilities to all organizational levels and stakeholders well structured, systematically, consistently, accurately, traceably and maintainable to promote IS effectiveness and continual improvement.

Firstly we establish the roles for IS measurement and improvement and describe their tasks [IV A].

As a second step we assign responsibilities for the established roles to the top and the executive management [IV B]. We start top down from top management (Fig. 1 in the top), functional unit responsibilities (Fig. 1 in the 2° level), business process and/or project responsibilities (Fig. 1 3° level) and eventually further service management role responsibilities, such as the change management role or IS management role (Fig. 1 vertically, right-most). Thereby we regard all relevant legal, statutory and contractual requirements and the IS policy and business requirements.

After that we elaborate and document all relevant business processes with their supporting IT services and their dependencies and relationships [IV C]. For all these IT services we describe based on an architecture oriented approach their supporting items with their dependencies and relationships going always deeper through all technical layers (Fig. 1 lower part). Based on definitions of the IT information library (ITIL) we understand by a configuration item any component that needs to be managed in order to deliver an IT service. Configuration items typically include IT services, hardware, software, buildings, people, and formal documentation, such as process documentation and service level agreements (SLAs) [9]. At the end we assign to each configuration item the specified IS roles and responsibilities (Fig. 1 vertically, on the right). The relationships and dependencies between the items, IT services, business processes and the top management define the information and escalation flow.

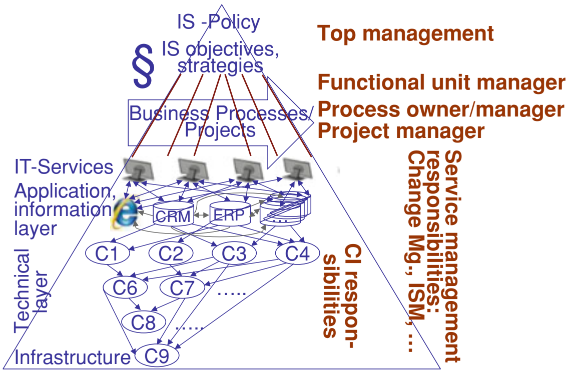


**Fig. 1** Role responsibility assignment model

# 4 Approach

## *4.1 Roles and Responsibilities*

Based on practical experiences of more organizations we enlarge the roles of a RACI (responsible, accountable, consulted and informed) chart to the following (see Table 1):

- The *accountable* is responsible for and decides the measurement requirements, provides direction and authorizes and reviews the effectiveness and performance. Thereby business and IS policy and strategies, legal, statutory, regulatory and contractual requirements, and the conducted risk assessment must be regarded. Additionally decision and authorization for continual improvements are part of his responsibilities. Measurement results are communicated to the accountable on request or by escalation, if measurement results exceed certain defined thresholds and/or time scales.
- The *responsible* contributes to the establishment of measurements and is responsible for their implementation. He controls the data collection, recording and analysis, communicates the results and proposes and implements possible improvements.
- *The responsible for execution and operating* is responsible for the measurement operation (collection and recording) and the improvements as part of his daily work.
- The *supportive* contribute and sustain him.
- The *informed and consulted* role contributes information and consultations to the responsible and eventually to the accountable and receives for this reason the measurement results.

The IS manager provides methods including possible metrics, evaluates and controls the effectiveness, performance and improvement of the whole system, conducts internal audits, proposes possible improvements, secures synergies and

**Table 1** Overview of assigned roles and their tasks

| Role | Tasks |
| --- | --- |
| Accountable | responsible for measurement requirements, provides direction, authorizes and reviews measurements, decides and authorizes improvements |
| | receives measurement results on request or by escalation |
| Responsible | responsible for implementation |
| | proposes and implements possible improvements |
| Responsible for execution and operating | responsible for measurement |
| | improves and adjusts as part of the daily work |
| Supportive for execution and operating | contributes to measurement |
| Informed and consulted | receives measurement results to consult and support responsible and eventually accountable |

promotes IS awareness and knowledge exchange. His role is more based on coaching, mentoring, coordinating, training and offering method support and expertise than one practical operation.

### 4.2 Management Responsibilities

We document in collaboration with the top management her IS roles and responsibilities regarding the organization chart, the approved organizational structure and IS policy, as well as all relevant legal and statutory regulations.

The functional unit responsibilities and eventually IT service management role responsibilities are taken from the approved organization chart and defined organizational structure.

After we analyze and optimize all business processes for IS objectives and requirements [17]: all management processes, core business processes including support processes, resources processes and optimization processes. In that way we define the responsible and eventually supportive or consulted and informed IS roles for all process steps over the whole value network and the accountable for each business process, the process manager. Further for each process step necessary documents and data with data protection class and required archiving methods for all archive types are identified.

The project responsibilities are copied from the established project documentation or the project management database.

### 4.3 Item Responsibilities

The greater challenge and effort is to analyze, structure and define the configuration model with all relevant items. We start top down from the business processes and bottom up from the physical infrastructure concurrently involving all collaborators concerned. Asset inventory, contract analysis, job descriptions, the documentation of the organizational structure and the organization chart provide helpful information. The necessary information is elaborated regarding the IS policy and all relevant IS requirements using different diagram techniques, brainstorming, and document analysis in workshops and by interviews.

In that way the IT service "Project management", for example, is defined as 100 % depending directly on two different servers and the local area network. Further we need for 50 % the internet, because the functionality of this application is limited, if the web services are not available. The local area network for example depends further on switches, cabling and others. Thereby we construct a configuration tree with upper or father items (e.g. "project management") and items, which support a service for the identified item, child or lower items (e.g. local area network). For each IT service the IS requirements concerning availability, confidentiality and integrity are defined. These requirements are inherit down through the whole tree regarding the dependency levels (e.g.50 % for the internet). Further all metrics for availability (e.g. uptime, unplanned downtime, mean time between failures and others) are inherit bottom up: if the network is down and project management depends on it (father), project management is down too. The priority and reaction time for corrective and preventive actions are calculated thereby on the inherited IS requirements.

The data protection requirements assigned to applications and archives by the business process analysis [IV B] are inherited to all child items, such as servers, networks, archives and rooms. The highest data protection requirement of all upper items must be regarded. In that way the responsible of each item receives clear and overall strategic and business aligned IS objectives and can define appropriate metrics, reports and overall corrective or preventive actions. A security breach, such as a too weak password for the access to sensitive data, for example, is scored higher and escalates earlier than the same breach regarding the access to personal data. Further details to the applied metrics, communication channels and corrective or preventive actions will be presented in other publications.

To each item we appoint exactly one collaborator as accountable. The accountable of each configuration item assigns the responsible role and the responsible for execution and operating role to exactly one collaborator each. Further he allocates all execution and operating roles and the informed and consulted roles to collaborators. In that way the assignment of responsibilities is as low as possible and the roles and responsibilities are distributed among all collaborators.

If measurement results exceeds defined thresholds or on request the results are communicated to the responsible of the father configuration item and on further escalation or on request also to the accountable of the father configuration item. All responsible and accountable of upper configuration items can receive on request or by escalation measurement results. In that way all measurement results are accessible also on request or by escalation to the top management.

Thus we assign all planning, operational and communication tasks for IS measurement to responsible, as well as corrective, preventive and improvement responsibilities to ensure sustainable IS.

On the top of the configuration model the IT services are linked to the business processes. Thereby the configuration model is connected with the management responsibilities [IV B].

### *4.4 Checks and Quality Assurance*

We furthermore integrate consistency and accurateness checks [9]:

- Is there assigned to all configuration items exactly one accountable, responsible and responsible for executing and operating? Are responsible or accountable roles assigned only to internal collaborators?
- Are all relevant external suppliers registered as supportive for execution and operating?
- Has somebody assigned too many duties? Has some assigned too less duties? Is somebody involved in too many tasks?
- Are duties assigned to all collaborators?
- Are all configuration items, detected by network and system analysis, part of the configuration model?
- Is the configuration model consistent with the actual organizational structure and organization chart?

### *4.5 Maintenance*

If an assigned accountable person changes, the structural organization is modified. Thereby the accountable is updated in the database.

The assigned accountable is responsible and has the access rights to change the distribution of all other role responsibilities to his collaborators. It is of his interest to assign clearly all new responsibilities to prevent eventual discussions, problems, duplication of work or uncompleted services.

## 5 Project Results

The presented concept for establishing and implementing IS measurement and improvement roles and responsibilities has been implemented since 2006 successfully by different medium sized organizations of distinct sectors (service, engineering and public). Implementing IS awareness, process and system thinking and defining the configuration model in a well structured, systematic and consistent way were great challenges.

## *5.1 Achieving Project Objectives*

The described concept leads to the following case study results collected by measuring the project process and interviewing the concerned management and collaborators:

- *Efficiency*: Establishing the whole configuration model and assigning management and configuration item roles and responsibilities required in medium sized organizations a work effort of approximately 1–2 weeks. This effort clearly varies based on the size and complexity of the organization. It depends overall on the IT services, the information risks that the organization faces, applicable legal, regulatory and contractual requirements and other success factors [V B]. To implement such a model for a telecommunication service provider needs for example essentially greater effort than for the IT department of an enterprise. The strategic alignment of all items with corporate objectives and business needs, the awareness of business drivers, process and system thinking and the understanding for the work and requirements of other functional and technical organizations' units was increased. Thus potential side effects and unplanned impacts of changes were reduced. The awareness for the supporting technology and supported business processes was enhanced and consequently the effectiveness of entire enterprise promoted.
- *Well structured, systematic, consistent and accurate roles*: Based on the developed configuration model the role responsibilities are defined over all layers and for all levels of the whole value network well structured and systematically. Due to the consistence checks [IV D] the assigned role responsibilities are consistent. For the collaborators a clear assignment of their responsibilities and tasks is essential in all organizations. Therefore they control the assigned roles continually and accurately. The developed model is an optimal basis for balanced, consistent and objective oriented IS improvement.
- *Traceability*: The role responsibilities were clearly assigned and all changes were documented, approved and communicated in a traceable way. All historical changes of responsibilities have been documented by versioning.
- *Maintainable*: Due to the great importance for management and collaborators to assign roles and responsibilities clearly, the documentation was maintained until today actually and accurately in all organizations.

Opposite to these advantages are the work effort for the establishment of the configuration model and the assignment of role responsibilities.

### *5.2 Success Factors*

The IS measurement and improvement roles and responsibilities must be designed for the appropriate level of details, accordingly to business objectives, regulatory, statutory, legal, contractual and stakeholder security requirements.

Clearly this model must be best adapted and scoped to the organization and continual maintained. Such a model cannot be purchased and introduced as standard. A good knowledge and appreciation of business impacts and priorities and overall the involvement of all collaborators and managers concerned are imperative.

As for the whole ISMS the commitment and support from management as well as from all levels of staff, and overall the daily application and usage of such tools and methods by relevant stakeholders are essential and key success factors.

Corporate culture, organization and technology must be consistent and integrated optimally according to the business objectives and to collaborators needs and requirements in order to sustain business success. If such a tool is only used to blame and abuse collaborators than the collaborators will try to prevent with all means the introduction and maintenance of the model. A confident based, cooperative, team and objective oriented culture promotes such a collaborative IS.

Adequate tools, technical staff skills, sufficient IT infrastructure and IT support are also important for a successful implementation. Based on the complexity of a configuration model an adequate objective oriented database with high IS level (confidentiality, availability, integrity and traceability) sustains IS effectiveness, performance and improvement. An optimal connectivity with other systems supports change management and system inventory. It should be very simple and intuitive to handle. All collaborators should be able to find their assigned role responsibilities and to update information effectively in accordance to assigned access rights.

## 6 Conclusion and Outlook

We presented a practice approved, efficient, traceable and easy maintainable model to assign clear IS measurement and improvement roles and responsibilities to all organizational levels well structured and systematically.

IS governance, business management and on the other hand software security and network security engineering have been handled for a longer period as separate areas [12]. The innovation of this model is overall the integration of these approaches, the fully strategic alignment and the systemic, systematic and consistent approach for IS measurement, reporting and improvement. It shows up also eventually diverse or disparate technologies and applications and contributes thereby to more IT performance, resource and cost efficiency. The assigned responsibilities to IS roles can be checked continually to balance workload and improve adequate skills.

As a by-product IS awareness, IT alignment with business goals, service orientation, process and system thinking, as well as the comprehension for the requirements of other organization units were increased.

It is the basis of our holistic, systemic and collaborative IS framework. Due to excellent project experiences in several organizations there should be enhanced a holistic, systemic, collaborative and management oriented IS approach by regarding all success factors [V B].

Accordingly the informatics curricula should regard also more IT management aspects based on a holistic, systemic approach.

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# Service and Information Security Improvement by Collaborative Business Process Management

**Margareth Stoll**

**Abstract** Due to globalization and ever shorter change cycles the largest potential especially of service organizations is the continual organizational development based on individual and collaborative leaning and an adequate information security. Many different organizations are implementing process oriented standard based management systems, such as quality management or others. Thereby business processes must be established, optimized regarding defined objectives, documented, communicated, implemented and continuously improved. Although this documentation is distributed mostly IT supported, the collaborators use it hardly as reference for solving ad hoc learning needs. Change proposals, new ideas or questions are scarcely related to established processes. In that way the process models are almost not totally corresponding with lived processes. Starting from this situation we established process models regarding information security, prepared them according to didactical principles and published them on a collaborative, constructivist organizational learning system. In the case study this innovative interdisciplinary collaborative process improvement concept supported by a confidence-based open corporate culture promotes operations integrated, need-oriented learning, practice-oriented process models, shorter initial training periods for new collaborators, employee involvement and collaborative process and information security improvement for continual service and organization development and sustainable organization success.

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# 1 Introduction

## 1.1 Starting Situation

Due to the impact of technology, globalization and ever shorter change cycles of market requirements and enterprise environmental conditions companies must improve increasingly faster their services, products, technologies and organization. Organizational development and continual improvement are differentiators and key performance drivers for long-term sustainability and growth. Each company must become a learning organization. However, existing systems supporting the daily work of knowledge worker in service organizations have not kept pace with the evolving complexity and diversity of challenges facing knowledge workers [1–4]. Integrating job relevant data, information, knowledge and learning into business operations are most important economic issues [1, 3–9].

Service organizations and their information and technology are faced with security threats from a wide range of sources, including computer-assisted fraud, espionage, sabotage, vandalism, fire or flood. 92 % of large enterprises had a security incident in the last year with an average cost of 280.000–690.000 £ for the worst incident [10]. Information security for long time was seen fundamentally as an only technical job and integral part of the information technology (IT) department [11, 12]. Organizations implemented a lot of technical security controls, but security problems persisted and increased. Security problems are complex and require a collaborative, socio-organizational and human related information security management approach [12, 13].

More than 1.2 million organizations of different sizes and scopes are implementing worldwide management systems in accordance to international standards (e.g. ISO 9001 quality, ISO 14001 environment, ISO/IEC 27001 information security management and others) [14]. Most of these management systems are process oriented. They are based on the fulfillment of common principles and must be documented, communicated, implemented and continual improved.

## 1.2 Purpose and Structure of the Article

In this respect one of the largest potentials for modern enterprises is the continual improvement by information security integrated process management and collaborative organizational learning based on individual learning.

The documentation of standard based management systems (system documentation) including the process models contains the whole explicit organizational knowledge. It was distributed for long time as books, whereby the collaborators received once the information and used them afterwards scarcely ever for solving ad hoc job problems. In the last ten years it was distributed more electronically through web-based intranets, document management platforms or as pdf. The most major impacts were the reduction in printed catalogs, offering too much information and it becomes harder to reflect and improve [1, 2, 4]. Changes, improvements and organizational learning are still isolated from the process models. Process modeling is used primarily as a tool for the first process improvement and due to standard requirements they are changed usually only once a year. Collaborators are not able to discuss new ideas or questions in a context-sensitive way. Thus the models frequently do not correspond to lived processes and do not push constantly the knowledge and learning spiral for sustainable organization development. Changes or new processes are quite frequently developed as hidden systems.

How we can use the process models of standard based management systems as knowledge base to promote operation integrated, individual and collaborative organizational learning for continual information security integrated process and service improvement and sustainable organizations' success?

In what a way the process models must be established, prepared, stored and communicated in order to promote operations integrated, need-oriented access and individual learning?

What are the main requirements for a process oriented collaborative learning system?

Firstly we present the project objectives (Sect. 2) and analyze the requirements for our approach (Sect. 3). Thereby we explain the main requirements of international standards for management systems (Sect. 3.1) and establish the requirements for a collaborative organizational learning system (Sect. 3.2). After that we report about our approach (Sect. 4) for the development of the information security integrated process models (Sect. 4.1), the didactical preparation (Sect. 4.2), and the introduction and use of the collaborative organizational learning system for process and service improvement (Sect. 4.3). Finally we document the project experiences and results of the implementation in different service organizations with distinct management systems (Sect. 5) including the achievement of the project objectives (Sect. 5.1) and the success factors (Sect. 5.2). At the end we reflect about cost and benefits (Sect. 5.3) and present an outlook (Sect. 6) and our conclusion (Sect. 7).

## 2 Project Objectives

By preparing the information security integrated process models in accordance with standard based management systems (Sect. 3.1) and didactical principles, and implementing it on a collaborative organizational learning system (Sect. 3.2) we expect to foster:

- workplace and operations integrated, need-oriented process model access and learning,
- process and information security improvement for service and organization development,
- employee involvement and collaborative process improvement,

- practice-oriented process models,
- shorter initial training periods for new collaborators.

Thus information security integrated process models promote knowledge representation, knowledge communication, for the implementation of the process models and collaborative learning and knowledge generation for process, information security and service improvement in accordance to established corporate objectives. In that way collaborative organization development for sustainable success is sustained.

## 3 Requirements

### *3.1 Main requirements of Standards for Management Systems*

The ISO 9001 quality management standard [15] and other international standards for management systems require common principles (Fig. 1):

- The vision, policy, objectives and strategies must be established and communicated regarding stakeholders requirements (top of Fig. 1).
- All business processes for service or product realization including management processes, support processes, resource processes and optimization processes must be defined to meet the organizations' objectives under the focus of the respective standard (horizontal graphic in the middle of Fig. 1).
- Objective and process oriented resource management must be promoted including human resource development and the management of necessary technology, infrastructures, tools and instruments (bottom of Fig. 1).
- The whole organization, their objectives and strategies, services/products and processes must be continually measured, analyzed and improved according to established processes in sense of a PDCA cycle (plan, do, check, act) (circle around of Fig. 1).

The established management system must be documented, communicated systematically, and implemented and improved continually by all collaborators.

Additionally to these basis principles ISO/IEC 27001 and other risk oriented standards require a risk assessment for establishing a risk treatment plan to reduce risks on acceptable levels of risk. For the identified remaining risks a suitable business continuity plan must be developed, implemented, maintained, tested and updated regularly.


**Fig. 1** Main requirements of standards for management systems

## 3.2 *Requirements for a Process Oriented Organizational Learning System*

Based on literature research, the requirements of standards for management systems and collaborators and management interviews a process oriented organizational learning system demands additional to general requirements of learning systems, following particular characteristics:

- It must be simple and intuitive to handle. It must provide the possibility to use different views of (or leading to) the same object, different start facilities, comfortable search functions, filtering of content using object types, simple uploads of content and links to external literature. It must promote individual learning by personal bookmarks, annotations, summaries and notes, as well as glossary, FAQs, etc. [1, 6, 8, 16, 17].
- It must offer secure context-sensitive communication (discussion forum, chat) to all elements, especially to all process model elements, as well as newsgroups, wiki, newsletters and whiteboards. It must support content distribution, collective process improvement and collective learning [1, 6, 17].
- Uploading and the administration of new content must be simple with as large didactical and media pedagogic support as possible [7]. There must be the possibility to insert, annotate and discuss context sensitive the content of most different documents and media formats (as text, graphic, table, picture, sound records, video). Also creativity tools should be integrated [7].
- Due to requirements of the standards for management systems we need the administration of access rights, the support of the change process, versioning with change history and the efficiently and traceable distribution/communication of new or changed content. Depending on organization culture also testing and examination tools for traceable learning must be integrated [18].
- The handling of collaborators ideas, their discussion contributions and problem reporting must be implemented for the collaborative process improvement and in accordance with the established systematic and structured process following the standard requirements. Due to standard requirements their effectiveness must be evaluated.

- Open interfaces must be available for fostering optimal connectivity with other systems in order to support process integration and simplify the administration [18]. Within the controlling and improvement process all measurement data should be communicated, evaluated by responsible departments and consequently changes or optimizations should be implemented using the process oriented organizational learning system.
- The web-based accessibility of the process oriented organizational learning system supports mobile working hour's independent learning, teleworking and sustains the integration of absent collaborators [1].

# 4 Approach

## *4.1 Development of the Process Model*

Firstly the process models and other parts of the system documentation must be elaborated. Considering the needs and expectations of all stakeholders, as well as legal and regulatory requirements we establish the organization policy with consistent objectives, priorities and strategies [19]. Thereby also the relevant information security requirements are integrated. All processes of the organization are analyzed bottom up by interviewing the collaborators involved. The responsible function, the applied documents, checklists, forms, used knowledge and information, the IT applications and other tools are studied for all activities. Afterwards the services with applied processes and related documents are optimized regarding the established objectives including information security, as well as stakeholder orientation, service quality, efficiency and effectiveness. The information flow including collection and passing necessary data and information by checklist, regulations, forms and workflow based databases is improved, too [1, 19]. Based on the collaborative approach implicit knowledge is externalized, knowledge identified and possible optimizations (knowledge generation) are discussed. In accordance with the organizational purposes and objectives are considered different aspects, like quality, information, communication and knowledge management, data protection and information security, ambient, environment, hygiene, occupational health and safety, as well as human resource development, resource management, IT-management, controlling and others and integrated by a holistic systemic process management approach [19].

For the process modeling we use a part from Gantt chart for time critical descriptions simple structured flow-charts, which are limited to one page. Therefore the processes are deeply structured. All processes receive also a short textual summary.

Furthermore the necessary resources, tools, instruments and required trainings for achieving the objectives and for improving the service and organization (e.g.

human resource development, IT-management, maintenance or facility management, if relevant) are analyzed, optimized and documented.

Afterwards the monitoring, measurement, analysis and optimization processes are planned and implemented to continually improve the effectiveness of the services and the organization. Based on the requirements of the standards all improvements or changes must be approved by the involved collaborators, documented, communicated, implemented and their effectiveness evaluated. Collaborative knowledge generation, knowledge representation by process models, knowledge communication and learning processes are structured, systematically planned and documented [1, 3–5].

The entire process models and system documentation must correspond with lived processes [1] and based on the constructivist method it must be practice oriented.

## 4.2 Didactical Preparation

After the development of the process models and the whole management system documentation we structure the content accordingly to ISO 9001 [15] and prepare it regarding didactical principles [8, 20]. To support collaborators need-oriented, process and operations integrated learning the access to the single modules must be as short as possible and optimal structured. All needs and expectations of the collaborators are analyzed and considered as early as possible [8, 16]. They demand particularly an efficient and effective search function and a clear structured system. Therefore the whole content is divided into small modules, typecasted and functionally well structured. We offer an effective indexing and different start assistances (for new collaborators, department oriented, management oriented, topics referred, based on the standard and others). Apart of the self-driven learning approach, the system offers also guided learning for new collaborators or for collaborators with little IT or learn competences.

After appropriate editing the process models and other parts of the system documentation can be published on the collaborative organizational learning system (Sect. 3.2). The upload function should be user-friendly, simple and intuitive to handle with as large didactical support as possible. The constructivist approach requires the possibility of linking different documents, sections and media formats, as well as concepts, objects and all elements of graphics and especially process models.

## 4.3 Introduction and Use

To promote the acceptance of the system the collaborators must be trained on handling the system. They must acquire also the necessary media competence [8].

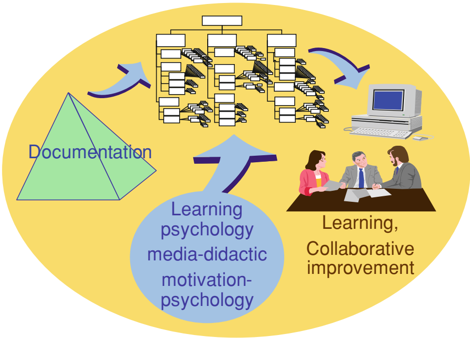


**Fig. 2** Steps of our approach

Subsequently questions are answered by means of the discussion forum, the help desk and personal partners, e.g. the business process manager.

Thus constructivist process oriented organizational learning system every collaborator can introduce his/her suggestions, ideas or questions directly in a context-sensitive way by referencing to processes or process steps. These questions and ideas are visible to all authorized collaborators. They can discuss these contributions introducing their opinions. The answers to the questions are also visible to all authorized collaborators. Thereby ambiguous models or formulations are showed up and eliminated in a collaborative way. The business processes are improved based on the process models in collaboration of all authorized users with a holistic, integrated approach. The process models represent the organizational knowledge base and become the basis for a continuously collaborative process oriented organizational learning for service, information security and organization development. Process modeling, process standardization and transparency are optimally integrated with need and objective oriented flexible process implementation, operations integrated process oriented organizational learning, collaborative process and information security optimization, and service and organization development. The collaborators have sometimes problems to distinguish between problem and optimization, or they do not know to which process they should relate their suggestion or question. Therefore we have integrated the process oriented organizational learning system with the existing workflow driven problem reporting system (help desk system) (Fig. 2).

Due to standard requirements the achievement of the organizational and process objectives must be constantly measured. The measurement results are communicated, analyzed and eventually necessary corrective or prevention actions are integrated and discussed using the collaborative organizational process oriented learning system.

## 5 Project Experience and Results

This innovative collaborative information security integrated process management concept for service and organization development has been implemented in several medium-sized service organizations with distinct management systems. Most of the organization's collaborators own good media competences and use frequently e-tools.

Interdisciplinarity was a great challenge and a great chance. Knowledge about process modeling, process measurement and process improvement, organization theory, standard based management systems, management methods and technical knowledge was required for preparing and structuring the content; information-technical knowledge was needed for extending the platform to meet the requirements of a collaborative process oriented organizational learning system (Sect. 3.2); didactical and media-pedagogical knowledge was required for editing the contents. The used collaborative organizational learning system should be still extended to fulfill all requirements (Sect. 3.2).

### 5.1 Achieving Project Objectives

Elaborating the organization best adopted secure process models, structuring it in accordance to ISO 9001 [15], preparing it regarding didactical principles based on constructivist theory and publishing it on an process oriented collaborative organizational learning system (Sect. 3.2) within a confident based open corporate culture leads to the following case study results. They were collected by measuring the system accesses and user contributions, as well as by interviewing the leadership and collaborators:

- Workplace and operations integrated, need-oriented process model access and learning: the accesses to the process models and system documentation are increased monthly at averaged two accesses per collaborator.
- Process and information security improvement for service and organization development: we receive five times more suggestions and ideas, which improve the processes, services, information security and the organization.
- Employee involvement and collaborative process improvement: the communicated ideas, problems and suggestions are discussed and read on the average by a quarter of the collaborators. On the average there are three annotations to each discussion contribution. Thus the advantages and disadvantages of ideas are discussed, examined and improved collaboratively by all departments before their possible implementation. Therefore they are substantially more balanced and more considered for implementation.
- Practice oriented process models: now unclear models, formulations or missing content are soon analyzed and immediately changed according to established processes and automatically communicated to all. Thus the process models and

documentation are adapted optimally to changing requirements of services, the organization, their stakeholder or environmental factors.

- Shorter initial training periods for new collaborators: new collaborators are quickly introduced into the handling of the learning system at their first working day. Thereby they focus on the system handling and on principle information. Afterwards they access and learn in a self-driven, need oriented and operations-integrated way when they have questions for fulfilling their job. The lead time could be abbreviated around a quarter. New collaborators can execute their job faster well. The productivity increase and possible errors are reduced.

The manager of an organization with a process oriented organizational learning system is particularly enthusiastic for the sustainable promotion of an open, confident based corporate and learning culture with criticism and change readiness.

The collaborators and particularly the management appreciate the structured, effective, need-oriented, location and working hour's independent collaborative learning. Thus no unnecessary documentation is distributed and nevertheless all collaborators can access exactly at appropriate time from desired location to necessary information and knowledge. The improved internal transparency and the discussion board promote organizational interrelationship, mutual comprehension and synergies. The knowledge sharing by the discussion forum is specially appreciated by collaborators, which work frequently in field service, or with flexible working-time model or teleworking.

Standard based management systems promote by their clear structure and systematic the building, control, approval, distribution, retrieval, use and continually collaborative improvement of processes, services and the organization.

Based on these experiences in different case studies the application of this collaborative process improvement concept is recommended for medium and large sized organizations and enterprises with an confidence-based, open and innovative corporate and learning culture, where all collaborators command sufficient IT competences, particularly in know-how or service enterprises or with distributed locations or many collaborators in field service or with flexible working-time models.

## 5.2 Success Factors

Corporate culture, services, processes, procedures, didactical principles, information security and information technology must be integrated optimally according to organizational objectives and to collaborators needs and requirements. The system and all methods are thereby only tools, which support collaborative service and process improvement and the development of the organization so far as this is admitted by corporate culture. Therefore we need an open, confident based, collaborative corporate culture with criticism and change readiness [1, 9].

The collaborators must be interested in new knowledge, able for self-driven learning, have personal employment, team ability and change willingness apart from necessary IT and media competences [1]. All managers must use constantly and actively the system and motivate their collaborators in following these principles. In this way they promote operations integrated learning and collaborative process and information security improvement.

The processes and system documentation must be analyzed and optimized bottom up by involving concerned collaborators and regarding all relevant aspects in accordance to corporate objectives and stakeholders requirements. In that way concerned collaborators support the project, develop practice oriented models with daily used terms and integrate most of the explicit organizational knowledge. A great challenge is the right process depth: to promote efficient and effective learning there should be regulated as much as needed and as less as possible.

This concept extends the job of the process manager. They need additionally didactical and media-pedagogical knowledge for preparing the content and necessary skills for supporting collaborative learning and knowledge management. Trainings and education in process management should consider more this interdisciplinary approach and teach basic knowledge in all areas.

Sufficient IT-infrastructure and IT-support are also very important for the project success. Only by using an process oriented collaborative organizational learning system, which meets as far as possible the stated requirements (Sect. 3.2) and by promoting workplace, need-oriented, operations integrated learning a continuously collaborative optimization of processes, services and the organization in accordance with established objectives including information security are secured. In that way a sustainable organization development is secured. E-learning systems or knowledge management platforms should be extended to collaborative process oriented learning systems in accordance to the stated requirements (Sect. 3.2) and integrated in workflow systems.

### 5.3 Cost and Benefits

This innovative interdisciplinary collaborative process improvement concept requires additionally in comparison to the common practice of process management systems and the common applied introduction of a standard-based holistic management system, which is adapted to the organization, the restructuring of the content in accordance to didactical principles, the learning system and the implementation of the documentation on it. The restructuring required in the case studies a slightly higher effort (approximately 1–2 % of the total effort).

Opposite to the costs are the large competition advantages through need-oriented operations integrated learning and collaborative process, information security and service improvement by means of collaborators ideas, suggestions and discussion contributions. These advantages can be measured on one hand by the reached objectives of the project (Sect. 5.1). The influence to the sustainable achievement of organizational objectives must be weighted essentially more strongly. In the sense of a systemic management approach the different strategies and there measurements influences each other and all individual actions together determine the achievement of the organizational objectives and the organizational success, which is at the end the essential critical factor. These effects must be evaluated in a longer term and could be objective of a subsequent study.

## 6 Outlook

Learning or knowledge management systems should be extended to process oriented collaborative organizational learning systems (Sect. 3.2) for need-oriented, workplace and operations integrated learning, and collaborative improvement.

By introducing a process oriented organizational learning system for standard based management systems and collaborative improvement all success factors should be considered (Sect. 5.2).

The training for system, or process or information security or knowledge manager or e-learning experts should consider more this interdisciplinary holistic and learning based approach in all areas.

The standards for management systems should underline more and promote the importance of an open, confident based, fault-tolerant corporate and learning culture, knowledge management and integrated learning.

## 7 Conclusion

Developing process models and the system documentation of holistic standard based management systems bottom up by interviewing the collaborators involved, preparing these in accordance to didactical principles and implementing it on a constructivist process oriented collaborative organizational learning system within an open, confident based corporate and learning culture promotes need-oriented, operations integrated, process oriented individual learning, practice-oriented process models, shorter initial training periods for new collaborators, employee involvement and collaborative process and information security improvement for continual service and organization development. This holistic collaborative process improvement concept foster service, process, information security and organization improvement and guarantees thereby sustainable organization success.

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# Software Design for Dynamic Stitching of Multi-Spectral Images of Field Crops

**Chi N. Thai, S. T. Jones and G. C. Rains**

**Abstract** We proposed an alternate configuration for dynamic multi-spectral imaging of plants at ground level, using a one-sensor monochrome FireWire-A camera combined with a liquid crystal tunable filter (LCTF) tunable at 760 nm and 695 nm. We developed an algorithm based on the traditional NDVI procedure to untraditionally solve the problem of image correspondence within sequences of spectral images collected from a moving platform. This algorithm was designed from a multi-threaded software engineering approach and had been shown to work well during acceleration, steady, and deceleration phases of a moving platform under laboratory conditions and one limited field test. The algorithm had two components: one to determine the optimal number of pixel rows passing by the camera viewport during the time period needed for the LCTF to switch between wavelengths; the other to determine the proper conditions to trigger an image saving event so as to minimize the number of images recorded that would however have enough overlaps to permit their assembly into potential field-level maps. The proposed system could process up to 14 image sets per second (3 images per set—760 nm, 695 nm and NDVI) and was found to tolerate light breezes under field conditions.

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## 1 Introduction

One of the main goals of precision agriculture is to reduce the use of chemical inputs in production agriculture, thus the issue of plant health in crop fields is quite important. This issue is of a biochemical nature, thus many spectroscopic and spectral imaging techniques had developed to quantify the health status of plants in open fields [1, 2]. As there are many ways to capture plant spectral energies, there are consequently many sensing technologies developed for this area, from satellite [3, 4] and aircraft [5–7] to ground vehicles [8–10], just to list a few references in a large set of recent works.

The reported work herein is more in the area of ground-based platforms applications. Reid [11] outlined a systems approach to the design of intelligent mobile equipment wherein the machine "perception" of its working environment was a key element. Sui et al. [12] reported on a multi-spectral sensor probe for nitrogen sensing in cotton with its own modulated light, while Noh et al. [13] reported on dynamic calibration under natural sunlight and multi-spectral image segmentation using a common aperture 3-CCD camera looking vertically down from a tractor. Other works applied 3-D vision technologies to crop density mapping and for automated vehicle guidance [14, 15]. The commonality among these machine vision approaches was that they relied on the use of multiple synchronized images, whether they were from a single camera with multiple CCD imagers, each with its spectral band filter [13], or from two cameras separated from each other with a known distance [14, 15].

As the image sequences were captured from a moving platform, the next task would be to process these image sequences into a useful field map, preferably geo-referenced, and due to the high computational needs, these operations are usually performed off-line at present. Image correspondence had been performed using markers left in the field [16], by premade-template matching [17], or by correlation-based pixel-matching techniques [18, 19]. The previous techniques were developed for monochromatic images where the basic assumption for pixel correlation between two images was that the pixel being matched would be simply displaced in 2-D space but that its pixel intensities would remain constant between the two images being considered. However this assumption cannot be upheld when processing sequences of multi-spectral or hyper-spectral images because they would possess different reflectance values at different wavelengths (i.e., between sequential images) for a given pixel. These time-varying illumination problems could be solved using phase correlation (PC) methods in the frequency domain [20, 21]. Erives and Fitzgerald [22] successfully implemented such an approach to register hyper-spectral field images captured from an aircraft flying at constant altitude, but they did not report on its performance in terms of computing time, thus it was not certain whether their PC method was suitable for real-time operation on an agricultural tractor. It must also be noted that most image registration research had been oriented towards 2-D images (whether monochromatic or multi-spectral) as obtained from satellites or aircrafts where the 3-D architectural

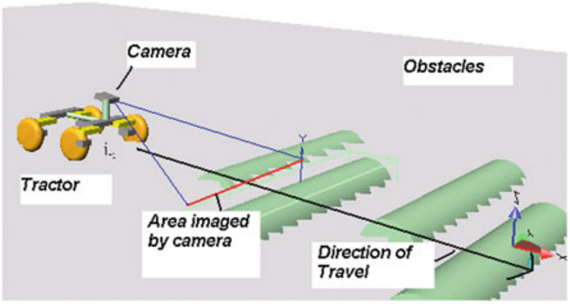


**Fig. 1** Proposed multi-spectral camera and tractor configuration

characteristics of plants could not be discerned in those images. Kise and Zhang [23] presented the most recent successful application of stereo vision to create a 3-D map corresponding to the top surfaces of field crops as viewed from a tractor in motion, but as monochromatic images were used, no biochemical-based plant health information could be extracted yet from this vision system.

In this report, we would like to present another multi-spectral imaging plant health sensing approach using a single sensor FireWire-A monochrome camera equipped with a liquid crystal tunable filter (LCTF) representing a "medium range" technology. The goal of our research was to adapt the traditional NDVI procedure in a non-traditional use to solve the image correspondence problem between two dynamic video images captured at different wavelengths, and also to reduce the number of overlapping image frames saved in the on-board computer of a moving platform, thus potentially combining the plant health evaluation and image mapping construction steps.

The configuration envisioned for our mobile multi-spectral imaging is depicted in Fig. 1, where our camera system is aimed forward of the tractor. This configuration suffers from the perspective problem in the captured image as shown in Fig. 2a. However, we plan to overcome this problem by instead capturing "thin" image strips having a "height of several pixel rows" and "stacking" them up one after another to recreate an "orthogonal" map of the field as the tractor moves forward (see Fig. 2b). Our unpublished preliminary research showed that there was a range of appropriate image strip heights to be used depending on the specific geometrical configuration of the vision system and its travel speed: too large a strip would require image warping procedures to address the perspective problem, too thin a strip would limit the travel speed of the vision system. In practice, the appropriate image strip height should also be matched to the working zone of sprayers for example [24].

Next, due to the platform forward motion we need to address the image correspondence problem between two consecutively captured spectral image strips, each at a different wavelength of the electromagnetic spectrum, for example in our case they are the 760 and 695 nm of the well-known "red-edge" that had been used to quantify the overall plant health and potential yield (Fig. 3). In Fig. 3 the number "5" on the plastic ID tag has moved slightly down in the 695-nm image as compared to its position in the 760 nm image and anyone can readily note the lack

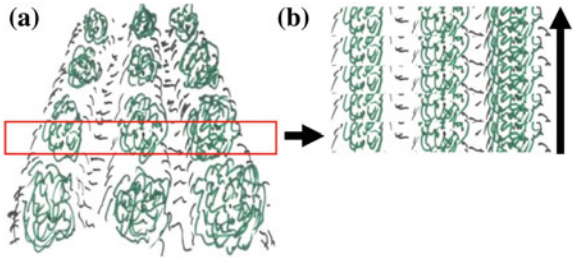


**Fig. 2** Proposed method to solve the “perspective” problem in captured images: **a** front view, **b** image strip

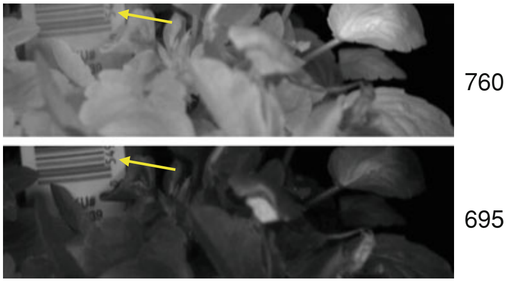


**Fig. 3** Image correspondence problem between two consecutive spectral images

of contrast between the plant and the background in the 695-nm image (695 nm corresponding to a strong chlorophyll absorption band), suggesting a difficult image registration problem to be solved. However this spectral imaging option does have the advantage of easy interchange and/or addition of relevant wavelengths over a fixed common aperture camera. This spectral imaging system also allowed the capture of geometrical/spectral data that would only be available from ground platforms whether in open fields or greenhouse situations, as they would be closer to the plants.

Figures 4a and 4b illustrated typical situations encountered when performing multi-spectral imaging on plants at ground levels.

In Fig. 4a, the camera was in static relationship to the plant leaves and thus a given camera pixel would receive the reflectances at 760 nm (R760) and at 695 nm (R695) coming off the edge of the top leaf for the “same physical distance” between leaf and camera pixel, resulting in a correct computation of the well-known NDVI (normalized difference vegetation index) value as shown in Eq. (1):

$$\text{NDVI} = (\text{R760} - \text{R695})/(\text{R760} + \text{R695}) \tag{1}$$

However in the case of Fig. 4b, because the camera platform was moving to the left and because the LCTF would need a small but finite time to switch from 760 nm to 695 nm (2 ms in our case), the same camera pixel would receive its R695 value from the “lower” leaf, as compared to its R760 value which came from the “upper” leaf. Even in the case when both leaves contained the same chlorophyll and biomass amounts, because of the longer “travel” distance for R695 (coming from lower leaf) as compared to R760 (coming from upper leaf)

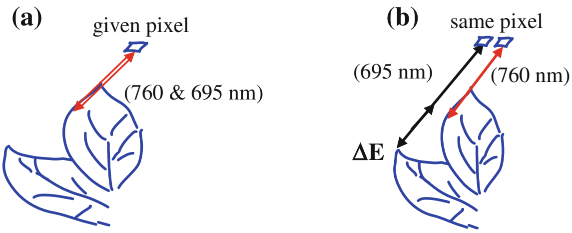


**Fig. 4** Spectral and geometrical shifts encountered in dynamic spectral imaging: **a** no relative motion between camera and plant, **b** When relative motion between camera and plant exists

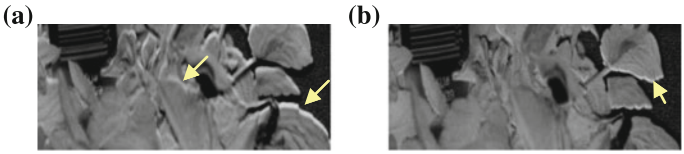


**Fig. 5** "Bright" edges resulting from NDVI operations with relative "forward" camera motion (**a**), and relative "backward" camera motion (**b**)

there will be a small energy loss ΔE for R695 as far as the camera pixel is concerned, meaning that its R695 value would be artificially lower than it should be, resulting in an NDVI value that was higher than it should be, i.e., a brighter pixel than the "regular" NDVI-plant pixel. In other words, the NDVI operation when performed under such conditions would produce "bright edges" on plant leaves as shown in Figs. 5a and 5b (see arrows on right sides of these images and mid-area of Fig. 5a).

In Fig. 5a the camera platform was moving forward with respect to the plant and in Fig. 5b the camera platform was moving in reverse with respect to the plant: ones could easily note the formation of "bright edges" along the "top" edges of leaves in Fig. 5a as compared to similar "bright edges" along the "bottom" edges of leaves in Fig. 5b. Figure 5a also showed that "bright edges" would form even more clearly between the outer leaves and the background below them (right side of Fig. 5a). The mid-area of Fig. 5b also illustrated the situation when a given camera pixel "sees" a leaf edge at a higher elevation when it is at 695 nm than when it was at 760 nm (i.e., reverse situation as compared to Fig. 4b: essentially no "bright edges" were formed however there were enough "bright edges" formed between the outer leaves and the background below them (right side of Fig. 5b) for the proposed system to be able to estimate the distance shift occurring between the 760 and 695 nm image strips captured.

Thus the NDVI operation when performed in close proximity to plants (several meters) could give us potential information about the amount of pixel shift due to motion and also about the direction of the relative motion between camera and plant. It must also be recognized that as the distance between camera and plant

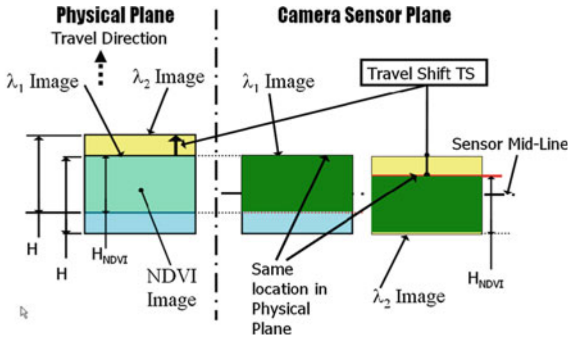


**Fig. 6** $\lambda_1$ and $\lambda_2$ image definitions and basic image acquisition problem (tractor going forward)

increases, as in the case for aircraft and satellite, the energy loss ΔE will be less and less quantifiable by the camera sensor while the relative motion would become "sub-pixel".

# 2 Materials and Methods

## *2.1 Spectral Imaging System Hardware and Image Acquisition Approach*

The video camera used was a FireWire-A monochrome camera (model A602f, Basler Vision Technologies, Exton, PA), with programmable area of interest (AOI) capable of providing 100 fps at 656 × 491 pixels and 8 bit gray levels (faster with smaller AOI). This camera also had programmable exposure time, gain, brightness and data output rate. The LCTF (CRI Inc., Woburn, MS) was custom designed for our research to switch between only two wavelengths (695 and 760 nm) and controlled via a digital port of an A/D card. The basic image acquisition problem was described in Fig. 6, whereas the camera was assumed to be mounted in a fixed position and aiming forward of the tractor as shown in Fig. 1. First let's consider the physical plane and let's assume that the spectral image strips were captured with a given height H (i.e., a given number of pixel rows). Due to the platform's forward movement, the $\lambda_2$ image would be shifted forward by an amount travel shift (TS) (in term of pixel rows) as compared to the $\lambda_1$ image, thus the NDVI image could only be computed for the overlapped area with height HNDVI as shown in the left hand side of Fig. 6. However in the camera sensor plane, the $\lambda_1$ and $\lambda_2$ images would be captured from exactly the same pixel buffer locations, except that the top edge of the $\lambda_1$ image would now be shifted downward by an amount TS correspondingly on the $\lambda_2$ image. Later, NDVI images are stacked together to create field maps.

Thus once the $\lambda_1$ and $\lambda_2$ images were captured into the PC memory buffers, the following procedure was executed in order to compute the NDVI image:

a. Delete bottom TS rows of $\lambda_1$ image strip.
b. Delete top TS rows of $\lambda_2$ image strip.
c. Perform NDVI operation on the "reduced" $\lambda_1$ & $\lambda_2$ image strips with height equal to HNDVI.

From simple geometry, the following Eqs. (2), (3) and (4) were obtained for parameters HNDVI, Row_Start_1 and Row_Start_2 and implemented in our image acquisition software:

$$\mathrm{HNDVI} = \mathrm{H} - \mathrm{TS} \tag{2}$$

where H is considered to be user-given, corresponding to a working strip height as needed by the implement pulled behind the tractor, and where TS is to be autonomously determined by the image acquisition software depending on the motion status of the tractor.

As the camera sensor has 491 pixel rows, Eq. (3) defined the starting row for the $\lambda_1$ image strip which was designed so that the resulting H image strip would be mostly centered along the camera sensor mid-line as shown in Fig. 6 to minimize image distortion due to the camera lens and the perspective effect:

$$\mathrm{Row\_Start\_1} = 245 - (\mathrm{H} - (\mathrm{H}\ \%2))/2 \tag{3}$$

where the " %" symbol was the standard C++ remainder operator for integer arithmetic, i.e., H % 2 = 1 if H was an odd number and H % 2 = 0 if H was an even number.

Equation (4) defined the starting row for the $\lambda_2$ image strip, as described in Fig. 6:

$$\mathrm{Row\_Start\_2} = \mathrm{Row\_Start\_1} \tag{4}$$

During laboratory experiments, this spectral imaging system was mounted on a computer controlled X–Y stage that had a maximum travel distance of 24 cm and an average speed of 6 cm/s. Using a digital inertial measuring unit (model IMU300, Crossbow Technology Inc., San Jose, CA), the following acceleration profile was obtained for a typical travel cycle showing clearly 3 modes of motion: acceleration, steady and deceleration (see Fig. 7). Thus although the X–Y stage may be slow as compared to a field tractor at operating speeds, it does have the dynamic features suitable for real-time multi-spectral imaging software development.

The proposed vision system was developed in the laboratory using Tungsten Halogen lamps located at both sides of the tested plants and oriented at 45 degrees so as to provide uniform lighting. This system also had been through several field tests under natural sunlight between 8 and 10 a.m.

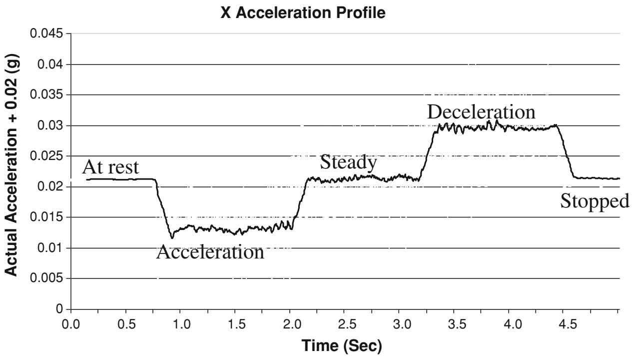


**Fig. 7** Typical acceleration profile of X–Y stage while traversing 24 cm

## *2.2 Software Development Approach*

The development platform was a Windows XP PC (model Optiplex GX270, with a Pentium 4 CPU with Hyper-Threading Technologies, 2.4 GHz and 1 GB of RAM, Dell Inc., Austin, TX). The software development tool was Microsoft Visual C++ V. 6. This imaging system must perform real-time wavelength switching, image capture, processing and storage, thus the software was engineered to run as efficiently as possible using a multi-threaded approach as our future goal is to further integrate GPS, digital gyroscope and selective sprayer systems into this vision system. Three threads were developed: the main "Image Capture" thread to control the camera and the LCTF, capture the images, and run the NDVI image processing routine and decide when to trigger an image saving event, a second "TS Search" thread to compute the optimal travel shift TS value to be used in performing the NDVI operation and a third "Image Saving" thread to actually save onto the hard disk the images as they are captured ($\lambda_1$ and $\lambda_2$ images) or finished being processed (NDVI images).

There were many restrictions on how the system operated. The first constraint was that each pair of images, $\lambda_1$ (760 nm) and $\lambda_2$ (695 nm), must be captured with as little delay between them as possible to minimize effects of vibrations and lens distortions. A major issue in minimizing this delay was the asymmetrical behavior of the LCTF needing only 2 ms to switch from the $\lambda_1$ wavelength to the $\lambda_2$ wavelength but requiring about 20 ms to return to the $\lambda_1$ wavelength. Other constraints were for the timely sharing (i.e., acquisition and release) of common image buffers between the 3 threads so that the overall system functioned smoothly, efficiently and without error. The result of these interactions was a system capable of capturing image strips of height 180 (i.e., 656 $\times$ 180 pixels) at rates greater than 14 sets per second (3 images per set—$\lambda_1$, $\lambda_2$ and NDVI). As a result, not every set of images needed to be saved, because the image sets overlapped with one another to a great degree. The image saving thread was only activated to record every nth set of images, where n was determined dynamically based on the varying speed of the platform and the chosen image strip height H (to be described in a later section). During our tests using a value of 180 pixel rows for parameter H, we found that the average overall cycle time between image sets was 63 ms when no image saving was needed, and about 78 ms when an additional image saving event occurred.

### 2.2.1 Travel Shift Search Algorithm

This algorithm was gradient-based and its goal was to find the optimal TS value that would minimize the number of "bright edges" found in an NDVI image (Fig. 5). From experimentation, we determined that these "bright-edge" NDVI pixels could have gray intensities varying from a lower threshold (around 220) up to 255. Thus we devised a procedure to be performed at the beginning of each series of tests, when the spectral imaging system was motionless with respect to the plants being scanned, whereby we "manually" force a TS value of 7 pixels on this set of static and matching $\lambda_1$ and $\lambda_2$ images to produce on-demand "bright edges" that could be examined using linear ROIs positioned across the displayed "bright edges" in order to determine the lower threshold value to be used in the TS search algorithm described below:

1. Starting from the current "optimal" value of TS (which equals 0 if the system was at rest, and non-zero if the system was currently in motion), compute (TS − 1) and (TS + 1). From these three possible values for the travel shift variable, process the three resulting NDVI images and compute the corresponding number of bright edge pixels obtained from each of the three NDVI images by simply counting the number of NDVI pixels that had gray intensities above the lower threshold determined earlier. Next, keep the travel shift value that yielded the minimum number of bright edge NDVI pixels. Please note that it was not necessary for this minimum to be zero for this algorithm to work, and that only a simple global threshold operation was needed instead of requiring more complicated local edge detection routines.
2. If TS turned out to be best among the three possible values, keep the current value of TS (i.e., no acceleration nor deceleration was detected).
3. If (TS + 1) was found to be best (i.e., acceleration had been detected), try two more possible values, (TS + 2) and (TS + 3), and follow the steps outlined in the flowchart of Fig. 8. Essentially to keep on incrementing TS by 1 as long as the number of bright edges kept on decreasing, however never go beyond TS + 3, as at that point it meant that high acceleration was occurring, therefore it was more beneficial to work with more up-to-date data from newly captured $\lambda_1$ and $\lambda_2$ images rather spend "more" time trying to optimize with the old data which might become obsolete by then.
4. If (TS − 1) was found to be best (i.e., deceleration had been detected), try 2 more possible values, (TS − 2) and (TS − 3), and follow steps similar to those outlined in the flowchart of Fig. 8, however the parameters (TS + 1), (TS + 2)

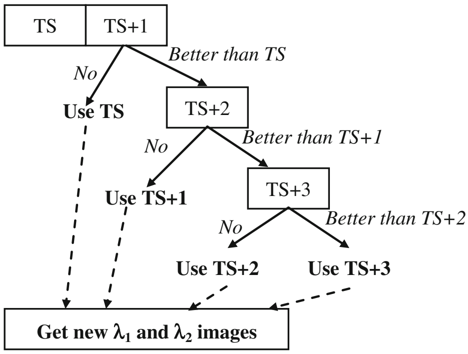


**Fig. 8** Steps to use when acceleration was detected (TS Search algorithm)

and (TS + 3) needed to be respectively replaced by parameters (TS − 1), (TS − 2) and (TS − 3).

5. This TS search algorithm was first developed for uni-directional motions (for example, platform moving forward only) thus the algorithm had an extra step to insure that all TS values were greater or equal to zero. However it could also be used for bi-directional motions such as for inside greenhouses equipped with an X–Y track system, then parameter TS would be allowed to become negative. However negative TS values would have to be applied from the bottom edges of the $\lambda_1$ and $\lambda_2$ images instead of the top edges as shown in Fig. 6, being the case for positive TS values only. Currently our system is using the bi-directional version as it was found to be more stable when dealing with sudden stops of the platform that tended to sway the camera assembly back and forth for short periods.

When used with image strips having an H value of 180 pixel rows, the TS search algorithm was found to use about 31–32 ms to find the optimal TS value for each image set captured.

### 2.2.2 Image Saving Trigger Algorithm

Another research goal was to reduce as much as possible the number of real-time $\lambda_1$, $\lambda_2$ and NDVI images saved on the hard drive of the development platform so as not to waste hard disk space saving overlapping image sets, i.e., redundant data.

Our image saving trigger algorithm was based on the correspondence between the optimal travel shift TS value (in terms of pixel rows) as determined by the previous TS search algorithm and the time span between the two image capture commands ($\lambda_1$ and $\lambda_2$ images) used in the image capture thread. These time spans were experimentally found to be 15–16 ms long when a value of 180 was used for H, while the overall average cycle time needed to process one set of spectral images was found to be about 63 ms. Figure 9 illustrates our basic assumptions and algorithmic approach which were:

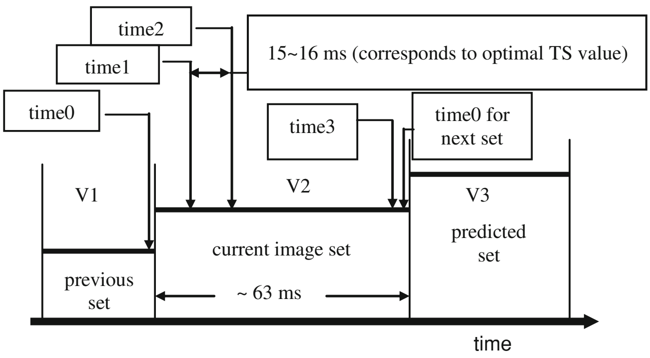


**Fig. 9** Assumptions about timing of events within current image set (image saving trigger algorithm)

```
cumRows = 0;  // init cumRows to zero for current image set
while(!PAUSE) {
...
imgGrabber->GrabImage(0);  // grab 760 nm image
time1 = clock();
...
imgGrabber->GrabImage(0);  // grab 695 nm image
time2 = clock();
... // Adaptive TS thread to find best TS
imgGrabber->ProcessImages(0);  // process NDVI with best TS found
time3 = clock();
speed = TS / (time2 – time1); // representative speed for current set
cumRows += speed * (time3 – time0); // current position
             // computing predicted speed and rows for next image set
predSpeed = speed + (speed – prevSpeed) * (time3 - time0) /
(prevTime3_0);
         predRows = predSpeed * (time3 - time0);
if (predRows < 0) predRows = 0;  // going forward only
prevSpeed = speed;
prevTime3_0 = time3 – time0;
time0 = clock(); //mark time0 for next image set
if (cumRows + predRows >= H) { cumRows = 0; SAVE = true; }
} // end of while loop
```

**Fig. 10** C++ code fragment highlighting logic and important steps of the image saving trigger algorithm

1. During each image set cycle time ($\sim$63 ms), the platform was assumed to have a certain constant speed but this speed can be different for each image set (i.e., V1, V2 and V3).
2. Using the MFC clock() function, a series of time markers could be set, corresponding to specific events occurring within each image set:
   a. "time0" marked the end of all operations for a given image set, this value would be used in the next image set to compute its overall image cycle time which equaled (time3 − time0).

b. "time1" marked the time when the image capture command for $\lambda_1$ image had been sent in the current image set.
c. "time2" marked the time when the image capture command for $\lambda_2$ image had been sent for the current image set. Thus (time2 − time1) corresponded to the optimal TS value just determined by the TS search algorithm. Therefore we could estimate the platform speed to be equal to the following parameter "speed":

$$\text{speed} = \text{TS}/(\text{time2} - \text{time1}) \tag{5}$$

d. "time3" marked the time after the NDVI process had just finished in the image capture thread. Extrapolating the "speed" just obtained to the current overall image set cycle time (time3 − time0), we could next estimate the parameter "cumRows", representing the cumulative number of pixel rows that could have passed by the camera sensor since the last image set was saved onto the hard disk:

$$\text{cumRows} += \text{speed} * (\text{time3} - \text{time0}) \tag{6}$$

in other words, "cumRows" marked the current position of the overall image processing procedure as it progressed towards the goal of processing "H" pixel rows as set by the user initially for the height of each image strip captured (Eq. (2)).

In order to better estimate effects of acceleration and deceleration and to minimize overshoots that could create gaps in consecutive image sets being saved, the algorithm also evaluated the potential speed and number of pixel rows that could be traversed in the next image set (an event that actually had not yet happened at this point in time). These variables were respectively named "predSpeed" and "predRows" in the actual C++ code fragment displayed in Fig. 10, highlighting the important steps of this image saving trigger algorithm. When the sum (cumRows + predRows) exceeded H, the Boolean variable SAVE was set to true, indicating that next image set would need to be saved onto the computer hard disk. One final point of clarification was that the image saving trigger algorithm described herein was integrated into the image capture thread, while the actual image saving operations were executed in a separate thread.

# 3 Results and Discussions

## *3.1 Behavior of Travel Shift Search Algorithm*

Figures 11, 12 and 13 displayed NDVI images "consecutively-recorded" (not "consecutively-captured") during a typical run distance of 24 cm on the computer-controlled X–Y stage, where only one set of images ($\lambda_1$, $\lambda_2$, NDVI) was recorded for every five sets of such images captured and processed.

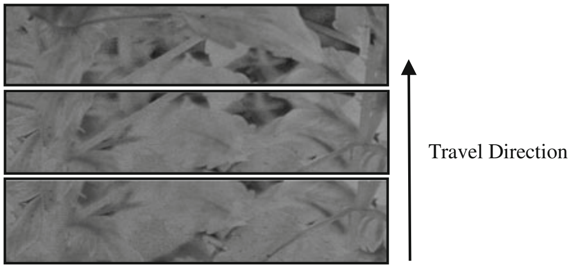


**Fig. 11** NDVI images processed using optimal TS values determined by TS search algorithm during acceleration phase

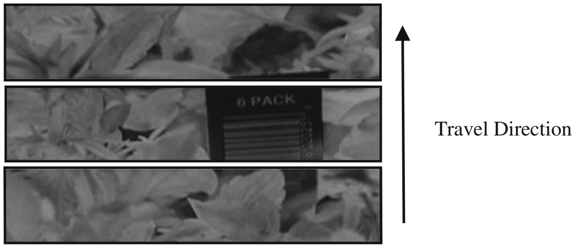


**Fig. 12** NDVI images processed using optimal TS values determined by TS search algorithm during steady phase

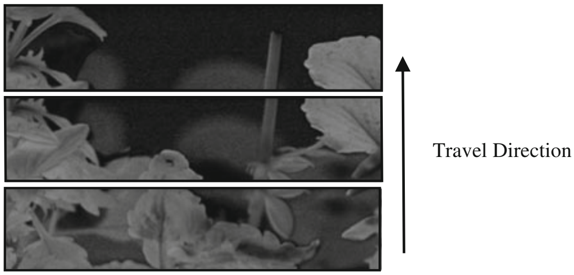


**Fig. 13** NDVI images processed using optimal TS values determined by TS search algorithm during deceleration phase

Results were shown in Fig. 11 during the acceleration phase, Fig. 12 during the steady phase, and Fig. 13 during the deceleration phase. In these figures, the chronological order for the images was from bottom to top and the thin white strips at the bottom of each image represented the “current” optimal TS value in terms of pixel rows (increasing for Fig. 11, steady for Fig. 12 and decreasing for Fig. 13). These results showed that the TS Search algorithm did adjust to all phases of motion for our test platform. In this experiment, the algorithm was capturing, processing and saving every other 5th image set for a total of 60 image sets within 4 s of travel, on the average.

Other experiments at 35 and 50 pixels strip heights showed that the system was limited by the 20 ms delay needed for the LCTF to go from 695 to 760 nm as these “thinner” strips required “less” processing time and thus did not allow enough time for the LCTF to stabilize itself when switching from 695 to 760 nm.

## 3.2 Behavior of Image Saving Trigger Algorithm

To test the behavior of this algorithm, the software was started with an image height H = 180 pixel rows and the X–Y stage motionless, then after a few seconds delay, this stage was made to travel the 24 cm test distance in two "hops" of 12 cm each, separated by a few seconds of standing still after the first hop. Figure 14 displays in terms of pixel rows the values of the parameters "predRows" and "cumRows" (as defined in Fig. 10) versus the sequential image set number (as counted from the running start of the algorithm). As "predRows" was designed to be an estimate of the number of pixel rows passing by the camera view between consecutive image sets that were saved, it had the expected pattern of "increasing-steady-decreasing" in values corresponding to the phases of accelerated, steady, and decelerated motion of the X–Y stage during each hop. Figure 14 also shows that because of the shorter travel distance of 12 cm, the X–Y stage stayed in steady mode for only a very short time during the first hop and that the stop at the end of the first hop was achieved smoothly as the first hop was under complete computer control. However, limit switches designed for safety triggered the end of the second hop, causing it to be more "jerky" as the camera system was swaying back and forth for a few seconds after a more uncontrolled second stop. This situation was analogous to the condition when the driver slammed on the brake of a moving vehicle, and the net result was that the system would be collecting redundant images during such situations until re-stabilization of the platform. The parameter "cumRows" was designed to "accumulate" with individual "actual" values of the term "speed * (time3 – time0)" until its current value almost reached the user-given value for H (=180 in this case), thus its trace had a saw pattern as "cumRows" was reset back to zero after every image-saving event (please refer to the second "if" statement at the bottom of Fig. 10). However, when we collected data on parameters "cumRows" and "predRows" for use in Fig. 14, from inside our code, we executed an output-file write-out statement located just above the clocking statement for "time0", thus as long as the platform was moving, the data trace for "cumRows" would show that its lowest value was equaled to "speed * (time3 – time0)" and not zero, even after a "reset to zero" command.

Figure 14 also shows that the image saving trigger algorithm used "cumRows" as a "bookmark" to know when to save images again after the camera platform had stopped its forward motion at the end of the first hop.

Figure 15 shows in chronological order (from bottom to top) the first seven NDVI images saved onto the hard disk during the two hops and they corresponded respectively to the image set sequence numbers 1, 48, 54, 60, 240, 248 and 254. Image (1) was recorded when the three threads were activated for the first time at the beginning of the experiment and subsequent images were recorded when the image saving trigger algorithm decided that it was the proper time to do so. First, it must be noted that the TS search algorithm was working properly at all times as no bright edges were shown in Fig. 15. Figure 14 and the output data file (previously mentioned) showed that the first hop must have begun between image

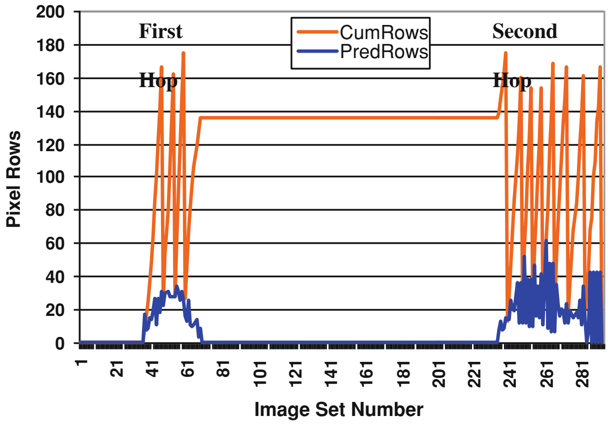


**Fig. 14** Plots of parameters “predRows” and “cumRows” versus sequential image set numbers as counted from beginning of experiment

set numbers 36 and 37 and ended between image set numbers 68 and 69. It also showed that the second hop must have begun between image set numbers 234 and 235. Figure 15 also shows that this algorithm did achieve its goal of saving a small number of image strips as much as possible within a given experiment (i.e., seven image sets saved out of 254 image sets captured and processed). However inspecting more closely at the matching arrows shown in Fig. 15 showed that there was a small gap of missing pixel rows between image (1) and image (48), but there were good (but unequal) overlaps between consecutive images shown from images (48) to (240). Unfortunately, there was a small gap again between image (240) and (248), and then good overlap (or at least less gap) between images (248) and (254). These results showed that we should have been more conservative in writing the “if” condition used in Fig. 10 in determining the trigger of an image saving event, i.e., use (cumRows + predRows $\geq 0.90 \times$ H) instead of (cumRows + predRows $\geq$ H) in order to save them sooner and thus have more overlaps between consecutive recorded image sets.

We also had performed several field tests under outdoors conditions between 8 and 10 a.m. and with occasional light winds. The vision system was mounted on a tractor traveling at a speed between 0.5 and 1.0 m/sec. The tested plants were potted cotton plants placed on a field of grass. Typical NDVI image strips consecutively saved are shown in Fig. 16.

Figure 16 shows that the TS search algorithm worked well when larger cotton leaves were in view of the proposed vision system (bottom three image strips) and also when only finer grass blades were in view (top image strip). Please note the higher TS values encountered as compared to the ones obtained in lab experiments (white strips beneath each NDVI image) as the tractor’s speed was greater than the X–Y table’s.

For the image saving trigger algorithm, we were using the (cumRows + predRows $\geq 0.90 \times$ H) criterion at this time thus resulting in more overlap consecutive recorded image sets.

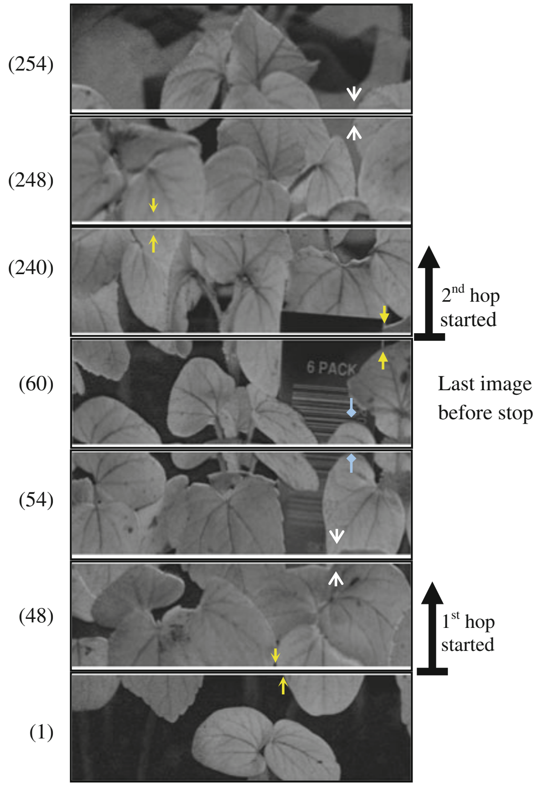


**Fig. 15** NDVI image strips recorded by image saving trigger algorithm during the two hops

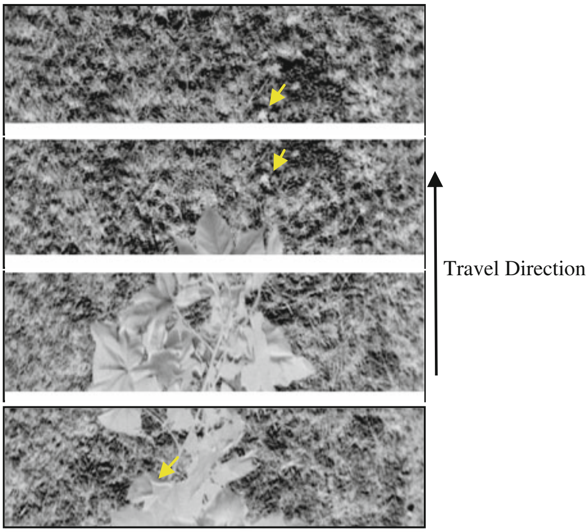


**Fig. 16** NDVI image strips recorded by image saving trigger algorithm for outdoors tests (chronological order is *bottom* to *top*)

between image strips (for example note the position of the small grass lump between the two top image strips). The bottom image strip also showed the effect of the light breeze occurring occasionally during this test resulting in the “unresolved” bright edge indicated by the arrow. However the overall image strip could still be used for plant health mapping or for selective spraying decisions to be made. In future research we will need to determine the upper limit of wind occurrences for the proposed system.

At the present time, as most of our experiments lasted no more than 2 h whereas we did not find the need to change the camera gain setting (usually below 50 %), we cannot be certain if the proposed method for determining the lower gray pixel intensity threshold used in the TS search algorithm will work for more extended time periods, however our algorithm is not using the I1 and I2 images directly, instead it is using the NDVI image which is known to be more robust regarding light intensity changes [25]. For future field tests with longer time periods, we plan to implement the dynamic light intensity calibration methodology developed in Noh et al. [13] by inserting a gray standard object into the view of the lower section of the camera sensor that is not used at the present time and to use its reflectance to readjust the camera gain cyclically as needed (for example, after a predetermined number of image sets that have been processed or after a given time span).

## 4 Conclusions

We have proposed an alternate configuration for dynamic multi-spectral imaging using a one-sensor monochrome FireWire-A camera combined with a discretely tunable LCTF and developed an algorithm based on the traditional NDVI procedure to untraditionally solve the problem of image correspondence within sequences of spectral images collected from a moving platform. This algorithm was designed from a multi-threaded software engineering approach and had been shown to work well during acceleration, steady, and deceleration phases of a moving platform in the laboratory and by extension to greenhouse environments where there would be minimal wind occurrences. This algorithm had two components: one to determine the optimal number of pixel rows passing by the camera viewport during the time period needed for the LCTF to switch between wavelengths and the other to determine the proper conditions to trigger an image saving event so as to minimize the number of images recorded that would however have enough overlaps to permit their assembly into potential field-level maps.

Laboratory experiments showed that this system could process correctly up to 14 image sets per second when the image strip width was set at 180 pixels. We can easily achieve more throughput if we only process every other column (a modified binning technique) in our NDVI and bright edge counting routines, but the system limitation will come from the required 20 ms delay of the LCTF.

Preliminary field tests showed the applicability of this approach to field conditions where there could be ground cover in addition to the plants of interest in the field of view of the proposed spectral imaging system and that the implemented algorithms could tolerate light breezes. For higher speed requirements for the moving platform or to account for stronger winds, ones would have to rely on the use of acousto-optical tunable filters which have "μs" switching times instead of the "ms" switching time of LCTFs, and Gigabit Ethernet or Camera-Link types of video cameras for faster frame rates, but the approach described herein should still apply.

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# Teaching Robotics to Students with Mixed Interests

**Chi N. Thai**

**Abstract** An innovative and flexible course in robotics was created to accommodate the interests of engineering and non-engineering students at UGA. It sought the integration of multi-threaded programming, advanced sensors interfacing (video camera and balance sensor), actuators control and wireless communications (Zigbee). It was based on the Bioloid Expert and Premium robotics systems from Robotis, Inc. Details of course design and materials, and of student projects are described herein.

## 1 Introduction

Educational interests in robotics at the University of Georgia are quite diverse:

- The artificial intelligence center (computer science department) emphasizes intelligent autonomous systems.
- The department of theatre and film studies is interested in using robots for dramatic productions [1].
- The college of education wants to incorporate robotics in their graduate degrees in technology education (http://www.uga.edu/teched/).
- In the engineering education area, we are looking at using robotics as an instructional approach to integrate hardware, software and communication

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DOI: 10.1007/978-1-4614-3558-7_5, 

technologies at a senior-year level whereas students would already have taken courses on microcontrollers and sensors and transducers.

Furthermore, the field of robotics itself is also quite diverse as described in several robotics handbooks [2, 3]. Thus our curriculum plan was to create a course that can serve as an elective for the B.S. degree in computer systems engineering and also for the mechanical systems or electrical and electronics emphasis areas of the B.S. degree in agricultural engineering.

Currently there are several suitable robotics textbooks for university level students [4–6] and several other works more oriented towards pedagogy, for small children as well as for engineering students [7–9]. To obtain flexibility, this course goal was to provide students with a medium to advanced practicum in embedded robotics wherein the students will learn about the programming of embedded controllers, the actuation of servo motors, the interfacing of sensors (sound, light, acceleration, wireless color video camera), inter-computer serial communications (RS-232 and ZigBee), and the control of autonomous as well as remotely piloted systems. Also to accommodate different student knowledge and skills, the students would start programming with a high-level integrated (but somewhat constrained) programming environment, and then towards the semester's end, the students would practice lower-level programming using the C/C++ language depending on the term project chosen.

## 2 Course Design

### *2.1 Hardware/Software System Description*

Balancing between potential sophistication of robot design and cost affordability, we decided on the Bioloid Expert and Premium systems from Robotis (http://support.robotis.com/en/). With the Expert system, we can build from basic car and bipedal robots to humanoid systems with wireless color video cameras (see Fig. 1). With the Premium system, we can add angular rate gyroscope, 3-D inertia measuring and magnetic heading sensors (see Fig. 2).

Regarding software tools, the student can start from a beginner IDE called RoboPlus Task and later go to direct API programming using Linux (gcc) or MS Windows (Visual Basic, C++, C#, LabView and MATLAB).

The Bioloid embedded controllers are based on the Atmel AVR microcontroller at 16 MHz, with either 128 KB or 256 KB of flash memory. The user-accessible memory area is divided into three independent and cooperating sections:

(a) The main user logic resides in the TASK section which has standard features such as "main" and other user-defined functions. Familiar selection and repetition structures are available, but no parameter arrays can be defined by the user currently. A special function named CALLBACK can also be defined here but only once.

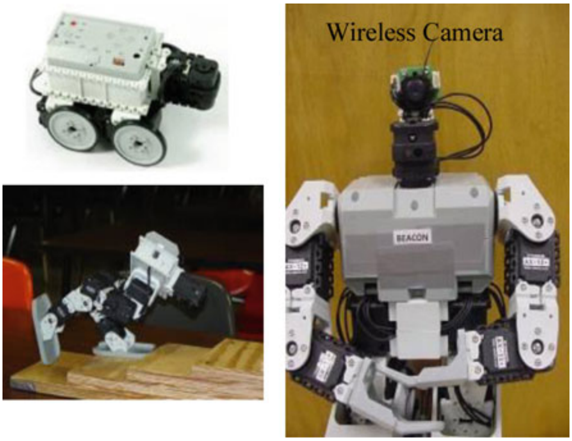



**Fig. 1** Bioloid Expert system configurations

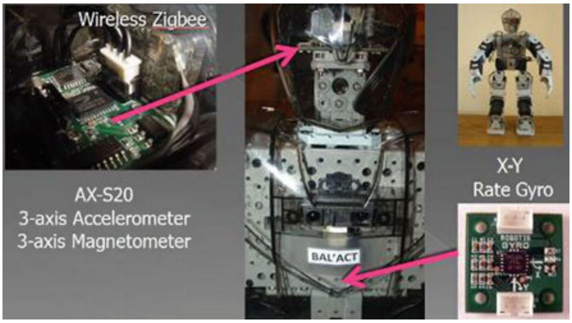



**Fig. 2** Bioloid Premium's advanced sensors

(b) The CALLBACK section is executed every 7.8 ms which is also the refresh time period for all servo motors. Limited commands are allowed in the CALLBACK section to prevent collisions with the other commands from the TASK section.
(c) The MOTION section contains the definitions of various static "poses" that the robot can take. Each pose is essentially a data structure representing coordinated absolute positions of the relevant servo motors used to build a given robot (e.g., humanoid). These static poses can be further modified by applying JOINT OFFSETs which can be computed during run-time from user-defined algorithms responding to changes in selected sensors. Up to seven poses, along with transitioning time periods between these poses, can be combined into one motion page which is "played" during run-time producing dynamic robot gestures or maneuvers. A maximum of 127 motion pages can be defined with a 128 KB system, while a 256 KB system would allow up to 255 motion pages.

## 2.2 Instructional Design

Building upon other engineering educators experiences in teaching robotics [10–12], this semester course was designed around three projects with lectures and laboratory demonstrations performed by the instructor to provide necessary background materials for students to carry on successfully with their chosen projects.

Foundational materials were presented in "Customized Opinion Mining Using Intelligent Algorithms" for the following concepts developed around a Carbot system (see Fig. 1):

- Description of main functional blocks for typical robotics systems (sense- think-act paradigm).
- Details of Bioloid systems.
  - Hardware capabilities, RS-232 communication concepts.
  - Software development tools (RoboPlus suite, V. 1.0.17.0)
- Hands-on practice using "MANAGER"—direct hardware observation tool and "TASK"—main IDE tool:

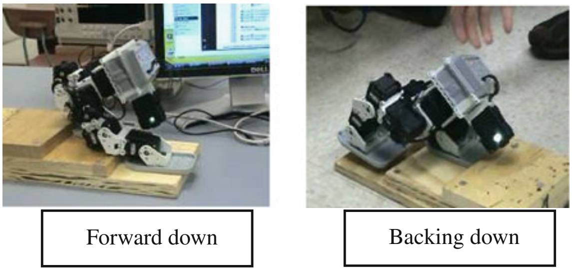
  Programming Servo Motors for the "Continuous Rotation" mode. Interfacing NIR and sound sensors integrated into Carbot.
  Autonomous obstacle avoidance programming for Carbot (two approaches—reactive control and behavior control). Application to maze navigation.
  Remote user control via Zigbee controller (RC-100). How to deal with signal loss.

- Homework 1—Add new "speed level" commands to existing TASK code that was made to accept Up-Down-Left–Right commands from user (via the RC-100).
- Project 1—automated carbot collision avoidance. Starting from the homework 1 code, this project goal was for students to practice combining remote control and autonomous behavior programming in one application resolving a "tail-gating" situation between two Carbots (both going forward under remote control by separate students using RC-100s). When the front Carbot suddenly stopped, the rear Carbot using its NIR sensors would trigger an autonomous response (i.e., ignoring further user commands from the RC-100) to help it avoid from colliding into the front Carbot. After the rear Carbot performed successfully a passing maneuver, user remote control commands would once again be accepted and acted upon by this Carbot.

In "Information Security Measurement Roles and Responsibilities", programming concepts for the (absolute) "Position Control" mode for servo motors were further explored:

- How to achieve "smooth" servo motions from "start" to "end" servo positions. Concepts of "Margin" and "Slope" parameters for a target servo position.
- Homework 2—independent (multi-threaded) control of multiple servos.

**Fig. 3** Two possible down-stairs gait solutions




- Motion programming using RoboPlus Motion tool as applied to simple bipedal bot (GERWALK) as shown in Fig. 1.
- Homework 3—wireless remote control of GERWALK bot combined with autonomous obstacle (wall) avoidance.
- Project 2—GERWALK negotiating stairs (see Fig. 1). The student could choose between two solution approaches. In the first approach, the bot would go forward and up the stair steps and then it would back down the steps. In the second approach, the bot would keep going forward during the up-stairs and down-stairs phases of this task. Figure 3 displays both approaches.

"Service and Information Security Improvement by Collaborative Business Process Management" expanded Zigbee communication concepts further into inter-bot communication packets manipulation whereas the students practiced shaping a 10-bit message into a standard Zigbee packet:

- This concept was demonstrated using an example TASK code that would send via Zigbee the current ID and present position of each of the seven servos used on a Master GERWALK bot to the embedded controller on another GERWALK bot set in Slave mode. The slave controller would then set its matching servos with these received values as their target positions, i.e., the Slave bot would imitate/repeat the Master bot motions (with a small time delay—Zigbee packets were sent at 57.6 kbps). Essentially this was an open-loop control application between the two bots.
- Homework 4—starting from this open-loop sample code, the goal was for the student to design a closed-loop solution that would allow the user to manually set the Master GERWALK bot into various random poses while the Slave Gerwalk bot would repeat these poses via ZigBee communications (as before with the open-loop version). However if any of the Slave bot's servos are "constrained "for some reasons (i.e., their "Present Load" parameter will increase over a threshold of 512), the Slave bot should send back "appropriate" information about this situation over to the Master bot which would then "stiffen" up its corresponding servo(s) so as to inform the user that there are some restrictions on the Slave bot's motion at that time and that the user should not continue his/her current bot operations.

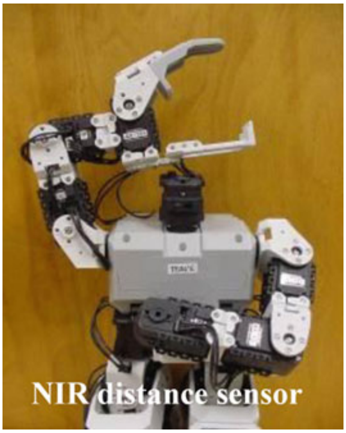



**Fig. 4** Bot "Teal'c" with Gripper (*right hand*) and NIR distance sensor (*left hand*)

"Software Design for Dynamic Stitching of Multi-Spectral Images of Field Crops" revisited servo control concepts presented in "Information Security Measurement Roles and Responsibilities" and added the torque limit parameter to be used in a force control algorithm:

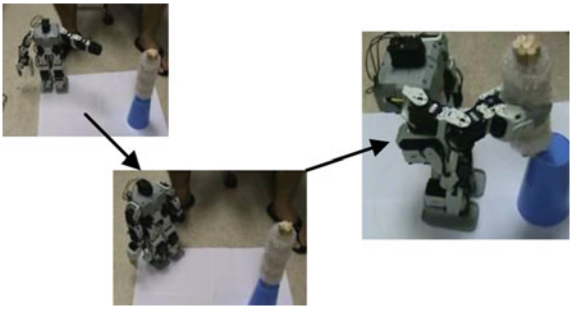
- Interactions between various servo parameter settings: goal position, slopes, margins, punch, present position, present load, and torque limit.
- Gripper Design & Programming (see Fig. 4)
- Gripper Force Feedback & Joint Offset programming with Motion Page and Callback Function.

"Teaching Robotics to Students with Mixed Interests" introduced students to sensors that can be used for balancing robots (see Fig. 2):

- The AX-S20 sensor can provide data for X–Y–Z accelerations and azimuth-roll-pitch angles at a 20 Hz refresh rate. As the azimuth angle was derived from a magnetometer, the AX-S20 was mounted in the bot's head so as to avoid magnetic interferences from the servo motors as much as possible.
- The gyro sensor can only provide X–Y angular velocities (Pitch and Roll) but at a faster refresh rate of 30 Hz. It is installed in the bot's belly (i.e., close to its C.G. as much as possible).
- An example TASK code was demonstrated to students showing how a Callback Function could be used to read acceleration data from the AX-S20 and use them in computing and set the proper Joint Offset values to selected servos so that the bot could maintain its original balanced position even though the platform where it stood was being moved to different random angles with respect to the ground surface (slowly of course due to the limitation of the 20 Hz refresh rate of the AX-S20). At present, we are still working on developing code using the gyro to allow the bot to walk on uneven terrain.

For the rest of the semester, there were no more formal lecture given, as the students were working on the final Project 3 and only needed occasional

**Fig. 5** "Teal'c" bot locating and grabbing dowel bundle



consultations with the instructor on some specific issues. The pedagogical approach used for Project 3 was inspired by the work of Patricia Stokes "Creativity from Constraints" [13], thus three humanoid bots were built with different capabilities/constraints and tasks to be performed and the students could choose their bots to match their own interests and abilities:

- The "Teal'c" bot (see Fig. 4) was equipped with a gripper and 2 NIR distance sensors (one on the tip of its left arm and one forming its head). Its task was to use its left arm sensor to locate the dowel bundle, turned an appropriate amount to face the bundle, approached it within a proper distance, then grabbed and lifted up the bundle (see Fig. 5). This project could be fulfilled using the RoboPlus TASK and MOTION tools.
- The "Beacon" bot (see Fig. 1) task was to use its wireless video camera to locate a blue dowel (its beacon) and walked to it, however it had to avoid the red dowels that were placed at random blocking its path towards the blue dowel (see Fig. 6).

  This project would require quite a bit of software integration work. As the wireless video camera was an analog USB device inputting into a PC, the student would have to create a Visual C++ program on the PC side to collect video frames in real time, process them to find the red and blue dowels, decide on the proper maneuvers for the bot, determine the equivalent bot commands to send through another USB to Zigbee device from the PC to the bot itself which would then decode and execute the commands received. Thus the "brain" was on the PC and the bot itself acted as an avatar. This project would require the RoboPlus TASK and MOTION tools, and also the Expert System binary C++ libraries for various function calls to the video camera and the USB-to-Zigbee communication device.
- The "Bal'Act" bot task (see Fig. 2) was to use the AX-S20 sensor to help it maintain balance as it walked up a ramp, however the inclination angle of the ramp could be varied at will by the user. The student would be provided with an example TASK code that first would set the bot into a static ready pose on a horizontal platform and record the corresponding "balance" values of the Pitch-Roll (X–Y) accelerations. Later when the platform's angles were changed by the user, the Callback Function would read the current X–Y accelerations, compute

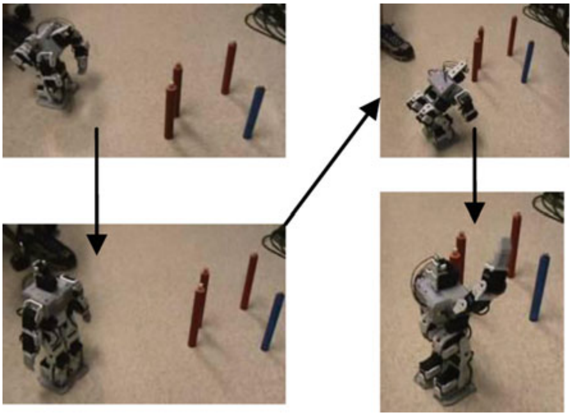


**Fig. 6** "Beacon" bot bending down to locate blue dowel, avoiding red dowels and finally reaching its destination

the required Joint Offsets to apply to the hip-leg-ankle servos in order to bring the X–Y accelerations back to the original "balance" values. This project could be fulfilled using only the RoboPlus TASK and MOTION tools.

## 3 Course Implementation

Spring 2010 was the first time that this course was offered, and five students enrolled for it: three senior-level engineering students, one graduate student from the department of mathematics and science education (MSE) and one graduate student from the department of theatre and film studies (TFS). During the first half of the semester, all five students were instructed together through "Customized Opinion Mining Using Intelligent Algorithms " and "Information Security Measurement Roles and Responsibilities", and Projects 1 and 2. From then on, each student pursued his or her own Project 3:

- The MSE student wanted to create a week-long short course for high-school teachers in robotics.
- The TFS student wanted to use a Premium Humanoid bot (see Fig. 2) and apply Disney animation principles [14] to the creation of "expressive" bot motions. He also wanted to compare the "Disney" results to those derived from standard inverse kinematics (which is a new tool provided inside the Robotis Motion tool).
- The three engineering students chose to work with the "Teal'c", "Beacon" and "Bal'Act" humanoid robots.

At this point in time, the MSE student had finished successfully with her final project. The "Beacon" project was also concluded successfully. The "Teal'c" project was achieved in three independent components: dowel bundle location with the left arm and appropriate body rotation to face the bundle, new walking gait to accommodate the extra weights due to the gripper and NIR sensor at the end of Teal'c arms, and in-place automatic body rotation to locate the bundle, grab and lift bundle (video clips had been obtained of these projects and public web links for them will be created shortly). Several control strategies had been tried unsuccessfully for project Bal'Act and the latest approach was to apply the servo balancing algorithm only for 0.125 s at the end of each motion page.

The official student course assessment data are not yet available from the BAE department, but informal student feedback indicated that this course was well accepted in terms of materials delivered and the challenging projects. The one complaint was about the RoboPlus Task tool being too "hobby-ish".

## 4 Conclusions

Our first attempt at creating an innovative and flexible robotics course to accommodate a range of interests at UGA was mostly successful. For some of the final projects, we had underestimated the level of complexity required. At the next iteration of this course, the plan is to go over the foundational materials more quickly and expand more on wireless and embedded techniques using C++ language.

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# An Initial Study Identifying Trends in Test Cases

**Shivsubramani Krishnamoorthy**

**Abstract** The paper presents a study where an attempt was made to understand the trends in test cases, generated for testing software programs. The main focus was to identify redundancies in the test cases that are generated, both, manually and in an automated fashion along with other significant trends. Three projects were considered for the analysis—two of which are widely used open-source projects and a course project. The analysis did reveal redundancies in test cases that could be easily avoided. It was attempted to equate redundancy with time. One of the projects was considered for the experiment, where the time to run the original test cases and the test cases after removing the redundancies was measured and compared. An improvement by about 40 % was observed. The analysis also revealed that the test cases were not designed to support all the environments/platforms the actual application does. This initial study shall, definitely, give a jumpstart for a full-fledged empirical study that needs to be performed to understand the actual impact of the redundancy in terms of time and cost. The study has made it clear that there are some significant concerns that need to be addressed when generating test cases for software programs.

## 1 Introduction

Every software program needs to be tested to verify whether it is behaving the way it is expected to. A lot of research is happening in the field of *Software Testing,*

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DOI: 10.1007/978-1-4614-3558-7_6, 

The focus of this research area has been into:

- Automating the process of test case generation.
- Efficient test case generation, in terms of time and cost.
- Efficiency, also, in terms of effectiveness of the test cases like coverage (code/branch etc.), maximizing bug/error detection, minimizing computation effort etc.

### 1.1 Motivation

No work was found in the literature (discussed in detail in Sect. 2) that specifically addresses redundancy in test cases and its impact. So it was an interesting problem to verify whether significant redundancies do occur in the test cases used for testing real world projects and whether they have any impact in terms of time and cost.

### 1.2 Objective

The main objectives of the study could be listed as:

- Study the trends in the test cases used in testing some real world projects
- The focus is specifically on identifying redundancies in the test cases
- To study the impact of the same in terms of time
- Discover any other interesting trends in the test case usage patterns.

The main objective was to perform an “initial study” determining whether it is significant to explore about redundancies in test cases.

Test cases for two open source software−GUITAR [1, 2] and Rachota (Version 2.3, 2.2, 2,1 and 2.0) [3]; and an undergraduate level class project were analyzed. The experiments show that there was significant number of redundancies in the sampled test case selected for the experiment. An attempt was made to redesign the test cases for the GUITAR application and it was noticed that the test case execution time was reduced by about 40 %. The study provides a jumpstart to a full-fledged empirical study that could be performed to understand the significance of avoiding redundancies and the impact it creates which I discuss in the Sect. 4 more in detail.

### 1.3 Overview

The paper is organized in the following way: Sect. 2 discusses about previous work done in the field of software testing; Sect. 3 lists the challenges encountered during the study; Sect. 4 explains the three applications considered for the experiments; Sect. 5 provides the experiments, results and discussion.

## 2 Related Work

Software testing is a very active field and a pretty rich literature is available about the work in this field. This section discusses only a few from the literature, relevant to this study.

It probably began in 1975 when Goodenough and Susan [13] tried to prove a fundamental theorem showing that properly structured tests are capable of demonstrating the absence of errors in a program.

Random test case generation is one of the easiest approaches followed, commonly, usually for small scare software projects. The un-deterministic nature of this approach was addressed and attempts were made to provide a more organized approach built upon the random generation approach, like ARTOO [16] and DART [17] etc. These approaches took advantage of the merits of random testing.

Lot of effort has been made in automating the process of test case generation [4]. The basic idea is to provide a test criterion based on which the test data could be generated without manual intervention.

Symbolic evaluation [5–9] was a mechanism adopted by many researchers. Symbolic evaluation involves executing a program using symbolic values of variables instead of actual values. Once a path is selected, symbolic evaluation is used to generate a path constraint, which consists of a set of equalities and inequalities on the program's input variables; this path constraint must be satisfied for the path to be traversed.

It was also learnt from the literature that UML diagrams are used to provide the criteria for test case generation. [11] discusses about applying state diagram in UML to class testing. A criteria is proposed based on control and data flow in the UML state diagrams. [10] also proposes an idea of using data flow analysis for test case generation. The authors argue that the control flow analysis of the program is not enough and the data flow should be analyzed to efficiently generate test cases. [12] also proposes the idea of utilizing dynamic models (state charts) for the same.

Some papers propose the idea of using AI planning [14, 15] for test case generation. [15] deals with testing GUI applications. It uses AI planning such that, given a set of operators, an initial state, and a goal state, a planner produces a sequence of the operators that will transform the initial state to the goal state.

"Coverage" [18] is one of the common criteria considered for test case generation. It could be in form of statement coverage, branch coverage, event coverage etc. It would act as a terminating factor when the maximum part of the program (in terms of statements, branches, events etc.) is covered by the used test case. The program is then considered adequately tested and no more test cases are considered required. To finally mention, there has been emphasis on intelligently selecting test cases for an application, like in [19, 20].

But, no work on studying or minimizing redundant test cases was found in the literature. That was the inspiration to perform an initial study to verify whether there exist significant redundancies in the test cases designed for real world projects and do they have any significant impact in terms of time consumed, for the test run.

## 3 Challenges

During the course of the study, a lot of challenges were encountered some of which had serious impact on the process. Some of the major challenges faced are discussed in this section.

The first and foremost challenge faced was with obtaining the data with which the study could be performed. It was a daunting task to obtain applications with available test cases which could be used for analysis. A lot of time was spent searching for data in the public domain—the Internet. Literally, no data could be obtained, in spite of a lot of effort put forth. About 15 projects were obtained with available test cases, but could not be used for the study because of either of the following reasons:

- the test cases were not usable
- the test cases were vague and no documentation/support was available
- The application was not an open-source which hindered the process to understand the application and the test case properly.
- Various versions of the applications along with the test cases were not available.

Sources in the industry were also approached in an attempt to have access to data. A request was put forth (though not in a very formal way) to people at senior software engineer and project analyst level at Cognizant Technologies, Bangalore, India and Celstream, Bangalore, India. The data could not be made available for many reasons like:

- Lot of formalities involved
- Highly time consuming.
- Policies that forbid them from sharing source code and test cases outside the company etc.

Though data could not be obtained from the industry, some employees volunteered to provide some feedbacks and their views on the findings of this study. Their discussions were in the industry point of view, based on policies actually followed in their project group.

The second major challenge was in normalizing the data that was used in this study. The nature of applications considered for the study differed and the test cases were designed accordingly because of which the way the test cases were to be run were totally different in each case. This hindered the attempt to automate the process. Moreover the results of the test cases, in each case, had to be manually analyzed and interpreted. This was an extremely daunting and time consuming process, which caused a lot of delay in the study.

## 4 Data

Since no available data was obtained from the public domain and the industry, data had to be obtained from research groups and class projects at the Department of Computer Science, University of Maryland. Though the data cannot be considered as good representative data, they are good enough for an initial study. A full-fledged empirical study could be performed with better data. Three applications, along with their test cases were considered for the studies.

- Guitar
- Rachota
- Mancala Game−class project.

### *4.1 Guitar*

GUITAR [1] is developed by the software testing group at the Computer Science Department, University of Maryland. It is a suite of models, components, and tools for automated testing of software applications that have a graphical user interface (GUI) front-end. It has been designed for Java Swing applications. Guitar is written in Java. It, mainly, comprises of four modules, as listed below:

- **GUI Ripper**—Rips the GUI. i.e., this tool creates a GUIStructure XML hierarchy, containing information of all windows, widgets, their attributes, and user events.
- **GUIStructure2EFGConverter**—Event-flow graph (EFG) generator, i.e., this tool creates an event-flow graph from the GUIStructure XML.
- **TestcaseGenerator**—Test-case generator. This tool uses a number of algorithms to generate GUI test cases that are sequences of events. Each test case would, typically, be a path in the EFG.
- **Replayer**—Test-case replayer. This tool automatically executes GUI test cases on the application under test.

GUIStructure2EFGConverter and TestcaseGenerator were considered for the study since the data for the same was more readily available and direct support from the developers could be obtained. The test cases available were at three levels:

- Large system tests
- Small system tests
- Unit tests (JUnit).

The test cases were Java Swing applications which the users design so as to obtain maximum coverage. The tests are in form of ANT script files which either builds successfully or fails. To analyze whether the test cases passed/failed, the

**Fig. 1** Rachota GUI


exceptions or other messages thrown by the ANT script were required to be assessed manually. Through the exception message, the corresponding part of code was analyzed to actually spot the reason why the test case failed and threw and exception. This was a very time consuming task.

### *4.2 Rachota*

Rachota [3] is a portable application for timetracking different projects. It displays time data in diagram form, creates customized HTML reports or analyses measured data and suggests hints to improve user's time usage. Figure 1 is a sample graphical user interface of Rachota.

This data was obtained from the event-based testing researchers community (http://comet.unl.edu), which is a collaborative initiative by some research groups at universities and the industry, hosted by University of Nebraska, Lincoln. The software testing group at the University of Maryland is also part of the community. The portal provides the Length 1 and Length 2 test cases generated by GUITAR for Rachota. Length 1 and length 2 refer to the length of the path in the EFG which is considered as a test case.

In this case too ANT scripts were to be built to perform the test runs. Guitar provides many.tst files as test cases. Figure 2 provides a sample.tst file which refers to a particular widget with a unique widget ID. In this case two widgets are tested in a sequence, whose unique IDs are e0 and e10, respectively. In case this test case produced an exception, I had to explore the .EFG XML file of the Rachota application to understand how the two widgets are related to each other and then trace it back to the.GUI XML file to actually understand what the widget it. The EFG file maintains the EFG graph structure in it and the .GUI file maintains the hierarchical

**Fig. 2** Sample test case XML file

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<TestCase>
    <Step>
        <EventId>e0</EventId>
        <ReachingStep>false</ReachingStep>
    </Step>
    <Step>
        <EventId>e10</EventId>
        <ReachingStep>false</ReachingStep>
    </Step>
</TestCase>
```

**Fig. 3** Part of the .EFG file for Rachota

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<EFG>
    <Events>
        <Event>
            <EventId>e0</EventId>
            <WidgetId>w7</WidgetId>
            <Type>EXPAND</Type>
            <Initial>true</Initial>
            <Action>edu.umd.cs.guitar.event.JFCSelectFromParent</Action>
        </Event>
        <Event>
            <EventId>e1</EventId>
            <WidgetId>w8</WidgetId>
            <Type>SYSTEM INTERACTION</Type>
            <Initial>true</Initial>
            <Action>edu.umd.cs.guitar.event.JFCActionHandler</Action>
        </Event>
```

GUI structure of the application. Figure 3 show parts of the EFG file generated from Rachota. The GUI file has too many details for even the smallest of the widgets, which cannot be accommodated in an image that could be displayed in this report.

## *4.3 Mancala Game—Class Project*

The final project considered for this study was an undergraduate level class project which the students developed as part of CMSC131—object oriented programming, in Spring 2010. The students were expected to implement certain methods in the incomplete project presented to them for which the course instructors had designed some JUnit test cases. A submit server, to which the students submit the projects, automatically tested the submissions and listed the results as a pass/fail (for each test case). There were 11 JUnit tests written for each submission. The students are encouraged to submit the project as and when the implement various parts of the project. Thus the typical situation on the submit server is that in the initial submissions, the students would have many red marks (which represents failure for each test) and eventually getting to all green marks.

### 4.4 Summary

Three applications were considered for the study.

- The test cases for Guiter and Mancala were generated manually and automatically for the Rachota.
- The test cases were tried only on one version of Guitar and Mancala
- Four versions of Rachota (V2.3, V2.2, V2.1 and V2.0) were considered for the study.

## 5 Experiment

As mentioned before, each application was different in nature and the test cases were designed accordingly. In this section I would explain how the experiment was performed with each of the applications, differently.

### 5.1 Guitar

Experimenting with Guitar involved:

- Running the test cases
  - Run the ANT script
  - Look for exceptions when build fails
  - Trace back the exception to the line of code in Guitar
- Explicitly generating failures
  - Based on the experience of running the test cases, the various part of Guitar code was learnt.
  - Some part of the code was purposefully changed so as some test case fails. (On average five changes were brought to each application)
  - It was verified whether any redundancy occurs in this case
- Informal discussion with the developers responsible for writing the code and generating the test cases. The redundancy, detected, was shared with them and their views were recorded on why the redundancy may have occurred.

In addition to just analyzing the test cases and their results, an attempt was to equate the redundancy in test cases to time. The system level tests results were analyzed, with the help of the developers and the cause of redundancies was figured out. Then, either the test cases were modified or replaced with non-redundant test cases. The test run times, with and without redundancy, were compared.

## 5.2 Rachota

The test cases, in this case, were generated automatically. Source code of four versions of Rachota (V2.3, V2.2, V2.1, V2.0) were available. Test cases generated by Guitar for the application (151 Length-1 test cases and 800 + Length-2 test cases) were also available. Length-2 test cases were considered for the experiment. The test cases were run for the different versions of the application in the following fashion:

- All the Length-2 test cases were run for Version 2.3.
- For the other versions, three randomly selected pools, of 50 test cases each, were used.
- The idea was to analyze those test cases for which the ANT script failed to build. This helped in filtering down the test cases and to analyze of a problem with a particular widget affected more than one test case.
- This did not mean that there were no redundancy in the test cases for which the ANT script built successfully. This helped understand that if redundancy occurred in such smaller set of test cases, then there would definitely be many more cases of redundancy in the whole pool of 50.

## 5.3 Mancala

Analysis of this test results of this application was comparatively easier as the submit server, where the students submitted their project, readily provided the results telling which test case failed or which one passed. A few submissions of the students and was analyzed looking for interesting trends in the same.

# 6 Results and Discussions

This section presents the results obtained in the experiments and the discussion pertaining to the findings. The results are discussed separately for each of the applications considered for the study.

## 6.1 Guitar

The test cases were run for testing the applications and all the tests ran properly. As the ANT script had instrumented code to display the coverage report using Corbetura (http://cobertura.sourceforge.net) the test case could be understood

**Table 1** Redundancy in test cases of Guitar

| System tests | | EFG converter<br>Test cases | Test case Generator<br>Redundant | Test cases | Redundant |
|---|---|---|---|---|---|
| | Large | 10 | 4 | 12 | 6 |
| | Small | 7 | 2 | 7 | 2 |
| Unit tests | | 28 | 0 | 24 | 2 |

better; it was convenient to trace which test case covered which part of the code. Table 1 shows the code coverage that each of the test suites produced. Then, an attempt to explicitly generate failures was made. Five failures were artificially caused by bringing changes into some part of the code (say, by changing condition of an "if" statements etc.). This approach was successful as it revealed some redundancies that existed on the test cases. Table 2 summarizes the findings in each of the case for both the modules of Guitar. Table 2 made it evident that there were obvious redundancies in the test cases generated for the application.

The next attempt was to equate the redundancy with time. With the help of the developer and the designers of the test cases, some of the small system test cases were either:

- modified
- discarded
- Or new test cases were developed.

The test cases were in form of small Java Swing application that would comprise of just a button, drop down menu, sub menu or simply a pop up dialog box. Finally seven test cases were set up for EFG converter module and six for Test case generator module. It was noticed that the time consumed to run the test cases reduced by a good margin. Table 3 exhibits the time recorded for running the test cases. On an average, 40 % improvement was observed when redundancy was avoided.

### *Discussion*

An informal discussion with the test case designers was conducted. From the discussion and from manual analysis of the test cases, it was understood that the main focus of the testers was "code coverage". All that they aimed for was to get maximum coverage with the test cases. The test cases generated by them followed the power law. For example for the small system test designed by them, just two out of seven test cases got them 84 % coverage. The rest of the five test cases were just to cover the rest of the 16 % of the code (as shown in Fig. 4). But then, the larger test cases unnecessarily cover the part that some of the smaller test cases cover individually. So, when an error was introduced artificially at the part of the program, both the test cases failed.

**Table 2** Code coverage produced by test cases of Guitar

| | | EFG converter (%) | Testcase generator (%) |
|---|---|---|---|
| System tests | Large | 94 | 91 |
| | Small | 100 | 98 |
| Unit tests | | 100 | 100 |

**Table 3** Time consumed in running the test cases

| | Time (seconds) | |
|---|---|---|
| | EFG Converter | TC Generator |
| Redundancy | 8 | 12 |
| No Redundacy | 5 | 7 |


**Fig. 4** Coverage produced by the small system test cases for Guitar−EFG generator module. Highlighted is the overlap between test cases

## *6.2 Rachota*

The experiment was performed using the Length-2 test cases generated by Guitar for Rachota. The test cases were initially run on Rachota Version 2.3 for which they were designed. All the ANT scripts were built successfully without exceptions. Thus not much could be inferred from this run. The test cases were then to be run on the other versions of Rachota. In a different version, there is a good chance that there is an additional widget or some widget would be absent. Thus, the unique widget ID/event ID assigned would differ. Thus, the objective is to find when a widget ID mismatch happens, how many test cases get affected by it. Typically, we would want to see only one test case that gets affected. If more than one test case get affected by the ID mismatch error, then it shows that the test cases are redundant.

Running all the 800 + test cases was impractical. So three pools of 50 randomly selected test cases were designed and applied on each version. The same set of three pools was applied on each of the versions. Table 4 summarizes the experiment findings. It was clear from the findings that V2.0 and V2.1 did not have much of any difference in the GUI design because no additional ID mismatch happened between the two versions. There were slight difference between V2.1, 2.2 and 2.3. The maximum number of changes my experiment discovered was eight which may be lesser than the actual number. Four different cases of redundancies were discovered (one of the redundancies discovered by pool1 and pool3 were the same). There are almost 650 test cases that could not be made use of. They could, probably, reveal many more redundancies.

**Table 4** Errors and redundancies discovered running test cases on Rachota (V2.3, 2.1 and 2.0)

| | Pool1 | | Pool2 | | Pool3 | |
|---|---|---|---|---|---|---|
| | Er | Redundant | Er | Redundant | Err | Redundant |
| V2.2 | 8 | 3 | 2 | 0 | 5 | 2 |
| V2.1 | 12 | 3 | 2 | 0 | 6 | 2 |
| V2.0 | 12 | 3 | 2 | 0 | 6 | 2 |

### *Discussion*

At the very first stage, it was noticed that many of the test cases generated by Guitar for Rachota V2.3 did not work properly with the V2.3 itself. Unexpected exceptions were thrown which was not comprehendible. With the help of the software testing group at University of Maryland it was understood that the test cases, automatically generated, would work only on Linux platform. I was trying to run it on Windows platform. After assessment, it was understood that because the GUI of the same program appears different on both Windows and Linux, the unexpected exceptions were thrown. The default colour of the window, or the default font face or the colour may differ in each platform. The test cases did not accommodate this flexibility. It was understood that redundancy was again probably caused because the focus was on event coverage. The algorithm was such that it tried to cover as many events as possible. For example, one of the redundancies reported for pool1 in Table 4 was regarding a pop up window. One of the test cases was dedicated in testing the open and closure of the pop-up window. But the same was again tested as a part of longer event sequence. Since the Id of the pop-up window differed in the different versions, the error was created and both the test cases failed.

## *6.3 Mancala*

The analysis with this project was quite straight forward. An interesting trend was easily visible in the test results generated by the submit server. Figure 5 depicts the submit server result for one of such submissions. It was found out of the 11 tests designed, tests 6 and 7 either passed/failed together. The same pattern appeared in 27 submissions.

### *Discussion*

It was understood that the two test case 6 and 7 were redundant because the tests were designed to test a method—toString() in both the cases. Test case 6 was dedicated to test the proper functioning of the toString() method. Test case 7 was

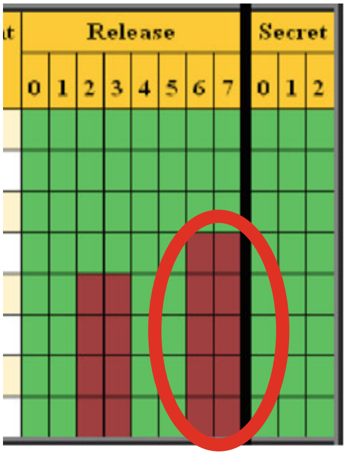


**Fig. 5** Two tests failed or passed together for the Mancala project submissions

to test the move() method, to verify whether the method made a legal move. The move() happened to call toString(), thus creating the redundancy. The students were, actually, misled because of this and they kept unnecessarily trying to debug the move(), whereas many of them had not implemented the toString() yet. So in this case redundancy was caused because the testers tried to play safe by being too rigid, testing the same part of the program more than once, which is not necessary.

# 7 Conclusion and Future Work

## *7.1 Summary*

It was understood from the study that:

- Redundancies do occur in a test suite and no effort is put forth in reducing or avoiding redundancies, by the testers
- These redundancies are caused because
  - The focus is only upon the adequacy criteria (coverage in this study) alone
  - The tester tries to be very rigid in the testing process and plays safe by testing the same part of the program more than once without any requirement.
- Redundancies do have impact in terms of time which could be very significant in case of large projects where tests are run on a very regular basis.

### 7.2 Suggestions

The redundancies could be easily avoided by:

- Better planning by the testers; by breaking down the test cases, covering smaller parts to minimize overlaps.
- In addition to breaking down the test cases, an attempt should be made to have a hierarchical organization of the test cases. A bottom-up approach could be followed where independent methods should be tested first before testing the dependent methods.
- Test cases should also be designed such that they are flexible and support all the environments the original application supports.

### 7.3 Feedback from the Industry

The volunteers from the industry seconded the findings agreeing to the fact that their groups focussed only on coverage (line, branch and class) for testing their applications and had never made an effort in discovering or avoiding redundancies in test cases. They also agreed that their test cases were not usually designed to be flexible with environments. Separate test cases were designed as and when required. One of them did raise the concern whether test cases actually needed to be flexible. This study does not provide a strong evidence for the point, I leave it for a future study.

### 7.4 Future Work

This study was performed with lack of enough time and lack of proper data. But this study itself provides some insights which can be significant.

This initial work does prove that redundancies do occur in test suites which can have significant impact. So a full-fledged empirical study could be performed to:

- Empirically prove that significant amount of redundancies exist in test suites
- These redundancies have significant impact on time and cost

Of course, for such a study, there is need to have access on better and richer data which should be obtained from the industry (in form of formal collaborative work) as my effort has also shown that rich data is not available in the open domain like the Internet.

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# Providing Strategies for Education in Engineering for Virtual Team Development

**S. E. McCaslin and M. Young**

**Abstract** The globalization of the new product development workforce is a growing trend as companies search to improve their effectiveness. This paper examined the education foundation necessary for engineering students to work effectively in virtual teams, especially new product groups. The paper suggests how small changes in group assignments may benefit students and eliminate potential problems in the organization. Implications include curriculum changes to increase team effectiveness and enhance collaboration among team members.

## 1 Introduction

The ability to use modern information technology has been identified as a major need for modern engineers [1]. Engineering students now need skills that include working across time and distance boundaries, and "collaborative competencies" in additional to technical knowledge and skills [2]. In other words, the modern engineer needs "the knowledge, skills, and habits of mind" that will aid in collaborative approaches to problems and challenges [3]. Students need knowledge of how to use available information technology to facilitate the sharing of information [4].

A formal survey of fifteen companies (conducted by the Industry-University-Government Roundtable for Enhancing Engineering Education) showed that a students' ability to demonstrate an "understanding that engineering is affected by information technology" was the most highly ranked outcome under the ABET "knowledge of contemporary issues" criterion [5]. In addition, "Skills in use of Office, Telecommunications, and Information Technology Systems and Tools"

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ranked as the number fourth outcome under "Ability to Use the Techniques, Skills, and Modern Engineering Tools Necessary for Engineering Practice" [5]. In a competitive market, virtual teams represent a growing response to the need for effective new product teams and must eliminate time and cultural barriers.

## 2 Literature Review

Stating the need for engineers to have strong skills in virtual product development, Zavbi and Tacar created an international course enable students to become successful members of global product development teams [6]. In their work, they described the resulting E-GPR (European Global Product Realization) course and concluded that the major strength of the course was its "real live" aspect [6].

Chin et al. found that leaders who give virtual team members feedback via written communication that was both directional and empathetic were perceived as more effective and lead to better performance [7], which emphasizes the need for both written and oral communication in a global engineering framework.

Shachaf [8] focused on the effects of cultural diversity, and his research showed "cultural diversity had a positive influence on decision-making and a negative influence on communication." His work also included recommendations for effective technologies to facilitate intercultural communication. Included in this list were email, teleconferencing combined with e-meetings, and virtual team rooms.

Alexander [9] performed a study involving students enrolled an introductory course who were allowed to choose when and where they did the required collaborative work. He discovered that the importance of teaching students social and technological skills cannot be over emphasized.

Van Ryssen [10] experimented with a course over a period of five semesters and successfully demonstrated that cross-cultural learning may be accomplished without expanding beyond the normal curriculum. Students were partnered with team members from another country, and the team then jointly analyzed the marketing of a product in both countries. Communicating primarily by email and the web, they worked together in virtual teams to complete this task. It is worthy of note that the professor/instructor's ability to help students overcome barriers to successful intercultural communications, not on mastery of technology, was a key point in their work.

## 3 Communicating Across Global Boundaries

One of the major goals of contemporary information technology in the context of engineering is to support communication among global team members. Communication is probably more important than ever before, since more and more engineering teams consist of people not only in different cities or states, but on different continents [11].

Communication may be defined as the process by which information is both transmitted and understood between two or more people [12] and is not limited to verbal communication: hearing, seeing, touching, and smelling are all forms of transmitting information [13].

Without adequate communication, any team's success in achieving its mission is impossible. The major communication barriers faced by global teams are language, time, and culture. Language issues are most prominent in verbal communication, where both lack of foreign language skills and strong accents can hinder communication. Time becomes an issue for team members working in widely differing time zones across the world. Cultural issues can be more difficult to detect since each of us filters what is communicated through our own culture and understanding of the world [14]. When properly used, information technology is a powerful tool for overcoming each of these hindrances.

Communication among global teams may be broken into passive (asynchronous) and active. Passive communication includes email, virtual private networks, online file access systems, and newsgroups. Active communication would describe face-to-face communication such as group meetings, web conferences, video conferences, and instant messaging.

The communication requirements change during the project in that trust is built through face-to-face communication. Real-time media (such as web conferencing or video conferencing) aids in keeping the team synchronized, and passive communication allow team members to retain a connection over time [15].

Due to the decentralization of global teams, the task of project manager has become even more important [16]. The project manager must have a solid understanding of the technological tools available for global collaboration [17], and how to effectively use them. However, as the use of global teams becomes more common, it is important than undergraduate engineering students be prepared to participate in these teams through familiarity with the technology involved and guidelines for their effective use. As an example, consider Stanford's Architecture/Engineering/Construction program. It includes global projects where part of the coursework includes training students on collaboration and information technologies to support their teamwork [18].

## 4 The Role of Information Technology

Information technology has been identified as a major supporting factor behind four basic tasks vital to global engineering teams [16]: (1) coordination of project activities occurring at various global locations; (2) exchange of technical information; (3) promotion of both creativity and quality of work; and (4) development of trust, all which are part of communication.

Tasks one and two can typically be achieved without reliance on face-to-face interaction, focusing rather on online access to technical information and project planning documentations. Task three is supported through web conferencing, video conferencing, and teleconferencing, all of which can reduce the stress load and time lost due to travel [16]. Trust in global teams is highly dependent on communication. Because of this, selecting the means that allows for the clearest mode of communication between team members becomes vital.

*Email*, a standard form of passive communication for both national and global teams, was used by globally-located undergraduate students working on an aerospace design project to communicate throughout the design process [19]. Documented issues with email communication included a series of requests and updates that gave conflicting instructions, failure to specify whether a response was required, and who is responsible for responding [19]. On the positive side, they noted that files are easily shared and responsibility clearly delegated [19]. Email also allows graphic, audio, and video files to be attached, which greatly increases its usefulness.

*Virtual private networks* enable a virtual team access to its confidential work from any location, while keeping it separate from the rest of company's network (and the Internet) [17]. Localized teams make use of group hubs, network drives, or web drives, with software such as *Microsoft SharePoint*. This approach is sufficient for localized teams, but risky for global teams because of the danger of slow transfer speeds. For global teams, one typical approach is *web hosting* [12], which provides users access to project documents and information through a web browser, independent of location.

*Newsgroups* (or listservs) are another low cost option for asynchronous team communication. News groups are "threaded" discussions stored on a remote web server. This option allows users to participate in a multi-way communication with other newsgroup members [20]. This technology captures discussions electronically, which provides documentation of the discussion [17] and works in a way similar to *discussion boards*; however, it is more general, typically stored indefinitely, and often accessible to anyone [21].

*Face-to-face communication*, also known as active communication, occurs in real time and is one of the best methods for both avoiding miscommunication and receiving timely feedback. However, it is also the most difficult to achieve for global teams. Without real-time discussion, the probability of miscommunication increases. Difficulties include trying to assemble the global participants at one time in one geographical location, along with the typically cost prohibitive travel expense.

*Teleconferencing* is a vehicle to reduce travel costs, but does not allow any type of visual contact between participants. The costs of extended long distance and international calls may be very high. To avoid such costs and improve the sound quality, Voice Over Internet Protocol (VOIP) provides a viable option. However, one drawback is the issue of setting up an agreeable time for all parties and this remains problematic for global teams.

*Video conferencing* is an alternate form of face-to-face communication that does not require all participants to be at the same geographical location. Web cams are readily available and are a cost effective means of accomplishing video conferencing through *web conferencing* [17]. While supported by a variety of software such as *Microsoft Net Meeting*, *Live Meeting*, and *Elluminate*, benefits include the ability to hold frequent, effective discussions that can last for several hours without issues such as losses due to travel time and jet lag [16]. Participants need Internet access, web cams, and headphones/ear buds to be able to communicate both visually and audibly.

*Instant messaging* is another popular means of active communication. It is probably the communication method most familiar to students. However, while it avoids the problems in understanding the spoken word, there still exists the possibility of time lost waiting for a response if the working hours of the participants do not overlap [19]. The lack of verbal cues may become a problem, but if the team members know each other the lack of non-verbal cues may be less of an issue [22]. It is worthy of note that at Stanford, students working on global design teams tended to prefer instant messaging as opposed to audio communication. Their reasoning was that typing saved more time than trying to understand each other verbally [4].

*Document sharing* is another major factor in almost any collaborative project, including those far outside of scope engineering. Software packages such as *MS Office* provide a variety of built in tools to allow a group of users to collaborate on a single document, whether it is a spreadsheet, presentation, or a technical report. Features such as change tracking, commenting, and comparison can save time and effort when properly used.

## 5 Student Skills and Knowledge

Most students will know how to use email when they enter college; however, its proper use may be another matter. Tone and non-verbal cues are almost impossible to transmit via email, which increases the possibility of miscommunication. No established etiquette for the proper use of email exists [22]. If email is to be used as a primary means of communication, students should be aware that rules need to be implemented in a team context to effective communication. An example would be this: if the intended information is not understood within two replies, then a face-to-face form of communication must be implemented [23].

Other dangers include the ease of which the “Reply All” button can be used, causing user’s inboxes to fill with email that only tangentially relates to them. International character sets can also pose a problem with email [24], and may become a hindrance for email communication with some companies. Users should also be aware that email is not appropriate for transmitting sensitive information or for multi-user discussions [17].

Email and instant messaging may have some unusual benefits. Team members cannot see each other or hear each other audibly, so perceptions of age, gender, race, and personal characteristics are eliminated. Participants may then focus entirely on the information transmitted without being distracted by accents or appearance, or hindered by cultural issues [25].

Students may be exposed to group access to files in a variety of ways. Online document sharing is possible through enterprise content management packages such as *Xythos*. [26]. At The University of Madison Wisconsin, *Xythos* has allowed students to collaborate on team projects by posting the documents involved and emailing a link to their team members [27]. Students can create contact lists and groups, upload (and download) files, allow access to certain files, and assign permissions to those files. An understanding of these concepts (especially permissions) will give new engineering students a definite advantage in the workplace even if they do not work on global teams.

Other asynchronous communication tools that students may easily be encouraged to use include instant messaging and email. Educational packages such as *Blackboard Release 9.1* include both synchronous and asynchronous tools, that include live group communication, discussion boards, wikis, and blogs [28]. Instructors may easily include these items as part of assignments.

Feedback, questions, and verifications communicated using passive communication may be delayed up to 24 h for global teams if there is not sufficient overlap between working hours. Workdays may have to be reorganized to fit the schedule of others, which will be inconvenient, and is one of the most difficult aspects of global teaming [29]. In addition, when team members are not readily available for discussion and clarification of major issues, frustration will result [30]. Engineering students should be taught that these issues are an unavoidable aspect of working on global teams. Also, they will learn to recognize which type of communication is best suited to a particular problem.

Web conferencing software such as *Elluminate* allows participants to see and hear each other, communicate privately through instant messaging, post information for others to see, and make permanent electronic records of the meetings [31]. Colleges and universities with access to similar packages can make them available for student use, while encouraging them to explore new means of collaboration. Students should become more comfortable communicating with a webcam for technical and professional purposes. This will make it possible for them to enter the workforce with a working knowledge of the process and technical issues that can occur.

With the exception of teleconferencing, face-to-face communication allows the participants to communicate more broadly through non-verbal means such as gestures and visual cues [22]. Also, the need for team members to "know" with whom they are communicating is enhanced [32].

Face-to-face communication has definite drawbacks. Unless careful minutes of the meetings are kept, no documented record of decisions made unless recordings are made. Some team members might be intimidated by others during face-to-face contact, even with web or teleconferencing. Language barriers may cause difficulty in deciphering the spoken word as opposed to the written word. Students need an understanding of both the advantages and drawbacks of face-to-face communication, and must realize that although it may be their preferred method of communication, it will not always be possible.

The use of word processing and spreadsheet packages is almost, if not totally, universal among undergraduate engineering programs. Through regular use of the software to write lab reports and design reports, most students will gain sufficient skill in using these packages. However, many students know little of the collaborative features that are available to them. Some demonstrations of how to use these features would probably be sufficient to encourage students in exploring these features.

Finally, Gartner Research provides these guidelines for global team communication [30]: "(1) Team members must identify when they are available to receive and respond to communication; these schedules must be respected by team members.; (2) Team members must be explicit in their communications regarding intent, relevance, situation and purpose; (3) Team members should strive to meet regularly on a synchronous basis to maintain rapport and continuity; (4) Senders must take responsibility for prioritizing communications as urgent, important, routine or informational-only."

A simple set of collaboration rules such as this could easily be provided with team based projects to get students in the habit of communicating in a clear, professional, responsible manner.

## 6 Recommendations

Many engineering schools find their curriculum pressed to the limit to include the necessary course material, without the added worry of courses to train students to function well in a globalized environment. However, small changes regarding how students approach collaborative projects have the potential to make a tremendous difference in their teamwork skills. Therefore, instructors should consider requiring students to make use of collaborative tools already available to them.

The students will then gain the experience and self-confidence needed to work with similar tools when they start their careers. The idea of working on a project with someone they may not see (or even hear) will not be a foreign idea to them, and they will be well practiced in communicating through a variety of mediums ranging from instant messaging to discussion boards. If these habits are instilled in engineers while still in college, their careers could be enhanced.

A team-based design project adapted to aid in preparing engineering students for global design assignments should focus on commonly used collaboration tools, and is recommended to curriculum planners. Five software tools and methods of utilization are offered:

- *On-line file storage* (*web hosting*): The student design team leader creates a design team group with a folder for the design project. Next, the leader would set up access to the design project for the team and the instructor. The entire team participates by posting project related files to the design project folder.

- *Student email:* All team members will complete additional training with student email. Topics covered will include how to add a contact, create a contact group, attach files, request read receipts, and set priority for email.
- *Webconferencing:* Using software, such as *Elluminate*, provide students with access to tools for communication among team members and encourage its use for communication with the instructor.
- *Microsoft Office Collaboration Tools:* All team members will receive fundamental training in collaboration in using Word, Excel, and PowerPoint. This will primarily focus on change tracking and commenting.
- *Discussion Forums*: Participation in discussion forums for group communication and communication with instructor would be required of all students.

Students will be required to post schedules discussing when they are available to meet physically and when they are able to receive communication. Teams will develop their own rules for how their team will communicate. Training on the software will be provided through short mp4 videos posted online. Student participation in the training sessions will be measured through short quizzes covering the material presented on the videos.

## 7 Conclusions

This study illustrates the challenges engineering schools encounter in providing effective education for global team effectiveness. Many schools are experimenting with technology to prepare engineers and providing a valuable role for their careers. This study provides a literature survey and specific methods for enhanced curriculum additions. Engineering colleges should continue to monitor and help improve technical expertise and cross-cultural training for new product development teams.

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# New Automated Assembly Model Based on Automated Route Card Scheme

**Yuval Cohen and Dina Goren-Bar**

**Abstract** This paper describes a new modelling technique that enables modelling and implementation of automatic assembly of complex products. The modelling scheme has two levels: The upper level is a Petri net formed around the product structure tree, and ensures that each sub-assembly starts its assembly only after all of its necessary resources are secured and all its components are ready. The lower level (the more detailed) describes the tasks necessary for the assembly of the sub-assembly (at each stage). The model can be translated automatically to ladder diagram and implemented using a Programmable Logic Controller (PLC).

## 1 Introduction

Currently, many assembly processes and their execution are documented and illustrated on assembly instruction cards called route cards (see Fig. 1) [1, 2]. This paper describes a new modelling technique that utilizes the information of route cards to automate the assembly process. The technique facilitates the generation and validation of automation control code of assembly processes. The model uses a specific framework to generate a Petri net (PN) that fully describes the assembly process. A comprehensive overview of PN is given in [3]. The generated PN has many advantages such as built-in deadlock avoidance, intuitive structure, and a straight forward translation option to Ladder Diagram (LD)—the popular Programmable Logic Controller (PLC) language. LD could be implemented on

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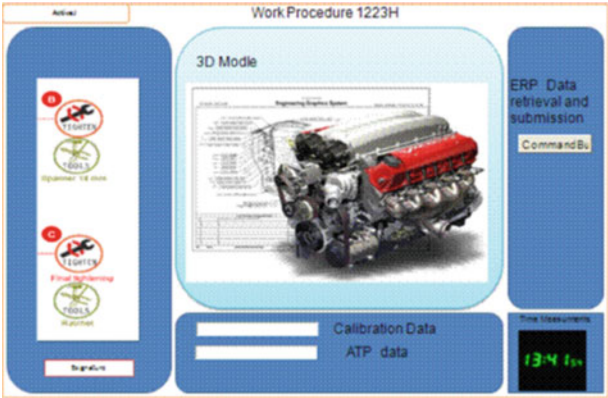


**Fig. 1** Typical assembly route card

readily *available* equipment in most shop floors. A comprehensive overview of LD is given in [4].

However, the proposed model greatest advantage is its compatibility with the route card system and the ability to automate only parts of the process while certain parts may remain manual assembly. The model takes advantage of some previous modeling developments such as [5, 6].

The rest of the paper is built as follows: Sect. 2 describes the static model structure, Sect. 3 describes the dynamic PN model, Sect. 4 discusses modelling of low level inputs and outputs, Sect. 5 describes the translation procedure to LD, and Sect. 6 concludes the paper.

## 2 The Static Model Structure

Traditionally, there are two very different ways to describe the assembly process: (1) precedence diagram [7, 8], and (2) product structure tree [9] [often called Bill of Materials (BOM) tree]. Typical examples of these two models are illustrated in Fig. 2.

In Fig. 2a the numbers are sub-assembly numbers and the numbers in brackets are quantities.

We examined hundreds of instances and found consist matching between Route cards and the nodes of the BOM tree. While in most cases we found a one to one correspondence, in other cases there were tow or even three route cards related to a node. But the rule is that a route card can always be associated with a BOM-tree node. On the other hand, the activities described within each route card could be easily arranged as a precedence diagram.

Thus, our static model is based on hierarchy of two levels. The upper level describes the product structure, and the detailed level describes the activities using

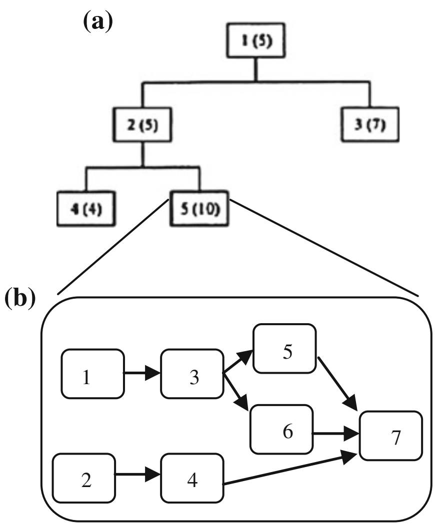


**Fig. 2** **a** An example of product structure tree (BOM tree). **b** An example of a precedence diagram

a precedence diagram. Depending on the shop floor characteristics the BOM tree either remains as it is or may require a re-arrangement. For example, sequential assembly line would require the tree-nodes to be re-arranged in a line. For example, re-arranging the tree of Fig. 2a in a line may give a sequence of: 5–4–3–2–1, or 5–4–2–3–1, or 4–5–2–3–1, etc.

The above model is static and would not suite the dynamic nature of control systems. Therefore, the next section describes the dynamic model is related to the static model.

## 3 The Dynamic PN Model

For the dynamic model a modified PN with dynamic tokens is used. In the upper level (the BOM tree) the PN modification includes three types of PN places: (1) sub-assembly places, replace the BOM tree nodes, (2) resource places for each non-consumable resource required for the assembly at each of the sub-assembly nodes. Such as machines, tools, operators, etc. (3) component/material place for elements consumed by the sub-assembly.

The difference between resource places and component/material place is that resources must be released once the operation is done, while the components become part of the sub-assembly and are not released. Another difference is that the availability of components and materials must be detected via sensors, while the dedication and release of most resources (machines and tools) may be done by the system control logic without external interface. Figure 3 depicts an example of a part of the proposed Petri net.

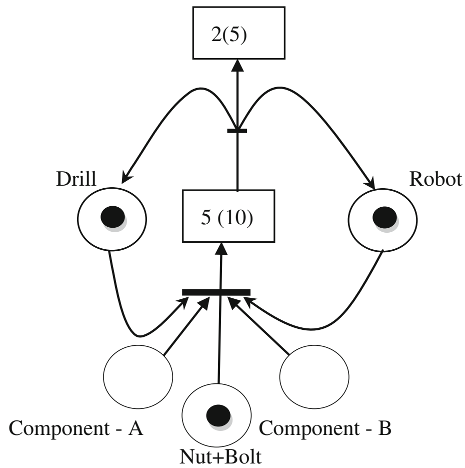


**Fig. 3** An example of a segment of the proposed PN

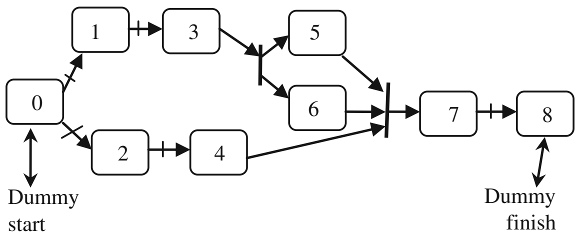


**Fig. 4** PN for the precedence diagram of Fig. 2b

In Fig. 3 the three lower places are component places, and the availability of nut and bolt is indicated by a token (implemented by a sensor).

Figure 3 shows that there are no available components of types A and B. So the transition is not operated. However the robot and the drill are idle (the token indicates that) and once the components arrive, the operation of building sub-assembly 5 could start. The numbers in brackets are quantities. So after generating 3 sub-assemblies (of type 5) the next transition is activated to release the robot and the drill and build sub-assembly number 2.

The PN model for the precedence diagram is pretty straight forward Each activity node is expressed as a PN transition followed by a place and each precedence relation is an arc from the corresponding place to the corresponding transition. A dummy place is added at the beginning and the end of the precedence diagram to ensure single starting and finishing points. When the sub-assembly place corresponding to the precedence diagram is activated, a token is passed to the starting dummy place. When the stage is completed, a token is passed from the finish dummy place to the next transition on the upper level PN. Figure 4 depicts the PN for Fig. 2b.

Committing the resources, components and materials at the upper level (BOM tree level) ensures that there would be no deadlock at this stage. However, in case of doubt—resources and components could be added to this level too.

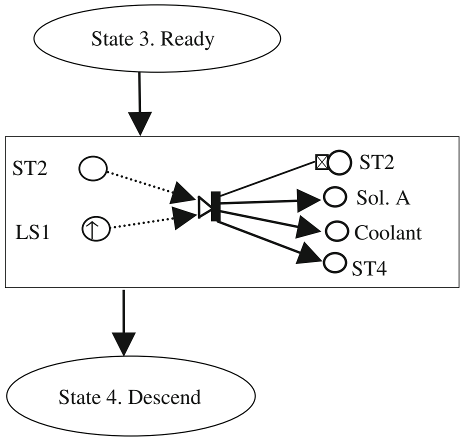


**Fig. 5** A segment integrating an E-Transition for transition from action 2 to action 4

Modelling the two levels with PN enable the full description of an automated assembly system, or a partially automated assembly system.

While the dynamic model (with its two levels) is complete, having a dynamic model cannot be implemented on current shop-floor equipment. Section 4 deals with translating the model to Ladder Diagram (LD) that works on most PLCs.

## 4 Modelling the Inputs and Outputs

Since automatic control uses electrical inputs and outputs, one more level of detail is necessary. Namely, tracking the changes in these elements at each transition between assembly activities (of the second level). The graphical scheme is named E-Transition (for Elementary transition). E-Transitions describe the changes in low level elements such as inputs, outputs, and registers, required for executing the model. E-Transitions arrange the elements in a meaningful way that enables immediate comprehension of a low level code. The E-Transitions are composed of the following elements: (1) places, (2) triggers, and (3) arcs. These elements are all depicted in Fig. 5. Each transition is activated by one or more triggers. The triggers are denoted by triangles pointing at a thick vertical line that symbolizes the transition. Places (denoted by circles) represent the inputs, outputs, events, and variables.

Events are assigned places with additional symbol to denotes the type of event (turn ON, and shut OFF). Places that use non-binary data (e.g., timers and counters) are denoted by rectangles. Additionally, places are added for logically denoting the states of the system. For example, a transition from activity 2 to activity 4 uses the corresponding ST2 and ST4 variables.

Two arc types used to activate triggers are as follows:

1. An enable arc ( ·······▶ ) the triggers can fire only while the source place holds a token.
2. A disable arc ( ···········● ) the triggers can fire only while the source place is OFF.

Enable and disable arcs are drawn with dashed lines to denote that they do not activate or deactivate elements. Tokens are used to denote activated places. Two types of arcs used to identify the effects of a transition as follows:

1. Activate arc ( ·······▶) turns ON the place when the corresponding E-Transition is activated.
2. Deactivate arc ( ———⊠) turns OFF the place when the corresponding E-Transition is activated.

Each trigger is invoked by places linked to the trigger by enable or disable arcs. Note the usage of the source state (STi) variable of the E-Transition to facilitate trigger's identification as one of the trigger's conditions. After the trigger is activated, a transition from the source state (i) to another state (j) occurs immediately. Each E-Transition also resets the source state variable (STi) and sets the destination state variable (STj). Note that each trigger has only on E-Transition, but a transition may have more than one trigger.

## 5 Translating the Model to Ladder Diagram (LD)

Ladder Diagram (LD) is a popular PLC code which was chosen to illustrate the translation of the model to PLC code. Today, most of the discrete control programs are developed using LD. The generated LD rungs are arranged in three main blocks as follows: (1) events identification (2) transition triggers, and (3) transition effects. The construction of the above three blocks is presented next.

### *5.1 Events Identification*

Inputs and outputs change their voltage level when turned ON or OFF. These changes are referred as rising or falling edges. The international standard IEC 61131-3 defines special LD contacts for detecting rising and falling edges. A rising edge corresponds to a place with "↓" and a falling edge to a place with "↑".

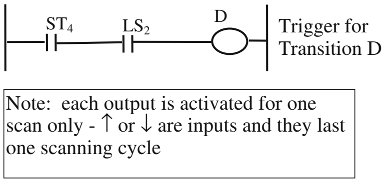


**Fig. 6** Ladder Diagram segment for triggering transition D

## 5.2 *Transition Triggers*

Each trigger activates one E-Transition. Each transition is assigned an internal variable in the LD. When the E-Transition is enabled that variable will be turned ON. In order to implement this logic, a set of rules is described as follows:

I. Each trigger forms an LD rung.
II. Each place (in E-Transition) that is input to a trigger forms a contact: (enable arc forms a normally open (NO) contact, and disable arc a normally closed (NC) contact.
III. The LD rung output is a variable that corresponds to the activated transition.

Figure 6 depicts a ladder diagram segment corresponding to the triggers of transition D.

## 5.3 *Transition Effects*

The rules for establishing the ladder diagram portion of transition's effects is as follows:

1. Dedicate a rung for each output place of the transition and add to it a corresponding LD output.
2. In each rung add a contact that corresponds to the relevant transition.
3. Activation arcs are translated into latched outputs, and Turn-off arcs are translated into unlatched outputs.

# 6 Conclusion

This paper presents a new automated assembly modeling technique for discrete control. The technique is intuitive (based on current documentation structure), and has a potential to be used also for simulation, validation, code generation and maintenance. The translation algorithm of the model to LD not only enables its implementation on currently available equipment (PLCs), but also carries the promise to reduce the cost of code generation and maintenance, and could contribute to progress towards more flexible automation.

Future research includes implementation of the proposed technique on an industrial shop floor. This would enable simulation and visualization of operation; it would assist in real-time tracking and failure analysis of the control system.

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# On Using a Semiotic Quality Framework to Evaluate the Quality of Conceptual Database Schemas

**Erki Eessaar**

**Abstract** In this paper, we introduce a semiotics-based framework for evaluating the quality of conceptual schemas of databases. We created it based on an existing semiotics-based framework that has been used to evaluate other types of software entities. We propose two measures for evaluating the perceived semantic quality of conceptual schemas. The measures consider correspondence between conceptual data models and conceptual schemas that are created based on the models. In addition, we describe how to use one of the measures to evaluate computer-aided software engineering systems in terms of transforming conceptual data models into conceptual database schemas.

## 1 Introduction

One of the first steps of database development is the creation of a conceptual data model [1]. Integrity constraints are integral and important part of conceptual models. They specify the semantics of problem domain [2]. Moody [3] identifies over 50 proposals about the quality of conceptual models. According to the transformational and model-driven approach [4], database developers create logical data models, physical data models, and statements of data definition language (DDL) by using a sequence of transformations. The resulting schema of each transformation should have the same descriptive power as the source schema, though with a different representation. One has to execute the DDL statements in a

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database management system (DBMS) to create database schemas. According to the ANSI-SPARC architecture, a database has one or more external views, one conceptual view, and one internal view. The conceptual view "is a representation of the entire information content of a database" [5, p. 39]. Each such view is defined by means of a schema. In this paper, we propose a novel framework for investigating the quality of conceptual schemas. We do not consider external and internal schemas. The development of views (that belong to the external schemas) and objects that help developers to improve the performance of database operations (that belong to the internal schema) is too DBMS-specific. Some authors use the concept "conceptual schema" to denote a conceptual data model but in this paper it denotes a part of implementation of a database.

For relational databases there exist a number of formal principles like the normalization theory and the principle of orthogonal design [5] that guide the development and evaluation of relational database schemas. Baroni et al. [6] present a set of measures for evaluating object-relational databases. The measures do not take into account how well a database schema corresponds to the requirements, based on which the database is created. The transformation rules for creating the conceptual schema of a SQL-database based on a conceptual data model, which is created by using UML, are presented for instance in [7]. In addition, Marcos et al. [8] present a set of rules for transforming generalization and whole-part relationships to an object-relational database schema. If the transformation rules are violated, then a high quality conceptual data model may result in a poor conceptual database schema. Blaha [9] and Cleve et al. [10] describe deficiencies in the existing database schemas. For instance, many integrity constraints are not enforced at the database level. It may decrease data quality [10] and productivity of application developers [11]. A possible reason of such state of affairs is that existing computer-aided software engineering (CASE) systems provide limited support for generating code that implements different integrity constraints [12]. In addition, SQL and SQL DBMSs limit the use of declarative integrity constraints [13] and hence one has to use complex trigger procedures to implement many constraints. However, such difficulties should not prevent us from trying to improve the quality of database implementations.

The *first goal* of the paper is to propose a semiotics-based framework for evaluating the quality of conceptual schemas of databases. It is based on the semiotic quality framework of conceptual modeling SEQUAL that was proposed by Lindland et al. [14] and has been revised and extended since then. We concentrate our attention to the *perceived semantic quality*. Our examples are based on SQL. However, the framework is usable in case of any database language, the abstract syntax of which can be specified by using a metamodel. The framework can be used to compare model transformation facilities of different CASE systems. The *second goal* of the paper is to present a method for evaluating CASE systems in terms of transforming conceptual data models into conceptual database schemas and the results of a small experiment.

The rest of the paper is organized as follows. Firstly, we specify a semiotic quality framework for evaluating conceptual schemas of databases. We apply it to evaluate the quality of a database schema. In addition, we propose a method for evaluating CASE systems in terms of their model transformation facilities. Finally, we draw conclusions and point to the future work with the current topic.

## 2 A Quality Framework of Conceptual Database Schemas

Some researchers have used semiotics as the basis of evaluation frameworks of different kinds of software entities. For instance, Lindland et al. [14] and Krogstie et al. [15] use semiotics to evaluate conceptual models and process models, respectively. Merriam-Webster dictionary [16] defines semiotics as "a general philosophical theory of signs and symbols that deals especially with their function in both artificially constructed and natural languages and comprises syntactics, semantics, and pragmatics".

Each database language provides a concrete syntax for creating data types, data structures, constraints, and operators. Each conceptual schema is created by using a set of statements in a data definition language (DDL). This language is a subset of a database language. Hence, it is interesting to evaluate such schemas in semiotic/linguistic terms. In this paper, we explain how to use semiotics as a basis to evaluate the quality of conceptual schemas and how some of the existing approaches fit to this framework. The proposal should *extend* existing evaluation approaches, but not replace them.

Krogstie et al. [15] use a set-theoretic approach to present a semiotics-based framework of evaluating model quality. They define model quality at different semiotic levels as the correspondence between statements that belong to different sets. We describe some of the sets in terms of our problem domain—evaluation of conceptual schemas.

*G* the goals that a database must help its users to achieve. *L* the set of all the statements that one can make by using a database language. The language is usable in a DBMS, based on which the database will be implemented. For example, it can be a dialect of SQL that corresponds to the SQL:2006 standard [17]. Each database language has the underlying data model—an abstract programming language—that determines the abstract syntax of L. *D* "the domain, that is, the set of all the statements that can be stated about the situation at hand" [15]. *Ks* the pertinent explicit knowledge of the set of stakeholders who are involved in modeling. This knowledge about the domain is specified by using a conceptual data model that represents stakeholders' perception of reality. It is created during system analysis. *M* the externalized model, which is the conceptual schema of a database in our case. We assume that the externalized model consists of statements that belong to L. *I* the social actor interpretation. It is the set of all the statements that the audience (database developers and users) thinks that M consists of.

## 2.1 Semantic Quality and Perceived Semantic Quality

Semantic quality is in our case the correspondence between a conceptual schema M and a domain D [15]. The goals of semantic quality are *feasible validity* and *feasible completeness*. In our case *validity* means that all the statements, which are made by a schema, are correct and relevant in terms of its domain [15]. *Completeness* means that a schema contains all the statements about its domain that are correct and relevant [14]. *Feasible* means that there is no improvement of the semantic quality such that its additional benefit to a schema exceeds the drawbacks of using it. We classify the use of normalization theory and the principle of orthogonal design as the means to improve the validity of conceptual schemas. They consider dependencies between data elements that are themselves integrity constraints and as such specify the semantics of the problem domain.

It is hard to measure the semantic quality because "both the problem domain and the minds of the stakeholders are unavailable for formal inspection" [15, p. 94]. Next, we propose how to measure *perceived semantic quality* of conceptual schemas. It covers correspondence between Ks (stakeholders' knowledge of D) and I (interpretation of M). Its goals are *perceived validity* and *perceived completeness*.

A *candidate* measure EV(M) can be used for evaluating the perceived validity of a conceptual schema M. A *candidate measure* is a measure that experts have not yet accepted or rejected. EV(M): Let X be the set of all the elements in a conceptual data model Ks. Let Y be the set of all the elements in a conceptual schema M. Let y be the cardinality of Y. Let W be the set of all the elements in Y that have a corresponding element in X. There exists an ordered pair (correspondence) of elements (*a, b*) if element *b* in Y is created based on an element *a* in X by using a sequence of transformations and without the loss of semantics. Hence, it must be possible to trace the origin of *b* to *a*. Let w be the cardinality of W. In this case EV(M) = w/y.

The possible value of EV(M) is between 0 and 1 (endpoints included). 0 and 1 denote minimal (total lack of) and maximal perceived semantic validity, respectively. Ideally, there must be a total surjective function f: X → Y.

Next, we present a candidate measure EC(M) for evaluating the perceived completeness of a conceptual schema M. EC(M): Let X be the set of all the elements in a conceptual data model Ks. Let x be the cardinality of X. Let Y be the set of all the elements in a conceptual schema M. Let Z be the set of all the elements in X that have a corresponding element in Y. There exists an ordered pair (correspondence) of elements (*a, b*) if element *b* in Y is created based on an element *a* in X by using a sequence of transformations and without the loss of semantics. Hence, it must be possible to trace the origin of *b* to *a*. Let z be the cardinality of Z. Then EC(M) = z/x.

The possible value of EC(M) is between 0 and 1 (endpoints included). 0 and 1 denote minimal (total lack of) and maximal semantic completeness, respectively. Ideally, there must be a total surjective function f: Y → X.

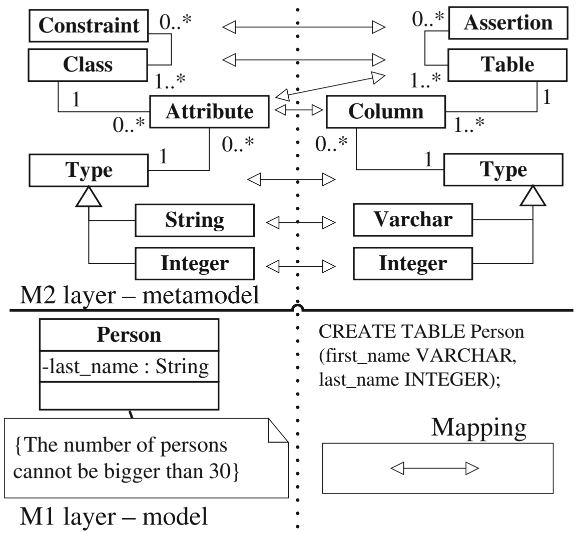



**Fig. 1** Identification of elements for the evaluation of perceived semantic quality of conceptual schemas

How to find the elements of a conceptual data model and a conceptual schema? Both of them are created by using a language. For instance, one could create a conceptual data model by using UML and implement a conceptual schema by using SQL. It is possible to specify the abstract syntax of a language by using a metamodel. If we use UML class models for creating metamodels, then classes specify language elements and properties/relationships specify relationships between the language elements [18]. One could perform the analysis of perceived semantic quality based on the language elements that correspond to the classes in the metamodels.

Meta Object Facility (MOF) Specification [19] describes four-layer metadata architecture. Metamodels and models, which are created according to the metamodels, belong to M2 and M1 layer, respectively. Figure 1 presents a fragment of a metamodel of a language that can be used to create conceptual data models (on the left) as well as a fragment of a metamodel of a database language that can be used to implement conceptual schemas (on the right). A class *c1* from a metamodel *m1* can have more than one corresponding class in a metamodel *m2* and vice versa. For instance, in case of SQL:2006, one could implement a constraint in a conceptual data model by using assertions or trigger procedures.

Next, we calculate the values of EV(M) and EC(M) based on the information at M1 layer in Fig. 1. In the analysis, we use elements that correspond to the classes at M2 layer.

X = {Person, Person.last_name String, String, {The number of persons cannot be bigger than 30}} and Y = {Person, Person.first_name VARCHAR, Person.last_name INTEGER, VARCHAR, INTEGER}. W = {Person, VARCHAR}, y = 5, and w = 2. EV(M) = w/y = 2/5 = 0.4. Column *last_name* is not in W because it has lost semantics during the transformation—it has a wrong type. In addition, the schema specifies column *first_name* that has no corresponding element in the conceptual data model.

Z = {Person, String}, x = 4, and z = 2. In this case EC(M) = z/x = 2/4 = 0.5. A reason of quite low semantic completeness is that the conceptual data model specifies an integrity constraint that has no corresponding elements in the conceptual schema.

## 2.2 Other Quality Levels

Syntactic quality is in our case the correspondence between a conceptual schema M and the set of all the possible database language statements L [15].

*Syntactic correctness* is the only syntactic goal [15]. In case of conceptual schemas the syntactic correctness is checked by a DBMS before the DDL statements for creating/altering the schema are executed. One can improve the syntactic quality by using code generators. In this case developers have to write less code and hence have fewer possibilities to make syntax errors. Unfortunately, existing CASE systems provide limited support for generating code that implements integrity constraints [12]. Hence, one could instead use specific code generators for that purpose. For example, Vasilecas et al. [20] propose template-based generation of SQL triggers based on business rules.

Pragmatic quality is in our case the correspondence between a conceptual schema M and actor interpretation I [15]. Krogstie et al. [15] write that *comprehension* is the only pragmatic quality goal. Conceptual schemas must be understandable to their audience. Baroni et al. [6] present a set of measures for evaluating conceptual schemas of object-relational databases. The measures help us to evaluate the *complexity* of schemas and as such can be used to evaluate the pragmatic quality of schemas.

Next, we list some means that DBMSs or separate database management applications can provide to improve the pragmatic quality of the conceptual schema of a database DB.

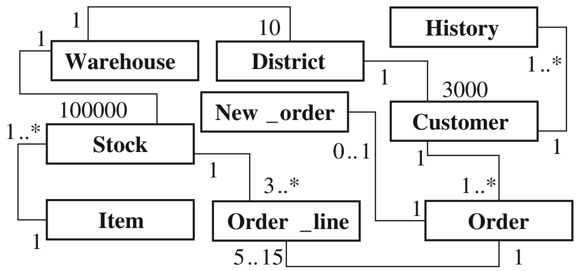
*Possibility to register comments about schema elements in the system catalogue of DB*. For instance, PostgreSQL™ [21] allows developers to use COMMENT statement.

*Possibility to search data about schema elements from the system catalogue of DB*. It must be possible to use the same query language as in case of other parts of DB. Views, like the ones defined in INFORMATION_SCHEMA [17], simplify the creation of such queries.

*Visualization of schema elements and dependencies between the elements*. Information about the elements and their interdependencies is in the system catalogue of DB.

A problem with the current SQL DBMSs is that the meaning of procedural code (for instance, in trigger procedures) becomes apparent only after careful inspection of the code. Hence, to improve the pragmatic quality of schema, one should

**Fig. 2** An entity-relationship diagram




comment the code and follow other guidelines to improve the readability of code. These means also increase the empirical quality of a database schema. Pragmatic means also include ensuring the continuous availability of models that have been used to create a schema because they help users to understand the schema. Krogstie et al. [15] write that *externalisation* and *internalisability* are the goals of physical quality. Externalisation means that each conceptual schema must be available as a physical artifact that consists of statements of database language. Some DBMSs provide means to generate data definition language statements based on information in the system catalogue of a database. Internalisability means that each conceptual schema must be accessible so that interested parties (database users as well as database developers) can make sense of it. Hence, each schema should be accessible as a part of a database. The means that increase internalisability are the same as the means to achieve high availability of databases.

## 2.3 Discussion

The proposed candidate measures EV(M) and EC(M) depend on the existence of conceptual data models that are rich in detail and have high quality. They are the most useful in the context of Model Driven Development, according to which one can create a database implementation from a conceptual data model by using a sequence of transformations.

Simsion [22] investigates the state of the art of data modeling and concludes that many practitioners do not create conceptual data models or create them as high-level preliminary artifacts without much detail. For instance, Simsion [22] notes that most of practitioners exclude identification of attributes from the activities of conceptual data modeling stage (see Fig. 2). It is possible that creators of a conceptual data model choose to present very few/basic integrity constraints. It may be caused by the existing work practices, lack of education, limitation of modeling languages, limitations of CASE systems that are used to create models, or frustration about difficulties of enforcing the constraints in a database. Hainaut [4] also notes that coping with constraint propagation during transformation-based database development is still a problem that needs to be addressed.

If a conceptual data model is a high-level preliminary artifact, then the value of EC(M) may be high although the conceptual schema does not sufficiently reflect the real world. A semiotic framework that is specified in [14] can be used to improve the quality of conceptual models.

It is also possible that database developers have not created the conceptual data model at all. In this case it is not possible to use the proposed measures. On the other hand, the proposed framework could encourage the creation of a conceptual data model during database development because it helps interested parties to measure the results of database development. The use of EV(M) and EC(M) requires the existence of metamodels of conceptual modeling languages and database languages. If these metamodels do not exist, then the use of the proposed measures will be time consuming because developers firstly have to create the metamodels.

The values of semantic quality measures depend on the quality of metamodels that are used for the analysis. For each language there can be more than one metamodel. They are used for different purposes like code generation, teaching, etc. For instance, let us assume that a metamodel of a conceptual modeling language (see Fig. 1) does not contain classes *Constraint*, *Attribute*, and *Type*. In this case X = {Person}, Z = {Person}, x = 1, z = 1, and EC(M) = z/x = 1/1 = 1.

The results of evaluation depend on the language that is used to create conceptual data models. Different languages have different levels of expressiveness. For instance, it is possible that in a language L1 one can represent a constraint by using a specific model element but in case of language L2, one has to use a separate language like OCL to represent the constraint. Therefore, in case of calculating EV(M) and EC(M) it is necessary to document the language that is used to create the conceptual data model and versions of metamodels that are used as the basis of analysis as well as the stakeholders who performed the analysis. This information is needed to decide whether two different measurement results are comparable or not.

It is possible that different stakeholders have different opinions about whether the semantics of a conceptual data model element is preserved in the corresponding conceptual schema. Therefore, the evaluation results are somewhat subjective in nature. To repeat, EV(M) and EC(M) allow us to calculate *perceived* semantic quality because the results depend on the users perception of M and D. One has to improve the pragmatic quality of conceptual data models and conceptual schemas so that interested parties can better understand them during the analysis of perceived semantic quality. It is also necessary to educate interested parties about conceptual modeling and database design to enhance the quality of their observations.

**Table 1** Correspondence between classes of metamodels

| UML metamodel [24] | SQL metamodel [25] |
|---|---|
| Class | Table |
| Property | (Table AND Column AND UniqueConstraint AND ForeignKey) OR Column |
| Association | (Column AND ForeignKey) OR (Table AND Columns AND UniqueConstraint AND ForeignKeys) |
| Multiplicity element | Column OR CheckConstraint OR Trigger OR UniqueConstraint |
| Constraint | PrimaryKey OR UniqueConstraint OR CheckConstraint OR Trigger |

## 2.4 An Example

In this section, we present an example based on a database that is created by using database language that conforms to the SQL:2006 standard [17]. The proposed framework and measures can be used in case of other database languages as well. TPC BENCHMARK™ C [23] specifies a database for the wholesale supplier company that has a number of geographically distributed sale districts and warehouses. The document presents entity types, relationship types, and additional requirements to the data in the database. These requirements help us to determine the multiplicity of relationships. Based on this information it is possible to create an entity-relationship diagram (see Fig. 2) that is a part of a conceptual data model.

One should implement the database as a SQL database according to the benchmark document. The document presents table layouts: column names, column types, primary key constraints, and foreign key constraints. The description of table layouts specifies the conceptual schema of the database.

In this paper, we calculate the values of EV(M) and EC(M) based on the specifications in TPC BENCHMARK™ C document. There is a non-conformance between the conceptual data model and the conceptual schema in the document. The conceptual data model does not include specifications of properties (attributes) and unique identifiers.

In addition, the conceptual data model specifies multiplicity constraints, some of which are not explicitly implemented in the conceptual schema. We assume that UML is used to create entity-relationship diagrams. In this case classes and associations are used to represent entity types and relationship types, respectively. Therefore, we use a UML metamodel [24] as a basis of our analysis. In addition, we use a metamodel of SQL that is specified as a part of Common Warehouse Metamodel (CWM) Specification [25].

Firstly, we have to determine the correspondence (mapping) between the classes of metamodels (see Table 1). In some cases, one has to create multiple different SQL elements based on one UML element (AND operation). In some cases, one could choose, which set of elements to create based on an UML element (OR operation).

Next, we calculate the value of EV(M). The number of elements in the conceptual schema (y) is 125: 9 tables, 92 columns, 8 primary key constraints, 10 foreign key constraints, and 6 different types. The types, which are used in the conceptual schema, are unique ID, variable text, fixed text, signed numeric, unsigned numeric, and date and time. Each table has a corresponding entity type. There is one foreign key constraint that does not have a corresponding relationship type (a foreign key constraint of table *History*). Hence, the number of elements of the conceptual schema, which do have the corresponding elements in the conceptual data model, is 18. EV(M) = 18/125 = 0.14. The validity of the conceptual schema is quite low. The main reason of such result is that the conceptual data model does not contain the specification of attributes. Therefore, the results are mainly indication of the problems of the conceptual data model.

Next, we calculate the value of EC(M). The number of elements in the conceptual data model (x) is 36: 9 entity types, 9 relationship types, and 18 multiplicity elements. Each entity type has a corresponding table in the conceptual schema. Each relationship type has a set of corresponding foreign key columns and a foreign key constraint in the conceptual schema. In addition, multiplicity elements 1 and 0..1 have been explicitly implemented in the conceptual schema. On the other hand, multiplicity elements 10, 3000, 100000, 1..*, 3…*, and 5..15 have not been explicitly implemented in the conceptual schema. They are used as implicit constraints that one has to take into account during the generation of test data.

Therefore, the number of elements of the conceptual data model that *do have* the corresponding elements in the conceptual schema is 28. EC(M) = 28/36 = 0.78. As you can see, the conceptual schema does not have the highest possible completeness (1).

One could argue that it is not feasible to increase the completeness any more due to difficulties in enforcing the multiplicity constraints. However, it also points to the problems with SQL and its implementations in various DBMSs. The next example illustrates difficulties in enforcing some integrity constraints in SQL databases and at the same time points to the need of good code generators. We implemented a multiplicity constraint [Parent]——m..−[Child] (m > 0) in a PostgreSQL™ 8.3 database. In PostgreSQL™ 8.3 it was not possible to implement the integrity constraint by using declarative means. We had to implement the constraint by using unstandardized constraint triggers, the execution of which can be deferred to the end of the containing transaction.

The number of physical lines of the implementation was 44 and the number of necessary statements was 3. The count of physical lines is influenced by the length of identifiers and the style of writing. We used the names *Parent*, and *Child* as the identifiers of base tables. We followed the rule that lines of the code cannot be longer than 60 symbols.

### 2.5 A Comparison of CASE Systems in Terms of Model Transformation Functionality

EC(M) values can be used to compare model transformation functionality of different CASE systems. Let us assume that there is a conceptual data model Ks. In addition, there is a set of CASE systems C that we want to compare. Let us also assume that we want to implement a database by using a DBMS *s*. In case of each CASE system from C, one has to perform the task: create DDL statements for creating the conceptual schema M of a database in *s* by using a series of transformations from Ks. Ks must have the same details in case of all the systems from C. In case of each resulting conceptual schema definition, one should calculate the value of EC(M). It would provide concrete numerical values for comparing CASE systems in terms how much information, which is specified in a conceptual data model, is taken into account while generating the specification of a conceptual schema. Ks should be rich in detail (to contain as much as possible different types of elements) in this investigation.

Next, we describe the results of a *small* experiment for comparing CASE systems in terms of their transformation functionality. Firstly, we selected two CASE systems that allow their users to create a conceptual data model and to generate a set of SQL statements from the conceptual data model by using a sequence of transformations. We selected IBM Rational Rose Enterprise Edition 7 [26] and DB-MAIN 9.1 [4]. We created a conceptual data model (see Fig. 2) with the same precision by using both CASE systems. The model specifies entity types (without attributes), relationship types, and multiplicity constraints. We stress the importance of multiplicity constraints because they are widely used in various conceptual data models [27] and are also presented in the taxonomy of integrity constraints [2]. In case of both CASE systems, we automatically generated SQL statements (in standard SQL) for implementing the conceptual schema. We did not manually specify the code for implementing the integrity constraints during the transformation. The information about integrity constraints was specified in the conceptual data models and we assumed that the system should take this information into account during transformations. Next, we calculated EC(M) values based on the conceptual data model and generated SQL statements based on the metamodels specified in [24, 25]. In case of Rational Rose 7 EC(M) = 0.79 ($x = 33 - 8$ entity types; 8 relationship types, 16 multiplicity elements; $z = 26$). In case of DB-MAIN 9.1 EC(M) = 0.88 ($x = 33$; $z = 29$). The reason why EC(M) is not 1 is that Rational Rose did not generate any code for enforcing the multiplicity constraints 10, 3000, 100000, 1..*, 3…*, and 5..15. DB-MAIN generated code for enforcing the constraint 1..* in case of all these multiplicity constraints.

One could claim that the proposed measures for evaluating validity and completeness are not very interesting because high validity and completeness can be ensured by rigorously following transformation rules. However, the results of the experiment demonstrate that some current CASE systems have still problems in transforming even the very common integrity constraints and hence the proposed measures are useful and necessary.

## 3 Conclusions

In this paper, we proposed a framework for evaluating the quality of a part of the implementation of a database—a conceptual schema. The framework is based on semiotics—the theory of signs. We developed the framework by adapting an existing semiotic framework that is used to investigate the quality of different kinds of software entities. Existing means to evaluate the quality of conceptual schemas (like the use of normalization theory) fit with the proposed framework. We evaluated a SQL database schema as an example. We extended the set of software entities that can be studied by using the semiotic framework and it is also one of the results of our study. We proposed two candidate measures for evaluating the perceived semantic quality of conceptual schemas. We also explained how one could use the measure of perceived completeness to compare different CASE systems in terms of their model transformation functionality. The advantage of using the measure in this context is that it gives us concrete numerical results. We performed a small experiment, the results of which demonstrate that some existing CASE systems should be improved to facilitate the generation of code that implements integrity constraints.

The future work must include further empirical evaluation of proposed measures in case of different conceptual data models and conceptual schemas. The future work should also include extending the framework to take into account the quality of the *process* of creating conceptual schemas.

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# Pareto Front Investigation of Multivariable Control Systems

**Ka Wing Ho and M. Braae**

**Abstract** A multivariable thermal system with two inputs and two outputs is investigated. Its inputs are a pair of heaters controlled by a computer while its outputs are temperatures measured by two sensors. The system is fully interactive so two different controller structures can be used to ensure that the temperatures track their respective set-points. Both are multivariable controllers though one has a diagonal structure while the other has a triangular structure. Multi-objective optimization with a posteriori decision-making based on Pareto efficiency, level diagrams, hyper volumes and other performance indices is used to compare quantitatively the two controller structures when applied to a highly interactive multivariable system based on this plant.

## 1 Introduction

Industrial systems often contain significant interaction between variables that either requires single variable loop controllers to be detuned to retain overall system stability or a pre-compensator in addition to single variable controllers to reduce the interaction [1]. Thus there are two types of controller structure that can be used to control such systems. These are a diagonal multivariable structure (consisting of two single–input–single–output or SISO controllers) shown in Fig. 1 and a triangular multivariable structure (a multi–input–multi–output or MIMO controller) shown in Fig. 2. Both diagrams assume a unit feedback loop for a two-

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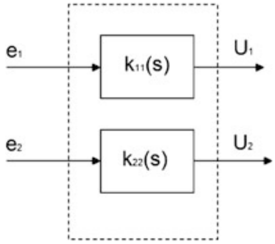



**Fig. 1** Structure of the SISO controllers

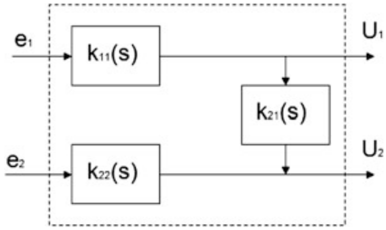



**Fig. 2** Structure of the MIMO controller

by-two plant where $e_i$ represents the two error signals, $u_i$ the two plant inputs and $k_{ij}(s)$ the non-zero elements of the controller transfer function matrix K(s).

In systems with severe interaction the traditional approach [2] is to design a pre-compensator $k_{21}$ first that achieves diagonal dominance of the MIMO system before the feedback controllers $k_{11}$ and $k_{22}$ are produced. The existence of the pre-compensator is held to result in more difficult design problems for elements $k_{11}$ and $k_{22}$ in the MIMO controller of Fig. 2 [1].

Recent advances in multi-objective optimization (MOO) [3] have provided the necessary theoretical tools to test such assertions quantitatively [4].

Thus the aim of this paper is to compare the two controller structures depicted in Figs. 1 and 2 when applied to a plant with severe interaction. The quantitative comparison is based on Pareto fronts of the two controller structures.

## 2 The Interactive Plant

A thermal system with two inputs and two outputs is used as the basis for the fully interactive MIMO system that will be investigated. The inputs are the heat supplied by its two heating units while the outputs are the temperatures measured by its two sensors. The system is both multivariable and interactive with a transfer function model as shown in Fig. 3.

The dynamic models for the thermal system were deduced experimentally from step response data and the resulting transfer function matrix model is given in (1).

$$G(s)_{original} = \begin{pmatrix} \frac{-0.405}{1+6.57s} & \frac{-0.141}{1+4.87s} \\ \frac{-0.115}{1+8.87s} & \frac{-0.435}{1+8.57s} \end{pmatrix} \quad (1)$$

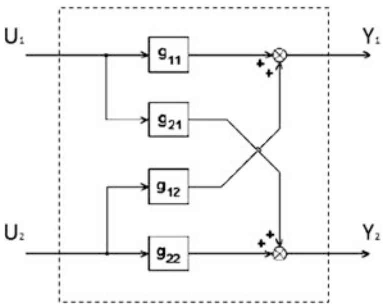



**Fig. 3** The experimental thermal system

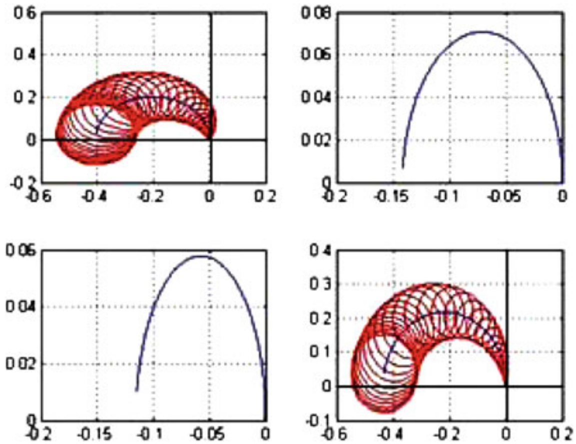


**Fig. 4** Direct Nyquist Array of $G(s)_{original}$

The Direct Nyquist Array or DNA [2] of the MIMO thermal system is shown in Fig. 4. Each graph shows the Nyquist plot of the associated element of the model in (1). The Gershgorin circles on the diagonal plots give a measure of the interaction and since none of these circles encircles the origin, the system $G(s)_{original}$ is diagonally dominant. This implies that the actual thermal plant does not contain sufficient interaction between its two loops to mimic a typical, highly interactive industrial problem that was envisaged for this comparative study.

Therefore virtual changes of the gains of the two off diagonal elements were made in order to increase the interaction within the system. The mathematical expression of the modified G(s) is given in (2):

$$G(s) = \begin{pmatrix} \frac{-0.405}{1+6.57} & \frac{-0.4}{1+4.87} \\ \frac{-0.4}{1+8.87s} & \frac{-0.435}{1+8.57} \end{pmatrix} \tag{2}$$

The DNA of the modified G(s) is plotted in Fig. 5 and shows significant interaction in that both the Gershgorin bands enclose the origin of the diagonal Nyquist plots for its $g_{11}$ and $g_{22}$ elements. Therefore severe interaction has been introduced to yield the system that will be investigated.

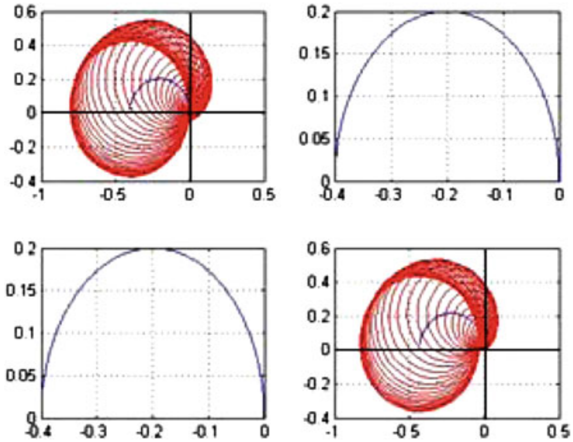



**Fig. 5** Direct Nyquist Array of G(s)

## 3 The Problem

The open loop transfer function matrix model for a two-input-two-output MIMO system that is controlled by means of SISO controllers (Fig. 1) is given in (3):

$$Q(s) = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \begin{pmatrix} k_{11} & 0 \\ 0 & k_{22} \end{pmatrix} \tag{3}$$

where Q(s), G(s) and K(s) are the transfer function matrices for the open loop, the plant and the controller respectively.

When a MIMO pre-compensator is included (Fig. 2) the open loop transfer function matrix becomes:

$$Q(s) = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \begin{pmatrix} 1 & 0 \\ k_{21} & 1 \end{pmatrix} \begin{pmatrix} k_{11} & 0 \\ 0 & k_{22} \end{pmatrix} \tag{4}$$

Assuming the popular PI control law for the single variable controllers in each case, the SISO control structure can be parameterized as given in (5).

$$K(s) = \begin{pmatrix} \frac{k_{11}(1+sI_{11})}{sI_{11}} & 0 \\ 0 & \frac{k_{22}(1+sI_{22})}{sI_{22}} \end{pmatrix} \tag{5}$$

When the pre-compensator is introduced the MIMO control structure can be parameterized by (6).

$$K(s) = \begin{pmatrix} \frac{k_{11}(1+sI_{11})}{sI_{11}} & 0 \\ \frac{k_{11}k_{21}(1+sI_{11})(1+sI_{21})}{s^2 I_{11} I_{21}} & \frac{k_{22}(1+sI_{22})}{sI_{22}} \end{pmatrix} \tag{6}$$

The improved dominance achieved by the pre-compensator can be observed by inspection of Figs. 5 and 6. The DNA for the uncompensated plant showed

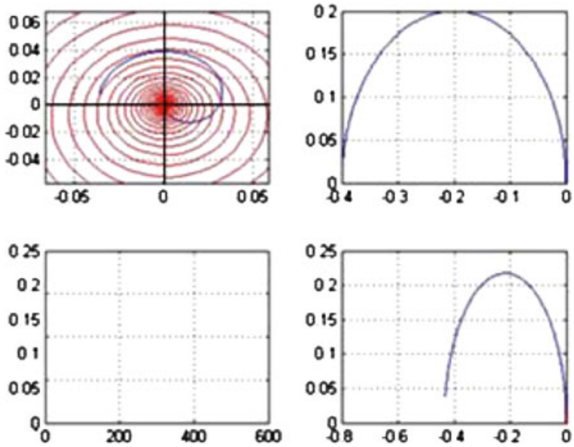


**Fig. 6** Direct Nyquist Array of $\begin{pmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{pmatrix}\begin{pmatrix} 1 & 0 \\ k_{21} & 1 \end{pmatrix}$

significant interaction while that for the compensated open loop system given in (7) showed no interaction from the first to the second loop.

$$\begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix}\begin{pmatrix} 1 & 0 \\ k_{21} & 1 \end{pmatrix} = \begin{pmatrix} q_{11} & q_{12} \\ 0 & q_{22} \end{pmatrix} \tag{7}$$

Clearly the pre-compensated system of (7) now forms an open loop stable system that is upper triangular in structure and two single variable controllers can be designed independently for its diagonal elements [5].

In support of the view held in [1] it appears that the difficulty of designing a controller for the resulting $q_{11}$ element increases when compared to that of designing a controller for the $g_{11}$ element of the system in (2). Specifically, the pre-compensator has changed the transfer function model $q_{11}$ from a simple first-order in the uncompensated system to a third-order with a reduced stability margin [6]. This means that the controller gain for this loop will have to be reduced to avoid encircling its critical point or equivalently that the controller in this loop needs to be detuned as noted in [1].

Many articles (such as [1]) mention that the MIMO controller performs better than the SISO controllers, but according to the DNA diagrams in Figs. 5 and 6 designing a MIMO controller may be more problematic than designing the SISO controllers. Therefore Pareto fronts and related tools will be used to quantify which controller performs better for the fully interactive thermal process of (2).

## 4 Methods Used

In order to quantify which controller structure (Fig. 1 or 2) is best for controlling the MIMO plant, the method of Multi-Objective Optimization is used to find the optimal variables for each of the two control schemes [7]. Unlike many comparisons that rely heavily on inspection of multiple time response plots [8], the approach adopted here aims to ensure that the comparisons are quantitative and as unbiased as possible (at least in terms of the criteria that are used for the investigation). In essence the approach uses the concepts of cost functions and Pareto efficiency to determine the optimum trade-offs that exist in the controller structures. The optimization can be formalized mathematically as follows [9]:

$$\begin{gathered} \theta = [\theta_1, \cdots, \theta_i] \in \Omega, \\ J(\theta) = [J_1(\theta), \ldots, J_k(\theta)], \\ min_{\theta \in \Omega} J(\theta) \end{gathered} \tag{8}$$

where $\theta$ is the input or decision vector, $\Omega$ is the decision space and J($\theta$) is the cost or objective vector. In this problem the decision vector $\theta$ consists of the controller parameters $k_{ij}$ and $I_{ij}$ as defined in (5) for SISO control and (6) for MIMO control. The cost vector J is defined to quantify the performance, the interaction and the movement in the manipulated variable.

To obtain the cost functions, specific error and input vectors are defined in (9) and (10) respectively.

$$e_{r_i}(s) = \begin{pmatrix} e_1 \\ e_2 \end{pmatrix} \tag{9}$$

$$u_{r_i}(s) = \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} \tag{10}$$

where $\begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$ represent the error signals in the two loops due to the change of set-point $r_i$ and $\begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$ represent the resulting inputs due to the same set-point changes.

Thus after one experiment in which the two set-points are changed sequentially, the cost functions used to judge the system become the cost function matrices:

$$J_e = \begin{pmatrix} J_{e_1 r_1} & J_{e_1 r_2} \\ J_{e_2 r_1} & J_{e_2 r_2} \end{pmatrix} \tag{11}$$

$$J_u = \begin{pmatrix} J_{u_1 r_1} & J_{u_1 r_2} \\ J_{u_2 r_1} & J_{u_2 r_2} \end{pmatrix} \tag{12}$$

where the cost function elements for the errors and inputs are defined in (13) and (14) respectively.

$$\mathrm{J}_{e_i r_j} = \frac{1}{\mathrm{Tmax}} \int_0^{\mathrm{Tmax}} \left(\mathrm{e(t)}_{\mathrm{i}_{\mathrm{r_j}}}\right)^2 \mathrm{dt} \tag{13}$$

**Table 1** The six different cost functions

| Cost function | Description of the cost function |
|---|---|
| $J_{e_1r_1}$ | Performance error of $e_1$ due to $r_1$ |
| $J_{e_2r_1}$ | Interaction error of $e_2$ due to $r_1$ |
| $J_{e_1r_2}$ | Interaction error of $e_1$ due to $r_2$ |
| $J_{e_2r_2}$ | Performance error of $e_2$ due to $r_2$ |
| $J_{ur_1}$ | Cost of input for change in $r_1$, use of Norm-2 to combine $J_{u_1r_1}$ and $J_{u_2r_1}$ together |
| $J_{ur_2}$ | Cost of input for change in $r_2$, use of Norm-2 to combine $J_{u_1r_2}$ and $J_{u_2r_2}$ together |

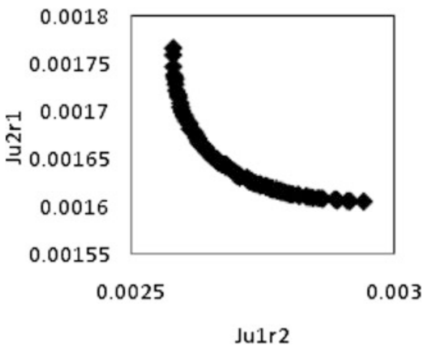



**Fig. 7** Pareto front

$$J_{u_ir_j} = \frac{1}{\text{Tmax}} \int_0^{\text{Tmax}} \left( u(t)_{i_{r_j}} - u_{0_{i_{r_j}}} \right)^2 dt \tag{14}$$

In order to analyze or optimize the controller parameters a comparison of either the performance or the interaction against the cost of inputs is used to quantify how efficient the controller under evaluation is. By comparing the interaction against the performance the trade-offs between these criteria become evident. Therefore six different cost functions are picked to evaluate the controllers as shown in Table 1.

Pareto fronts and (Pareto) dominance of points in cost function space are both part of Pareto efficiency; the combination provides the analytical data to rate one cost function performance against another cost function. A cost function point is (Pareto) dominated if another cost function point can be found that has smaller cost function values in all of its cost components. Alternatively a cost function point is non-dominated if it performs better in at least one dimension than any other of the cost function points. When a series of non-dominated points in the cost function space are combined, an approximation to the Pareto front is formed. Thus a Pareto front represents a series of optimal solutions mapped out by changing the variables within the controller. A typical result is the simple two-dimensional Pareto front shown in Fig. 7.

Unfortunately realistic engineering design problems require multi-dimensional cost functions that are impossible to represent in this 2-D manner. Thus level diagrams [10] and hyper volumes [10] are two methods that have been devised to

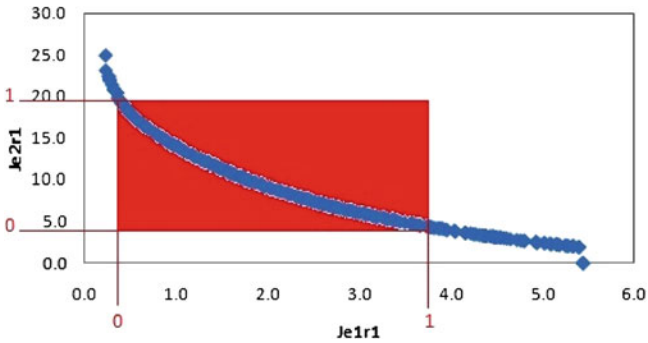



**Fig. 8** Level diagrams of 4-dimensionals

visualize cost functions in dimensions higher than 3-D [9]. In level diagrams each cost function is the x-axis coordinate of a point on a separate graph in which the y-axis is the Norm-2 of all the cost functions used in the comparison. These plots simplify visualization of the trade-offs between cost functions and extend the visualization to multi-dimensional comparisons. Figure 8 shows an example of a set of level diagrams for 4-Dimensional cost functions.

When two Pareto fronts (A and B) of more than 2-Dimensions are presented, it is critical to determine which one is performing better. In this paper the Pareto front that dominates a larger hyper volume in cost function space is taken to be the one performing better in the sense that it dominates more points in the assumed cost function space. Estimating the hyper volume in 3-Dimensions or below is relatively simple, but for higher dimensions it becomes more difficult. Thus the unary hyper volume indicator $I_H(A)$ [9] is used to calculate the volume that has been dominated by the Pareto front A.

Two different systems can be compared more directly by means of the binary hyper volume indicator $I_{H2}(A,B)$ [11, 12], referred to as the coverage difference indicator in [11]. It determines the volume in cost function space that is dominated by Pareto front A but not by Pareto front B. Its mathematical expression is based on set theory and given in (15) [9].

$$I_{H2}(A,B) = I_H(A \cup B) - I_H(B) \tag{15}$$

Experience with multi-objective optimization has shown [13] that a Region of Interest needs to be defined to focus the optimization when dealing with engineering problems. This adds an element of a priori decision-making to the a posteriori decision-making implied in the use of visualization.

An ideal part of the Pareto front known as the Region of Interest will be selected to calculate the hyper volumes for the thermal controllers. As illustrated by Fig. 9, the shaded region is the Region of Interest that effectively normalizes the cost functions under consideration. Thus the resulting Region of Interest becomes a unit hypercube with side lengths and hyper volume equal to 1. The upper region is then

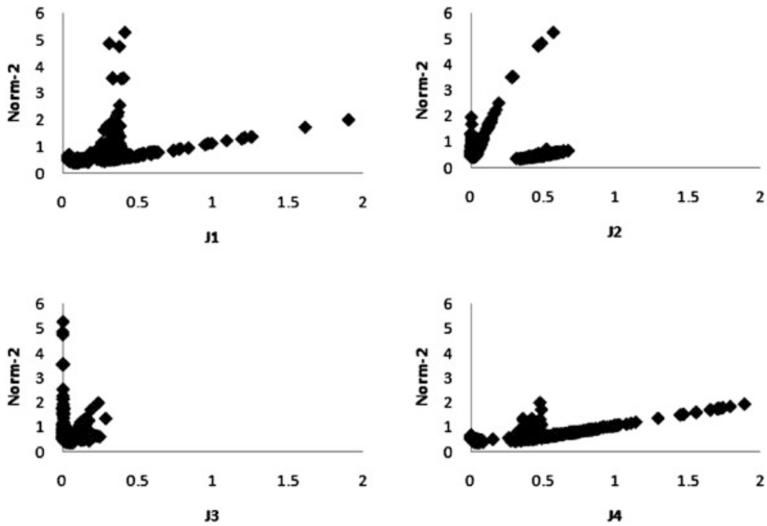
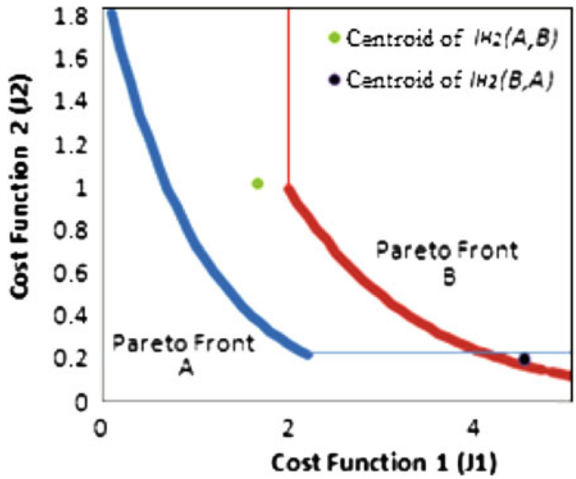



Fig. 9 Region of interest in 2-dimensionals

Fig. 10 Two Pareto fronts




the hyper volume dominated by the Pareto front. This volume is estimated by filling the cybercube with randomly distributed points and determining the fraction that is eliminated as being dominated by the Pareto front. This fraction yields the unary hyper volume indicator $I_H(A)$ for the given Pareto front A.

In the case of two systems with individual Pareto fronts as shown in Fig. 10 the binary hyper volume indicator $I_{H2}(A,B)$ of the Pareto fronts can be obtained in a similar manner [9]. These 2-dimensional examples are readily generalized to deal

**Table 2** Centroid results of Pareto front A and Pareto front B

| | Cost function 1 ($J_1$) | Cost function 2 ($J_2$) |
|---|---|---|
| $I_{H2}(A,B)$ | 1.66160 | 1.01719 |
| $I_{H2}(B,A)$ | 4.52230 | 0.198290 |

with the 6-dimensions needed to compare the SISO and the MIMO control structures.

In addition to the coverage index, the centroid is the mean of each non-zero, binary hyper volume that is found when two Pareto fronts are compared. It can be applied to two Pareto fronts with any number of dimensions.

As a simple 2-dimensional example consider the two Pareto fronts in Fig. 10, where the centroid will be used to compare the Cost Function 1 and Cost Function 2 of the two Pareto fronts separately. The computed centroids of $I_{H2}(A,B)$ and $I_{H2}(B,A)$ are given in Table 2.

According to the centroid in Table 2, $I_{H2}(A,B)$ is performing better than $I_{H2}(B,A)$ in terms of Cost Function 1 ($J_1$). However $I_{H2}(B,A)$ is performing better than $I_{H2}(A,B)$ in terms of Cost Function 2 ($J_2$). Centroids do not merely show that a specific Pareto front is better than another Pareto front, but they also determine which cost functions within a Pareto front are performing better compared to the cost functions of another Pareto front.

## 5 Discussion

The set of six level diagrams for the SISO and the MIMO systems are combined in Fig. 11. These can be inspected to provide valuable engineering insight into the control systems not only in terms of overall performance (the a priori approach to MOO) but also for individual features (the a posteriori approach). Specifically the tracking performance of each loop, the interaction from one loop to the other and the control effort needed to achieve the performance can be seen.

Clearly the overall cost function for the MIMO controller is consistently better than that of the SISO controller so the conclusion from multi-objective optimization based on a priori decision-making indicates that the MIMO system is best. However level diagrams allow inspection of individual cost functions so it can readily be seen from $J_{e_1r_1}$ that the performance of the MIMO controller can be significantly worse for some optimal designs. The diagram for $J_{e_2r_1}$ shows clearly that the interaction from loop 1 to 2 is reduced by the pre-compensator (as expected). The level diagram for $J_{e_2r_2}$ shows that the performance of loop 2 is similar for both the MIMO and the SISO controllers. The interaction from loop 2 to 1, given by $J_{e_1r_2}$, is predominantly similar for most of the designs for the two controller structures.

The level diagrams of $J_{ur_1}$ show that the MIMO controller uses significantly less input than the SISO controller. And finally $J_{ur_2}$ shows that the two control

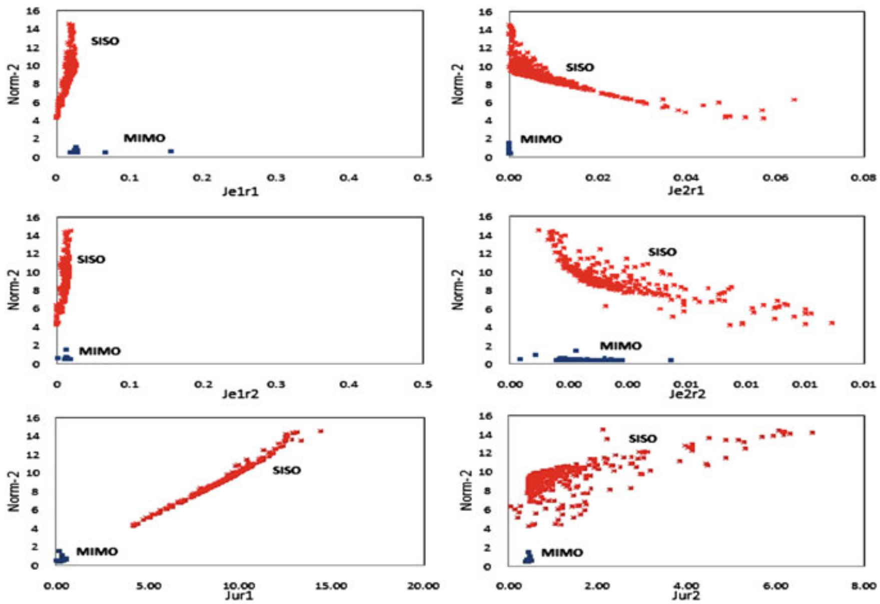



**Fig. 11** Level diagrams of the optimal SISO and MIMO systems

**Table 3** Hyper volume results

| | SISO system $I_H(A)$ | MIMO system $I_H(B)$ |
|---|---|---|
| Hypervolume | 0.403407 | 0.930472 |

**Table 4** Centroid results

| Cost function | $I_{H2}(A,B)$ | $I_{H2}(B,A)$ |
|---|---|---|
| $J_{e_1 r_1}$ | 0.464119 | 0.732657 |
| $J_{e_2 r_1}$ | 0.0486404 | 0.0302868 |
| $J_{e_1 r_2}$ | 0.421009 | 0.428883 |
| $J_{e_2 r_2}$ | 0.00800855 | 0.00485689 |
| $J_{ur_1}$ | 10.1404 | 4.63205 |
| $J_{ur_2}$ | 1.59381 | 3.61437 |

structures mostly use the same input for changes to the set-point in loop 2, though some optimal SISO controllers use less input.

Table 3 gives the hyper volume results that determine if the SISO system or the MIMO system performs better (in an a priori, global sense). It shows that MIMO systems dominate more space in the Region of Interest than SISO systems.

The 6-Dimensional centroids of the coverage indices $I_{H2}(A,B)$ and $I_{H2}(B,A)$ where A is the Pareto front of the SISO system and B is that of the MIMO system, were computed for the six cost functions and are shown in Table 4.

Since no controllers will be optimal in every situation the centroids for the coverage indices given in Table 4 quantify the strengths and weaknesses of the (Pareto) optimal SISO and MIMO control structures in terms of individual cost functions.

The first row in the table indicates that the SISO controllers can achieve a much lower centroid value for $J_{e_1 r_1}$. Thus this structure can achieve better performance for loop 1 than the MIMO structure. This is confirmed by closer inspection of the x-values in the level diagram for $J_{e_1 r_1}$ in Fig. 11.

On the other hand a lower interaction from loop 1 to 2 can be achieved by the MIMO controller since its centroid value for $J_{e_2 r_1}$ is smaller.

Considering all the rows in Table 4 the comparison based on the centroid shows that the SISO control structure is better than the MIMO for $J_{e_1 r_1}$ and $J_{ur_2}$ while the MIMO is better than the SISO for $J_{e_2 r_1}$, $J_{e_2 r_2}$ and $J_{ur_1}$. As expected there is virtually no difference between the two structures for $J_{e_1 r_2}$ which quantifies the interactive effect that loop 2 has on loop 1.

## 6 Conclusions

Visualization in multi-objective optimization with a posteriori decision-making is critical for producing effective engineering designs since it provides the engineer with invaluable insight into the problem under investigation and its proposed solutions. For high dimensional problems this becomes difficult and level diagrams are a means to visualize such spaces effectively.

Further enhancements of Pareto efficient design methods through the centroid of coverage indices for two or more designs provide quantitative measures of the relative performance of these designs, within the region of interest and based on the chosen cost functions, as illustrated here by their application to SISO and MIMO control structures.

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# Multi-Objective Performance Evaluation of Controllers for a Thermal Process

**T. Koetje, M. Braae and M. Tsoeu**

**Abstract** Most engineering systems are multivariable in nature, where more than one input controls more than one output. The challenge arises in controlling these types of systems due to interaction among inputs and outputs. In an attempt to optimise the performance of these processes, many performance objectives need to be considered simultaneously. In most cases, these objectives often conflict hence a need for Multi-objective Optimisation (MOO) analysis. In this paper MOO design for Model Predictive Control (MPC) and Proportional Integral (PI) control are investigated for a multivariable process. The Pareto sets for both controllers is generated using Pareto Differential Evolution (PDE) and then compared using n-dimensional visualization tool, *Level Diagrams* to evaluate which controller is best for the process. Solutions which provide a preferred performance are then selected and tested experimentally on a thermal process.

## 1 Introduction

A multi-objective optimization (MOO) problem is a problem of trying to simultaneously satisfy a number of design objectives which most often conflict. MOO is a field which has been used extensively for decades to obtain the optimal controls systems [1]. Many MOO applications in controller designs can be found in [2].

Model Predictive Control (MPC) and Proportional Integral (PI) control are considered to be the most popular control strategies in use up to date [1, 3]. These

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methods have been compared to each other on various systems. These comparisons can be found in [4, 5] and recently in [6]. However, none of these papers treat the comparison using multi-objective optimisation.

The MOO application of these controllers mostly exists separately in the literature. The MOO PI or PID has been applied in various control systems in tuning the controller parameters for performance optimization [7, 8]. The most recent MOO PI or PID can be found in [3] where the primary goal was to optimize the load disturbance rejection. The multi-objective optimization algorithm NSGA-II is also used to optimize PI controllers of a magnetic levitation system [9] and ALSTOM gasifier problem [10]. MOO for MPC has been presented in [11] in which a genetic algorithm is combined with multi-objective fuzzy decision-making (MOFDM) in an attempt to find MPC tuning parameters that optimize a MIMO system's performance. In [12], MPC parameters are tuned using MOO to improve disturbance rejection. The MOO control based on both PID and MPC is found in [1]. However, the paper discusses the MOO of these controllers in theory with no simulation or practical implementation.

In MOO the goal is to obtain an optimal set in which no solution is dominated by any other solution. This set is known as a *Pareto-optimal set* [13]. Generating this set can be computational expensive. However, there exist many methods in MOO literature that try to find a good approximation of the set. Recently Multi-objective Optimisation Evolutionary Algorithms (MOEA's) have been used to provide the approximation of the optimal set [13].

In the Pareto set, all points are equally acceptable as solution. However, to implement a controller only one point should be selected. The selection rests entirely on the Decision Maker (DM). As a result, tools are needed to aid the DM to decide the set which best fits the problem based on the DM's preference. Visualization tools have been widely accepted as valuable tools to help the DM to analyze the Pareto set and select good solutions [14]. Traditionally a Pareto front is represented in 2-Dimension (2-D) or 3-D which are relatively easy to visualize but for dimension higher than 3-D, it becomes difficult to visualize or extract useful information from such plots. Different methods for aiding n-Dimensional visualization and decision making have been proposed. In [15], Visually Interactive Decision-making and Design using Evolutionary Multi-objective Optimisation (VIDEO) is presented but it can only be used for design objectives up to four (or 4-D). *Parallel coordinates* and *scatter diagrams* are popular methods in use for any dimensional space but their plots are complex [14] and hence difficult to interpret.

In this paper, MOO is used to design MPC and PI controllers to optimize the performance of a highly interactive thermal system. The 8-D Pareto fronts are generated for both controllers and then visualized and compared using a new visualization tool for n-Dimensional Pareto front, i.e. *Level Diagrams* presented in [14]. Then the solution which gives a better compromise from each controller is simulated and compared in real time. Experiments are then conducted in order to evaluate the performance on the thermal plant.

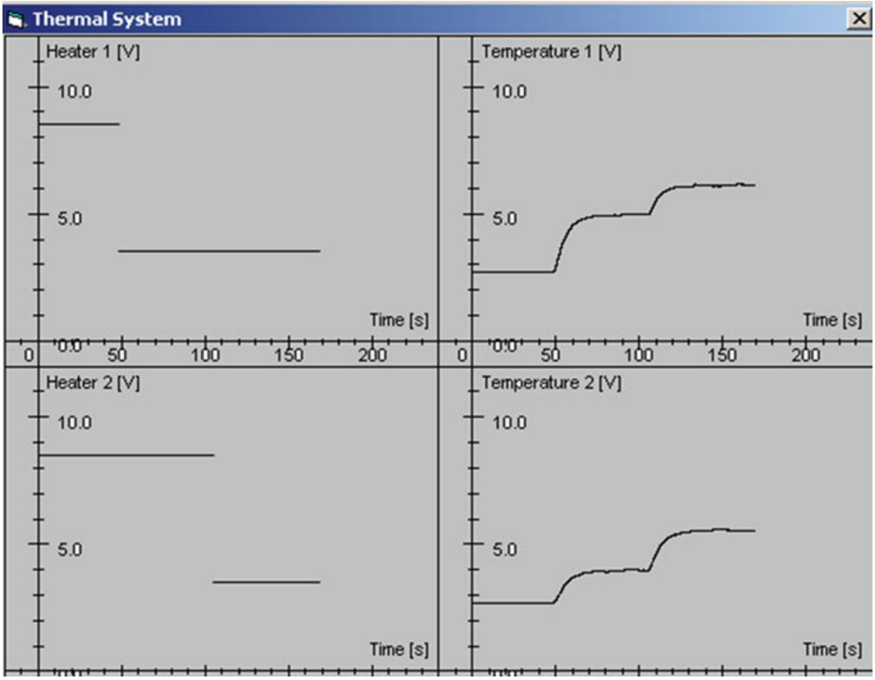


**Fig. 1** The step test data

## 2 The Thermal System

Thermal system in Control laboratory consists of two heaters and two temperature sensors and forms a multivariable system process. Depending on the physical location of the sensors the system can either be diagonal, triangular or full structure. The system used here is in full structure hence full interactive multivariable system.

For a full structure $(2 \times 2)$ system, the transfer function matrix model is given by:

$$G(s) = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \tag{1}$$

### 2.1 System Model

To find the model of the system, step test data were generated as shown in the Fig. 1.

On the graph, time is in seconds while the output temperature and the input heater are measured in volt (V). Graphical analysis techniques were applied to these time response data to approximate the dynamic process as first order model. This was found as the transfer function matrix model:

$$\mathrm{G(s)} = \begin{bmatrix} \frac{-0.37}{8.0\ \mathrm{S}+1} & \frac{-0.2317}{7.6\ \mathrm{S}+1} \\ \frac{-0.19}{8.0\ \mathrm{S}+1} & \frac{-0.3483}{8.0\ \mathrm{S}+1} \end{bmatrix} \tag{2}$$

This is linear and stable system with negative gains.

# 3 Controllers

## 3.1 MPC Formulation

In the MPC control method an explicit model of the system to be controlled is used to predict the future output behavior. This compromises of a family of controllers ruled by the same design philosophy and similar characteristics [1]. The design uses the model to predict the system output, y, to optimize a cost function, $J$ and uses of the idea of *Receding Horizon principle*.

Consider the stable discrete state-space model

$$\begin{gathered} x(x+1) = Ax(k) + Bu(k) \\ y(k) = Cx(k) \end{gathered} \tag{3}$$

where k denotes the current sampling point, and ‘x’, ‘u’, and ‘y’ represents the state, the input and the model output respectively, while A, B, C are matrices of appropriate dimensions. Augmenting the system in (3) to eliminate steady-state errors, complete velocity form [16] is used. This gives

$$\begin{gathered} \xi(k+1) = \bar{A}\xi(k) + B\Delta u(k) \\ y(k) = \bar{C}\xi(k) \end{gathered} \tag{4}$$

where

$$\begin{gathered} \bar{A} = \begin{bmatrix} A & 0 \\ CA & I \end{bmatrix}, \bar{B} = \begin{bmatrix} B \\ CB \end{bmatrix} \bar{C} = \begin{bmatrix} 0 & I \end{bmatrix}, \xi = \begin{bmatrix} \Delta x(k) \\ y(k) \end{bmatrix} \\ \Delta x(k) = x(k) - x(k-1) \\ \Delta u(k) = u(k) - u(k-1) \end{gathered}$$

and A, B, C are matrices in (3). The tracking cost function which penalizes the increments in change in control action (i.e. u) and error (i.e. e) is defined as

$$J = \sum_{j=0}^{j=N_p} e(k+j|k)^T \bar{Q} e(k+j|k) + \sum_{i=0}^{i=N_c-1} \Delta u(k+j|k)^T \Delta u(k+j|k) \tag{5}$$

where

$$e(k+j|k) = r(k+j|k) - y(k+j|k)$$
$$\bar{R} = \begin{bmatrix} \lambda_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \lambda_h \end{bmatrix}$$
$$\bar{Q} = \begin{bmatrix} \beta_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_q \end{bmatrix}$$

The constants $\lambda_h$, $\beta_q$ are weighting coefficients on control action and error respectively, h is the number of inputs and q is the number of outputs. Then $J$ is optimized to give the unconstrained optimal control law [17]

$$\Delta \mathrm{U} = \left(\Phi^{\mathrm{T}}\bar{\mathrm{Q}}\Phi + \bar{R}\right)^{-1}\Phi^{\mathrm{T}}\bar{Q}(\mathrm{R_s} - \mathrm{Fx(k)}) \tag{6}$$

where $\Phi$ is a Toeplitz matrix containing the step response coefficients of the plant, and F is the free response matrix and depends entirely on the model used. ΔU is vector of all control action velocities, i.e. [Δu(k|k),···,Δu(k$N_c$−1|k)]. According to the technique of receding horizon principle, at each time step not all of the calculated control actions are used, but only the first Δu(k|k) is used. At the next step, then the batch of calculation of control actions is repeated based on the new output and set-point, and the new Δu(k|k) is applied and so on.

## 3.2 PI Formulation

Historically the PI Controller is one of the popular control methods and has been used in industry for decades due to its simplicity and competitive in performance [18].

The structure of a PI controller in discrete form, is given by

$$K(z) = K_P + \frac{K_I z}{z-1} \tag{7}$$

The MIMO PI is designed as

$$K(z) = \begin{bmatrix} K_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & K_q \end{bmatrix} \tag{8}$$

where $K_q$ takes the form shown in (7), which give the MIMO control law

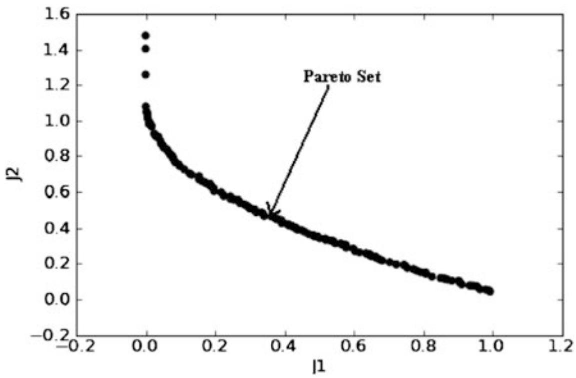


**Fig. 2** Pareto set for 2 cost objectives

$$\begin{bmatrix} \Delta u_1 \\ \vdots \\ \Delta u_q \end{bmatrix} = \begin{bmatrix} K_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & K_q \end{bmatrix} \begin{bmatrix} \Delta e_1 \\ \vdots \\ \Delta e_q \end{bmatrix} \tag{9}$$

where $\Delta u_q$, $\Delta e_q$, and $K_q$ are the control velocity of output $q$, the change in error of the output $q$ due to reference q and the controller on output $q$ respectively.

# 4 Multi-Objective Optimization

## *4.1 General Definition*

Multi-objective optimization (MOO) problem is a problem of simultaneously minimizing the n objectives, $\mathrm{J_n}(\theta)$, that is,

$$\min_{\theta \in \Omega} J(\theta) \tag{10}$$

$$\begin{aligned} \theta &= [\, \theta_1 \quad \theta_2 \quad \cdots \quad \theta_i \,] \in \Omega \\ J(\theta) &= [\, J_1(\theta) \quad J_2(\theta) \quad \cdots \quad J_n(\theta) \,] \end{aligned}$$

where $\theta$ is the input or decision vector, $\Omega$ is the decision space, and $J(\theta)$ is the cost or objective vector. This generates a set of mutually optimal solutions $\Omega_P$ in which no point dominates any other. The set is known as Pareto-optimal set [13]. A point $\theta^0 \in \Omega_P$ is defined as being Pareto-optimal if and only if there does not exist another point, $\theta \in \Omega_P$, such that, $J(\theta) \leq J(\theta^0)$ and $J(\theta) < J(\theta^0)$ for at least one function. A typical Pareto front is shown in Fig. 2 for 2 cost functions (J1 (Set-point Tracking cost) and J2 (Interaction cost)).

MOO is a huge field with many different algorithms. Some of the very popular types of MOO methods are Evolutionary Algorithms (EA) [19]. One of the recent MOEA method, Differential Evolution (DE) [20] used here is discussed.

**Table 1** Cost functions design

| Cost functions | Mathematical description |
|---|---|
| $J_1$ | $\int_{t_i}^{t_f}(e_{11})^2dt$ |
| $J_2$ | $\int_{t_i}^{t_f}(e_{12})^2dt$ |
| $J_3$ | $\int_{t_i}^{t_f}(e_{21})^2dt$ |
| $J_4$ | $\int_{t_i}^{t_f}(e_{22})^2dt$ |
| $J_5$ | $\int_{t_i}^{t_f}(\Delta u_{11})^2dt$ |
| $J_6$ | $\int_{t_i}^{t_f}(\Delta u_{12})^2dt$ |
| $J_7$ | $\int_{t_i}^{t_f}(\Delta u_{21})^2dt$ |
| $J_8$ | $\int_{t_i}^{t_f}(\Delta u_{22})^2dt$ |

### *4.2 Pareto Differential Evolution*

There are different competing EA algorithms. Most of the recent important MOEA methods are: MOGA (Multiple Objective Genetic Algorithm), NSGA-II (Non-dominated Sorting Genetic Algorithm), SPEA2 (Strength Pareto Evolutionary Algorithm), NPGA-II (Niched Pareto Genetic Algorithm), Particle Swarm Optimization and DE [1, 19].

DE is one of the most competitive methods as compared with other EAs [20]. This method is also of advantage since it deals with real numbers rather than binary encoding as many EAs do [19]. The PDE algorithm discussed in [21] is used.

### *4.3 Cost Objectives*

MOO as contrary to Single-objective Optimisation (SOO) optimises two or more objective functions to generate the Pareto front. The resulting Pareto front depends entirely on the cost functions used [19] hence these functions are selected to be as applicable as possible in the field of control designs. In this investigation 8 cost functions are considered and designed as shown in Table 1.

$e_{ij}$ is the error on output i due to a set-point change in output j and $\Delta u_{ir}$ is the amount of control action change in input i due to a set-point change in output r. $J_1$ and $J_4$ defines set-point tracking errors while $J_2$ and $J_3$ defines the interaction errors.

**Table 2** Different norms

| Norm | Notation | Mathematical description |
|---|---|---|
| 1-norm | $\bar{J}_i(\theta)_1$ | $\sum_{i=1}^{n}\lvert\bar{J}_i(\theta)\rvert$ |
| 2-norm | $\bar{J}_i(\theta)_2$ | $\sqrt{\sum_{i=1}^{n}\bar{J}_i(\theta)^2}$ |
| $\infty$-norm | $\bar{J}_i(\theta)_\infty$ | $max\{\bar{J}_i(\theta)\}$ |

$J_5$ and $J_8$ gives the change in control action that must be applied in order to track the given output set-point while $J_6$ and $J_7$ gives the change in control action used to overcome the interaction on one output due to set-point changes in the other output. The first four objectives provide a good reference tracking and interaction rejection while the last four reduces the amount of control effort (in voltage) used hence the cost of control design. These cost functions are Integral Square Error (ISE) so large values of their amplitude are greatly penalised.

## *4.4 Level Diagrams*

*Level Diagrams* are one of the visualization tools for n-Dimensional Pareto front [14]. *Level Diagrams* normalizes each objective with respect to its minimum and maximum values, that is,

$$\bar{J}_i(\theta) = \frac{J_i(\theta) - J_i^m}{J_i^M - J_i^m} \rightarrow 0 \leq \bar{J}_i(\theta) \leq 1 \tag{11}$$

$$J_i^M = \max_{\theta \in \Omega_p} J_i(\theta)$$
$$J_i^m = \min_{\theta \in \Omega_p} J_i(\theta)$$

where $i = 1, \ldots, s$ and s is the number of objectives. Then a norm is evaluated to approximate distance to the ideal point

These norms are shown in Table 2. The values of each norm ranges as shown in (12)

$$\begin{array}{c} 0 \leq \bar{J}_i(\theta)_1 \leq s \\ 0 \leq \bar{J}_i(\theta)_2 \leq \sqrt{s} \\ 0 \leq \bar{J}_i(\theta)_\infty \leq 1 \end{array} \tag{12}$$

Euclidean norm (or 2-norm) is mostly used since it provides an accurate evaluation of the conventional geometrical distance to the ideal point and offer a

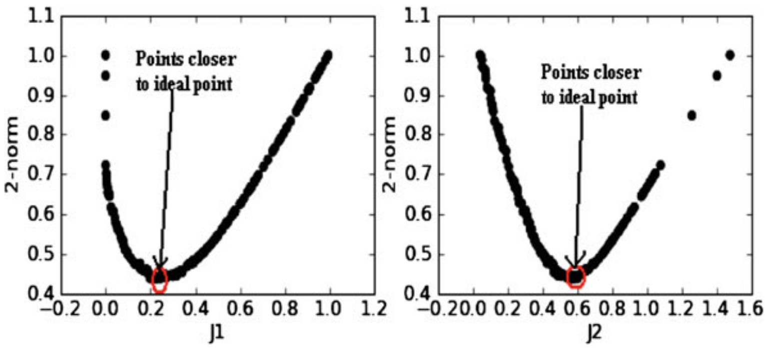


**Fig. 3** 2-norm level diagrams

better view of the '*real*' shape of the Pareto front in n-D space [14]. To plot *Level Diagrams*, each cost function or decision variable is drawn on its own graph where the y-axis corresponds to the value of $\bar{J}_i(\theta)_n$ and x-axis corresponds to the value of the objective or decision variable, in physical units.

To give an example of what *Level Diagrams* plots looks like, the Pareto front for a 2-D problem given in Fig. 2 is plotted using 2-norm as shown in Fig. 3.

Since the x-axis is in physical units, the DM can easily obtain points which are closer to the ideal point, that is, points with minimum norms (J1 $\approx$0.2, J2 $\approx$ 0.6) and also they shows the range of values which cannot be obtained for a given objective, in this case J2 $\approx$ [1.1$\rightarrow$ 1.3].

## 5 Simulations and Results

Using the design objectives discussed in Table 1, the PDE optimizer was run for 50 generations with a crossover rate and mutation rate set to 0.15. The population size for the optimizer was set to be 200 so that enough points are initially generated for the optimizer.

For the PI controller, four tuning parameters for the optimizer were assumed $(K_{P1}, K_{P2}, K_{I1}, K_{I2})$. Each parameter was bounded on the range [−2,0]. The range was selected based on the fact that the model gains of the system are negative hence negative gains required. Large gains were not practically implementable on the physical system hence lower gains opted. These could be due to noise on the system which is easily amplified by large gains.

For MPC controller, the five parameters to be tuned are control horizon, $N_C$, prediction horizon $N_P$, move and weighting suppression coefficients for each output ($\lambda_1$, $\lambda_2$, $\beta_1$, $\beta_2$). The parameter$N_P$, does not need to be tuned using an

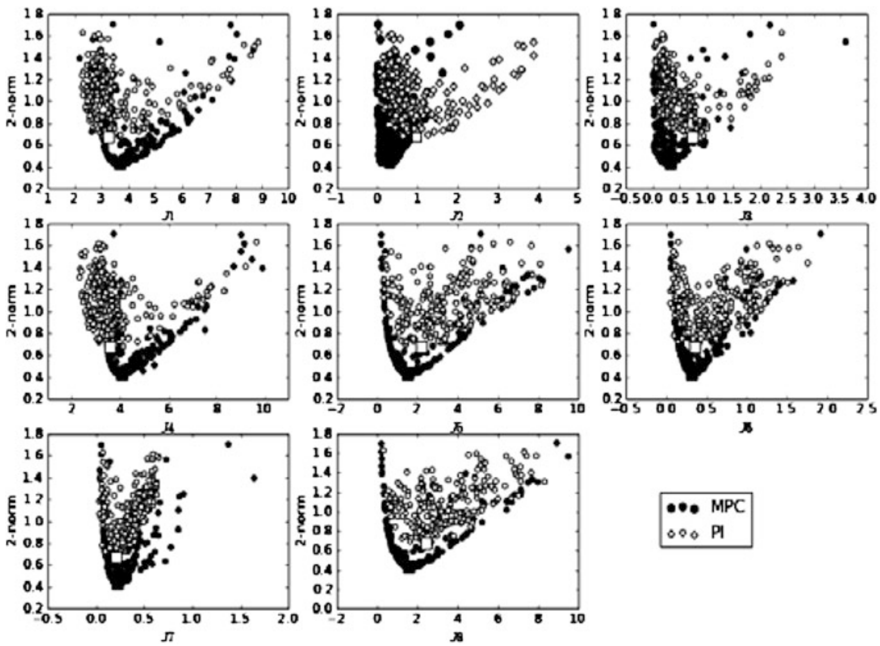


**Fig. 4** Level diagrams of the cost objectives

optimizer since any increase in the value does not affect controller performance as long as initially a value large enough (equivalent to largest settling time of 12.6 s in this case) is chosen to fully cover the system dynamics [22]. $N_P$ was set to be 30. $N_C$ was bounded on the range [1, 30]. This was based on the fact that the value should be greater or equal to 1 [22] but should be less than $N_P$. The ($\lambda_1$, $\lambda_2$, $\beta_1$, $\beta_2$) were each bounded on the range [0, 1]. These weighting coefficients are used to condition the system matrix [17] hence any range can be used.

The *Level diagrams* plots for the 8-D Pareto front are shown in Fig. 4 and for the controller tuning parameters in Figs. 5 and 6.

From the *Level diagrams* plots, a number of observations can be drawn. In Fig. 4, by observing all the plots, MPC gives more point with lower norm than PI. This shows that MPC has more points concentrated towards an ideal point and hence generally a better method to use for controller design. However, on the $J_1$ and $J_4$ plots most points for PI seem to be more concentrated towards the lower values of the cost objectives $J_1 \approx J_4 \approx 2)$ than MPC. If minimising these two cost objective is of higher priority for the DM then PI gives more chances of getting a minimum values for both cost objectives hence a better set-point tracking on both outputs. However, care must be taken as these points could be far worse in other objectives. From $J_1$ plot

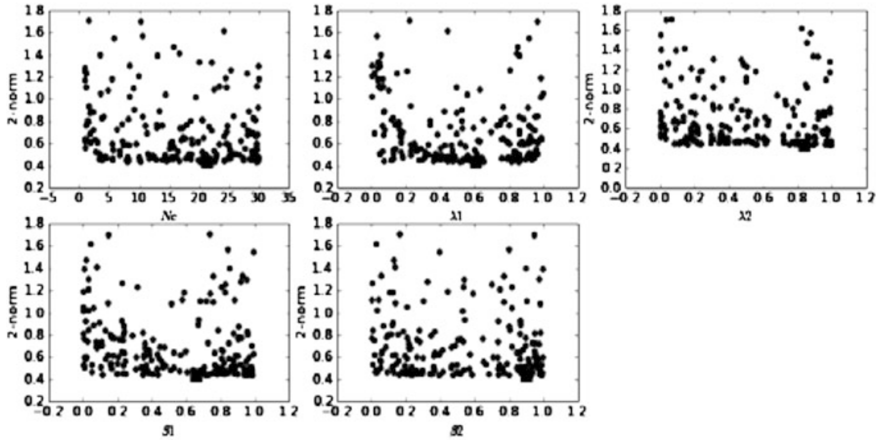


**Fig. 5** Level diagrams of the MPC tuning parameters

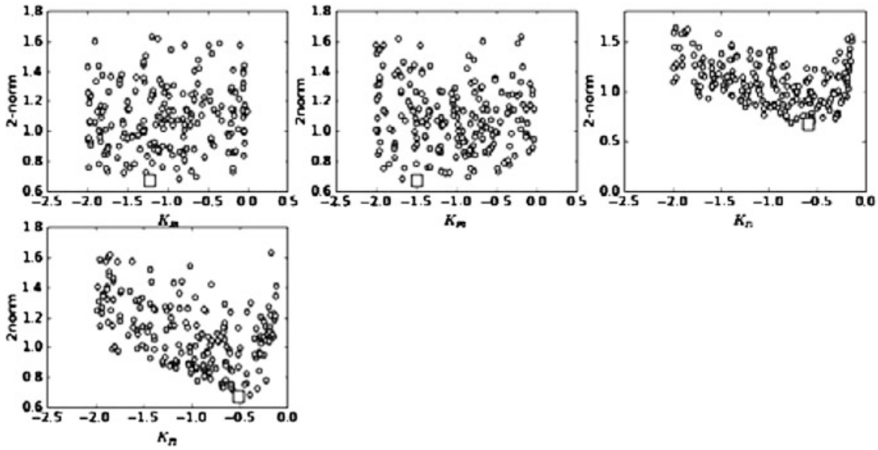


**Fig. 6** Level diagrams of the PI tuning parameters

it can be seen that most points for MPC are concentrated below 1 with a maximum value less than 2 while for PI all points are distributed over the range [0, 4]. This shows that MPC gives a better interaction rejection on output 1 than PI. From $J_3$ plot, both controllers' points seem to be clustered around the same values hence gives no significant difference in output 2 interaction rejection. In essence, PI gives better set-point tracking and worse interaction rejection.

Plots from $J_5$ to $J_8$, all points for both controllers seem to be widely spread for all objective values. This means that in terms of the amount of the controller effort

**Table 3** Tuning parameters preference and cost values

| Controller | Input parameter values | Cost objective values |
|---|---|---|
| MPC | $N_C = 2$, $\lambda_1 = 0.607358967$, $\lambda_2 = 8.41393172$, $\beta_1 = 6.59386333$, $\beta_2 = 9.02622758$ | $J_1 = 3.74779852$, $J_2 = 0.02847814$, $J_3 = 0.02903746$, $J_4 = 3.96279494$, $J_5 = 2.73538776$, $J_6 = 0.73592977$, $J_7 = 0.45687317$, $J_8 = 2.93167291$, |
| PI | $K_{P1} = -1.22144115$, $K_{P2} = -1.48962279$, $K_{I1} = -0.58771734$, $K_{I2} = -0.50906865$ | $J_1 = 3.26777078$, $J_2 = 0.98262328$, $J_3 = 0.74613356$, $J_4 = 3.59060838$, $J_5 = 2.23069877$, $J_6 = 0.36163213$, $J_7 = 0.21222551$, $J_8 = 2.45174848$, |

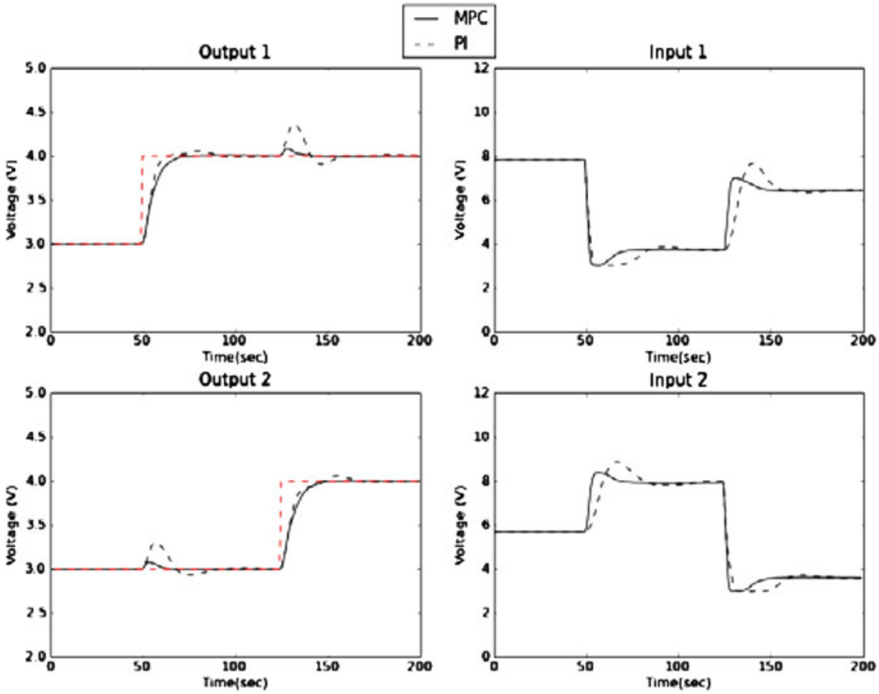


**Fig. 7** Simulation results for system response

applied, both controllers perform similarly. However for MPC, it can be observed that the norm of the objectives decrease with an increase in objective values until a certain value (i.e. $J_5 \approx 1.7, J_6 \approx 0.3, J_7 \approx 0.25, J_8 \approx 1.9$) and then start increasing.

Figure 5 gives plots for MPC tuning parameters. For all the tuning parameters, the points seem to be distributed over the whole range of values with no range of

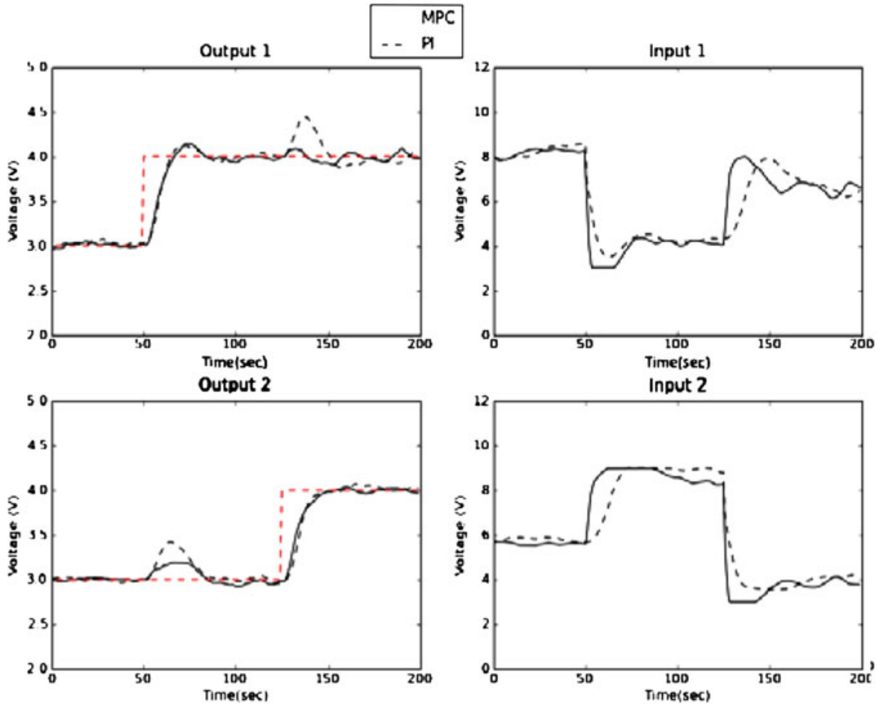


**Fig. 8** Experimental results for the controllers

values preferably better than any other. This shows the difficulty of tuning MPC parameters. This is different for PI tuning parameters (Fig. 6), as it can be seen from $K_{I1}$ and $K_{I2}$ plots that lower norms can be achieved with lower absolute values of $K_{I1}$ and $K_{I2}$.

Note that practically, it is a challenge to generate the Pareto front from the real plant. This is because the optimizer will have to be left running for many hours under which the system will be subjected to some external disturbances. In addition, since the optimizer randomly generates the input parameters, some parameters will give the response which may potentially cause problems on the physical system.

The points with minimum norm from each controller (i.e. points noted with square on the plots) shown in Table 3 were selected as preference points for controller design and their time responses are plotted as shown in Fig. 7 and their experimental responses as shown in Fig. 8.

From the results in Figs. 7 and 8, MPC gives a better performance than PI in eliminating interaction among the system outputs. However, when it comes to set-point tracking, both controllers perform more or less the same. These plots conform to the analysis and conclusions derived from the *Level diagrams* plots.

## 6 Conclusion

This paper has outlined the MOO design and performance of MPC and PI controllers on a multi-variable process. The optimum performances of these controllers were generated and comparisons were conducted using *Level diagrams*. Both controllers were found to be competitive with each other based on different performance objectives but MPC was found to be better on most objectives as compared to PI. *Level diagrams* was found to be a useful tool to visualize higher dimensions of Pareto fronts and also helpful in guiding the selection of the preferred solution for an optimal performance for a given controller.

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# Design Considerations for Generalized Predictive Controllers and Systems with Fractional Dead Time

**Christopher Domenic Cecchini**

**Abstract** Non-integral dead time in computer-controlled systems causes a zero to be created on the real axis in the **z**-plane, the position of which can be outside the unit circle or near the ringing pole position $(z = -1)$. Generalized predictive control (GPC), under certain circumstances, uses an inverse plant model to place closed-loop poles on open loop zeros. Non-minimum phase systems and some systems with fractional dead time can have zeros that are outside the unit circle or near the ringing pole. GPC, under certain circumstances, would place closed-loop poles in positions that result in undesirable ringing or instability in the closed-loop system. An analysis into the effect of the GPC control variables, plant gain and fractional dead time on the closed-loop poles positions is presented.

## 1 Introduction

Dead time in dynamic systems has been a problem for theoreticians and industry specialists for a long time [1]. It can prove to be difficult to control such systems with simpler control schemes such as three-term or PID controllers [2].

Generalized predictive control (GPC) is well known for being able to handle dead time well however its robustness is dependent on the dead time [3, 4]. By using the receding horizon theory and a prediction model, it can bypass the dead time in the system and apply a control signal for the expected output.

To control a real system with a computer requires digitisation of the system model. This usually involves a transform into the digital $(z)$ plane.

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Transforming systems with integral dead time into the z plane is very easy as dead time appears as a series of backward shift operators $(z^{-1})$ in the digital model.

However transforming a system with a fractional dead time into the z plane requires a different transform, the Modified Z-Transform [5], and the resulting digital model contains a zero which simulates the effects of the fractional dead time. The position of this zero is critically dependent on the fraction of dead time.

GPC, under certain circumstances $(\lambda = 0)$, uses an inverse plant model to optimize a cost function over a prediction horizon [3]. For non-minimum phase systems this can be a problem as the open loop zeros from the plant appear as closed loop poles that can cause instability in the closed-loop system. This is the same for a system with a fractional dead time that positions the digital zero outside the unit circle. Even if the zero is not placed outside the unit circle, a ringing pole can still be created in the control law whose output accelerates wear and tear on the plant actuator, for example.

An investigation into the effects of $\lambda$, fractional dead time and system gain on the closed loop poles is made and this paper is based on the comparison of the results.

## 2 Background

### 2.1 CARIMA-Based Model

The CARIMA (Controlled Auto-Regressive Integrated Moving Average) model has been used for approximating the open loop dynamics under investigation. It takes the form of:

$$B\left(z^{-1}\right)y(t) = A\left(z^{-1}\right)z^{-d}u(t) + \frac{T(z^{-1})}{\Delta}e(t) \tag{1}$$

where $A(z^{-1}), B(z^{-1})$ and $T(z^{-1})$ are polynomials in the backward shift operator. Signal $e(t)$ is assumed to be white noise, $T(z^{-1})$ is a filter and is the integral dead time of the discrete system. The plant input variable is u(t) and its output variable is y(t). $\Delta = (1 - z^{-1})$.

### 2.2 The Modified Z-Transform

Consider a system of the form:

$$g_p(s) = g(s)e^{-\tau s} = \beta\frac{a}{(s+a)}e^{-\tau s} \tag{2}$$

where $\tau$ is the dead time of the plant $\left(g_p\right)$, $\beta$ is the gain and $a$ is the inverse of the plant time constant, $T_c$. Traditionally the model of the plant is converted to a *discrete-time* model using the Z transform:

$$v(z) = \mathbf{Z}[v_n(t)] = \sum_{n=0}^{\infty} v_n z^{-n} \tag{3}$$

The arbitrary discrete signal, $v_n(t)$, is not a continuous signal but rather a number sequence of the values of the continuous signal, $v(t)$, at each sampling instance. $T_s$ is the sampling time of the controller.

In the case where $\tau$ is not an integral multiple of $T_s$, the dead time can be expressed as $\tau = \theta + nT$ where $nT$ is the integral portion of the dead time and $\theta$ is the fractional portion.

The Z-transform is modified to become:

$$g_p(z) = \mathbf{Z}[g(s)e^{-s\tau}] = z^{-n}\mathbf{Z}\left[g(s)e^{-s\theta}\right] \tag{4}$$

This fractional dead time requires the use of a modified transform that approximates the effect of the fractional dead time [5].

In the case of a first order system with fractional dead time and assuming the step invariant transform, the modified transform for:

$$g_p(s) = \beta \frac{a}{(s+a)} e^{-\tau s} \tag{5}$$

is:

$$gh(z) = \beta \frac{(z-1)}{z} \frac{z(1-e^{-amT_s}) + (e^{-amT_s} - e^{-aT_s})}{(z-1)(z-e^{-aT_s})} z^{-n} \tag{6}$$

where $T_s$ is the sampling time and $m = 1 - (\theta/T_s)$. The *discrete-time* model, $gh(z)$, contains a zero due to the non-integral dead time.

As $m$ lies between 0 and 1, the position of the zero created by approximating the behaviour of the fractional dead time is

$$z = -\frac{(e^{-amT} - e^{-aT})}{(1-e^{-amT})} \tag{7}$$

For an arbitrary value of $T_s = 1$ and $a = 1$, a graph of $m$ versus zero position can be produced. It can be seen that the zero created will lie between negative infinity and zero.(Fig. 1).

It is interesting to note that for a value of $m \geq 0.379$ the zero will be placed inside the unit circle for these assumed values of $T_s = 1$ and $a = 1$.

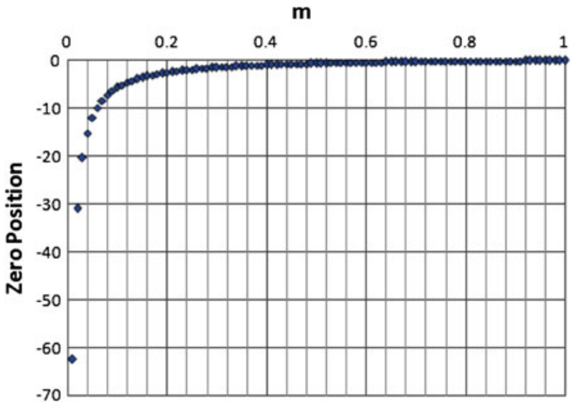


**Fig. 1** A graph of m versus the created zero position

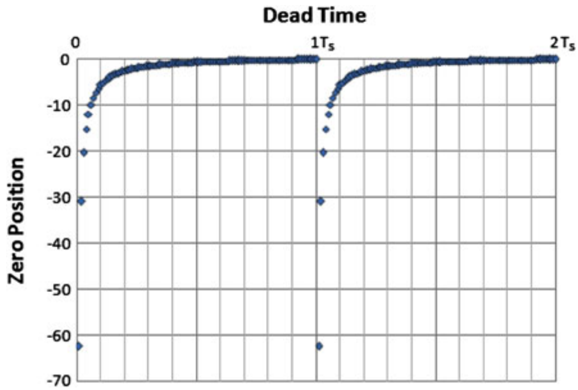


**Fig. 2** As $\tau$ increases and crosses an integral multiple of $T_s$, the curve repeats itself

This curve is repeated for every full integral instance of sampling time so the dependence of the zero position in Eq. (6) on the system dead time is cyclic as shown in Fig. 2.

## *2.3 Ringing*

When a pole falls on the negative real axis within the unit circle on the Z plane, ringing may result. Briefly, ringing is a well known phenomenon that is caused by a dominant system pole falling in the range $-1 \leq real(z) \leq 0$.

It is characterised by having an output that oscillates with a frequency of exactly $\pi$ divided by the sampling time. For example, Fig. 3 shows the output of a system with sampling time of 1 s.

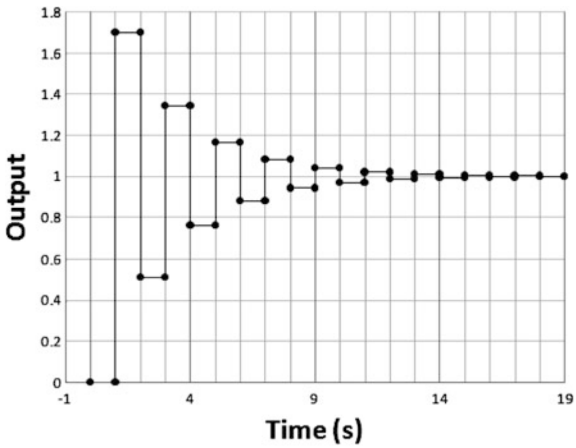


**Fig. 3** An example of a system with a dominant ringing pole

# 3 General Predictive Control

## *3.1 Background*

GPC is a control scheme that predicts the output of a system and computes the control action, at each sampling instance, by solving a finite horizon control optimization problem. This yields an optimal sequence of control actions and only the first action is applied to the system [6].

One of the main features of GPC is its ability to handle constraints [4]. However, for the purposes of this paper, that investigates non-integral dead time, the unconstrained case will be considered.

The control law is calculated over a control horizon of Nu sampling steps ahead beginning at N1 and ending at N2. Typically N1 $= 1$ unless there is dead time in system in which case N1 $=$ d $+ 1$ where d is the integral dead time.

## *3.2 The Control Law*

For a plant model of the form Eq. (1), assuming a specific case with $C(z^{-1}) = 1$ and solving a Diophantine equation of the form $1 = E_j(z^{-1})\widetilde{A}(z^{-1}) + z^{-j}F_j(z^{-1})$ the prediction of the output is:

$$\mathbf{y} = \mathbf{G}\mathbf{u} + \mathbf{G}^{'}\Delta u(t-1) + \mathbf{F}y(t) \tag{8}$$

with $\Delta = (1 - z^{-1})$ and $\widetilde{A}(z^{-1}) = A(z^{-1})\Delta$.

The elements of $\mathbf{G}$ are obtained from:

$$G_j(z^{-1}) = E_j(z^{-1})B(z^{-1}) \tag{9}$$

**G** is a matrix containing step response data of the system to be controlled and **y**, **u** and **G′** are column vectors. The output is split into two categories, the forced and free responses, **Gu** and $[\mathbf{G}'\Delta \mathrm{u}(\mathrm{t}-1) + \mathbf{F}\mathrm{y}(\mathrm{t})]$ respectively. The forced response is the portion of the output that results from changing control action whereas the free response is the response assuming no change in the future control action.

GPC minimises a cost function of the form:

$$\begin{aligned} J(N1, N2, Nu) = &\sum_{j=N_1}^{N_2} [y(t+j|t) - w(t+j|t)]^2 \\ &+ \sum_{j=1}^{N_u} \lambda(j)[\Delta u(t+j-1|t)]^2 \end{aligned} \tag{10}$$

The weighting variable, $\lambda(\mathrm{j})$, is typically taken to be a series of constants such that $\lambda(\mathrm{j}) = \lambda$.

Substituting Eq. (9) into Eq. (10) and minimising with respect to u gives the well known optimal control sequence [3]:

$$\upsilon = \left(\mathbf{G}^T\mathbf{G} + \lambda\mathbf{I}\right)^{-1}\mathbf{G}^T(\mathbf{w} - \mathbf{f_r}) \tag{11}$$

$\upsilon$ is a column vector of optimal control actions but only the first action is applied. $\mathbf{f_r}$ is the free response and **w** is the reference vector. This first control action can be viewed as

$$\begin{aligned} \Delta u(t) &= K(\mathbf{w} - \mathbf{f_r}) \\ &= \sum_{i=N_1}^{N_2} k_i[w(t+i) - f(t+i)] \end{aligned} \tag{12}$$

where K is the first row of the $\left(\mathbf{G}^T\mathbf{G} + \lambda\mathbf{I}\right)^{-1}\mathbf{G}^T$matrix.

### 3.3 Closed-Loop Relationship

The equivalent closed-loop relationship can be shown in a standard control structure presented below:

$$R(z^{-1})\Delta u(t) = T(z^{-1})w(t) - S(z^{-1})y(t) \tag{13}$$

$\mathrm{R}(\mathrm{z}^{-1})$ and $\mathrm{S}(\mathrm{z}^{-1})$ are polynomials.

By taking Eq. (1) and solving the Diophantine equation, the following optimal prediction is obtained:

$$y(t+j|t) = \frac{E_j(z^{-1})B(z^{-1})}{T(z^{-1})}\Delta u(t+j-1) + \frac{F_j(z^{-1})}{T(z^{-1})}y(t) \tag{14}$$

The $e(t)$ term has been omitted as an optimal output prediction contains zero disturbances and error for future outputs.

This prediction involves known values and past and future control inputs.

The control input can be separated into past values and future values (that are to be calculated) by the Diophantine equation such that:

$$y(t+j|t) = H_j\Delta u(t+j) + \frac{I_j}{T}u(t-1) + \frac{F_j}{T}y(t) \tag{15}$$

where the coefficients of $H_j$ are the row elements of $\mathbf{G}$ and $I_j$ are the row vectors of $\mathbf{G}'$. The free response is given by the current and past values of y and u.

After substituting the free response portion of Eq. (15) into Eq. (12) and performing some mathematical manipulation:

$$\begin{aligned}&\left(T(z^{-1}) + z^{-1}\sum_{i=N_1}^{N_2} k_i I_i\right)\Delta u(t)\\ &\quad = \left(T(z^{-1})\sum_{i=N_1}^{N_2} k_i\right)w(t) - \left(\sum_{i=N_1}^{N_2} k_i F_i\right)y(t)\end{aligned} \tag{16}$$

Comparing Eq. (16) to Eq. (13), $R(z^{-1})$ and $S(z^{-1})$ can be defined as:

$$R(z^{-1}) = \left(T + z^{-1}\sum_{i=N_1}^{N_2} k_i I_i\right) \tag{17}$$

and

$$S(z^{-1}) = \left(\sum_{i=N_1}^{N_2} k_i F_i\right) \tag{18}$$

Substituting the control law into the model and omitting the $(z^{-1})$ term, the characteristic equation for the closed loop system is:

$$RA\Delta + BSz^{-1} = 0 \tag{19}$$

Therefore, it is possible to compute the closed-loop pole positions from Eq. (19) based on Eqs. (14) to (18). (Fig. 4).

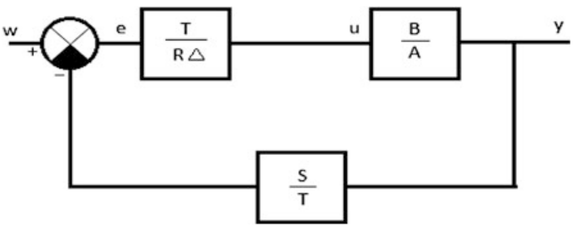


**Fig. 4** A standard control structure

## 3.4 Pole Zero Cancellation

It is well known [3] that for certain conditions ($\lambda = 0$), the GPC algorithm tries to cancel the open loop zeros with closed loop poles during the optimal control minimization of $\mathrm{J(N1, N2, Nu)}$ by using an inverse plant model. For non-minimum phase systems this would cause the output to become unstable as the closed loop poles correspond to the unstable open loop zeros.

This is illustrated below in which the plant model is:

$$g(s) = \frac{1}{10s + 1} e^{-8.9s} \tag{20}$$

The sampling time is 1 s. Since the dead time is non-integral, the discrete model after transforming with zero order hold is:

$$g(z) = \frac{0.01z + 0.0852}{z - 0.9045} z^{-9} \tag{21}$$

It contains a zero lying at $-8.5638$. For a value of Nu $= 3$ and $\lambda = 0$, **G** is calculated to be:

$$\mathbf{G} = \begin{bmatrix} 0.01 & 0 & 0 \\ 0.1042 & 0.01 & 0 \\ 0.1894 & 0.1042 & 0.01 \end{bmatrix} \tag{22}$$

$K = [100.500]$ and the closed loop pole positions are calculated using:

$$R(z^{-1}) = 0.01 - 0.0852z^{-1} \tag{23}$$

$$S(z^{-1}) = 1.9048 - 0.9048z^{-1} \tag{24}$$

Substituting these polynomials into Eq. (19), the characteristic equation is:

$$\phi_c(z^{-1}) = 0.01 + 0.0852z^{-1} \tag{25}$$

which is the same as the open loop zero polynomial, indicating that the closed loop system is unstable. This is due to the non-integral dead time that

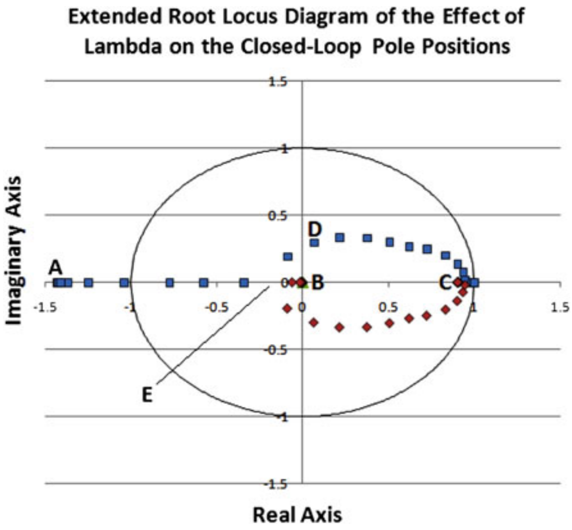


**Fig. 5** Marker A and B correspond to $\lambda = 0$, C corresponds to $\lambda \to \infty$ and D corresponds to $\lambda = 0.001$. A third pole has been omitted as it sits at the origin and does not change. E is the approximated break away point

has an m value resulting in a zero being placed outside the unit circle in the z-plane.

# 4 Results

## 4.1 The Effect of $\lambda$ and $\theta$ on the Closed Loop Pole Positions

For the following class of systems:

$$g(s) = \frac{a}{sT_c + 1} e^{-s\tau} \tag{26}$$

where $\tau$ is a fractional dead time in the order of $T_c$, the time constant, an extended root locus diagram can be plotted to quantify the effect of $\lambda$ and $\theta$ on the closed loop pole positions. The system is to be controlled with a GPC controller using Eq. (10) as a cost function and Nu = N2 – N1.

Consider the system:

$$g(s) = \frac{1}{10s + 1} e^{-8.6s} \tag{27}$$

Nu has been fixed at 3.

An extended root locus diagram for the above system is shown in Fig. 5.

The plotted pole positions correspond to a vector of $\lambda$ values such that $\lambda = [0; 3^{-10}; 1^{-9}; 3^{-9}; 1^{-8}; \ldots; 100000]$. The pole positions corresponding to $\lambda = 0$

**Table 1** Table of fractional dead time and their consequent break away points and created zeros

| m | Break away point | Created zero | Left(%) | Delta(%) |
|---|---|---|---|---|
| 0.9 | −0.047 | −0.106 | 55.15 | – |
| 0.8 | −0.093 | −0.238 | 61.06 | 5.91 |
| 0.7 | −0.132 | −0.408 | 67.64 | 6.58 |
| 0.6 | −0.161 | −0.634 | 74.69 | 7.05 |
| 0.5 | −0.174 | −0.951 | 81.75 | 7.06 |
| 0.4 | −0.168 | −1.427 | 88.25 | 6.5 |
| 0.3 | −0.143 | −2.212 | 93.57 | 5.32 |
| 0.2 | −0.120 | −3.806 | 97.32 | 3.75 |
| 0.1 | −0.052 | −8.564 | 99.39 | 2.07 |

are $z = -1.427$ and 0, $\lambda \to \infty$ are $z = 0.905$ and 1 and for $\lambda = 0.001$ are $z = 0.067 \pm 0.296i$. The approximate break away point, E, is $z \cong -0.1677$.

According to [3], increasing the prediction horizon (and consequentially the control horizon) will cause the closed loop poles to tend to the open loop pole positions. Increasing $\lambda$ will have a similar effect due to the correlation between Nu and $\lambda$ in the cost function as defined in Eq. (10).

Altering the fractional dead time and consequentially the position of the created digital zero will cause the position of the break away point (marked E in Fig. 5) on the real axis of the extended root locus to change.

Table 1 shows the break away points for the system given in Eq. (27). The percentage is a ratio of the distance the closed-loop pole placed on top of the created zero has to travel to the break away point over the sum of the distances the closed-loop poles have to travel to the break away point. The increasing percentage indicated that the closed-loop pole being placed on top of the created zero becomes less and less dominant.

The rate at which the closed-loop pole becomes less dominant is greatest around a $\theta$ value of approximately 0.5 before dying away. This indicates that the effects of the created zero are more pronounced when the zero lies close to the ringing pole, $z = -1$.

Figure 6 shows the effect of varying $\theta$ and keeping $\lambda$ constant. In this case $\lambda$ has been chosen to be zero as this shows the worst case zeros.

## 4.2 The Effect of System Gain on the Closed-Loop Pole Positions

For the same class of systems as Eq. (26), it can be shown that increasing the system gain for a given $\lambda$, Nu and $\tau$ will cause the closed loop pole positions to be drawn back towards the open loop zero positions.

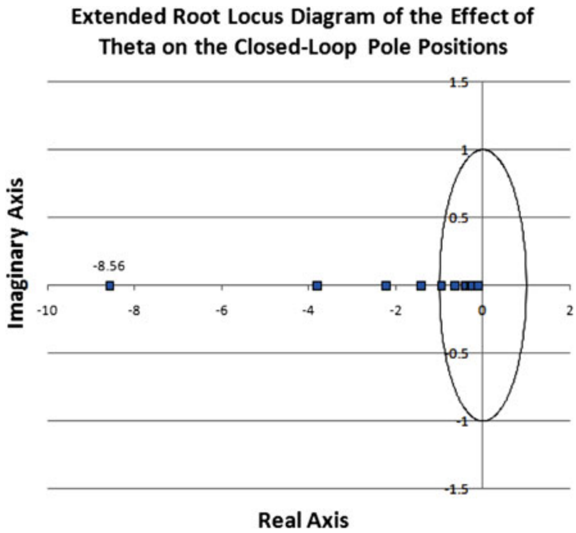


**Fig. 6** For a value of $\lambda = 0$ and $\theta$ range from 0.1 to 0.9 in increments of 0.1

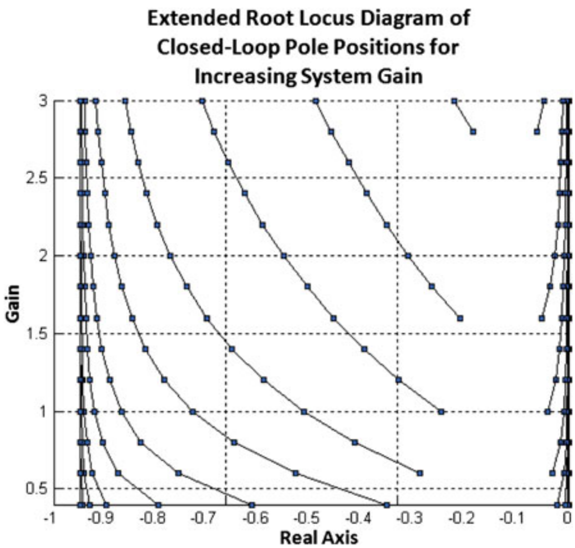


**Fig. 7** The concentration of pole positions at 0 and $-0.9259$ correspond to $\lambda = 0$.

Figure 7 shows a plot of the closed loop pole positions for the GPC control system given in Eq. (27). The closed-loop pole positions form curves parameterized by the system gain. For a given value of $\lambda$, the associated pole position will be drawn back towards its corresponding open loop zero position as the gain is increased. The lines terminate when the next pole has an imaginary component a.k.a. it has passed over the break away point.

## 5 Conclusion

This paper has shown that in the design process of generalized predictive controllers for systems with fractional dead time that the choice of control parameters is crucial.

The closed-loop pole positions are very sensitive to small changes in $\lambda$ when $\lambda$ is near zero.

Small changes in the fractional dead time can cause large changes in the digitally created zero. As a result, a system that was previously stable can become unexpectedly ringing or unstable.

A poorly modelled system with incorrect gain can also result in a misleading control law. Increasing the gain of the system requires more emphasis to be places on the input weighting variable, $\lambda$; an increased $\lambda$ is required for the same closed loop pole positions as the gain is increased.

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# R-Mesh Simulator Using C++

**Abdelwadood Mesleh, Omar AlHeyasat, Mohammad Al-Rawabdeh and Mazen AbuZaher**

**Abstract** A multi-core processor technology integrates many processing cores on a chip to achieve an increased performance. One strategy to define the relationships between cores is reconfigurable mesh (R-Mesh). R-Mesh has drawn much attention in the recent years because of its speed and efficiency compared with traditional parallel strategies. The novel contribution of this paper is to introduce a simple R-Mesh simulator that can be used for educational purpose. The purposed simulator can assist in the analysis of algorithms implemented using R-Mesh within an educational environment. We have used the Open Multi-Processing (OpenMP) in MS Visual Studio.Net 2008 (C++) to implement the R-Mesh architecture code part "rmesh.h", and the Open Graphics Library (OpenGL) to implement the R-Mesh graphics part "rmgraphic.h". Simulation of a variety of problems (addition, counting, and sorting) shows the robustness of the proposed R-Mesh simulator.

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## 1 Introduction

Future technology [1] will enable us to increasing the number of cores integrated on a single chip. The main challenge is how we can interconnect these cores in an effective way to increase processor performance in term of minimum power. The best choice is using R-Mesh which is an array of processors with an underlying bus system that traverses the processors using packet-switched technique [1].

R-Mesh can give us greater computational power; in addition it can solve many more problems in constant time, which lead to significant reduction in computation times [2]. Accordingly studying R-Mesh might introduce new approaches for the design and programming of many-cores.

There is a lack of programming environments for R-Mesh [3]. In [3], an architecture, the Polymorphic Processor Array (PPA), uses a strict SIMD programming model to simulate a very restrictive variant of the R-Mesh model, limited to only a subset of the entire body of reconfigurable mesh algorithms [3]. A language called Polymorphic Parallel C (PPC) [4] is also used as a programming model for R-Mesh.

Based on [5], an R-Mesh Parallel C (RMPC) language is used to simulate R-Mesh. The R-Mesh simulator RMSIM [6] simulates RMPC algorithms while allowing for the visualization of bus configurations through LaTeX pictures. Further R-Mesh simulators were presented by [2, 7, 8].

A recent work [9] presented a new language ARMLang for the specification of lockstep programs on regular processor arrays, in particular R-Meshes, where the target is real implementations using FPGA.

In this paper we introduce a simple R-Mesh simulator that can help students to understand R-Mesh. In addition our simulator can be used to study R-Mesh behavior within different algorithms and to compare the results with the output of traditional technique (serial and parallel).

In this work, our simple R-Mesh simulator uses C++ programming language to implement any algorithm on R-Mesh. The proposed simulator enables any student with a C++ basic information and with an R-Mesh basic knowledge to understand R-Mesh, and to compare its performance with other parallel approaches.

R-Mesh [10] is a set of processors ordered in linear or multidimensional arrays. Each processor connects to its neighbors by external bus. The ports of processors are connected together by internal bus. Each processor in R-Mesh architecture has its own local data memory. And all processors share a code memory—single instruction multi data model (SIMD). There are two main types of R-Mesh [10]:

- A one-dimensional R-Mesh with N processors (see Fig. 1) allows each processor to either segment or not segment the bus traversing. Each processor has two ports, the East and West ports (abbreviated E and W), that connect it to its neighbors. In addition to these external connections between processors, each processor can internally connect its ports to form a bus that passes through the processor. Indeed, if all processors connect their E and W ports, a bus spans the entire linear array. The internal connections in a processor of a one-dimensional

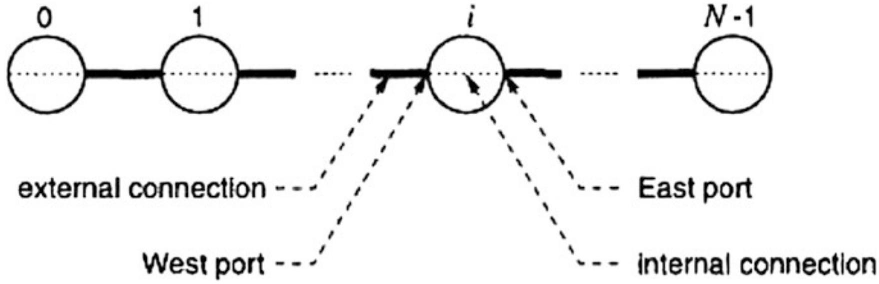



**Fig. 1** Structure of one-dimensional R-Mesh [10]

R-Mesh are viewed as a partition of the set, {E, W}, of ports of the processor. The two possible partitions here have the following meanings:. $\{\overline{WE}\}$ indicates that the E and W ports are connected within the processor, on the other hand, $\{\overline{E}, \overline{W}\}$ indicates that the E and W ports are not connected within the processor.

- A two-dimensional R-Mesh arranges processors in an R × C 2-dimensional mesh (R is number of rows, and C is the number of columns in the 2-dimensional mesh), where each processor has four neighbors. Assuming that each processor has four ports, N, S, E, and W, through which it connects to processors (if any) to its North, South, East, and West. Besides these external connections, each processor may establish internal connections among its ports that correspond to partitions of the set, {N, S, E, W}, of ports. Figure 2 shows a structure for a 3 × 5 two-dimensional R-Mesh [10].

In this project we have designed a simple simulator for R-mesh architecture that implements three types of R-Mesh connections ({N, S, E, W}, $\{\overline{EW}\}$, and $\{\overline{WS}, \overline{NE}\}$). Figure 3 illustrates the class of R-Mesh architecture for our proposed simulator. Figure 4 shows the 15 possible port partitions along with the corresponding internal connections.

Implementation includes two parts: R-Mesh architecture part and R-Mesh graphic part. R-Mesh architecture part shows the final results of an operation and the values stored in each processor in each execution. R-Mesh graphic part shows the internal and external bus configuration and the status of the processor.

We used C++ language to implement the proposed simulator. We have used the Open Multi-Processing (OpenMP) in MS Visual studio.Net 2005 to implement the R-Mesh architecture code part "rmesh.h" and the Open Graphics Library (OpenGL) to implement the R-Mesh graphics part "rmgraphic.h". The functions in the two C++ header files (rmesh.h and rmgraphic.h) can be used to implement many algorithms on R-Mesh.

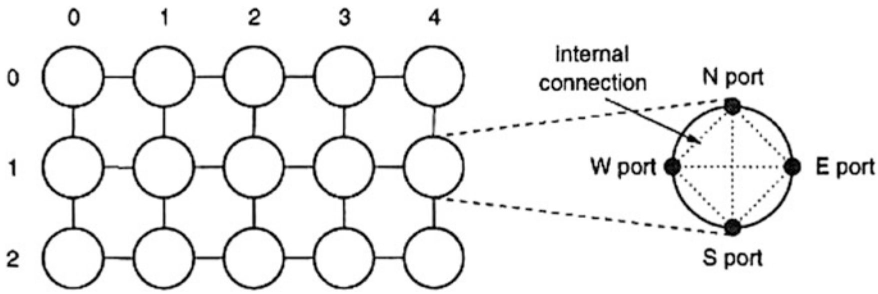
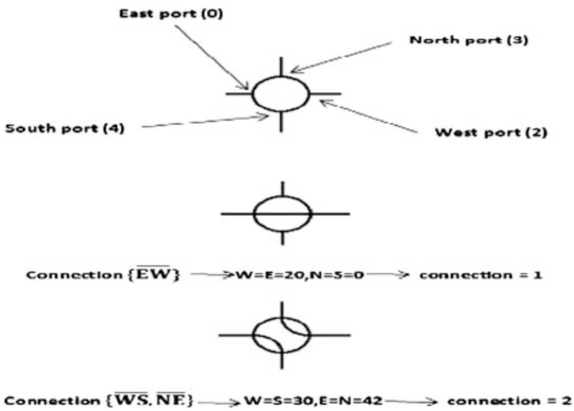



**Fig. 2** Structure of two-dimensional R-Mesh [10]

**Fig. 3** Class illustrations of the simulator [10]




The main contents of "rmesh.h" are the following:

- R-Mesh class: contains variables and connection functions:

```
class rmesh{
public:
int north, south,east,west;
//ports of CPUs
int connection;
//type of the connection
int busy;
int active;
int next;
int first;
int last;
int link;
int pred;
```

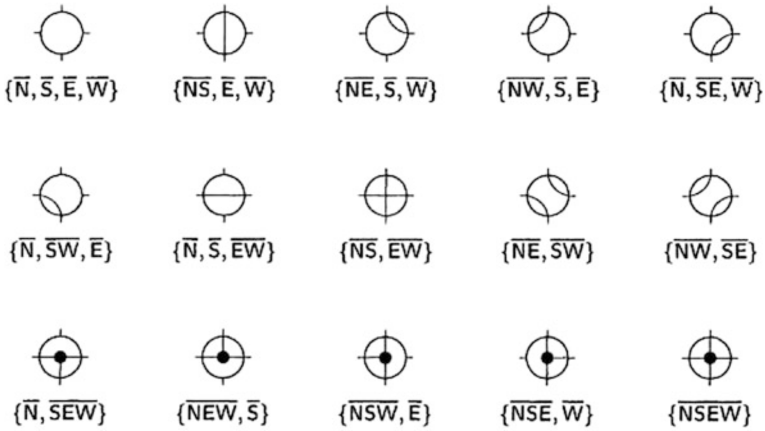



**Fig. 4** Port partitions of R-Mesh [10]

```
int next_list;
void connection_EW(){
east=west=20;
north=south=0;
connection=1;
}
//function connect both east &
//South ports and both north
//and west ports
void connection_NW_and_SE(){
west=30;
south=30;
north=42;
east=42;
connection=2;
}
};
```

The main contents of “rmgraphic.h” are the following:

- A variable to define dimensions of R-Mesh, i.e. row × column:
  `int column, row;`
- A variable to define the R-Mesh size: size= row*column:
  `int size;`
- A buffer to store the input data:
  `char *pr=new char();`
- A variable to store the type of connection of each processor:
  `int connection[200];`

- variables to store data in processors:
  `int d [200];`
- A variable to define the status of the port of each processor:
  `int port[100];`
- A variable to store the number of processor:
  `int cpu_num;`
- A function to input a set of numbers {b0, b1,…., bn−1} and to assign then to processors:
  `Void enter_number();`
- According to executed operation, some functions are designed to draw the paths that connect the ports of each processor for the one/two dimensional R-Mesh architectures and to draw the background of r-mesh:
  ```
  void draw_path();
  void draw_path2;
  void CALLBACK display(void);
  ```

# 2 R-Mesh Simulation Results

To test the proposed R-Mesh simulator, we have used it to simulate the Non-Recursive Binary Tree Addition (NRBTA), Bit Counting (BC) and Chain Sorting (CS) algorithms.

## 2.1 Non-Recursive Binary Tree Addition Problem

Let processor $i$ ($0 \leq i \prec N$) initially holds an input $a_i$. The Non-Recursive Binary Tree Addition (NRBT) algorithm [10] aims to compute $\sum_{i=0}^{N} a_i$.

The following is the consol output results for NRBT implemented on a one-dimensional R-Mesh with 8 processors.

```
Enter (8) numbers:
1, 2, 3, 4, 5, 6, 7, 8
Value of rank 4=11
Value of rank 6=15
Value of rank 2=7
Value of rank 0=3
Value of rank 4=26
Value of rank 0=10
Value of rank 0=36
```

Figure 5 shows the simulation output of the NRBT implemented on the same one-dimensional R-Mesh.

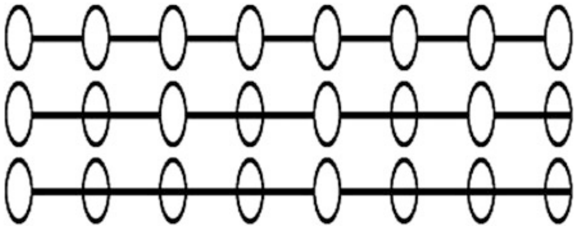


**Fig. 5** R-Mesh simulation output of the NRBT algorithm implemented on a one dimensional R-Mesh with 8 processors

## 2.2 Bit Counting Problem

Let processor $i$ $(0 \leq i \prec N)$ initially holds an input $a_i$. The bit counting algorithm [10] is to count the number of ones in the processors.

The following is the consol output results for the bit counting algorithm implemented on a $4 \times 3$ two-dimensional R-Mesh:

```
Enter a Binary Number: 101
Matrix
1 0 1
1 0 1
1 0 1
1 0 1
North port is connected with
E E E
- - -
E E E
E E E
East port is connected with
N N N
W W W
N N N
N N N
South port is connected with
W W W
- - -
W W W
W W W
West port is connected with
S S S
W W W
S S S
S S S
Path = 0→3→4→5→8
```

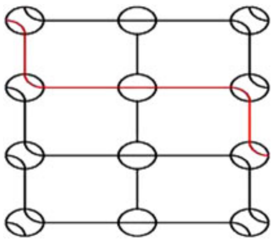


**Fig. 6** R-Mesh simulation of the bit counting algorithm implemented on a 4 × 3 two-dimensional R-Mesh

Figure 6 shows the simulation output of the same algorithm implemented on the same 4 × 3 two-dimensional R-Mesh.

## *2.3 Chain Sorting Problem*

Let processor $i$ ($0 \le i \prec N$) initially holds an input $a_i$. The chain sorting algorithm [10] is to sort $a_i$ values.

The following is the consol output results for chain sorting implemented on a 4 × 5 two-dimensional R-Mesh:

```
Enter a Number: 32210
R-Mesh (row=4 X column=5)
Matrix:
1 1 2 2 3
1 1 2 2 3
1 1 2 2 3
1 1 2 2 3
List of active processors;
L(0)= {}
L(1)= {01}
L(2)= {23}
L(3)= {4}
Active processors:
0 0 0 0 0
1 1 0 0 0
0 0 1 1 0
0 0 0 0 1
First pointers:
Fp(0) = #
Fp(1) = 0
Fp(2) = 2
Fp(3) = 4
Fp(4) = #
Last pointers:
```

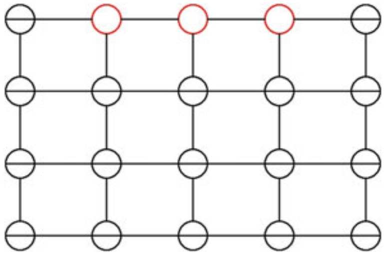


**Fig. 7** R-Mesh simulation of the chain sorting algorithm implemented on a 4 × 5 two-dimensional R-Mesh

```
Fp(0) = #
Lp(1) = 1
Lp(2) = 3
Lp(3) = 4
Lp(4) = #
Active processors:
0 1 1 1 0
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
L= {123}
Link (1) = 2
Link (2) = 1
Link (3) = 1
Pred (3) = 2
Pred (2) = 1
Pred (1) = 3
First (1) = 0
First (2) = 2
First (3) = 4
Last (1) = 1
Last (2) = 3
Last (3) = 4
Next (0) = 1
Next (1) = 2
Next (2) = 3
Next (3) = 4
Next (4) = 0
```

Figure 7 shows the simulation output of the chain sorting implemented on the same 4 × 5 two-dimensional R-Mesh.

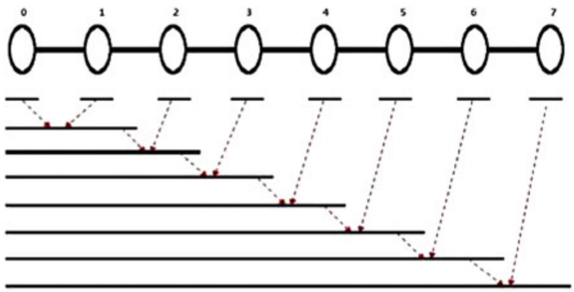



**Fig. 8** Serial implementation of the logical OR-ing algorithm using eight processors

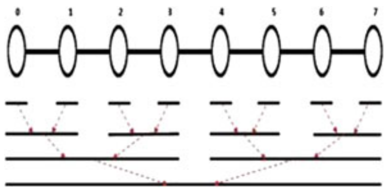



**Fig. 9** Parallel implementation of the logical OR-ing algorithm using eight processors

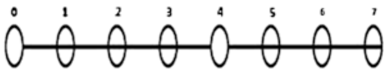



**Fig. 10** One-dimensional R-Mesh implementation of the logical OR-ing algorithm using eight processors

## 3 R-Mesh Performance Comparison Results

For comparison purposes, we have implemented serial, parallel and R-Mesh schemes for the Logical OR-ing and compared its performance using different performance measures such as the execution time, performance, and speed up [11]:

- Execution Time = n × Clock Cycle Time.
- Performance = 1/Execution Time.
- Speed Up = Old Execution Time/New Execution Time.

Assuming that all processors have the same properties, n is the number of steps, each step requires one clock cycle and Clock Cycle Time = 1 ns.

Let processor $i$ $(0 \leq i \prec N)$ initially holds an input $a_i$. The OR-ing algorithm [4] is to compute the logical OR of $a_1, a_2, \ldots, a_N$.

Figure 8 shows the serial implementation of the OR-ing algorithm, Fig. 9 shows the parallel implementation and finally, Fig. 10 shows the R-Mesh implementation. The numbers of processors were 8, 16, 32, 64, 128 and 256. Seven iterations are required in each of them.

**Table 1** R-Mesh speed up compared with serial and parallel implementations

| Number of processors | Serial | Parallel |
|---|---|---|
| 8 | 2.33 | 1.33 |
| 16 | 5 | 1.667 |
| 32 | 10.33 | 2 |
| 64 | 21 | 2.33 |
| 128 | 42.33 | 2.667 |
| 256 | 85 | 3 |

It is clear that the speed up of the R-Mesh is much faster (see Table 1). For example, R-Mesh is 2.33 times faster than serial implementation when using eight processors.

## 4 Conclusion and Future Work

In this paper, we have implemented a simple simulator for R-Mesh. We have used it to simulate the Non-Recursive Binary Tree Addition, Bit Counting, and Chain Sorting algorithms.

Using our simulator, we have conducted a comparison between R-mesh, parallel, and serial implementations for finding logic OR algorithm. Evaluation results reveal the superiority of the proposed R-Mesh in these applications.

Our future work is to extend our simulator to adapt the 15 connections of R-Mesh (see Fig. 4), so that students can perform a simulation for any algorithm using the R-Mesh.

**Acknowledgment** The authors like to thank Dr. Dmitriy for the kind programming help.

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# Image Pre-Compensation for Visually Impaired Computer Users with Variable Pupil Size

**Jian Huang, Armando Barreto, Miguel Alonso and Malek Adjouadi**

**Abstract** Visual perception is one of the most important processes involved in human–computer interaction. However, many users with visual impairments may suffer from various visual aberrations which hamper their perception of the images displayed on the computer screen. To facilitate the interaction of these users with computers, the pre-compensation of computer images according to their particular visual aberration has been proposed. The pre-compensation process used is based on a priori knowledge of the visual aberration of the user's eye, which can be measured by a wavefront analyzer. Unfortunately, the visual aberration is measured for a specific pupil size. If the pupil size changes, the visual aberration is modified and, therefore, the pre-compensation model should also be modified, otherwise the efficiency of the pre-compensation method will be deteriorated. This paper presents a pre-compensation method that uses an algorithm to adapt the wavefront aberration function to a new pupil size if the wavefront aberration for a larger pupil size is known. Applying this algorithm, it is possible to keep the pupil size assumed for image pre-compensation matched to the effective pupil size of the user's eye during viewing. Preliminary tests are implemented with aberration data of a human eye through simulation. The results demonstrate that the image perceived after pre-compensation adjustment is better than the one without adjustment, verifying the capability of the resizing algorithm to adjust the pre-compensation model.

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# 1 Introduction

Visual perception is one of the most important processes used by humans to interact with computers, as vision provides us with a natural and instantaneous mechanism for information perception. This is utilized in various graphical user interfaces which have been developed to suit the need of the general population. For computer users with visual limitations, especially users with serious visual impairments, the process of interaction with computers is hampered by aberrations of their eyes. Visual perception of physical objects is determined by the formation of their optical images upon the retinal mosaic of light-sensitive photoreceptors [1]. If a human eye were perfect, the refractive system in the eye would create an exact mapping of the image of each physical object on the retina. However, the eyes of many computer users are not perfect and, in some cases (e.g., for users with severe myopia, severe astigmatism or keratoconus), assistive technology approaches are needed to facilitate the interaction of these users and computers.

In general, corrective lenses, in the form of spectacles or contact lenses, are used to overcome many vision limitations. However, optical lenses are only efficient to correct low order aberrations such as myopia, hyperopia, presbyopia and astigmatism. Visual impairments involving high order aberrations may not be corrected by general optical lenses. Alonso et al. [2], have proposed an image processing approach to pre-compensate the intended display image for computer users with impaired vision. In contrast with the traditional optical correction through lenses which modify the images of external objects before reaching the eye, this approach modifies computer images at their source. This kind of pre-compensation or inverse filtering is based on the a priori knowledge of the visual aberration (wavefront aberration) of the user's eye, which can be measured by a wavefront analyzer. Alonso's pre-compensation method has been shown to help computer users with visual impairments, under controlled experimental conditions. However, there is an important limitation to this method: it compensates the images based on the wavefront aberration measured at a single pupil size. In practical human–computer interaction scenarios, the human eye will behave as a dynamic system and its pupil size may vary. The pupil size of the human eye may change due to accommodation or changes in illumination. It also depends on other factors such as emotional factors and attentional factors [3]. Therefore, it is likely that there will be a mismatch between the characteristics of the eye as measured by the wavefront analyzer and the eye at the time of viewing the images displayed, even for the same computer user. This kind of mismatch will deteriorate the effect of pre-compensation. Fortunately, Schwiegerlin [4], Campbell [5] and Dai [6] have developed efficient numerical methods to derive the new wavefront aberration function on the basis of the original aberration of the same eye but with different pupil size. This paper extends Alonso's pre-compensation method by using Campbell's matrix method to adjust the pre-compensation model of the eye's aberration for different pupil sizes. This makes it possible to reduce or remove the negative effects caused by the mismatch of the pupil size when viewing the computer images, in comparison to the pupil size present during the measurement of the wavefront aberration using a wavefront analyzer.

# 2 Modeling of Human Vision System

## 2.1 Wavefront Aberration and Zernike Coefficients

The wavefront of the light entering the eye can be visualized as a surface over which light has a constant phase. An ideal spherical wavefront will make light coming into the eye converge to a single point in the retina. In this context, the wavefront aberration is the function of optical deviations of the wavefront from the ideal spherical wavefront. Any wavefront aberration will cause deterioration in the quality of point images, and also in the quality of an actual image as a whole. The wavefront aberration function can be represented as:

$$W(r,\theta) = \sum_{i=0}^{\infty} c_i Z_i(\rho,\theta). \tag{1}$$

In the equation above $c_i$ represent the Zernike coefficients and $Z_i(\rho,\theta)$represent the corresponding Zernike polynomials. Zernike coefficients and Zernike polynomials are the most popular way to represent the wavefront aberration function.

## 2.2 PSF of the Human Eye

Human visual perception is created by the projection of the image of external objects on the retina, which is the light sensitive portion of the human eye. Any object, when being viewed by the eye, can be thought of as a two-dimensional array of point sources with variable intensity. In the context of human–computer interaction, when the user views the computer screen, each pixel of the image displayed on the screen can be treated as a point source, and the corresponding image of that pixel is projected upon the retina. An ideal imaging system would establish an exact point-to-point mapping between the external object and the retinal image. However, there is no such ideal imaging system in the real world. All imaging systems involve more or less aberration, and therefore, every point source is distributed to an extended area on the retina, with variable intensity. This intensity distribution is called the point spread function (PSF), which is analogous to the two-dimensional impulse response function of the imaging system. The PSF is widely used to describe the imaging quality of an optical system. It is usually derived from the wavefront aberration function.

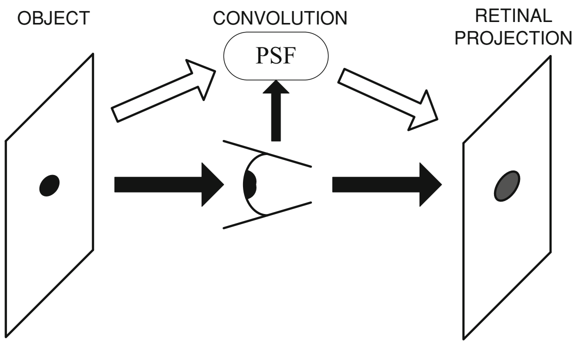


**Fig. 1** Linear human vision system model

### 2.3 Linear System Description of Human Vision

Generally speaking, the retinal image formed when we view an object can be represented by convolution of the eye's PSF and the image of this object (Fig. 1), under the assumption that the human visual system approximates a linear and space-shift invariant system. The properties of a linear system enable us to easily evaluate the actual retinal image from knowledge of the PSF and the spatial distribution of intensities in the object.

## 3 Pre-Compensation Algorithm

As mentioned before, the pre-compensation method is based on the a priori knowledge of the wavefront aberration of a computer user's eye. In practice, this wavefront aberration function can be obtained from a wavefront analyzer as a set of Zernike coefficients [7]. If the wavefront aberration is known, the PSF of the eye can be calculated. Further, the optical transfer function (OTF) can also be calculated by implementing the Fourier Transform of the PSF.

### 3.1 Deconvolution

Deconvolution is commonly used to restore the original image from a distorted image if the distortion is known. The use of deconvolution introduced here is different from the traditional use (for image restoration) because the distortion in the problem being considered occurs due to internal aberration of the human eye, which is the terminal end of the human vision system. Therefore, instead of applying deconvolution to a distorted image, after the fact, deconvolution here needs to be implemented at the source of the image.

The assumption is that the computer images will be distorted by the eye of the user, in a way described by the known PSF of that eye. Let's say an image

$O(x, y)$is degraded by the PSF of the user's vision system which is represented as $PSF(x, y)$, resulting in a distorted image on the user's retina $I(x, y)$. As mentioned before, this can be described as a convolution process:

$$I(x, y) = O(x, y)^{*}PSF(x, y) \tag{2}$$

The OTF is calculated by applying the Fourier Transform to the PSF as:

$$OTF(fx,fy) = F\{PSF(x, y)\} \tag{3}$$

Therefore, mathematically, in order to counteract or remove the distortion introduced by PSF, the pre-compensated image in frequency domain $RD(fx,fy)$ should be:

$$RD(fx,fy) = \frac{O(fx,fy)}{OTF(fx,fy)} \tag{4}$$

Accordingly, the actual image that should be displayed on the screen $RD(x, y)$ can be obtained through inverse Fourier Transform:

$$RD(x, y) = F^{-1}\left\{\frac{O(fx,fy)}{OTF(fx,fy)}\right\} \tag{5}$$

However, deconvolution is always an ill-posed problem. This is mainly caused by noise components which will be greatly magnified, especially when the value of $OTF(fx,fy)$ is small. Regularization is introduced to solve this problem as:

$$RD(fx,fy) = \frac{O(fx,fy)}{OTF(fx,fy)}\frac{|OTF(fx,fy)|^2}{|OTF(fx,fy)|^2+K} \tag{6}$$

where $K$ is the regularization parameter that limits the amplification of noise components, $N(x, y)$. Therefore, the perceived image on the retina can be considered as:

$$P(x, y) = F^{-1}\{RD(fx,fy)[OTF(fx,fy) + N(fx,fy)]\} \tag{7}$$

The objective of implementing deconvolution here is to develop a pre-compensated image to be displayed on the computer screen. The pre-compensated display image should be such that, when naturally convolved with the PSF of the user's eye, it will yield a retinal image that is as close as possible to the original object image.

### 3.2 Adjusting the Pre-Compensation Model

The deconvolution method described above has been shown to improve the interactions of computer users with visual impairments and graphic user interfaces [8]. This method is based on the wavefront aberration of the user's eye considered with a constant pupil size. If the user's pupil size at the time of viewing the images is the same as the pupil size during the measurement in the wavefront analyzer, the assumption is verified. However, under ordinary circumstances the pupil size of a computer user may change due to variations in ambient lighting conditions or even due to emotional factors (e.g. increasing fatigue). When Zernike coefficients are calculated, a pupil diameter defining the circular area in which the Zernike functions are defined must be specified. Therefore, the PSF will be different for different pupil sizes, which means that the pre-compensation model should also be modified. In order to avoid the possible pupil size mismatch between the conditions during wavefront aberration measurement and those at the time of viewing a pre-compensated image, a matrix method developed by Campbell can be used to adjust the pre-compensation model to the viewing pupil size.

The basic idea in Campbell's method is that the same area of a surface will be described by different sets of Zernike coefficients if a different aperture radius is used to find the coefficients. With the information available only in the form of a set of Zernike coefficients related to a given aperture radius, Campbell developed a conversion matrix $[C]$, that will properly convert the vector of one Zernike coefficient set $|c\rangle$ corresponding to an original aperture radius to the vector of another Zernike coefficient set $|c'\rangle$corresponding to a new aperture radius as:

$$|c'\rangle = [C]|c\rangle \tag{8}$$

The conversion matrix $[C]$ is derived as:

$$[C] = [P]^T[N]^{-1}[R]^{-1}[\eta][R][N][P] \tag{9}$$

In this equation the "$T$" and "$-1$" superscripts mean matrix transposition and inversion, respectively. Further, $[P]$ represents the permutation matrix, $[N]$ indicates the normalization matrix, $[R]$ indicates the weighting coefficient matrix and $[\eta]$ indicates the powers of ratio matrix. Among these matrices, only $[\eta]$ is related to the new aperture radius. Specific details for the computation of these matrices can be found in [5].

In the case of the pre-compensation approach described in this paper, since the original pupil size of the user's eye and the corresponding wavefront aberration are known, Campbell's conversion method makes it possible to calculate the set of Zernike coefficients that represent the wavefront aberration at a different, smaller pupil diameter. If the current "viewing" pupil size can be determined utilizing a device such as an eye gaze tracker, and if this pupil size is smaller than the one that existed during the original wavefront aberration measurement, Campbell's method can be used to perform the pre-compensation based on the adjusted Zernike coefficients, so that the pre-compensation process will be appropriate to the effective viewing conditions (effective pupil size). Figure 2 shows an example of wavefront aberration resizing. The original wavefront aberration at pupil radius $R$ is illustrated in Fig. 2a. Derived from that, the resized wavefront aberration at 80 % of the original pupil size is illustrated in Fig. 2b. It is important to indicate that, despite the apparent presence of different contour lines, the aberration in Fig. 2b is exactly the same as the portion of Fig. 2a confined by a circle with

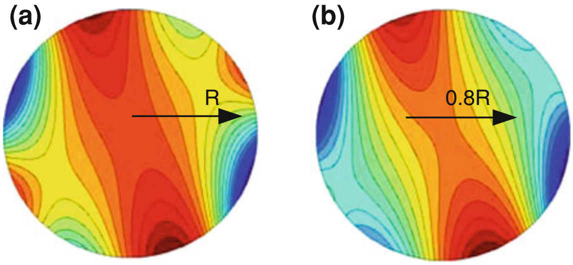


**Fig. 2** Contour maps of **a** wavefront aberration with pupil radius R and **b** wavefront aberration resized with constricted pupil radius 0.8R

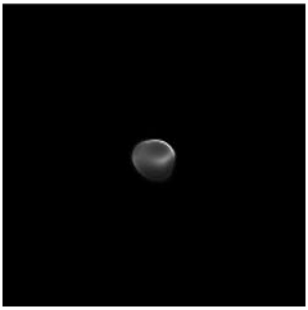

**Fig. 3** PSF of human subject's eye with pupil diameter 4.5 mm

radius 0.8*R*. However, the sets of Zernike coefficients that describe these two surfaces over the generic "unit circle" are different (That is why the set of re-calculated Zernike coefficients is needed).

Additionally, it must be noted that it is not advisable to attempt the calculation of the wavefront aberration at a pupil size that is larger than the measured one. This is because the aberration information outside the measured pupil area is unknown. Thus it is always recommended that wavefront aberration be measured (for these purposes) under darker illumination conditions than expected in use of the pre-compensation process, so that re-calculation of the wavefront aberration function for pupils larger than the size in the original measurement will not be necessary.

## 4 Results and Discussion

The pre-compensation method in this paper aims to improve the visual perception of computer users with visual impairments when they view images on screen. In order to verify the effectiveness of this improved pre-compensation method, some preliminary tests have been performed, through simulation.

First the wavefront aberration of a human subject's eye (left eye) with a −4 diopter prescription was measured using the COAS-HD wavefront analyzer (Wavefront Sciences, Albuquerque, NM), to be used in the pre-compensation model. The PSF derived from this originally measured wavefront aberration, with pupil diameter of 4.5 mm, is shown in Fig. 3.

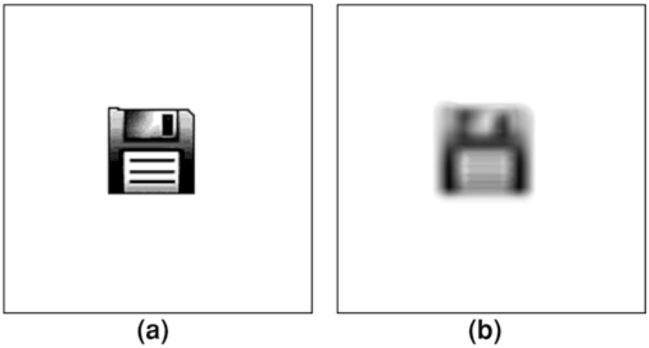


**Fig. 4** **a** Intended image on screen. **b** Perceived image of (**a**) without pre-compensation

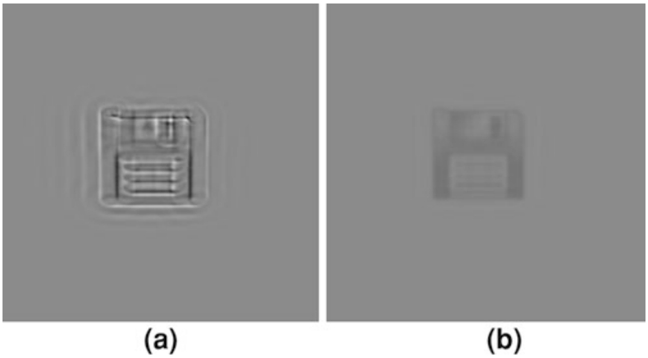


**Fig. 5** **a** Pre-compensated image corresponding to pupil diameter of 4.5 mm. **b** Perceived image of Fig. 5a when pupil diameter is 4.5 mm

For simplicity, a grayscale image, illustrated in Fig. 4a, was used for this experiment. As Fig. 4b shows, after convolution with the originally measured PSF of the eye, the intended image has been blurred and appears with some distortion. It is important to emphasize that the PSF used for this convolution corresponds to the pupil diameter at the time of measuring the wavefront aberration, which is 4.5 mm. The image shown in Fig. 4b simulates the image perceived by this human subject, if the original image in Fig. 4a is displayed on the computer screen.

Applying the deconvolution process with an assumed pupil diameter of 4.5 mm, to the original intended image, we obtain the image illustrated in Fig. 5a which appears strangely distorted to a normal-vision subject. However, if this image is convolved with the PSF determined for a 4.5 mm pupil diameter, the result is as shown in Fig. 5b. This is the simulation of what the human subject would perceive. In this case, in which the pre-compensation model was based on the wavefront aberration originally measured at 4.5 mm and in which the convolution used to simulate the distortion in the subject's eye was also performed with the PSF

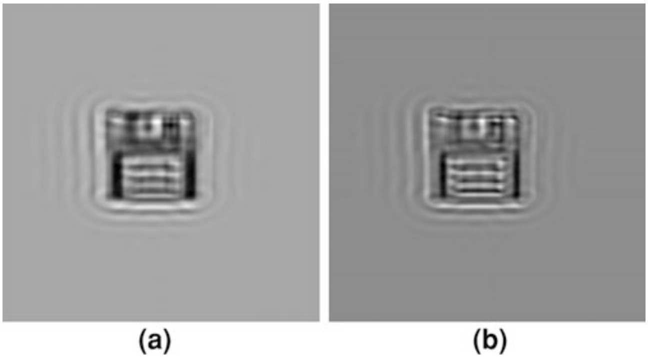


**Fig. 6** Perceived image of Fig. 5a when pupil diameter is **a** 3.6 mm **b** 2.7 mm

associated with 4.5 mm, the result is a focused perceived image, although this resulting image has decreased contrast.

However, if the viewing process is simulated using a PSF associated with a different pupil size, the effectiveness of the pre-compensation process is dramatically deteriorated, as expected. Two examples of this deterioration are given by the simulated images that the human subject would perceive with smaller viewing pupil sizes, as shown in Fig. 6. In Fig. 6a the viewing process of the pre-compensated image shown in Fig. 5a (which assumed a pupil diameter of 4.5 mm) has been simulated with a PSF associated to a pupil diameter of 3.6 mm, resulting in a distorted image. The distortion is even worse in Fig. 6b, for which the convolution was performed with a PSF associated to a pupil diameter of 2.7 mm.

To verify the viability of using Campbell's method to adjust the pre-compensation model to a smaller viewing pupil, the pre-compensation method is next repeated, but now using the Zernike coefficients resulting from eq. (9) set up for a new pupil diameter of 3.6 mm and then, again, re-calculating for a new pupil of 2.7 mm in diameter. Once the Zernike coefficients after resizing are obtained, the corresponding PSFs can also be derived. These re-calculated PSFs are shown in Fig. 7. Both these PSFs are clearly different form the original PSF (4.5 mm pupil diameter) shown in Fig. 3.

With the PSF based on the Zernike coefficients that were adjusted to a new pupil diameter of 3.6 mm, it is possible to repeat the pre-compensation process applied to the original figure, Fig. 4a. The new pre-compensated image that results is shown in Fig. 8a. When viewing of Fig. 8a is simulated using the PSF associated with 3.6 mm pupil diameter the result is as shown in Fig. 8b.

It can be seen in this figure that, once the pre-compensation process was repeated on the basis of Zernike coefficients that were adjusted to the same pupil diameter as the viewing process (3.6 mm), the pre-compensation process is again effective in providing a well-focused image, i.e., Fig. 8b.

By comparing the pairs of images shown in Figs. 5 and 8, it is possible to realize that, indeed, the adjustment made to the pre-compensation process, using

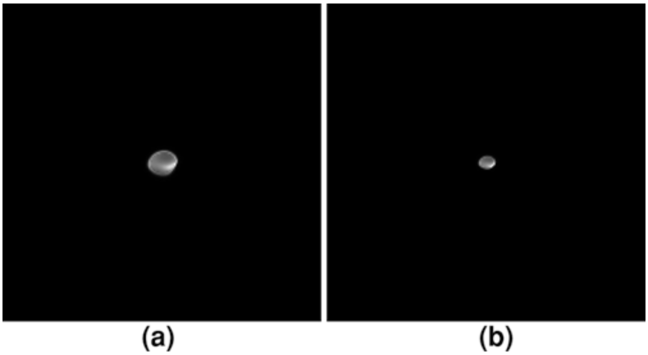


**Fig. 7** PSF of the same eye as in Fig. 3 but at pupil diameter of **a** 3.6 mm **b** 2.7 mm

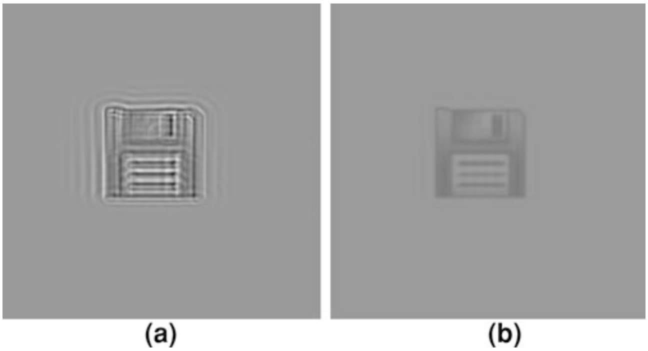


**Fig. 8** **a** Pre-compensated image corresponding to pupil diameter of 3.6 mm. **b** Perceived image of Fig. 8a when pupil diameter is 3.6 mm

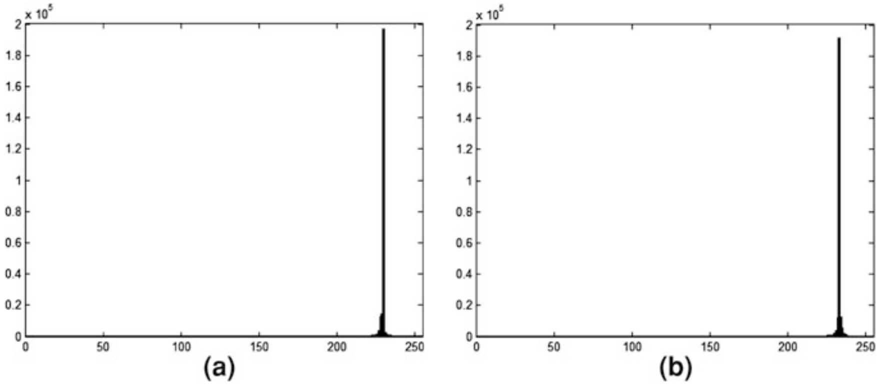


**Fig. 9** **a** Histogram of image shown in Fig. 5b. **b** Histogram of image shown in Fig. 8b

Campbell's method to match the pre-compensation to the new viewing pupil size, has been successful in restoring the efficiency of the pre-compensation method, now for a smaller pupil size.

It is noted that the contrast of the pre-compensated and perceived images in Figs. 8 and 5 is much lower than the original image shown in Fig. 4a. This is made even more evident by the histograms shown in Fig. 9. After pre-compensation, all the gray levels of the perceived image concentrate on a narrow band. This is due to the intensity scaling that must be applied to the pre-compensated image in order to display it on the computer monitor [9]. In general, digital display devices have limited intensity levels, typically in the range of [0, 255].

## 5 Conclusion

Aiming to counteract or reduce the visual distortion caused by visual impairment in some computer users, this paper improves the pre-compensation method by extending its application to more realistic conditions in which the pupil size is no-longer assumed to be fixed. For that, one matrix conversion algorithm is introduced to resize the Zernike coefficients and PSF of a human eye on the basis of available wavefront aberration measurements collected under a specific pupil size. Preliminary verification of the feasibility of this approach was performed by simulation. The results demonstrate that the improved pre-compensation method is capable of solving the problem of a mismatched pre-compensation model caused by pupil size variations. However, the problem of contrast loss incurred by the pre-compensation process is still present in the results obtained. Future research will address this additional side effect of the pre-compensation approach, which also limits the benefits derived from this process.

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# Digital Filtering of the Pupil Diameter Signal for Affective Assessment of a Computer User

**Peng Ren, Armando Barreto, Ying Gao and Malek Adjouadi**

**Abstract** There is an increasing interest in investigating means to detect the level of stress of a computer user for applications such as computer-based tutoring. This study presents a new approach to recognize the affective state (relaxed vs. stressed) of a computer user through filtering of the pupil diameter (PD) signal. Wavelet denoising and Kalman filtering are applied for the removal of abrupt changes in the PD signal, which are not likely to be the actual pupillary reactions. Wavelet denoising comprises three steps: Wavelet decomposition, threshold setting and signal reconstruction. Kalman filtering includes prediction and correction applied as two recursive blocks. This study summarizes the preliminary results obtained for noise removal and imposes a threshold on the filtered signal to identify the "stress" state of the computer users. Direct classification applied on the filtered PD signals achieved 75 % or better accuracy for stress detection in ¾ of the subjects tested. These encouraging results indicate that the combination of wavelet denoising and Kalman filtering seems to be an appropriate processing approach to emphasize the PD signal changes due to affective variations in the subject. The results also show that the PD signal is an important physiological signal that can be monitored non-invasively for the affective assessment of a computer user.

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## 1 Introduction

Affective computing is a relatively new branch of human computer interaction research, which seeks to give the computer the ability to detect the emotional states of the user, and adjust its interaction behavior appropriately. Key scientific findings indicate that emotions play an essential role in rational decision making, perception learning, and a variety of other cognitive functions [1, 2]. Therefore, developing new technologies and theories that advance basic understanding of affect is a meaningful and promising work for improving the human–machine interaction experience. A computer could attempt to estimate the user's affective state from various types of observations, such as the user's posture, gestures, speech, and facial expression and so on, which can reveal human emotions to some extent. However, when monitoring these aspects of the user, some inevitable factors such as environmental interference or voluntary masking may result in inaccurate or even incorrect affective assessment. Because of this, some relevant physiological signals, which are controlled by the sympathetic and parasympathetic divisions of the autonomic nervous system (ANS), have been chosen to recognize the emotions of the computer user. Examples of those signals are the electroencephalogram (EEG), the electrocardiogram (ECG), blood pressure (BP), blood volume pulse (BVP), skin temperature (ST), galvanic skin response (GSR), etc. Recently, for example, Partala and Surakka found that the pupil size provided an evident indication of affective state, in their experiment, using auditory emotional stimulation [3]. However, the monitoring of the PD variations for affective sensing is not yet fully explored.

The pupil is the opening at the center of the iris of the eye through which light passes towards the retina. The size of the pupil is determined by the relative activity of two smooth iris muscle groups, the sphincter pupillae and the dilator pupillae. The pupil of the human eye can constrict to 1.5 mm in diameter or dilate to about 8–9 mm [4]. The reaction time to light stimuli is nearly 0.2 s, with the response peaking in 0.5–1.0 s. The constriction and dilation of the pupillary aperture are mainly controlled by the ANS. It has been proven that if the sympathetic division of the ANS is activated (e.g., due to stress), the size of PD tends to increase; whereas if the parasympathetic division of the ANS dominates (e.g., during relaxation), the PD will remain small [5].

The goal of this study is to investigate digital filtering techniques that can be applied to the PD signal obtained from the TOBII T60 eye tracker monitor, to use it for affective assessment of a computer user. The paper first introduces the instrumental setup used to record the PD signals, while simultaneously eliciting stress in the subject at known intervals, using an affective stimulation paradigm. Then, the wavelet denoising and Kalman filtering methods are applied to the raw PD signal, sequentially, to make it more representative of the affective shifts of the subject. Finally, a threshold mechanism is implemented on the processed PD signals to obtain a stress indication signal, based on them.

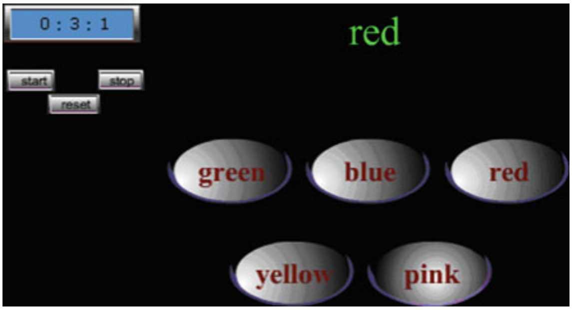


**Fig. 1** Sample of the Stroop test interface

## 2 Signal Monitoring

In this work PD signals are recorded and analyzed to determine the affective state of a subject. When the subject is under stress, the pupil size is expected to increase. Otherwise, it is expected to remain small.

### *2.1 Software Development*

The "Stroop color-word interference test" [6] is used to elicit mild mental stress during controlled intervals in order to observe the changes in the PD signals and their correlation to the affective states of "stress" and "relaxation".

In the Stroop test, a word presented to the subject designates a color that may ("Congruent") or not ("Incongruent") match its meaning. The subjects were instructed to click one of the five screen buttons to identify the font color. A typical (Incongruent) example of this test interface is shown in Fig. 1.

Figure 2 shows the stimuli schedule in this experiment from the beginning of a session to its end. In total, the experiment included three consecutive sections and each section had four segments. They are:

- 'IS'—the introductory segment to let the subject get used to the task environment;
- 'C'—the Congruent segment of the Stroop test, in which the subject was asked to click the on-screen button naming the font color of a word that spelled the actual font color being displayed. Each 'C' segment comprises 45 Stroop congruent word presentations.
- 'IC'—the Incongruent segment of the Stroop test, in which the subject was asked to click the on-screen button naming the font color of a word that spelled the name of a different color. Each 'IC' segment had 30 words presentations.
- 'RS'—a Resting Segment to let the subject relax for some time.

The mental stress is expected to be elicited during the incongruent Stroop segments (IC) according to previous research found in the psychophysiological literature [7–9]. On the other hand, during congruent Stroop segments (C), it is expected

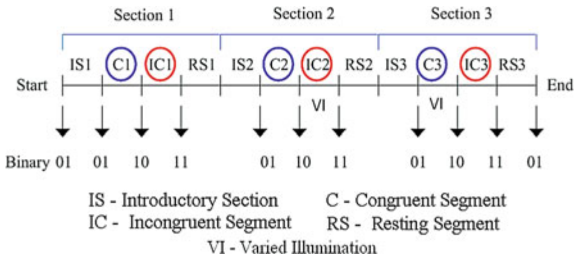


**Fig. 2** Stimuli schedule

that the subject will remain relaxed. The binary codes (01, 10 or 11, respectively) shown in Fig. 2 represent the de-multiplexed output of the stimulus generator, which inserted the corresponding values (1, 2, 3) in the event channel of the PD record obtained from the system, along with the PD values. These binary codes served as time-stamps for the recorded physiological channels [10], helping to identify the start and the end of each 'C' and 'IC' segment.

### 2.2 Hardware Setup

In this study, the TOBII T60 eye tracker monitor was used to record the PD values during the Stroop test. The program developed for the eye tracking system stores the PD values of both eyes with a sampling frequency of 60 Hz. The resulting files were later read into MATLAB.

## 3 Signal Processing

### 3.1 Physiological Signal Processing by Interpolation

In this research, wavelet denoising and Kalman filtering were applied to the PD signals recorded as described above to make them more representative of the stress level of the subject. However, as a first step, the disruptions of the PD signal caused by blinking had to be identified by the special validity code registered by the TOBII system with each blink, and compensated by linear interpolation of the PD data. Figure 3 below shows the results of the blink elimination process (bottom) on a raw PD signal (top).

### 3.2 Wavelet Denoising

It is evident from appearance of the signal in Fig. 3 (bottom) that even after the elimination of blinking artifacts; the PD signals provided by the TOBII T60 Eye Tracker have a substantial amount of high frequency variability that is not likely to

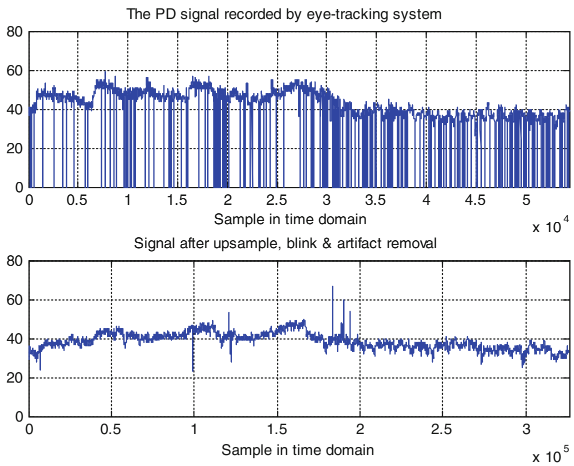


**Fig. 3** PD signal recorded by the Tobii T60 Eye Tracker and signal after blink artifact removal

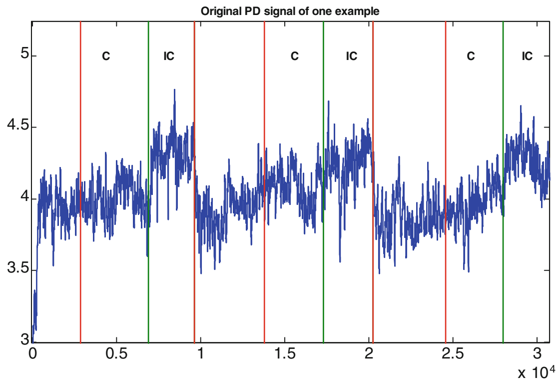


**Fig. 4** Original signal of one example

be due to the changes of the actual pupil size. Furthermore, some previous research also showed that the high variability of the signal in the PD record may, in fact, be due to quantization noise, since the pupil only occupies a small portion of the camera's field of view, which, in turn, is sampled at a relatively low resolution.

Figure 4 shows the complete PD signal recorded during an experiment. The vertical lines are the segment transition boundaries. The most important boundaries are those that separate each congruent Stroop segment (C) from the incongruent Stroop segment (IC) that follows. Figure 4 shows clearly that it would be difficult to successfully classify the segments by using a threshold on the raw PD data, because of the noise included in the raw PD signal. Therefore, investigating ways for the removal of this noise is a crucial and fundamental issue for further study.

The first part of the two-stage approach we propose for the processing of the PD signal is wavelet denoising, which is better in preserving the shape of the original

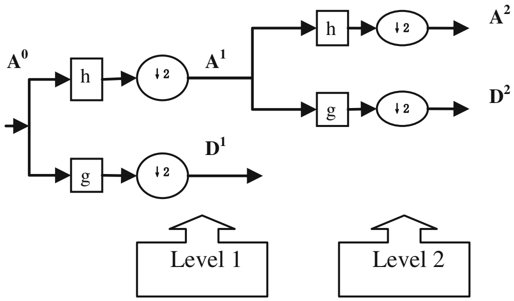


**Fig. 5** Multi-resolution wavelet decomposition. h = low-pass decomposition filter; g = high-pass decomposition filter; (↓2) = down-sampling operation. $A^1(t)$, $A^2(t)$ are the approximation coefficients of the original signal at levels 1, 2 etc. $D^1(t)$, $D^2(t)$ are the detail coefficients at level 1, 2

signal, especially for signals with abrupt changes [11–13]. Considering the noisy mixture observation form:

$$\mathrm{x}(k) = \mathrm{d}(k) + \mathrm{n}(k) \quad k = 1, 2, \ldots, \mathrm{N} \tag{1}$$

where d($k$) is the noise-free component and n($k$) is the additive noise. In general, there are three main steps needed for this form of processing.

The first step is to apply the wavelet transform to the noisy signal to produce the noisy wavelet coefficients (approximation coefficients and detail coefficients) to the level in which we can properly remove the noise. Figure 5 illustrates the implementation of the discrete wavelet transform (DWT) where the incoming signal $x(k)$ is passed through low- and high-pass filters and its scale is changed by down sampling operations. The low pass filter and the high pass filter are complementary (i.e., they form a quadrature mirror filter). The approximation coefficients correspond to low frequency components present in the signal, while detail coefficients represent high frequency components. In this study, the Daubechies wavelet and eight decomposition levels are utilized.

The filtering and downsampling operations are expressed by:

$$A^i[k] = \sum_n A^{i-1}(t) \cdot h[2k - n] \tag{2}$$

$$D^i[k] = \sum_n A^{i-1}(t) \cdot g[2k - n] \tag{3}$$

The second step is to select an appropriate threshold limit at each level and the threshold method to best remove the noise, which changes the values of the detail coefficients. The classical rules for applying the threshold to wavelet coefficients are hard thresholding, which means "keep-or-kill" and soft thresholding, which means "shrink-or-kill". In addition, an appropriate choice of the threshold value is also significant for the effectiveness of the described wavelet denoising procedure. A threshold that is too high might remove important parts of the underlying signals whereas a threshold that is too low may still retain part of the noise in the

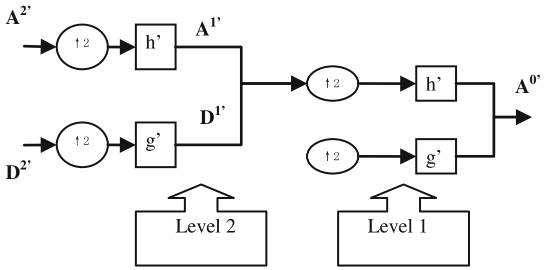


**Fig. 6** Multi-resolution wavelet reconstruction. h = low-pass decomposition filter; g = high-pass decomposition filter; (↓2) = down-sampling operation. $A^1(t)'$, $A^2(t)'$ are the processed or non processed approximation coefficients of the original signal at levels 1, 2 etc. $D^1(t)'$, $D^2(t)'$ are the processed or non processed detail coefficients at level 1, 2

reconstruction [13]. In this study, soft thresholding was used as the procedure of noise reduction in the signal $x_i(k)$ in the $i$-th channel. The threshold values for detail coefficients at every level of decomposition are determined below:

$$THR_i = \sqrt{2\log||D^i||} \tag{4}$$

Then the modification of values of $i$-th level detail coefficients is based on the designed threshold, according to the relationship expressed as follows: If $D^i > THR_i$

$$D^i = \operatorname{sgn}(D^i)(|x| - THR_i) \tag{5}$$

If $D^i \le THR_i$

$$D^i = 0 \tag{6}$$

The final step is to perform inverse wavelet transform on the approximation coefficients and the altered detail coefficients to obtain a denoised signal, as shown in Fig. 6.

The reconstruction formula can be expressed as below and an example of the output after wavelet denoising is shown in Fig. 7.

$$A^i[k] = \sum_{k=-\infty}^{\infty} \left(D^{i+1}[k] \cdot g[-n+2k] + A^{i+1}[k] \cdot h[-n+2k]\right) \tag{7}$$

The trace displayed in Fig. 7 shows a better differentiation of the levels in the ‘C’ and ‘IC’ segments, but it still shows wide variations within each segment, which would prevent a successful classification by imposition of a threshold.

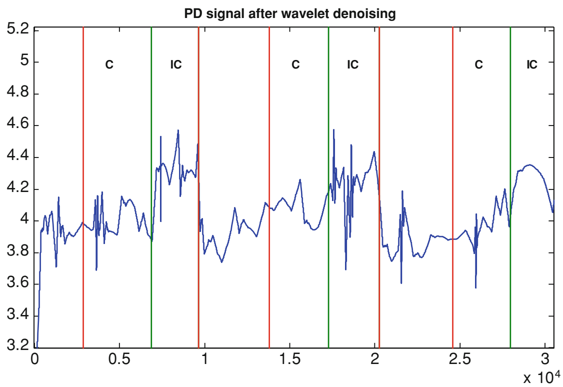


**Fig. 7** Output after the wavelet denoising

## 3.3 Kalman Filtering

In order to further emphasize the PD components that represent the affective changes of the subject, Kalman filtering is applied to the signal resulting from wavelet denoising. Kalman filtering is an iterative algorithm designed to reduce noise components, estimate the current state of a model and forecast future states of time series models [14–16]. The algorithm is based on the principle of minimizing mean squared error by refinement of the weights of a model in sequential iterations. The process includes prediction and correction as two recursive steps that are applied to a process represented by the equation:

$$s_{k+1} = As_k + w_k \tag{8}$$

where $s_k$ is the state vector of the process at time k, $(n \times 1)$; A is the state transition matrix of the process from state k to state $k + 1$, $(n \times m)$; and $w_k$ is the associated white noise process with known variance, $(n \times 1)$.

Observations on this variable can be modeled in the form:

$$z_k = Hs_k + v_k \tag{9}$$

where $z_k$ is the actual measurement of s at time k, $(m \times 1)$; H is the noiseless connection between the state vector and the measurement vector, $(m \times n)$; and $v_k$ is the associated measurement error.

The covariances of the two noise models are given by:

$$Q = E\left[w_k w_k^T\right] \tag{10}$$

$$R = E\left[v_k v_k^T\right] \tag{11}$$

The mean squared error is given by:

$$P_k = E\left[e_k e_k^T\right] = E\left[(s_k - \hat{s}_k)(s_k - \hat{s}_k)^T\right] \tag{12}$$

Assuming the prior estimate of $\hat{s}_k$is called $\hat{s}'_k$. The new estimate can be updated by the old estimates and the measurement data.

$$\hat{s}_k = \hat{s}'_k + K_k\left(z_k - H\hat{s}'_k\right) \tag{13}$$

$K_k$ is the Kalman gain, which can be given by:

$$K_k = P'_k H^T\left(H\, P'_k H^T + R\right)^{-1} \tag{14}$$

Substitution of Eq. 9 into Eq. 13 gives:

$$\hat{s}_k = \hat{s}'_k + \ K_k\left(Hs_k + v_k - \hat{s}'_k\right) \tag{15}$$

Substitution of Eq. 15 into Eq. 12 gives:

$$P_k = E\left[\left[(I - K_k H)(\hat{s}_k - \hat{s}'_k) - K_k v_k\right]\left[(I - K_k H)(\hat{s}_k - \hat{s}'_k) - K_k v_k\right]^T\right] \tag{16}$$

It should be noted that $\hat{s}_k - \hat{s}'_k$ is the error of the prior estimate. This is uncorrelated with the measurement noise and therefore the expectation can be written as:

$$P_k = (I - K_k H)E\left[(\hat{s}_k - \hat{s}'_k)(\hat{s}_k - \hat{s}'_k)^T\right](I - \ K_k H) + K_k E\left[v_k v_k^T\right]K_k^T \tag{17}$$

Substituting Eq. 11 and Eq. 12 into Eq. 17 gives:

$$P_k = (I - \ K_k H)P'_k(I - K_k H) + K_k R K_k^T \tag{18}$$

Finally, substitution of Eq. 14 into Eq. 18 gives:

$$P_k = (I - \ K_k H)P'_k \tag{19}$$

which is the update equation for the error covariance matrix with optimal gain. From Eqs. 14, 15 and 19, the state projection equation can be formed as:

$$\hat{s}'_{k+1} = \ A\hat{s}_k \tag{20}$$

It is also necessary to find an equation which projects the error covariance matrix into the next time interval, k + 1:

$$\begin{aligned} P_{k+1} &= E\left[\hat{e}'_{k+1}\hat{e}'^T_{k+1}\right] \\ &= E\left[(Ae_k + w_k)(Ae_k + w_k)^T\right] \\ &= AP_k A^T + Q \end{aligned} \tag{21}$$

Where $e'_{k+1} = s_{k+1} - \hat{s}'_{k+1} = (As_k + w_k) - A\,\hat{s}_k = Ae_k + w_k$.The total predictor–corrector algorithm for implementing this complete process, numerically, is outlined in Fig. 8.

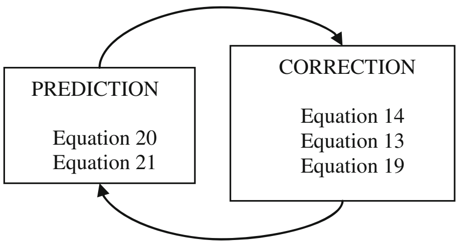


**Fig. 8** Outline of the operation of the Kalman filter

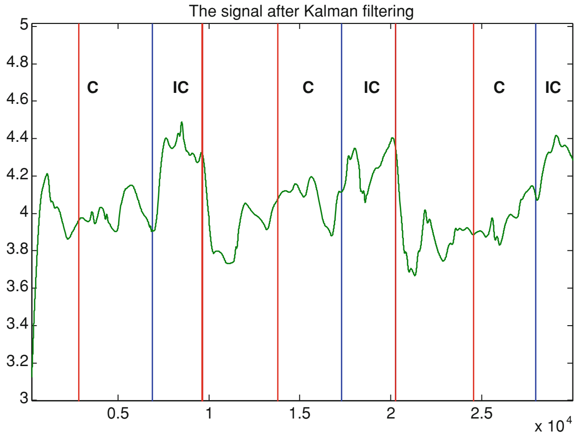


**Fig. 9** Denoised PD signal after processing by Kalman filtering

The result of processing the denoised signal shown in Fig. 7 by applying Kalman filtering is shown as Fig. 9.

## 3.4 Stress Detection

Applying wavelet denoising and Kalman filtering to the PD data from experimental sessions of 36 different subjects we found that the IC segments typically showed the expected increase compared with the preceding C segments. However, different subjects had different baseline pupil size levels (even during the relaxation intervals of the experiment).Therefore, in attempting to set a threshold capable of separating the relaxed and stressed segments in the recording, based on the processed PD signal, individual characteristics of each subject must be taken into account.

It should be noted that the customization of the threshold for each subject only used the congruent Stroop segments (C) and incongruent Stroop segments (IC) of the processed PD data from that subject. Specifically, we defined the custom threshold for a subject's data as follows:

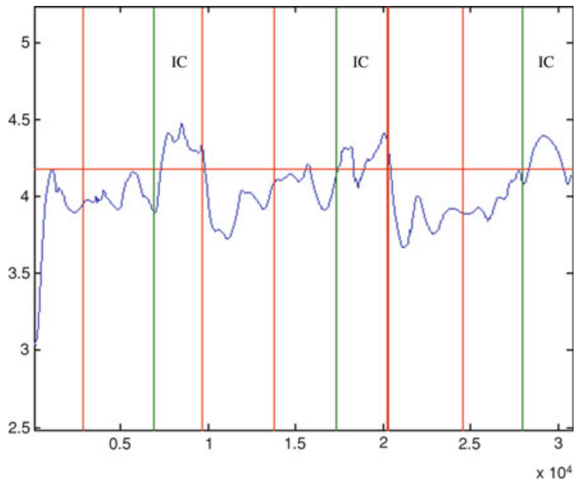


**Fig. 10** C and IC Stroop identified by threshold

$$\lambda = m + 2 \times \text{var} \tag{22}$$

where m is the average value of the congruent and incongruent segments; var is the variance of the processed PD data within the segments mentioned above and $\lambda$ is the threshold defined for the subject in question.

## 4 Results

In total, 36 individuals volunteered to participate in the experiment with ages ranging from 24 to 34 years. Diverse professional and ethnic backgrounds were also included. Figure 10 shows the processed signal after wavelet denoising and Kalman filtering of one particular subject whose threshold value was calculated as $\lambda = 4.1805$, which is shown as a horizontal line in the figure. After setting the threshold, the relaxed state (congruent Stroop segment) and stressed state (incongruent Stroop segment) can be determined from the processed PD signal, PDp(k) according to this rule:

$$\begin{array}{ll} \text{if} \quad \mathrm{PD_p(k)} < \lambda & \mathrm{PD_p(k)} \rightarrow \text{Relaxed} \\ \text{if} \quad \mathrm{PD_p(k)} > \lambda & \mathrm{PD_p(k)} \rightarrow \text{Stressed} \end{array}$$

Figure 10 allows a graphical comparison of the intervals of the signal that would be marked as “stressed” (because they are above the graphical threshold), and the boundaries of the ‘IC’ segments, marked on the figure as vertical lines. The particular processed PD trace, with the customized threshold used, yields segments marked as “stressed” (above the horizontal threshold), which have an 88.73 % coincidence with the ‘IC’ segments identified by their vertical boundaries.

**Table 1** Agreement Distribution of 36 Sets PD Data

| Agreement (%) | Number of Subjects |
|---|---|
| 85–90 | 6 |
| 80–85 | 13 |
| 75–80 | 10 |
| 70–75 | 5 |
| 65–70 | 2 |

When the processed PD signals from all the 36 subjects are evaluated in the same manner, the percentage of coincidence between samples above the custom thresholds ("stressed") and the known 'IC' segments ranges from 65 % to 89 %. Table 1, below, groups these levels of coincidence (interpreted as correct stressed detection levels), in groups of 5 % each.

## 5 Disscussion

The objective of applying wavelet denoising and then Kalman filtering to the PD series obtained from a TOBII T60 eye tracker was to remove noise components that do not represent the variations of pupil size due to affective changes in the subject. The noise observed in the original PD signal included components that change quickly and abruptly, similar to "salt-and-pepper" noise in an image. Therefore, a median filter could have been a possible solution, but that type of filter yielded a resulting signal that was not smooth. Similarly, some traditional filtering methods, such as FIR and IIR filters, were tried on the PD signal, resulting in different levels of improvement, but without providing a clear differentiation of the PD increases expected during the 'IC' segments.

The results obtained after applying wavelet denoising to the raw PD signal (as shown, for example, in Fig. 7), indicate that this first level of processing can significantly remove the artifactual sudden changes from the original PD signal. The DWT decomposes the original signal into different scales with different levels of resolution by dilating a mother wavelet. So it is possible to capture (and separate) small spikes or sudden changes which occur in a short period of time. The crucial issues for the application of wavelet denoising are the selection of the right mother wavelet, the setting of appropriate thresholds and the use of a suitable number of decomposition levels.

To complete the processing of the PD signal from the TOBII T60 eye gaze tracker, we applied Kalman filtering to the results from wavelet denoising. As shown in the example trace of Fig. 9, this method removes the remaining noise of the PD signal and makes the increases in the processed signal that occur when the subject was stressed (i.e., during the incongruent Stroop segments) more evident.

There were a total 36 subjects who participated in the experiment and the results show that the combination of wavelet denoising and Kalman filtering, with the type of adaptive threshold implemented, can achieve encouraging stress classification accuracy levels by imposing a simple threshold on the processed PD signal. It is expected that the extraction of specific features from the processed signal and the use of more involved classification methods on those features, which are currently under study, may result in even better levels of accuracy in user stress detection from PD monitoring.

## 6 Conclusion

This paper presented a new approach to differentiate the "relaxed" vs. "stressed" affective states of a human subject by detecting the changes in his/her PD, which is a non-invasive measurement, achievable with currently available eye gaze tracking systems.

In order to obtain a processed PD signal that represents the affective states of the computer user faithfully, the wavelet denoising method has been applied on the PD signal first to remove high frequency, impulsive noise from the original signal. In this study, the Daubechies wavelet and eight decomposition level were used. Although the wavelet denoising method achieves a marked improvement in the signal, its output still contains some abrupt changes which are not representative of the affective changes of the subject. Therefore, Kalman filtering is utilized to remove the remaining noise after the first processing stage.

From the 36 sets of data in total, there are 29 in which the agreement of recognized stress and incongruent Stroop is more than 75 %. We conclude that the application of wavelet denoising and Kalman filtering seem to constitute an appropriate approach to obtain a processed PD signal that reflects the stressed states in the experimental subject. Our results suggest that the PD signal is an important physiological signal to monitor for affective assessment of a computer user.

**Acknowledgments** This work was sponsored by NSF grants HRD-0833093 and CNS-0959985.

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# TCCT: A GUI Table Comparison Computer Tool

**Ali Alzaabi, Georges Alquié, Hussain Tassadaq and Ali Seba**

**Abstract** The interface Table Comparison Computer Tool (TCCT) is a graphical user interface (GUI) table which has been constructed during the exploration phase in the frame work of using our own images to apply filtering, differentiating and optical flow techniques. TCCT is an educational tool using Matlab, to help students and researchers in study the image processing. This tool can process both grayscale and color images. It implements a number of low-pass filtering and differentiating techniques. Many traditional optical flow extraction techniques are available, in addition to some novel color-based methods.

## 1 Introduction

In the image processing field technology is changing rapidly. There is big change going on hardware. And new programming languages are introduced. Particularly for computer vision, technology is lead regarding memory and number of processor used for computation such as GPUs.

It certainly has more resources than when computer vision technology started. Now we can run very complex research algorithm that for real-time applications. Also we can do programming of applications and languages such as HDL or

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SystemC to support implementation of Matlab algorithms. In this work we are designing image recognition system that can do as follow:

- Comparing a copy tablet with the reference tablet in museum.
- Helping artists paint good copies of the reference image.
- Creating a graphical interface tool (GUI) in order to help researchers to use the exciting techniques and to implement their own new techniques.

We provide parameter of different techniques accessible to user in GUI.

This way, user can select best parameters for matching, depending upon environment.

## 2 Reference and Copy Images Function

We create database of original images in order to compare with test images.

Reference image button: that allows the user to choose from the database the original image.

Tested image button: that allows the user to choose the images that will be tested with the reference image.

*img=imread('picture.jpg');*

*imwrite(img,'mg_n.jpg','bitdepth',8,'mode','lossy','quality',100);*

The parameters involved are defined in the following:

*Bitdepth*: A scalar value indicating desired bitdepth; for grayscale images this can be 8, 12, or 16; for color images this can be 8 or 12. The 12-bit JPEG format has been part of the JPEG specification for some time, but again, this format is not as widely supported, eight (grayscale) and eight bit per plane for color images.

Comment: A column vector cell array of strings or a character matrix. *imwrite* writes each row of input as a comment in the JPEG file.

*Mode*: Specifies the type of compression used, "lossy" or "lossless".

JPEG compression method is usually lossy, meaning that some original image information is lost and cannot be restored (possibly affecting image quality.) There is an optional lossless mode defined in the JPEG standard; however, that mode is not widely supported in products.

*Quality*: A number between 0 and 100; higher numbers mean higher quality (less image degradation due to compression), but the resulting file size is larger (Fig. 1).

## 3 Show Points Function

There are two operators performed to get different points. First step reduce the response to noise. This can be affected by optimal smoothing, and can be done by Gaussian filtering [1].

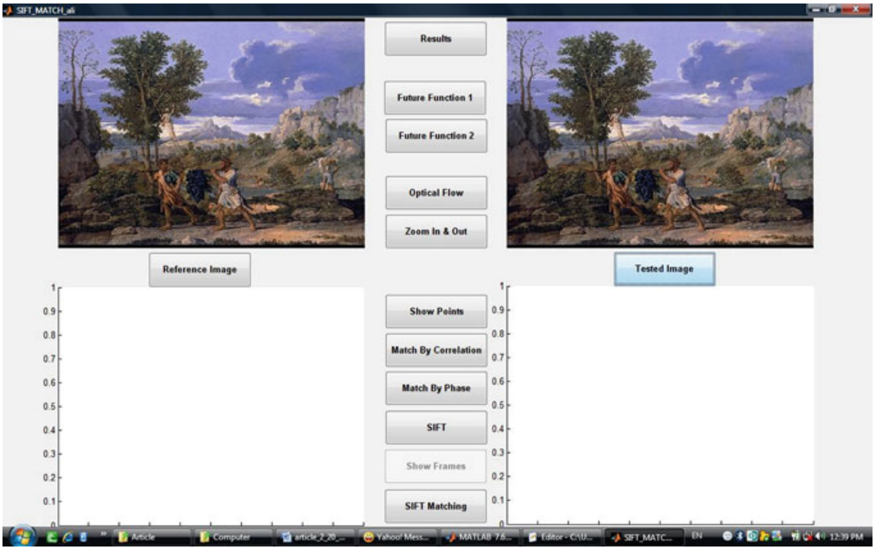


**Fig. 1** Reference image and tested image

$$\text{Gaussian operator} = g(x, y) = e\left(\frac{-(x^2 + y^2)}{2\sigma^2}\right) \tag{1}$$

*I(n x,y)* is an image with x and y dimension.

The second criterion aims for accuracy: edges are to be detected, in the right place.

$n_\perp$: Is estimated from the first-order difference of the Gaussian function g convolved with the image P show in Eq. (2).

$$n_\perp = \frac{\nabla\ (P * g)}{|\nabla(P * g)\,|} \tag{2}$$

The location of the true edge point is then at the maximum point of *Gn* convolved with the image. This maximum is when the differential (along$n_\perp$) is zero:

$$\frac{\partial^2\ (G * P)}{\partial n_\perp^2} = 0 \tag{3}$$

Where;
*P*: is the image to be processes

$$G_n = \frac{\partial y}{\partial n_\perp} \tag{4}$$

Where; $G_n$: is a first derivative of a Gaussian function g in the direction of the normal, $n_\perp$:

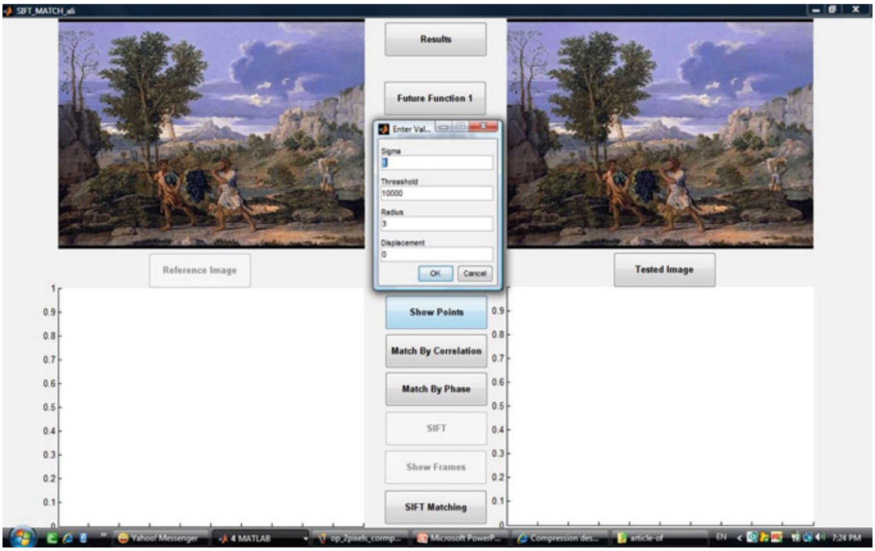


**Fig. 2** Parameters windows for show points function

It needs following inputs for computations [2].

*Sigma*: Standard Deviation of smoothing Gaussian.

*Harris corner* power varies with the intensity gradient raised to the fourth power. Small changes on input image contrast will result in huge changes in the appropriate threshold.

*Radius*: Radius of region measured in non-maximal (Figs. 2 and 3).

## 4 Match by Correlation Function

This function produces supposed matches among previously detected feature points in two images by looking points that are highly correlated with each other within windows nearby each point. Only points that match strongly with each other in both orders are returned [4].

(*f*) and (*g*) are function contain point variable.

Probability Density of difference (*f*-*g*) could be give by cross correlation of (f *g).

$$(f * g)[n] = \sum_{m=-\infty}^{\infty} f''[m]\, g[n+m] \tag{5}$$

Where; $f'$ denotes the complex conjugate of (*f*).

Arguments required for Correlation

*Window size (in pixels)*

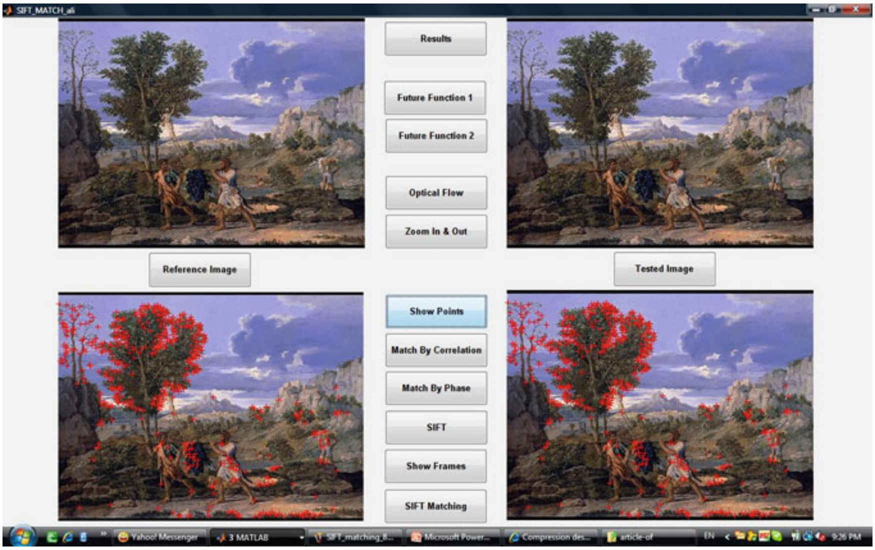


**Fig. 3** Show points function results

Over which the correlation around each feature point is performed. This should be an odd number.

*Maximum search radius*

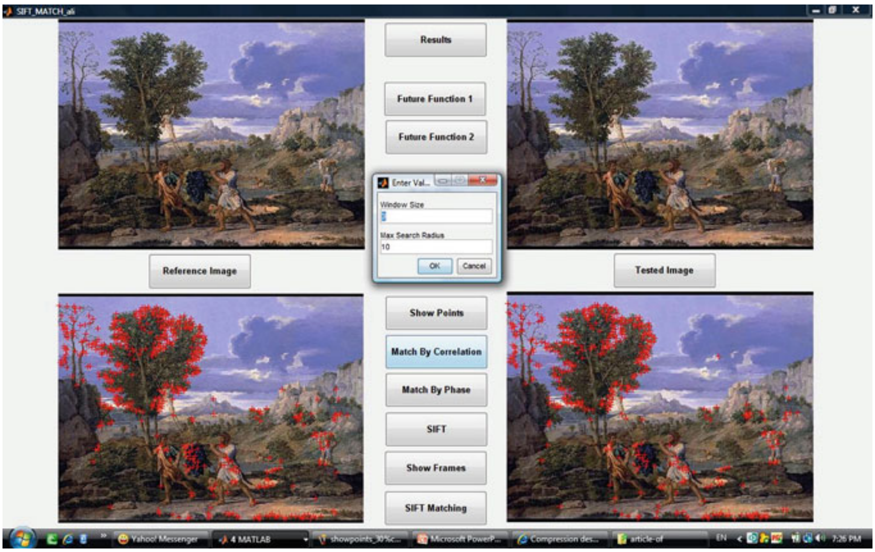


**Fig. 4** Parameters windows for match by correlation function

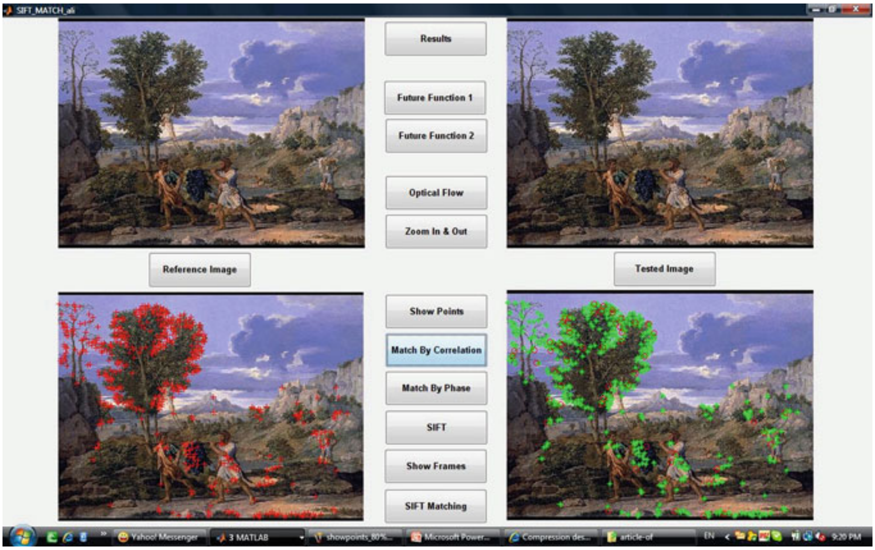


**Fig. 5** Match by correlation function results

This value is used to improve speed when there is little disparity between images. Even setting it to a generous value of one-fourth of the image size gives a useful speedup. If this parameter is omitted it defaults to Inf (Figs. 4 and 5).

## 5 Match by Phase

The use of the monogenic phase has lead to nearly perfect matching confirmed by visual inspections [3].

Monogenic signal analysis needs fewer convolutions and generates more compact feature vectors.

The monogenic phase vector preserves most of the important information of the original signal.

The local phase vector contains not only the local phase but also the orientation information of the original signal, which enables the evaluation of structure and geometric information at the same time. The embedding of local phase and local orientation into monogenic scale space improves the stability and robustness (Figs. 6 and 7).

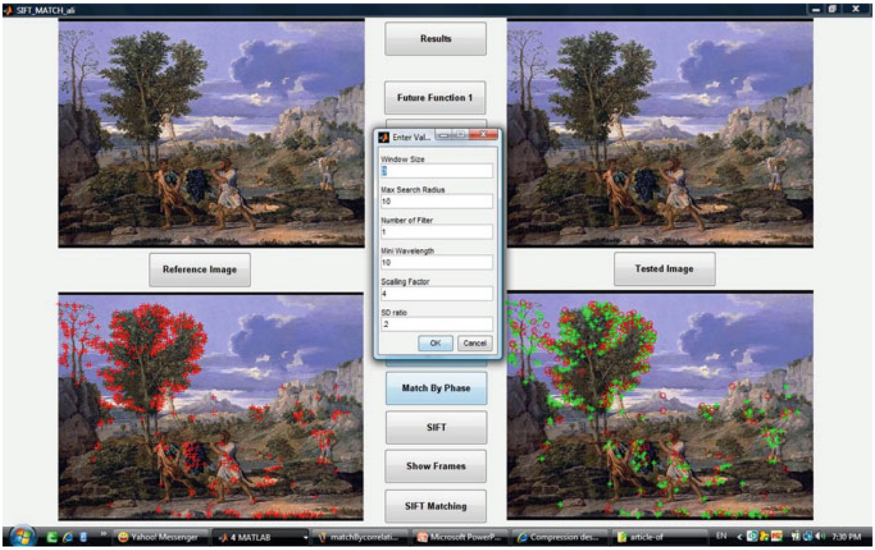


**Fig. 6** Parameters windows for match by phase function

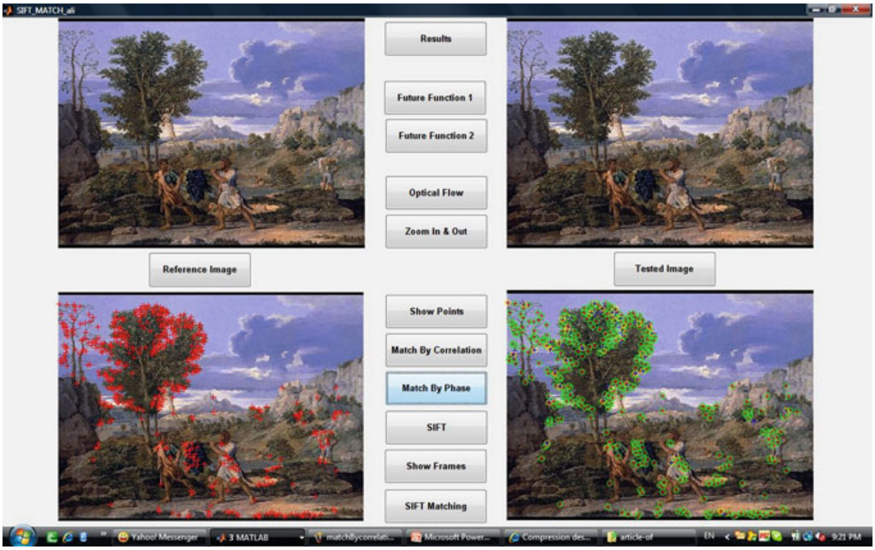


**Fig. 7** Match by phase function results

## 6 SIFT

As scaled invariant features transform (SIFT) features are invariant to rotation and scaling, we employ SIFT to extract feature points. Then circular patches are

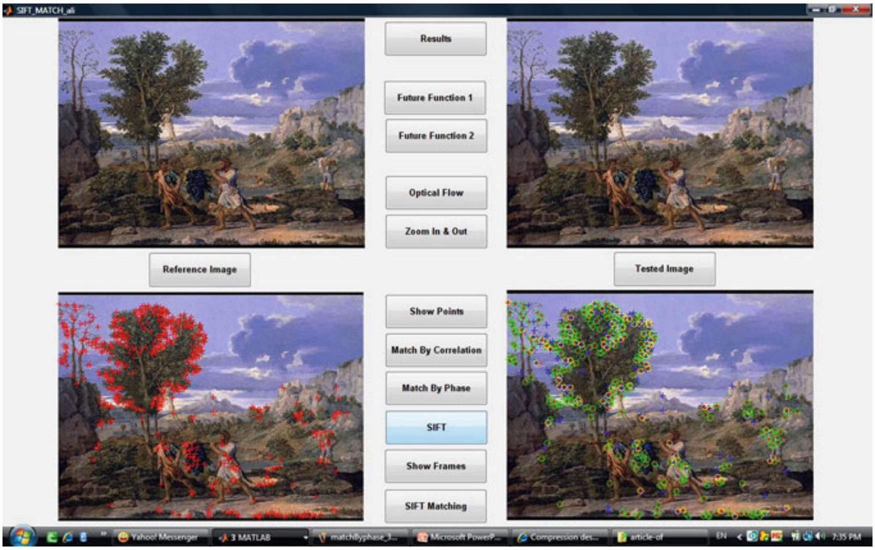


**Fig. 8** SIFT function

generated using the most robust points [1].

Gaussian image pyramide = $L(x,\ y,\ \sigma)$

$$L\,(x, y, \sigma) = \ G(x, y, \sigma) * I(x, y) \tag{6}$$

* is convolution with Image $I$ and $G$. $I(x,y)$:
Gaussian filter = $G(x,\ y,\ \sigma)$

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{-\left(x^2+y^2\right)/2\sigma^2} \tag{7}$$

$D(x,\ y,\ \sigma) = (G(x,\ y,\ k\ \sigma) - G(x,\ y,\ \sigma))$ * $\mathrm{I}(x,\ y) = L(x,\ y,\ k\ \sigma) - L(x,\ y,\ \sigma)$
Where; $k$: constant multiplicave factor (Figs. 8 and 9).

## 7 SIFT Matching

This function matches the two sets of SIFT descriptors DESCR1 and DESCR2. The function uses the same algorithm suggested by D. Lowe to reject matches that are too ambiguous. The function uses a specified threshold (THRESH). A descriptor D1 is matched to a descriptor D2 only if the distance d (D1, D2) multiplied by THRESH is not greater than the distance of D1 to all other descriptors (Figs. 10 and 11).

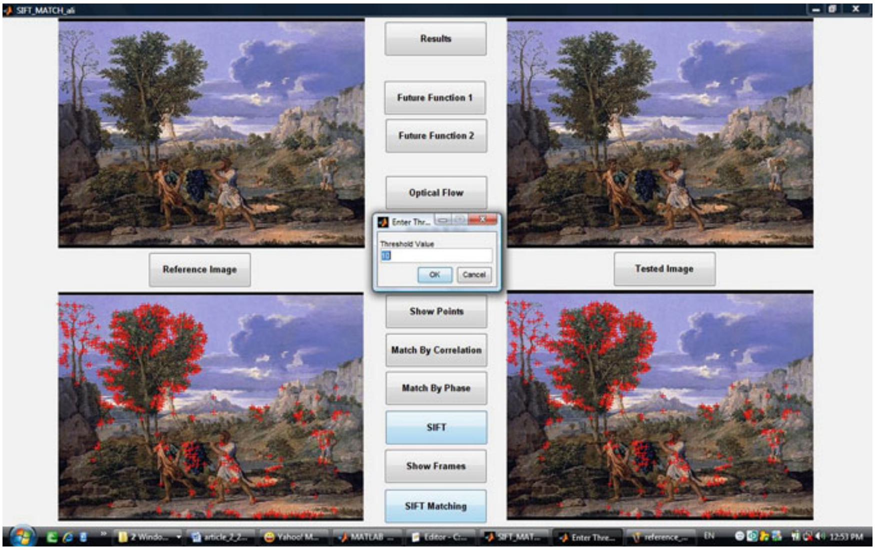


Fig. 9 Parameters windows for SIFT function

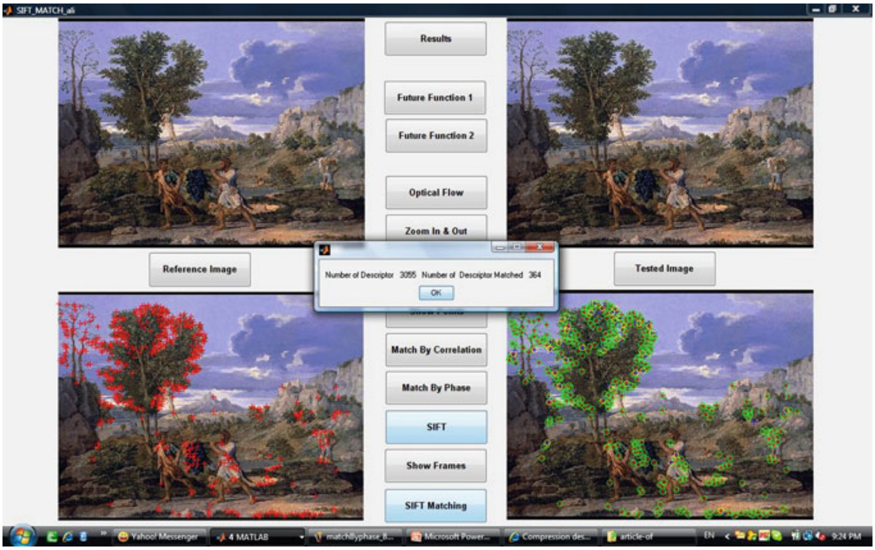


Fig. 10 SIFT matching results in descriptors matched

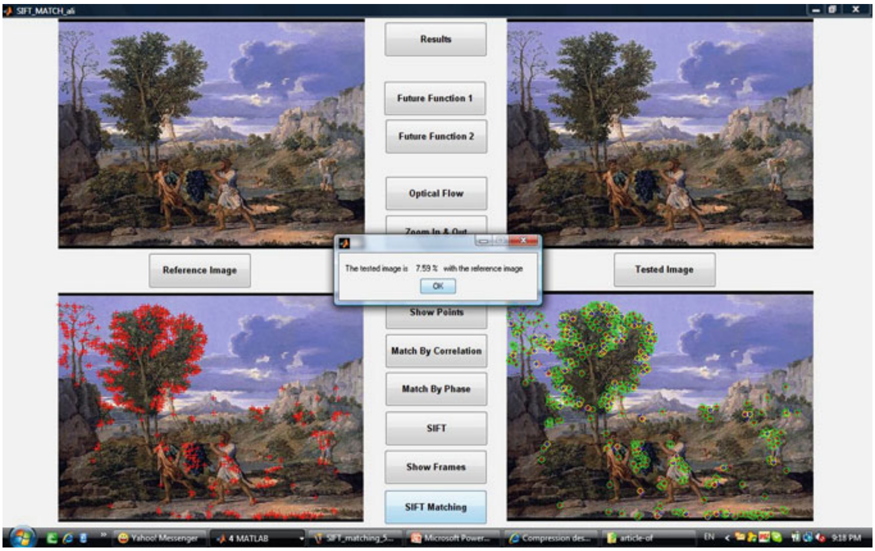


**Fig. 11** SIFT matching result in percentage

# 8 Optical Flow Function

Optical flow is usually used to study the movement. Our motivation to test it in an application such as ours is related to the similarity of the algorithms, and the optical flow is based on the analysis of two successive images. In the absence of movement two images are perfectly the same pixel near. We suppose that through the study of paintings by master a difference can be explained simply by moving all of a texture or a point from the original canvas.

Techniques for measuring optical flow have their source in studies of insect movement and the contribution of their visual systems. The general principle is based on the extraction rates by analyzing the successive images captured by the camera; the illustration below shows how to build the displacement of a point on the CCD (Charged Coupled Device) (Fig. 12).

Moving 3D point from *P (t)* to *P (t ')* produces an optical flow on the CCD at the point *Y(t)* to *Y(t')*.

The calculation of optical flow between two successive images through the resolution of an under constraint equation is obtained under the assumption that the intensity is constant between two short moments: $\frac{dI(x,y,t)}{dt} = 0$

$$\frac{dI(x,y,t)}{dt} = \frac{\partial I}{\partial x}\frac{dx}{dt} + \frac{\partial I}{\partial y}\frac{dy}{dt} + \frac{\partial I}{\partial t} = 0 \tag{8}$$

Hence

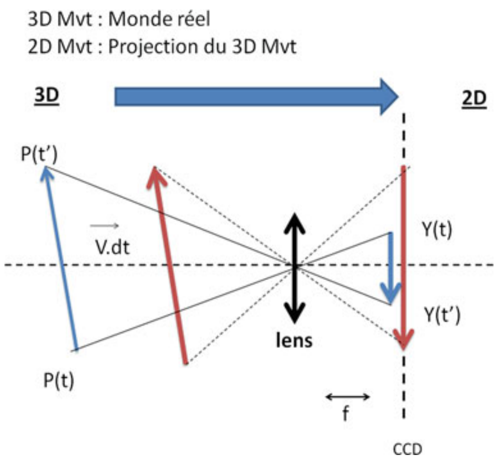


**Fig. 12** Optical flow function

$$\frac{\partial I}{\partial x} = I_x, \frac{\partial I}{\partial y} = I_y \text{ spatial image gradients}$$

$$\frac{\partial I}{\partial t} = I_t \text{ temporal image derivative}$$

$\frac{dx}{dt} = u$, $\frac{dy}{dt} = v$, $x$ and $y$ velocities.We obtain

$$I_x u + I_y v + I_t = 0 \tag{9}$$

This equation is under constraint, two unknown and one equation, according to our literature research, there is more than 14 methods of resolution to calculate u and v, the most common methods are mainly methods: Horn-Schunck [5] and Lucas-Kanade [6] (Figs. 13 and 14).

## 9 Conclusion and Future Work

The interface Table Comparison Computer Tool (TCCT) is a visual analysis tool, intended for students learning about image processing or for researchers implementing their own methods. Adding new algorithms for filtering, differentiating or computing optical flow [7] to TCCT is simple. TCCT provides quantitative and qualitative error analysis, making it easy for researchers to compare their new method(s) with traditional ones. Extra models can be implemented in the near future. The user must have Matlab and Intel's IPL installed.

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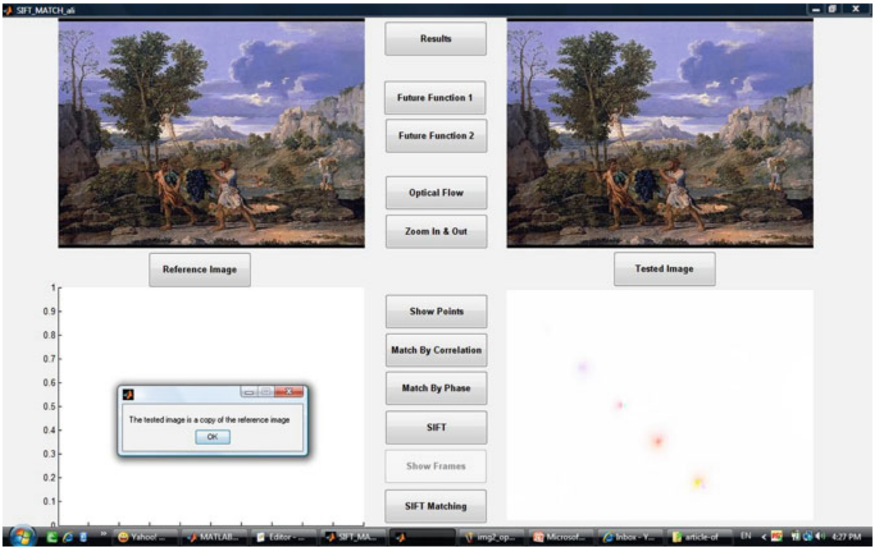


**Fig. 13** Optical flow result for an image corrupted with five pixels

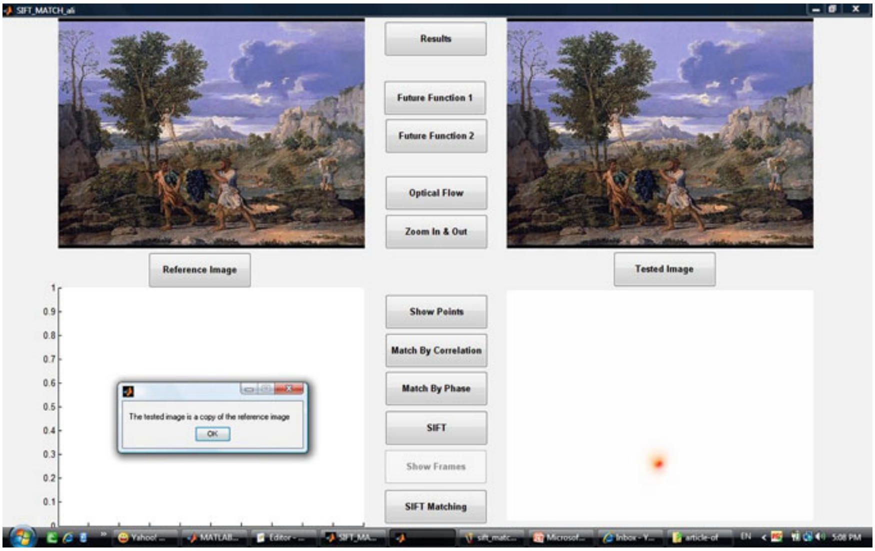


**Fig. 14** Optical flow result for an image corrupted with one pixel

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# Information Management for Holistic, Collaborative Information Security Management

**Margareth Stoll, Michael Felderer and Ruth Breu**

**Abstract** The importance of information, asset and technology as key differentiator for modern organizations is increasingly recognized. More than 6,600 organizations worldwide are implementing an information security management system (ISMS) in accordance to ISO/IEC 27001. An optimal information management is a critical success factor for the effectiveness, performance and sustainability of ISMS. Information security (IS) has been considered as technical job for a long time. In the last years IS research has developed further an IS governance and people oriented direction. Additionally, different best practices such as control objectives for information and related technology (COBIT) and the information technology infrastructure library (ITIL) have been published. In accordance to the IS approaches the information management for ISMS was studied either only from a technical perspective or a measurement perspective. In this paper we integrate all perspectives by defining a holistic, generic IS management taxonomy. To establish this taxonomy we start from a collaborative ISM framework that considers the different IS research approaches and best practices. Based on our novel IS management taxonomy we define the requirements for information system integration and information processing for a holistic, collaborative IS management.

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# 1 Introduction

## *1.1 Starting Situation*

Due to globalization and ever stronger competition information management and supporting technologies have become key assets and differentiators for modern organizations. They are main performance drivers for continual innovation and sustainable success. Organizations and their information are faced with security threats from a wide range of sources, including computer-assisted fraud, espionage, sabotage, vandalism, fire or flood. Causes of damage have become more common, further ambitious, and increasingly sophisticated [1]. 92 % of large enterprises had a security incident in the last year with an average cost of 280.000–690.000 £ for the worst incident [2]. Mobile and cloud computing, off-shoring, social networks, as well as the increasingly interconnected, flexible and virtualized business complexity and dependency are still great challenges for IS.

IS has for long time been considered as a solely technical job and has been an integral part of the information technology (IT) department [3, 4, 5]. The corresponding frameworks are based overall on enterprise architecture and focus on technical aspects. Organizations implemented numerous technical security controls such as authentication and network security management. However, IS problems persisted and increased. They are complex and require a collaborative, socio-organizational and human related IS management approach [4, 6, 7]. Further organizations have to meet many different legal and regulatory requirements, such as data protection, sound and integer financial practices and internet crime. Lack of security compliance may result in loss of confidence of customers, partners and shareholders, as well as severe civil and criminal penalties for Board members. In this respect the availability of all essential assets, confidentiality, data integrity and legal and regulatory compliance are central for organizations' success and integral part of good IT and corporate governance [3, 4, 8].

More than 6,600 organizations worldwide [9] are implementing ISMS in accordance to ISO/IEC 27001. This international standard provides a model for establishing, operating, monitoring, maintaining and improving ISMS to meet the specific security and business objectives of the organization, and legal and regulatory obligations [1, 10]. Several best practices for IS management have been developed, such as COBIT [11], ITIL [12] and national guidelines, such as NIST 800-53 [13].

More than 1.2 million organizations of different sizes and scopes are worldwide implementing management systems in accordance to international standards (e.g., ISO 9001 quality, ISO 14001 environment, ISO 20000-1 IT service management and others) [9]. All these management systems are based on the fulfillment of common principles: the establishment and communication of organization objectives and strategies, the management of business processes, an adequate resource management and the continual improvement of the organization. The management system must be documented, implemented and continuously improved.

## 1.2 Purpose and Structure of the Article

An increasingly faster changing environment (market, customer, technology, law or regulations) requires a continual adaption of business objectives, processes, controls and procedures. It is a widely accepted principle that an organization and its management system cannot be managed and improved if there is not sufficient information available with adequate quality: relevant information must be timely, accurate, verifiable, flexible, complete and accessible for only authorized stakeholders. In that way an effective information management is a critical success factor for the effectiveness, performance and sustainability of an ISMS [1, 3, 4, 5, 6, 8, 10, 11, 13]. Information demonstrates the value of IS to top management, promote qualified decision making, demonstrate compliance, improve security confidence and enable stakeholders to continually implement and improve IS and the ISMS itself [11, 13, 14, 15].

IS management, business management and on the other hand software security and network security engineering have been treated for a longer period as separate areas [14]. Relevant IS information are obtained at different levels and from most different sources within an organization. They are used to plan and establish the ISMS, to operate the ISMS, to evaluate the effectiveness and performance of the ISMS and to improve the ISMS [1, 10]. Information about stakeholders and legal requirements, strategic, business, market, technical and organizational information, asset information and a lot of other information are needed to establish ISMS. Business, market, legal and technical information are used to operate an ISMS. We analyze information to detect errors and security events, to identify attempted and successful security breaches, incidents, threats and external events (such as changes to the legal or regulatory environment, changed contractual obligations, and changes in the physical environment), to define effectiveness and performance of the implemented controls and the ISMS, and to reflect the actual risk and compliance situation [1, 10]. Based on this analysis appropriate corrective and/or preventive actions are elaborated, prioritized, approved, implemented and evaluated [1, 10, 13]. The ISMS must be continually adapted to changing internal and external conditions to deliver sustainable business value to all stakeholders [1, 3, 4, 8, 10, 11]. Further the organization should maintain and improve the ISMS itself.

Valuable IS management is based on an adequate information management. In the literature we found some papers about IS metrics taxonomy [14, 16] or taxonomies for technical oriented IS approaches [17, 18]. We found no taxonomy for holistic ISMS.

Which information we need for holistic, collaborative IS management? With which type of IT systems we exchange this IS information?

Firstly, we present our holistic collaborative ISMS framework. It integrates the IS governance frameworks with the more technical oriented architecture frameworks, the IS culture research, different best practice methods (COBIT, ITIL), the requirements of the ISO/IEC 2700x family and other standard based management systems (Sect. 2). Based on this framework we explain in Sect. 3 our innovative holistic IS management taxonomy. We describe the taxonomy overview (Sect. 3.1) and further details for the first level sub-categories. After that we analyze the main types of IT systems with which IS information are exchanged (Sect. 4). Finally we conclude and give an outlook (Sect. 5).

## 2 A Holistic Collaborative Information Security Management System Framework

We developed a holistic collaborative ISMS framework [19]. This innovative framework integrates for the first time stakeholder oriented IS governance frameworks [3, 4, 5, 8], with more technical IS architecture oriented frameworks [20, 21, 22], IS culture research [1, 3, 4, 5, 6, 11, 15], as well as different best practice methods (COBIT, ITIL), the requirements of the international standards ISO/IEC 2700x [1, 10] and other standard based management systems. It is further based on our practical experiences and a holistic, interdisciplinary approach.

The holistic, collaborative ISM framework (Fig. 1) is composed by:

- The corporate vision, policy, objectives and strategies are extended by information security aspects regarding all stakeholders, legal and regulatory requirements (see top of Fig. 1).
- In the next step we define with the collaborators concerned the holistic, systemic *IS configuration model* (see middle until bottom of Fig. 1: starting from business processes, IT services down until the physical infrastructure). We elaborate and describe all relevant business processes with their supporting IT services and their dependencies and relationships. For all these IT services we document their supporting items with their dependencies and relationships. Based on an architecture oriented approach we continue going always deeper through all technical layers until the physical infrastructure. In accordance to ITIL [12] we understand by a configuration item any component that needs to be managed in order to deliver an IT service. Configuration items typically include IT services, software, hardware, buildings, people, and formal documentation, such as process documentation and service level agreements (SLAs) [12]. The non-technical assets of the whole value network are analyzed process oriented and integrated within the IS configuration model. In that way IS objectives, requirements and the value of the assets are deduced and aligned with corporate objectives, strategies and business processes. The risk assessment (see graphic on the left side of Fig. 1) is conducted using the IS configuration model for establishing a risk treatment plan to reduce risks on acceptable levels of risk. The IS configuration model is the fundament of our framework. It determines all further definitions and decisions (e.g., assignment of roles and responsibilities, information flows, investment decisions).

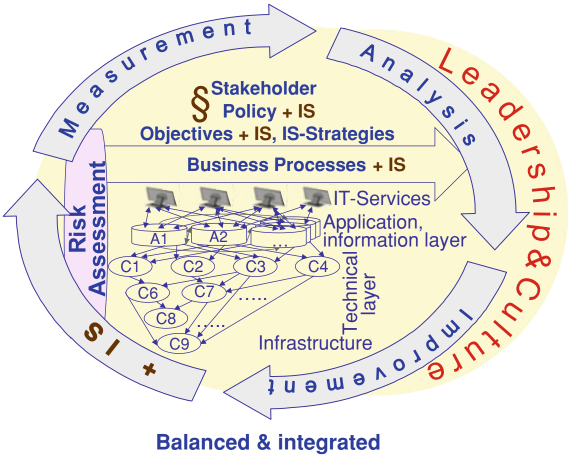


**Fig. 1** Holistic, collaborative ISMS framework

- All business processes with their requirements are analyzed over the whole value network and optimized accordingly to the deduced IS objectives (see middle of Fig. 1). Thus for example the strategic and tactical planning processes, measurement and improvement processes, support processes, resource and facility management processes, training and awareness processes are improved in accordance to IS strategies and corporate objectives. All IS measures and controls identified in the risk assessment and business continuity planning are integrated into the business processes.
- The main role of an adequate IS culture is shown by the circle in the background (see the circle on the right and background of Fig. 1). IS must be best integrated into all strategic, tactical and operational business processes and becomes a fundamental part of the daily job of all collaborators and partners throughout the whole value network. Therefore all managers must regard constantly IS, trust, legal, ethical and social issues by all their decisions and actions. That cultivates responsibility for IS, uses synergies and promotes a sustainable lived IS.
- The effectiveness, performance, compliance and adequacy of the established holistic, collaborative management system are continually measured, analyzed and reported in a stakeholder oriented way. We integrate relevant IS information within corporate controlling. Based on the actual risk situation, compliance and the achievement of the IS objectives necessary measures to maintain and improve IS and the ISMS are elaborated and implemented proactively by all concerned collaborators (see the measurement, analysis and improvement circle in Fig. 1).
- A strategic aligned, multi-disciplinary, systemic and balanced approach (security/risk, costs and usability) for the entire ISMS, as well as an optimal integration and equilibrium between people/culture, organization/processes and technology in accordance to strategies are crucial (see "balanced and integrated" at the bottom of Fig. 1). As each organization's requirements and environment are different an ISMS must be best adapted to the specific business,

legal, regulatory and organizational requirements and fully integrated into the existing strategic, tactical and operational processes and organizational structure. All relevant standards and best-practices for the organization have to be considered.

# 3 Holistic Collaborative Information Security Management Taxonomy

Due to different business and organizational, as well as legal and regulatory IS requirements of each organization the specific ISMS can be very different. Therefore we present a generic high-level taxonomy. It explains the main categories of IS information and must be adjusted to the specific requirements and objectives, and the efficiently available information of each organization.

In this section we first give an overview of our taxonomy and then we describe single sub-categories.

## *3.1 Overview*

Based on our holistic ISMS framework we grouped the relevant IS information at the highest level in:

- IS Planning: To establish the IS objectives and conduct the risk assessment for elaborating the IS strategies we first determine all relevant stakeholders and their requirements. The balanced scorecard perspectives [24] are used to control the completeness of the objectives and strategies. For the established strategies adequate programs and projects are elaborated.
- IS Architecture: Basis of our holistic sustainable ISMS framework is the IS configuration model. The IS configuration management is composed by this model and all related living configuration information (e.g., status, version). We regard the service assets and configuration management requirements of ITIL and ISO/IEC 2700x. In accordance to the ISO/IEC 2700x family we need also a system documentation and further meta-data for the ISMS, such as access rights and conditions for change.
- IS Operation: To operate the established ISMS we need different information from business processes, such as service levels, as well as log files and protocols. Further we use all relevant information from ITIL service management processes and IS processes accordingly to the ISO/IEC 2700x family. Adequate knowledge management and organizational learning promote need oriented, operation integrated information access to all relevant IS information [23] (Fig. 2).
- People oriented IS: Based on the requirements of different relevant IS approaches (e.g., COBIT, ISO/IEC 2700x family), legal and regulatory requirements

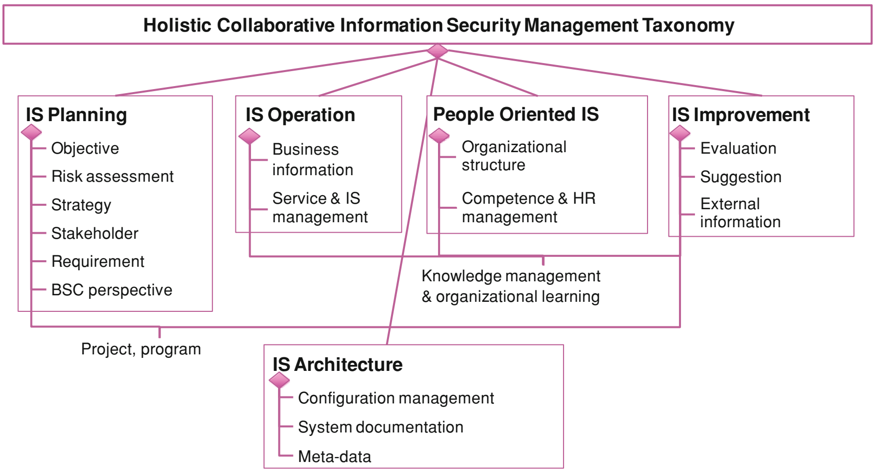


**Fig. 2** Holistic, collaborative information security management taxonomy

and good management practices we assign in accordance to the established organizational structure to all strategies, programs, projects, processes, controls and activities roles and responsibilities. Further we need competence and training information to guarantee adequate competences for all collaborators with IS relevant tasks. Knowledge management and organizational learning promote operation-integrated and need oriented learning and competence acquisition. Relevant information from human resource management is used to fulfill people oriented requirements from standards, regulations and laws for recruitment and termination of employments.

- IS improvement: For the continual measurement, analysis and improvement we need evaluation data based on measurement or audit/assessment, as well as suggestion and improvement ideas of the collaborators and from external parties, such as customers, auditors. Further we use external information, such as technical reports, literature, studies, legal and regulatory requirements, standards, best practices and others to maintain and improve IS.

In the next sections we describe the main sub-taxonomies in more detail.

## *3.2 Information Security Planning*

Here we described the IS planning information on the next level of detail.

For all objectives we need a description, must establish their priority and align adequate metrics with long-term and medium-term targets. To establish IS objectives we also use information from financial management. Depending on the IS objectives and requirements, and the availability of information a specific

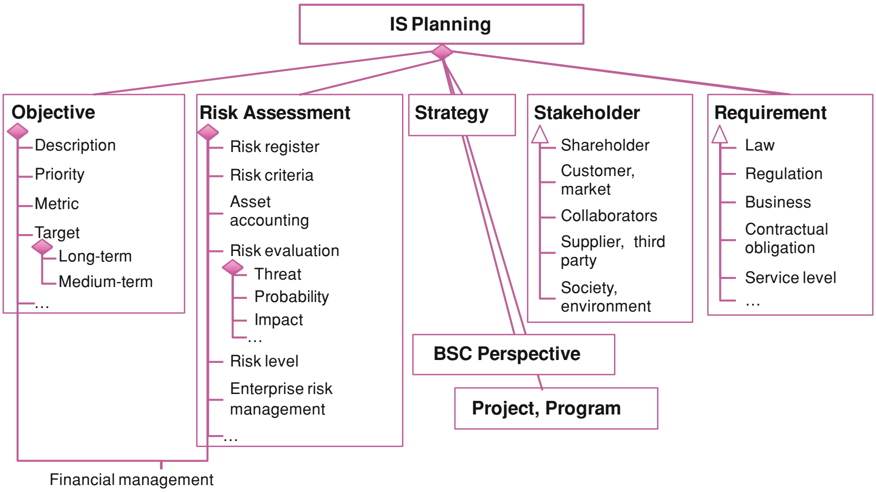


**Fig. 3** Information security planning sub-taxonomy

organization may need further information, which is represented in all graphics by three dots (Fig. 3).

The main information categories of a risk assessment can be divided in the risk register information, criteria for accepting risks (risk criteria), and information from asset accounting to establish together with other information the value of the single asset for the organization, all the information needed for risk evaluation, the remaining risk level and others. The risk assessment must be aligned with the enterprise risk management. The risk evaluation category can be divided in potential threats with the assigned probability, the estimated impacts and eventually further information (e.g., scenario analysis, protocols, and studies).

The information categories for strategies, projects and programs are very complex and not described in detail in this paper. The four balanced scorecard perspectives are clearly defined by Kaplan and Norton (financial, customer, process and learning and growth) [24]. To guarantee an adequate overview we do not insert these details.

Based on an economic oriented stakeholder theory we distinguish shareholder, customer or potential customers (market), collaborators, supplier and third parties, and the society and environment.

The main categories of the requirements can be divided in legal, regulatory and business requirements, contractual obligations, agreed service levels or others (e.g., conservation requirements for a museum collection or historical archives).

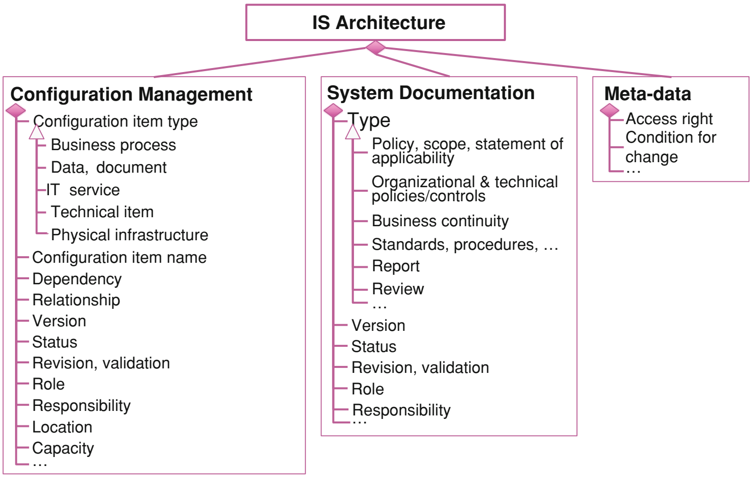


**Fig. 4** Information security architecture sub-taxonomy

### *3.3 Information Security Architecture*

Here we explain the first level of the IS architecture sub-category.

Configuration management contains the type and name of all relevant configuration items with their dependencies and relationships (II). To manage all changes of the IS configuration model for a sustainable implementation we need almost the version, status and the next revision or validation date for each item. Accordingly to ITIL, COBIT and the data protection code of most countries we assign different roles (e.g., accountable, responsible, informed and communicated) and responsibilities to each item. Further we need the location, capacity and other information depending also on the ITIL implementation level. ITIL suggests a lot of further information for a configuration management database [12].

The system documentation consists of different document types, such as the IS policy, organizational and technical policies, business continuity plans, controls, reports, reviews and others. For each document an adequate versioning with status and revision date or validation limit, as well as roles and responsibilities (e.g., for elaboration, verification, approval, revision) and other information (e.g., archives) are essential (Fig. 4, 5).

Meta-data support the maintenance of the IS architecture.

### *3.4 Information Security Operation*

The established IS controls and measures must be continually implemented, security events promptly detected, incidents responded on time and problems and changes managed in such a way that the defined IS level can be always maintained.

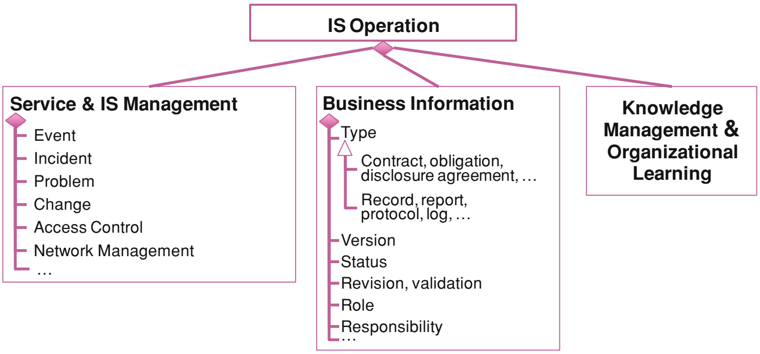


**Fig. 5** Information security operation sub-taxonomy

Based on the holistic approach of our ISMS framework we regard apart from ISO/IEC 2700x also ITIL and COBIT requirements.

The service and IS management category groups all relevant information for event, incident, problem and change management, as well as all information for the continual implementation of established technical controls and measures, such as access control, network management and others (e.g., identification and authentication management, configuration management, malicious software management, availability management). Apart from IT operation information we use business information, which can be grouped on the one hand in contracts, obligations and agreements and on the other hand in procedural information, such as records, reports, protocols, logs. Further we need for these information versioning information, role, responsibilities and others.

Knowledge management and organizational learning sustain an operation integrated need-oriented information access to all relevant policies, controls, procedures and documents.

### 3.5 *Information Security Improvement*

The IS improvement category is composed by the following sub-categories.

For the evaluation we need measurement information, which are divided in the measurement program and the measurement results. Audits and assessments also offer important information for the IS evaluation.

The suggestion management needs almost the type, a shortdescription, the cause for reactive suggestions (problems) or The suggestion management needs almost the type, a short description, the cause for reactive suggestions (problems) or the objective for pro-active suggestions (proposed improvements), necessary measures or projects, the proposer, status and other information, which can differ from the aligned suggestion management process (e.g., approval data) (Fig. 6).

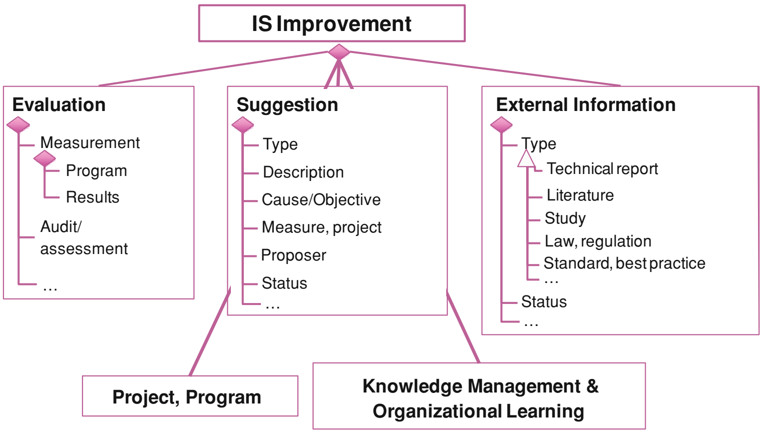


**Fig. 6** Information security improvement sub-taxonomy

Knowledge management and organizational learning promote collaborative knowledge generation. Projects and programs are essential for a successful implementation of improvements.

External information is useful to create new knowledge for improving the ISMS itself and to recognize on time necessary adoptions to changed environmental conditions. Thereare different types and sources of external information: technical reports, literature, studies, legal and regulatory requirement, standards, best practices and others. The status and other information, such as relevance or source are useful, too.

## 4 IT System Interfaces for a Holistic Collaborative Information Security Management

Based on the developed holistic collaborative ISMS framework and the presented taxonomy we elaborated a generic overview of necessary IT system interfaces.

Each organization has a different IT landscape depending on the requirements and the historical evolution. Figure 7 show categories of IT systems. Our interface overview is intended to underline the crucial importance of an adequate and integrated information processing and extensive information exchange for holistic IS management.

Information from document management, process management, supply chain management, ERP-systems and CRM-systems are used overall to plan and operate the ISMS. The supply chain and ERP-system process also people oriented IS information. IT service management, all the operating information from each configuration item of all technical layers, as well as facility management and/or maintenance tools provide IS planning and operation information. The

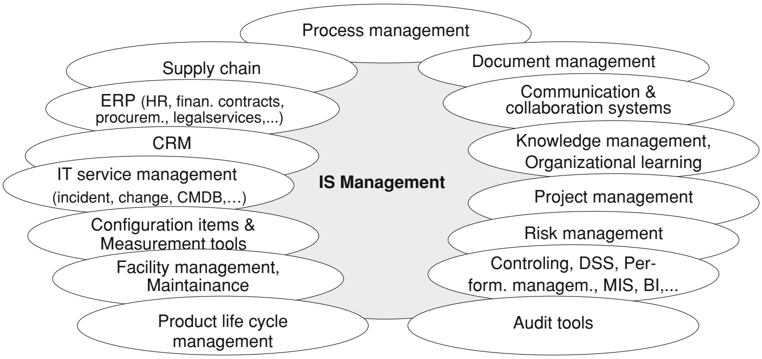


**Fig. 7** IT system interfaces for holistic collaborative IS management

measurement information of the single items and measurement tools are the basis for IS improvement. If IS is part of the product requirements, such as for technical equipment with high availability requirements (e.g., airplane, automotive) it is essential to maintain the IS configuration model for each product over its whole life cycle and to exchange such information with the product life cycle management. Audit tools, controlling systems, decision support systems (DSS), performance management systems, management information systems (MIS), business intelligence (BI) and other controlling and improvement tools are essential for IS improvement. Based on our integrated approach IS should be part of all planning and controlling processes of an organization. Risk management and risk assessment is an essential step of IS planning and IS improvement. Project management sustains on the one hand IS projects and on the other hand each project should be checked for IS impacts and potential IS risks to continually maintain and improve the IS level. Knowledge management, organizational learning and communication and collaboration systems promote information providing, knowledge exchange and knowledge generation. They sustain overall people oriented IS for IS operation and IS improvement.

## 5 Conclusion and Outlook

In this paper we first presented our holistic collaborative ISMS framework. It integrates the different IS research directions with best practice methods (COBIT, ITIL), the requirements of the international standards ISO/IEC 2700x and other standard based management systems. Based on this interdisciplinary and holistic IS approach we developed a novel holistic collaborative ISMS taxonomy and deduced necessary system interfaces for an adequate information processing and information exchange.

IS management is continually more considered as collaborative and ongoing task, which must be part of the daily operation of all collaborators. This integrative and holistic approach requires an optimal information processing and information exchange from huge different sources. In that way IS underlines the requirements for enterprise application and information integration, a common system meta-model and overall a systematic handling of changes [25] for sustainable IS management.

The proposed ISMS taxonomy provides a systematic approach for holistic collaborative IS management and pushes forward a research agenda for holistic and integrated IS management. Information engineering for holistic collaborative IS management is supported. This taxonomy serves further as a bridge from the holistic ISMS framework to its implementation by application and information integration with adequate meta-models.

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# Towards Passive Walking for the Fully-Actuated Biped Robot Nao

**Gareth Priede and Alexander Ferrein**

**Abstract** Many biped robots deploy a form of gait that follows the zero moment point (ZMP) approach, that is, the robot is in a stable position at any point in time. This requires the robot to be fully actuated. While very stable, the draw-backs of this approach are a fairly slow gait and high energy consumption. An alternative approach is the so-called passive-dynamic walking, where the gait makes use of the inertia and dynamic stability of the robot. In this paper we describe our ongoing work of combining the principles of passive-dynamic walking on the fully-actuated biped robot Nao, which is also deployed for robotic soccer applications. We present a simple controller that allows the robot to stably rock sidewards, showing a closed limit-cycle. We discuss first results of superimposing a forward motion on the sidewards motion. Based on this we expect to endow the Nao with a fast, robust, and stable passive-dynamic walk on the fully-actuated Nao in the future.

## 1 Introduction

The most basic task for mobile robots is to move from A to B. While this task is rather simple for wheeled robots, the challenge is much bigger for biped humanoid robots. Unlike wheeled robots, humanoid robots easily become instable. Therefore, most humanoid robot gaits are designed so that the robot hardly ever leaves a stable state while walking. This can, for instance, be achieved by planning the

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trajectory of the robot so that the robot's projection of its centre of gravity onto the ground never exceeds the area that is enclosed by the robot's feet. A more robust calculation including the moment around the ankle is called ZMP walking [14] and this is the most commonly used gait generation technique for fully-actuated biped robots. Although this ZMP walking on fully-actuated biped robots produces a stable gait, it comes with a number of disadvantages. The gait is comparatively slow since the robot may not leave its stability region, and it consumes a significant amount of energy because all joint motors are driven at all times.

An alternative approach tries to exploit the inertia of the robot better. The field of passive-dynamic walking [3] investigates how non-actuated or only partially actuated biped robots can achieve human-like gait. The principle works as follows. Consider a robot being pushed from behind. While falling over, the robot swings one of its legs forward to catch the fall. Then, by having too much inertia, the robot pivots over this stance leg. As the robot continues to fall forward, the previous stance leg lifts off the ground and is swung forward to repeat the pattern. With this method, only intermittent control and actuation is needed as most of the time the robot's inertia is utilized. The drawback is that the platforms where passive-dynamic walking is applied to be usually custom-built robots with particular dynamics and often without a torso and it is not in general possible to apply these principles to fully-actuated robots.

One observation of having participated in the Standard Platform League of the robotic soccer world cup (RoboCup) [10] with the biped robot Nao [1] is that most teams employ a form of ZMP walking, either developed by themselves or making use of the walking engine that comes with the robot. For a competition it is crucial to walk faster than your opponents to reach the ball first.

In this paper we describe the first steps of our ongoing work to apply the principles of passive-dynamic walking to fully-actuated robots such as the Nao. Passive-dynamic gait seems to be feasible on the robot Nao, as the joint stiffness can be reduced and the robot then behaves similar to the custom-built walking machines which are deployed in passive-walking experiments. Further, the Nao comes with a rich set of sensors such as a gyroscope and accelerometer, joint position sensors and pressure sensors in the feet. However, challenges include controlling the robot in such a way that the swing leg is accelerated fast enough to stop the robot from tipping over while maintaining lateral stability. We present a simple controller that allows the robot to rock sideways (in its coronal plane). It turns out to have a limit-cycle with this motion. This yields a very stable motion on which a forward motion can be superimposed. We describe some first results on superimposing both motions. While this paper presents ongoing work, it seems to be very promising for endowing the Nao with a faster and more stable work in the future.

The rest of this paper is organised as follows. In Sect. 2, we review some important works in the field of ZMP and passive-dynamic walking as well as related work that tries to combine both. In Sect. 3 we introduce the robot Nao and discuss the feasibility of combining passive-dynamic walking on a fully-actuated robot, before we present our control algorithm for sideways motion in Sect. 4. We present first experimental results on our gait, yielding a limit-cycle for the sideward motion, in Sect. 5. We conclude with Sect. 6.

## 2 Related Work

The most widely used walking style for biped robots is fully-actuated, in which the trajectories of all the limbs of the robot follow a path that is known to maintain the robot's overall stability at all times. The most common stability calculation is based on the ZMP [14], which is a point on the walking surface where all reaction forces sum up to zero with zero moment; stability is ensured if this point lies within the convex hull created by the supporting foot or feet of the robot. A state-of-the-art robot employing this walking style is the Asimo robot built by Honda [11], which can walk smoothly at almost human-speeds and with great versatility.

One of the attractions of fully-actuated walking is that it is applicable to a wide range of robots and there is substantial flexibility in the design of the walking gait, within the stability limits proscribed by the ZMP criteria. Since the walking methodology is easily integrated into robots which have arms and grippers, this offers the potential to combine walking with other tasks. However, there are a number of drawbacks to this style of walking, not least of which is that it has a high energy usage which, by some estimates, may be up to a magnitude higher than that of humans [3]. In addition, the control mechanism involves some potentially complex calculations on an accurate kinematic model of the robot.

An alternative approach to walking, called passive-dynamic walking, was first studied by McGeer in 1990 [12] and describes robots which harness the particular dynamic structure of the robot instead of actuating each joint. The simplest such robots are constructed as two straight legs freely hinged at the hip and no motors. If the proportions and weights of the limbs are carefully chosen, the robot can walk unaided down an incline in a so-called compass gait where the robot pivots forward over the stance leg while the other leg swings forward. In this motion, the robot is always falling forward and the free leg naturally swings under gravity into a position to catch the fall. With the correct design, the overall walking motion exhibits a limit-cycle, meaning that small instabilities and inaccuracies diminish over time [6] and that while the robot may be unstable at any one moment, the overall walking motion is stable and can continue indefinitely.

Since there are no motors, these robots use gravity to overcome losses in the joints and in the collision when the swing leg strikes the ground, which means they can only walk downhill. More versatile designs include hip motors to drive the swing leg forward and so can walk on flat surfaces and even up shallow inclines, notable examples include the Flame robot [4] amongst others [3, 13]. Despite having some actuation, the overall control system is relatively simple, typically using foot sensors to trigger the hip actuator movement and without an overall motion definition. As an added measure to prevent the swing leg scuffing the ground as it passes the stance leg, the knee may also be hinged [4]. Other methods of controlling the overall leg motions are also possible, such as using telescoping legs [7, 9].

An important design criterion for passive-dynamic robots is maintaining stability in both the sagittal (sideways) and coronal (forward) planes. Wisse et al. [15]

showed that coronal stability is ensured if the swing leg can be moved into a forward position quickly enough, and that this exact position has a wide range of stable values as long as it is not so far forward that the robot's momentum is insufficient to pivot over the leg. Also while most dynamic robots have no torso, meaning the centre of mass is positioned in the hip, Hobbelen, De Boer and Wisse [4] show torso balance can be maintained by adjusting the hip angle of the stance leg.

In general calculating a stable dynamic walk is difficult because of the complex equations of motion for the robots (which is one reason for the popularity of the ZMP method). Therefore in many dynamic walkers, the robot is constrained to 2D movement by attaching the robot to a boom which prevents the robot falling sideways. Robots which are stable during 3D motion maintain stability either by careful construction of the foot and mass distribution [13] or by adjusting the swing leg laterally based on feedback from the torso roll angle [4] or angular velocity [2].

The last significant feature of most dynamic walkers is their large curved feet, which helps to improve disturbance rejection in the sagittal plane. While the exact shape is significant for the dynamics of the robot, it presents a small contact surface which limits traction due to friction. Recently Hobbelen and Wisse [5] showed that a flat foot stiffened using springs is a suitable substitute which allows the design of more human-like feet.

A notable characteristic of all dynamic walkers is their low energy usage, which is on the order of human walking, and their ability to take longer strides which improves walking speed. This coupled with their simple control structure makes it an attractive walking methodology. However it requires careful design of the robot in order to obtain appropriate passive dynamics and to the best of our knowledge they have not been shown to be readily applicable to the more easily obtained and widely available fully-actuated robots.

## 3 Applying Dynamic Walking Principles to the Nao

In this section we describe the motion pattern that we want to deploy on the Nao. First, we introduce the Nao robot platform and compare its features with passive-dynamic walkers showing the general applicability of passive walking on the Nao. Then we describe the motion pattern in detail.

### 3.1 The Biped Robot Nao

The Nao is a general purpose robot built by the French company Aldebaran and available commercially [1]. It is humanoid in shape, weighs 4.5 kg, is 57 cm tall and has 21 degrees of freedom distributed in the arms, neck and legs, each of which is actuated. A schematic of the robot is shown in Fig. 1. The joints relevant to this paper are labelled as ankle pitch $\theta_{ankle}$ and roll $\phi_{ankle}$, knee pitch $\theta_{knee}$, and

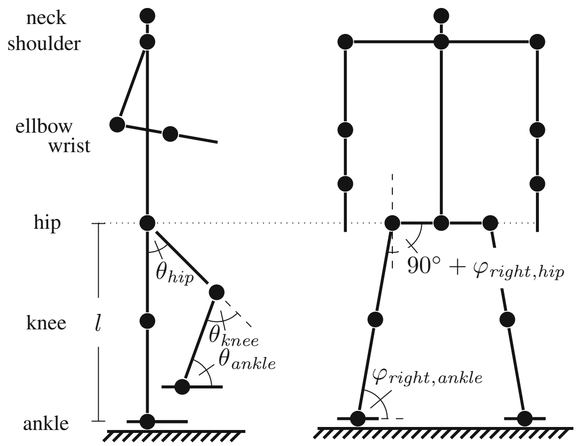


**Fig. 1** Schematic drawing of the Nao from the *side* and *front*

hip pitch $\theta_{hip}$ and roll $\phi_{hip}$. Note that for readability reasons, we depicted $\phi_{hip} + 90°$. Each joint is actuated and has a stiffness which can be controlled from 1.0 to 0.0. This stiffness determines how accurately the real joint position matches the intended position, where 1.0 means that the joint position is completely stiff and can only be moved by actuation. Lower values cause the joint to be more compliant and at 0.0 the joint can be moved manually and actuation has no effect; however, even with stiffness at 0.0 there is still some resistance in the joint. The legs end in a large flat foot with four pressure sensors in the soles. The torso contains a gyroscope and an accelerometer to measure angle and acceleration.

The robot can be accessed via an ethernet or wireless connection and has an AMD CPU with 1 Gb flash memory. It ships with a Linux operating system and an API is provided for access to the sensors and actuators via Python or C/C++. Through the API it is possible to request any joint to move to an angular position at a specified speed, there are safety mechanisms built into the API to prevent impossible or damaging movements. The API also provides functions for reading the joint angles and sensor values and for setting the stiffness of the joints.

One of the showcases for the Nao's abilities is the RoboCup competition, where the Nao competes in the Standard Platform League [10]. Figure 2 show a scene from a soccer match. The soccer games are contested by two teams of autonomous Nao robots, three on each team, where each game consists of two 15 min halves. The rules are modified from regular human-soccer rules, for example the pitch is much smaller, there are no throw-ins and robots can be temporarily removed from the field for bumping, falling down or becoming inactive. The intention of the competition is to drive improvements in various aspects of robotics and different skills are required to be successful, including vision to track the ball, locomotion to move to the ball and kick it. During play there is a significant advantage in being the first robot to reach the ball, partly since the collision rules favour the closest robot to the ball and also because it allows time for the robot to position itself for a scoring kick. It is also important for the walking motion to be resilient because

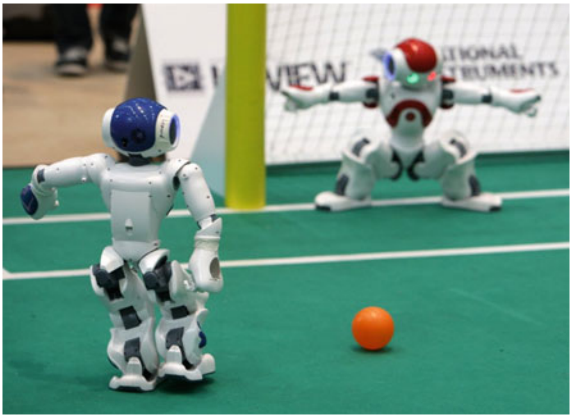

**Fig. 2** The biped robot Nao at RoboCup competitions

the robots frequently bump into each other while moving around the field. All the competing teams in the last few years have used fully actuated walks, either the standard walk supplied with the Nao API or a custom-designed walk. However there is room for improvement in both speed and stability and also notably for energy usage. Currently the robots require recharging between halves of the game, a more energy efficient walk could either increase the operation time or allow use of a lighter battery, which becomes more important outside the soccer arena in real-world applications.

The advantages of dynamic walking, namely low energy usage, speed and inherent stability, arise through exploiting the natural dynamics of the robot. Since the Nao is designed for fully-actuated walking, the weight distribution, joint stiffness and limb weights are not necessarily suitable for passive-dynamic walking. As we pointed out in the related work section, the Flame robot is one of the most humanoid dynamic robots [4], with a torso and flat feet, albeit with specifically constructed joints, limbs and motors. However, with its centre of mass being in its hip region, the Nao is also similar to many other dynamic walkers. As regards the controller, the foot sensors in the Nao are analogous to the foot sensors in actuated-dynamic walkers used to trigger hip movements, while the Nao's gyroscope provides an accurate indication of the angular velocity of the torso. It appears therefore that the most important features for dynamic walking are present in the Nao. It is also worth noting that a standard ZMP-style Nao walk with all the joint's stiffness slightly lowered has been previously implemented [8] and while not a true dynamic walk, it showed increased energy efficiency with enhanced disturbance rejection because of the dampening effect of the partially-compliant joints. Other potential problems could be if the joints can maintain their position for extreme movements, or if the weight of the robot is not sufficient to overcome the residual resistance in the unstiffened ankle joints. However, there is good evidence that dynamic walking can be achieved on the Nao platform, as we show in the next sections.

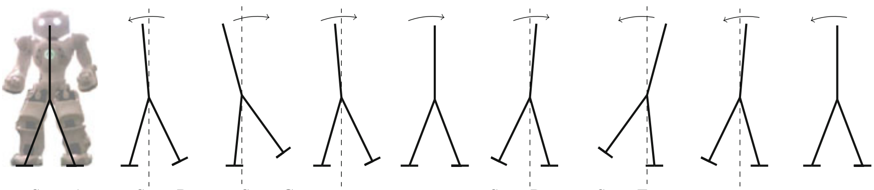


**Fig. 3** Rocking in the coronal (*frontal*) plane with control states labelled

## 3.2 Description of Intended Motion

We take the non-standard approach of creating a stable motion in the coronal (frontal) plane first, since it is expected that the left–right symmetry of the robot will simplify the control. This will provide a proof of concept as well as a basis onto which a forward motion can be applied. Figure 3 show a stylised version of the intended rocking motion of the robot, with a simplified hip geometry and omitting the arms. The arrows show the direction the robot is rocking in and the dotted line is the approximate position of the centre of mass in the sagittal plane. The states relate to the controller implementation and are described in Sect. 4.

The robot is stable while both feet are on the ground, small sideways deviations cause the robot to rock into a single-support state where one leg is carrying the weight of the robot and the other leg is raised, as shown in state B and state D of Fig. 3. If the disturbance is not too large such that the centre of mass remains on the same side of the support leg, then the robot will rock back towards the stable double-support position, where its momentum will carry it over onto a single-support state on the other leg, and the cycle repeats. The splay of the legs controls how much energy is lost in the collision when entering the double-support state, where a large splay is more stable, but dampens the rocking motion more quickly.

In order to maintain the rocking motion indefinitely, an energy source is required. A minimal mechanism which has little impact on the overall dynamics of the robot is to adjust the length of the stance leg, by simultaneously changing the hip pitch, knee pitch and ankle pitch. Since by conservation of momentum the change in leg length is directly related to the angular velocity $\omega$ of the robot, this change of leg length $\Delta l$ can be used as a proportional control law. Shortening the leg causes $\omega$ to increase and lengthening the leg slows the robot down. If $\omega$ is not so large that the maximum extension of the leg is reached, the robot can maintain the rocking motion indefinitely by one or more adjustments of the leg length shortly after leaving the double-support state.

With lateral stability achieved, a forward dynamic motion can be incorporated in which the robot falls forward onto the swing leg. Closing the ankle pitch of the stance leg will cause the robot to tip forward; simultaneously the raised leg is swung forward to catch the robot as it falls. With sufficient forward momentum, the robot will pivot over this new stance leg in the typical dynamic walking step.

## 4 Implementation of the Preliminary Controller

The walking controller acts during the five states labelled in Fig. 3. State A is the initial state where the robot is stationary and both legs are the same length. The ankle roll joint stiffness of both feet are set to 0.0 which allows the feet to remain flat on the floor while rocking left or right. Either a manual sideways push or a special start-up routine initiates the robot rocking and the robot enters single support on the right leg as shown in State B. The momentum of the robot causes the robot to reach a maximum rocking angle shown in State C as it starts to return to the double support state, and soon the robot returns the double-support state, with angular velocity. The momentum of the robot carries it onwards into a single-support state on the left leg shown in State D, and then to the maximum rocking angle as shown in State E. The cycle then repeats in reverse, so that States D and E are identical to states B and C respectively but with the legs reversed. The two superimposed motion patterns are:

(1) *Sideways motion:* The sideways rocking motion is controlled during states B and D, i.e. shortly after entering the single stance state, by a single adjustment of the stance leg length $\Delta l$ to correct the angular velocity $\omega$ of the robot towards the a reference angular velocity $\omega_{ref}$, which controls how far the robot rocks in each direction. Since the upper and lower leg lengths are constant, the change in leg length is achieved by adjusting the hip pitch $\theta_{hip}$, knee pitch $\theta_{knee}$ and ankle pitch $\theta_{ankle}$ calculated using the cosine law.

The reference velocity $\omega_{ref}$ is tightly coupled to the timing of other elements of the controller, including the speed with which the leg length is adjusted and the span of the robot legs. Despite this, experimental values for both $\omega_{ref}$ and $\phi_{hip}$ which provide a stable rocking motion were found relatively easily. The inherent robustness of the controller is sufficient that the robot can be given a substantial sideways push during any state of the rocking motion and the rocking motion will resume the original rocking frequency within a few rocks.

(2) *Forward motion:* The forward motion is controlled during states C and E. The stance ankle pitch is decreased, causing the robot to tip forward, while at the same time the stiffness of the ankle pitch is lowered, allowing the robot to fall forward under gravity. Simultaneously, the hip pitch angle of the swing leg is set to a fixed angle to swing the leg forward to arrest the robot's fall. The ankle pitch stiffness of this leg is also lowered to allow the robot to pivot over the foot when it lands. With careful selection of parameters for the swing leg angle and the initial ankle pitch of the stance leg, the forward momentum of the robot is sufficient to carry it over the swing leg and execute a single step. The robot is then straightened upright by decreasing the hip pitch angle and stiffening the ankle pitch joints, in preparation for the next step on the other leg. The full controller is shown in Algorithm 1.

**Algorithm 1.** Pseudo-code for walking controller showing both sideways and forward control

**Input** : $\omega^{(t)}$ – angular torso velocity at time $t$; $fsr_{\circ}^{(t)}$ with $\circ \in \{left, right\}$ – feet sensor reading at time $t$; $l_{ref}, \omega_{ref}, \theta_{ref}$ – the reference values for the leg length, the angular torso velocity and the hip pitch

**Output**: $l_{\circ}$ with $\circ \in \{left, right\}$ – the leg length; $stiff_{ankle,\circ}$ with $\circ \in \{left, right\}$ – the stiffness of the ankle roll joint; $\theta_{hip,\circ}$ with $\circ \in \{left, right\}$ – the hip pitch angle

**function** selectstate()
  **while** *true* **do**
    **if** $fsr_{right}^{(t)}$ **and not** $fsr_{left}^{(t)}$ **and** $fsr_{left}^{(t-1)}$ **then**
      goto(*state B*) **end**
    **if** $\omega^{(t)} < 0$ **and** $\omega^{(t-1)} > 0$ **then**
      goto(*state C*) **end**
    **if** $fsr_{left}^{(t)}$ **and not** $fsr_{right}^{(n)}$ **and** $fsr_{right}^{(t-1)}$ **then**
      goto(*state D*) **end**
    **if** $\omega^{(t)} > 0$ **and** $\omega^{(t-1)} < 0$ **then**
      goto(*state E*) **end**
    wait for new sensor readings;
  **end**
**end**

**controller**
  **state** *A* // start rocking motion
    selectstate ();
  **end state**
  **state** *B* // swing to left
    $l_{left} \leftarrow l_{ref}$;
    $l_{right} \leftarrow l(\omega/\omega_{ref})$;
    $stiff_{left} \leftarrow 1.0$;
    $stiff_{right} \leftarrow 1.0$;
    $\theta_{hip,left} \leftarrow 0.0$;
    selectstate ();
  **end state**
  **state** *C* // max. tilt angle (left)
    $\theta_{ankle,left} \leftarrow \theta_{ankle,ref}$;
    $stiff_{ankle,left} \leftarrow 0.1$;
    $stiff_{ankle,right} \leftarrow 0.1$;
    $\theta_{hip,left} \leftarrow \theta_{hip,ref}$;
    selectstate ();
  **end state**
  **state** *D* // swing to right
    (symmetric to state B)
  **end state**
  **state** *E* // max. tilt angle (right)
    (symmetric to state C)
  **end state**
**end**

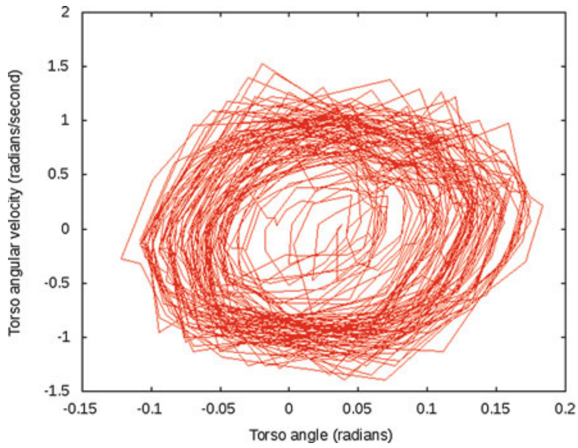


**Fig. 4** Pseudo-code for walking controller showing both sideways and forward control

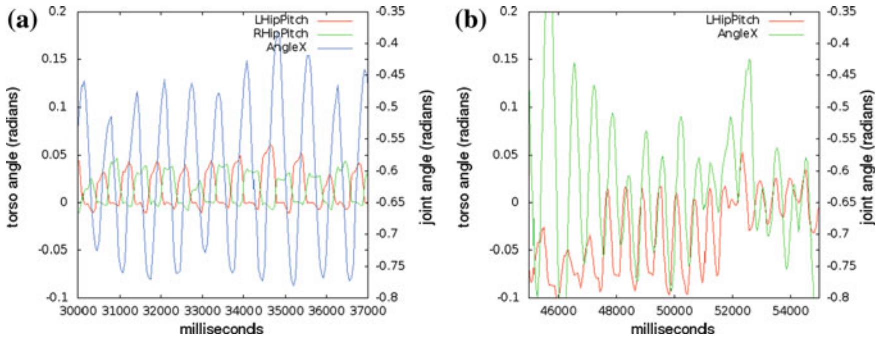


**Fig. 5** Portions of sample data for the rocking motion showing the roll motion of the torso

## 5 First Experimental Results

In this section, we give some first experimental results on our rocking motion. The overall stability of the rocking can be seen in Fig. 4, which shows a time slice of the rocking motion as the torso angular velocity versus the torso pitch. The limit-cycle becomes evident with the circular band in Fig. 4. The variability in the rocking is also visible as the outliers on the inside and the outside of the limit-cycle. The sharp angles in the graph are artifacts of the relatively low sensor sample rate.

In Fig. 5 we give some graphs showing the stability of the sidewards motion and the sidewards motion with the forward motion superimposed. Figure 5a shows a short time slice of the rocking motion where the forward motion in the controller has been disabled. The plot with the larger amplitude shows the torso angle of the robot (Angle X in the figure). The variance in the maximum tilt angle with each rocking motion is clearly seen and indicates the effects of disturbances in the system. Also shown is the pitch of the left and right hips, which is representative of the leg length. Although the controller only initiates a single leg adjustment command per rocking cycle, the Nao API smooths the movement which is why the pitch changes are not instantaneous.

When the forward motion is enabled, the overall stability of the robot is decreased. With a small leg swing distance the robot walks forward in a stable gait, however the rocking motion is more variable and sometimes decays almost to the point where the robot is not rocking at all. Figure 5b shows a portion of the erratic rocking motion. It is likely that this effect is due to timing errors in the controller between the state of the forward motion and the rocking motion, and requires further investigation. Sometimes stability can be recovered by applying a sideways push, which appears to re-energise the rocking and forward motion operation and the walking motion recovers. With larger swing leg angles it appears that the timing errors become accentuated and the stability decreases dramatically.

## 6 Conclusion

It is apparent that the implementation of a dynamic biped walk on the Nao robot is desirable, since it combines the low energy usage and intrinsic stability of dynamic walking with the versatility of a fully-actuated and controllable robot. We approached the walking motion by considering first a lateral rocking movement. A controller has been implemented which controls the amplitude of the rocking motion by intermittently bending or unbending the legs as the robot transfers its weight from leg to leg. Coupled with a lowered stiffness in the robot's ankle joints this controller utilises the robot's inertia and natural dynamics to achieve a stable rocking motion. By including a forward motion into the controller, a walking gait with small steps was achieved. For larger step lengths some timings in the controller appeared to be problematic and the robot's rocking motion became unstable and occasionally decayed until the robot stopped walking.

These initial results indicate that in general the principles of partially-actuated dynamic walking are applicable to the Nao robot. Continued work concentrates on improving the controller to better coordinate the forward and sideway motions, which will enable us to increase the forward step length while also decreasing the rocking amplitude. This brings us closer to the goal of a stable, efficient and quick walk in the Nao.

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# The Multi GPU Accelerated Waveform Inversion in Distributed OpenCL Environment

**M. Kloc and T. Danek**

**Abstract** Seismic waveform inversion is a problem with demand of high computational power. This demand can be fulfilled by supercomputers or by the modern graphics units. However GPU solution is much more accessible and cheaper. To implement this problem on GPUs one of GPGPU environments should be used. The newest one is OpenCL. To obtain higher speedup the MPI technology and additional graphic units can be used. Tests in such an environment were performed and results are presented and discussed in the following paper.

## 1 Introduction

Seismic inversion is one of the main problem in geophysics [1]. This method makes possible recovery of Earth's subsurface properties, such as velocity and depth of each layer, from reflection seismic survey. One of the possible solutions of this problem is full wave form inversion through Monte Carlo sampling. Unfortunately this method needs high computational power to finish in reasonably short time. It is mostly because it is necessary to generate thousands of waveforms to find final solution distribution. Fortunately it can be easily parallelized using GPU units in composition with MPI.

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## 2 Seismic Inversion Through Monte Carlo Method

The method described in this paper is a solution of an inverse problem. At first a waveform $\boldsymbol{u^{sur}(t)}$ from reflection seismic survey and ranges of subsurface velocities and depths of underground layers needs to be known. Then random artificial waveforms $\boldsymbol{u_m^{art}(t)}$ are generated using finite difference equation. The real and artificial waveforms can be compared and its similarity can be evaluated. In this study similarity of two waveforms is measured by the sign of corresponding waves parts. To find final solution distribution thousands of waveforms of known velocities and depths should be generated and compared with the original one. Parameters of the model which best fits the results of seismic survey should describe Earth's subsurface on the base of measurements results.

However, there are some factors like measurement errors that do not allow trust all results of this method. That is why the a *posteriori* probability is calculated [2]:

$$\rho(m) = \text{const} \times \exp\left(\frac{\|u^{sur} - u^{art}\|}{\sigma}\right) \tag{1}$$

where $\sigma$ is standard error parameter which have to be tuned by calculating the acceptance rate before main calculation and $\|.\|$ stands for a norm in the data space.

On its basis, using Metropoolis–Hastings algorithm, probability density from thousands of samples is generated. Thanks to this approach the most probable and reliable results can be shown.

## 3 Parallelization

Architecture of the newest GPUs allows executing SIMD streams. As it was mentioned above, waveform is generated using numerical finite difference method. In this case creating artificial waveform can be easily parallelized using GPU because at the same time values in many nodes of grid are calculated [3]. Fortunately, in addition to faster single waveform generation on single GPU, many models can be created in parallel on many GPUs. To obtain this mpich implementation of MPI was used.

## 4 Numerical Experiment

To check speedup of waveform generation and probability density sampling on multi GPUs the following experiment has been conducted. Firstly, waveform $\boldsymbol{u^{sur}(t)}$ (Fig. 1.) based on the 100 × 100 three-layered velocity model (Table 1) was generated and times needed for this simple computation were measured

**Fig. 1** Waves registered on the model's surface. In analyzed example waveform was generated numerically. Waves reflected from layers are visible

(Table 2). Secondly tests were run for 1,000, 10,000 and 100,000 waveforms generation (iterations) and varying (1–3) number of GPUs used. Using Metropolis–Hastings sampling algorithm the probability density was drawn. Figures 4 and 5 show example results as one and 2D histograms. Finally, the average times from test runs were calculated.

# 5 Implementation

## *5.1 Hardware Specification*

Waveform modelling was performed on the three IBM Blade HC10 servers. Specification of each node was:

– Intel Core2 6700 2.66 GHz processor,
– 8 GB RAM,
– Nvidia Quadro4 1600 M GPU with 256 MB memory, (Table 3)
– Gigabit Ethernet network adapter.

All nodes were connected by Gigabit Ethernet switch.

**Table 1** Parameters of simple model

| "Survey" model parameters | |
|---|---|
| x size [m] | 100 |
| y size [m] | 100 |
| Top of second layer [m] | 50 |
| Top of third layer [m] | 80 |
| Velocity in first layer [m/s] | 1,000 |
| Velocity in second layer [m/s] | 500 |
| Velocity in third layer [m/s] | 2,000 |
| Source location (x,y) [m] | 50, 25 |

**Table 2** Comparison of average computing time on CPU and GPU. 100 test waveforms was generated

| Comparison of CPU and GPU computing time [s] | |
|---|---|
| CPU | GPU |
| 0, 52 | 0, 17 |

**Table 3** Parameters of GPUs used in tests

| Core clock | Memory clock | Cores |
|---|---|---|
| 625 MHz | 700 MHz | 32 |

### 5.2 *Programming Language and System Environment*

The application for this study was written in C programming language using Nvidia's implementation Version 1.1 of OpenCL [4, 5] standard and mpich implementation of MPI standard.

## 6 Results and Discussion

Table 2 shows average time from 100 test runs on CPU and single GPU. As it can be seen average speedup is about 3.08 what is not a great result, but it should be emphasized that model size is really small ($100 \times 100$) and as it is common in case of many parallel problems, speedup should increase with model size, as communication stops to play main role. As additional tests showed that at model size $1000 \times 1000$ speedup can be about eight but this scale related speedup changes need further investigation.

Multi GPU solution, which was the main aim of this part of the project, was also tested. Results are shown in Fig. 2 and in Table 4. According to number of iterations investigations showed that logarithm of time increases linearly (Fig. 2).

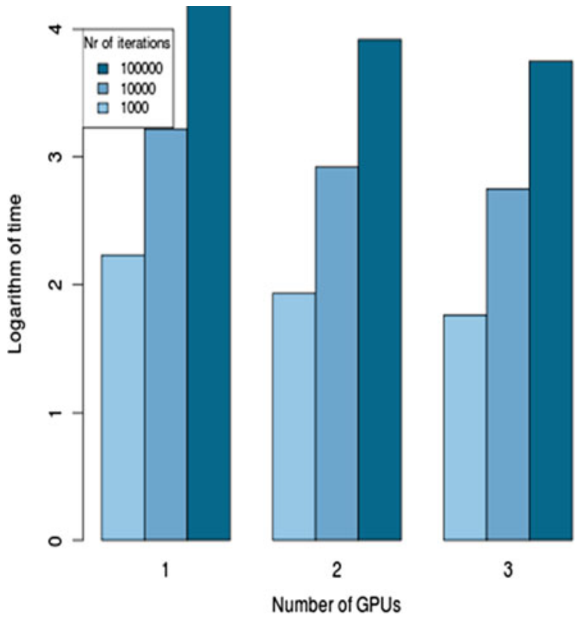


**Fig. 2** Logarithm (base 10) of time of waveform's inversion as function of iteration's number for each number of GPUs used in tests

**Table 4** Times of waveform's inversion

| Average time of seismic inversion [s] | | | |
|---|---|---|---|
| Nr of iterations | Number of GPUs | | |
| | 1 | 2 | 3 |
| 1,000 | 169, 71 | 85, 64 | 57, 49 |
| 10,000 | 1678, 68 | 840, 04 | 561, 16 |
| 100,000 | 16735, 24 | 8403, 72 | 5559, 8 |

It is a promising result because number of iterations (generated waveforms) has great impact on the final result which is typical for Monte Carlo methods. Number of 100,000 iterations gives the best result for model 100 × 100 in comparison to 1,000 and 10,000 iterations according to our research. Linear increase of logarithm of time in function of iterations' number makes this method acceptable and usable in real life situations. What is also interesting is that time of 1,000 iterations multiplied by 10 to give us 10,000 iterations will be greater than time of one run of 10,000 models generation. The same thing we can observe for greater number of iterations. This is the result of system's optimisations and smaller communication impact on the whole process.

The speedup is almost linear in function of GPUs number (Fig. 3). Such result was expected because in case of coarse grain parallelization where each GPU calculates one waveform and there is no communication between graphic units. Time needed by single processor to calculate 100,000 waveforms would be about

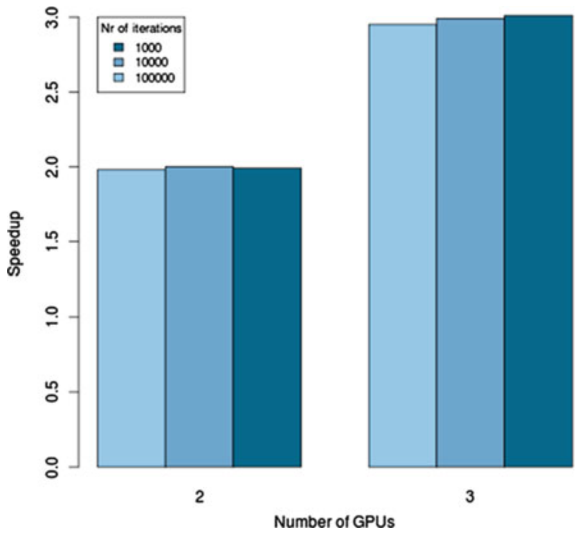


**Fig. 3** Speedups for 2 and 3 GPUs. In function of iteration's number speedup for 2 GPUs is almost constant and for 3 GPUs it slightly increases

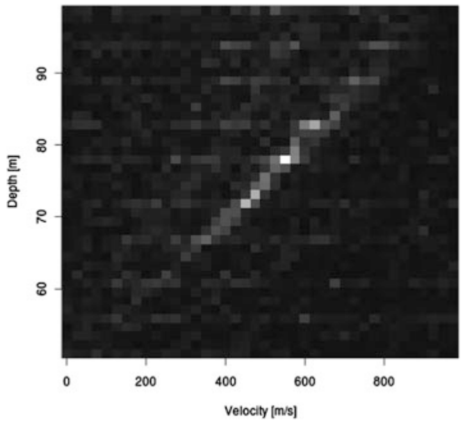


**Fig. 4** Histogram of velocity clearly shows some of probable values. Obtained distribution is close to normal

14–15 h. To compare time needed by 3 GPU units with use of MPI is about one hour and half. This gives final speedup of more then 9.5 what is very promising.

It is important to mention that tests were done on Nvidia Quadro4 1600 M GPU which is not the newest model and has only 32 cores. That is 32 threads can be run in parallel on single GPU while the not so expensive (about 500$) newest models of graphic cards on the market have hundreds of cores. Additionally the OpenCL Version 1.1 is a new technology. There are still some lacks in Nvidia's implementation but as it is shown by results of our research it is stable and promising GPGPU alternative. Linearity of results can be pointed as prove. Lack of this implementation is that it does not allow parallel computations on CPU and GPU in the same time what could increase speedups.

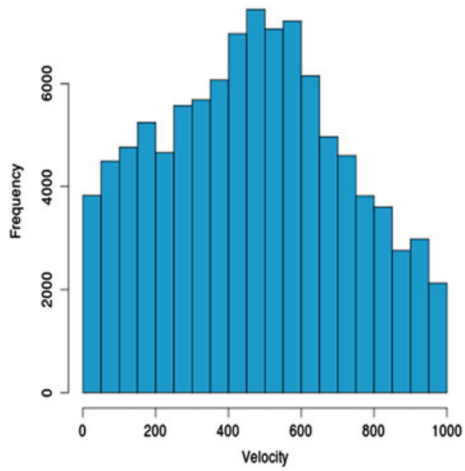


**Fig. 5** 2D histogram showing number of accepted results. Brightest dots show the most probable parameters

Focusing on numerical results, proposed implementation results were exactly as it what was expected. 1D histogram (Fig. 4) estimates velocity of "survey" model's second layer very well. Moreover, on the 2D histogram (Fig. 5) we can point parameters which are close to the real one (80 m, 500 m/s). But these are not single values and they are not exact. That is because of inverse problems nature. That can be many various parameters for which generated model (waveform in our case) is the same or close to the real one. For example high velocity and low thickness of the second layer can generate very similar waveform as low velocity and high thickness model.

## 7 Summary

Parallelization of waveform inversion problem with use of standards such as MPI and OpenCL in connection with modern GPU can be applicable and gives reliable results. Moreover, this solution is relatively cheap and easy to implement. That should be emphasized that this solution will become more applicable, efficient and accessible in the future because OpenCL is still in development phase. Obtained inversion results are promising and the problem of waveform inversion in distributed environment with use of OpenCL should be further investigated and tested.

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# The Analysis of the Efficiency of Parallelization of Existing Serial Code on the Basis of Seismic Migration

**K. Oleszko and T. Danek**

**Abstract** Seismic migration is the most important procedure in hydrocarbons prospecting and is aimed to correct reconstruction of underground structure. It is one of the most complicated and time−consuming task of whole seismic processing chain. Many types of seismic migration algorithms were created and implemented in both commercial and free software. One of the most important of free and open seismic procedure packages is "Seismic Un*x". Many possible solutions of migration problems are available in this widely used system, unfortunately most of them were written as a serial codes. Authors focused on one of the serial migration code−time–wavenumber (T-K) domain migration for common–midpoint stacked data−and made an attempt of parallelization of existing code.

## 1 Introduction

Seismic data processing is a very complicated process composed of many procedures. Each data portion, almost always needs different sequence of processing procedures which are compound in exact way to give best possible results. One of these procedures is a seismic migration. Through many years scientists created many types of seismic migration algorithms. In this variety, algorithms migrating seismic data in different domains both before and after stack can be found [1]. For example: finite difference depth migration, Fourier finite difference depth migration, migration by phase shift with turning rays, Gazdag's phase shift plus

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interpolation depth migration, split−step depth migration, Kirchhoff depth migration of 2D postack/prestack data etc. All of listed above algorithms are implemented in popular SU (Seismic Un*x) system [2] but most of them were written as serial codes. The algorithm which was selected for tests was *the time—wavenumber (T-K) domain migration for common-midpoint stacked data*. This method was created by D. Hale professor of Exploration Geophysics Center for Wave Phenomena (CWP), Colorado School of Mines. Central computations used in T-K domain migration are based on wavenumbers vector. This kind of approach seems to be natural for parallel environment.

## 2 Code Parallelization

Traditionally, computer programs are written to be executed on single processor (CPU) or single core, where problem is divided into small single instructions. All the instructions are executed one after another. Parallel computing, simply, is the usage of multiple computing units, capable to work cooperatively, solving computational problem. In parallel environment general problem is divided into discrete parts executed simultaneously at the same time on different processors [3]. Serial computers technology is slowly going to the end of its possibilities. Speed of light limits transmission speed of data through hardware. Also miniaturization is not boundless. Number of transistors placed on a chip is limited by technology. Economically, it is more expensive to make single processor faster than use more together connected processors to achieve same performance.

It is widely known that parallelization gives many new performance and economic opportunities in case of analyzed problem of seismic migration [4, 5] and in general [5]. Usage of more resources may shorten time of execution with cost savings. Machines used for parallel systems can be built from cheap, long series, common hardware which is inexpensive in maintenance. Concurrency, where multiple tasks can be processed simultaneously at the same time, together with access almost unlimited amount of memory and computing resources, gives possibilities unreachable never before. Such systems provide tools for solving much bigger and more complex problems than could ever be solved on single CPU machine, which is great advantage of parallel computing over serial methods.

Serial implementation of migration procedures in SU system limits its possibilities. It is especially clear in case of full scale seismic investigations [5]. Evolutionary parallelization of existing serial code and creation of new parallel code seem to be the only possible way of progress for this long life and meritorious project.

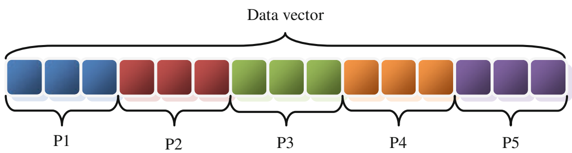


**Fig. 1** Straight decomposition. P1–P5 are processes to which are assigned new vector parts

# 3 Implementation

## *3.1 Hardware Specification*

The project programs were tested in two types of environment. First type was a PC cluster with 1 Gbit Ethernet, second was IBM Blade cluster.

The PC cluster was build from 30 PC nodes and master node. Each node contained Pentium IV 2.8 GHz processor with hyper threading technology and 1 GB RAM. Master node was compound of Pentium IV 3.2 GHz processor with hyper threading technology and 2 GB RAM. Both, work nodes and master nodes have installed Linux systems. Single node of the IBM Blade HS21 was build from 2× Quad-Core Intel Xeon 2.0 GHz processor and 16 GB RAM.

## *3.2 Data Decomposition*

Generally, data were decomposed in two ways, straight and cyclic. T-K domain migration algorithm is based on computation over wavenumbers stored in a vector. Thus, decomposition was restricted by algorithm specification.

Straight decomposition algorithm is relatively simple. Data vector is split into parts. Number of the parts is equal to number of processes in each test. Size of each part is number of processes dependent. Not always processes receive parts of the same size. Sizes are restricted by length of the data vector and number of processes. Firstly, data vector is divided by number of processes. If after division, there are left some elements of base vector (maximum is: number of processes minus one), each left element, in turn, is add to already created parts of the vector. Straight decomposition is shown on Fig. 1.

Cyclic decomposition algorithm was similar but more complex than the straight algorithm. Namely, the base vector was divided into parts. Number of parts was equal to number of processes. Sizes were not always equals as in the straight algorithm. Division proceeded in a loop over vector elements, starting from the first element. First element was assign to the group which was sent to the first process, second element to the second group and so on. When number of groups reaches number of processes the process started from the beginning. Cyclic decomposition is shown on Fig. 2. In both analyzed decompositions were used two types of communication provided by MPI standard: group and point-to-point communication.

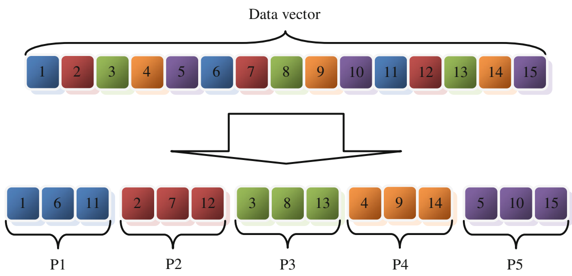


**Fig. 2** Cyclic decomposition. P1–P5 are processes to which are assigned new vector parts

## 4 Numerical Experiment

Generally, tests were run in four different types of configuration:

- Straight decomposition and group communication
- Straight decomposition and point-to-point communication
- Cyclic decomposition and group communication
- Cyclic decomposition and point-to-point communication.

For the tests synthetic data files were created. Data size contained in files was dependent on number of receivers in assumed models. Nineteen data files were created. Number of receivers varied from 100 to 1,000 with 100 step and from 2,000 to 10,000 with 1,000 step. The tests were run on different number of processors. Serial program was run on single processor. Parallel program execution was started from two processors and number of CPU's was successively increased by one to number of twelve. Each test contained single data file was repeated ten times on given number of processors. From ten repetitions was taken average result which was used for further considerations. All the tests were run in both types of environments: PC cluster and IBM Blade cluster. Four types of algorithms configuration multiple by nineteen data files proceeded ten times in two types of environments on twelve different number of processors gives 18240 tests.

## 5 Selected Results and Discussion

In the first approach tests were run in two configurations with only one type of data decomposition:

- Straight decomposition and group communication
- Straight decomposition and point-to-point communication.

After first tests and analysis there came out first problem, namely, the data used for tests were irregular. Always in each test there was one process, which was the slowest one because of data portion received for computations. There was assumption that in some parts of computed data vector was more complicated data

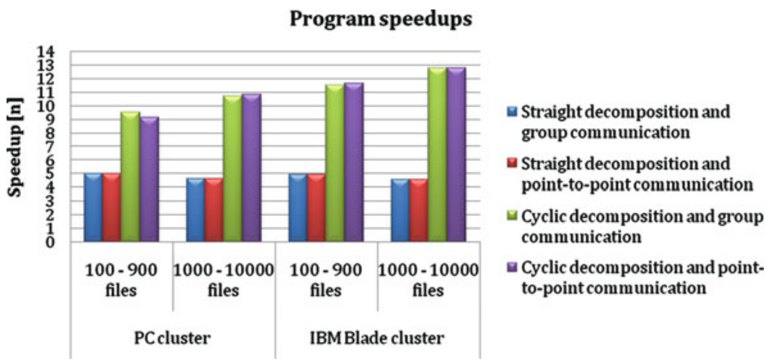


**Fig. 3** Twelve processes program speedups for all the test types

than in other its parts. Thus from that reason cyclic decomposition algorithm were created for more equal data division. Then two more test cases were analyzed:

- Cyclic decomposition and group communication
- Cyclic decomposition and point-to-point communication.

In following discussion big files results for max number of processes are presented, compared and discussed. Reason of that action is simple: obtained speedups were more or less linear, thus results for six or twelve or different number of processes in general comparison is very similar. Moreover, in real projects big data files are used, thus big files results are more instructive. Also, both big and small files have very similar results. One difference from principle are results for very small files for PC cluster environment, where some irregular execution times were recorded. The main reason of those irregularities could be very small execution time, which may be easily disturbed by operating system scheduled maintain actions.

Figure 3 shows general program speedups of all the test configurations for twelve processes. It can be easily noticed that for both environments, PC cluster and IBM Blade cluster best speedups were achieved by cyclic decomposition algorithm. Some of best results were achieved by group and other by point-to-point communication, thus communication types seem to be equal in efficiency. PC cluster speedup values are bit smaller than IBM Blade cluster values. It can be easily explained. PC cluster was slowed down by communication which is natural for that kind of environment. The other factors were: efficiency of data reading/writing and general CPU and other hardware speed (Figs. 5 and 6). Environments like IBM Blade cluster, provides best efficiency without communication or data traveling time lost. Speedup value achieved for big data files was almost 12.8. It means that the speedup is more than linear.

On Fig. 4 computations speedups which were a little bit better than general program speedups are presented. It is caused by non computational program

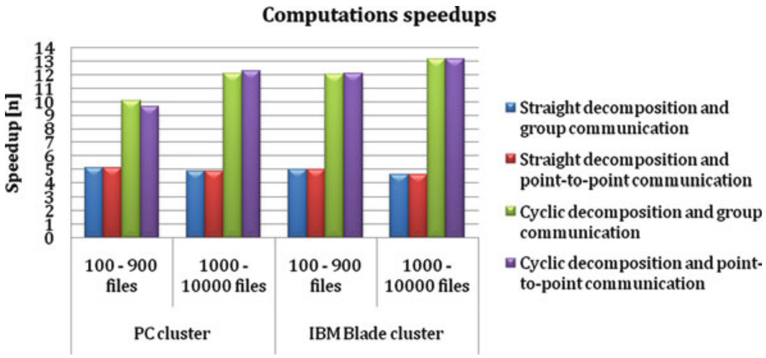


**Fig. 4** Twelve processes computations speedups for all the test types

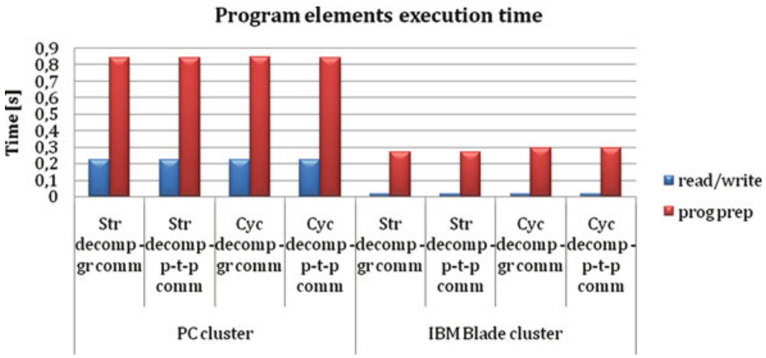


**Fig. 5** Twelve processes computations speedups for all the test types

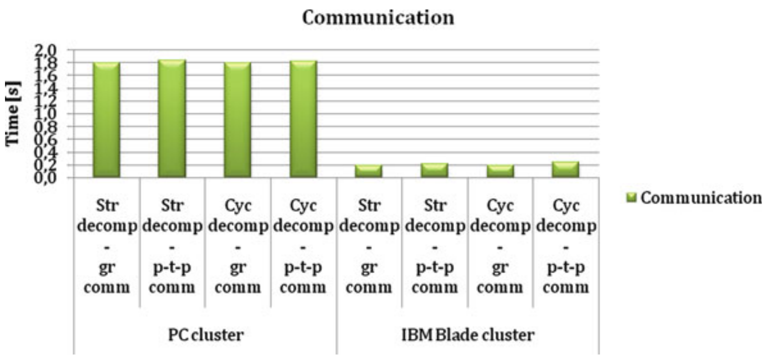


**Fig. 6** Twelve processes communication time for all the test types

elements which must be performed for successful program execution. Of course execution of these elements take some time, thus computational speedups values are better than general program speedups values.

Figure 5 shows program elements execution time of the entire test configuration for twelve processes. It is clearly noticeable that both program preparation time and reading/writing time are greater for PC cluster which is strictly connected with environment specification.

Figure 6 shows twelve processes communication time for all test configuration types. It can be noticed that PC cluster with characteristic environment specification achieve much bigger communication time values than IBM Blade cluster.

## 6 Summary

The problem of parallelization of selected migration procedure which is a part of widely used seismic processing software was presented in this paper. The efficiency of parallel solutions was the main scope of experimental tests. Obtained speedup results proofs, that even in case of old, complicated and not very well documented code, well planed and careful parallelization can be successful, and brings new opportunities.

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# A Cluster Analysis for Determining the Effects of Codes of Conduct in the Business Administration

**David López-Jiménez, Salvador Bueno and M. Dolores Gallego**

**Abstract** In recent years, the impact that e-commerce has had on the economy has motivated many organizations to adopt codes of conduct. Considering the current wide-spreading of codes of conduct, we aim to analyze the effects that adhering to them have in different areas of firm management as synergy generators that are advantageous to the company. To achieve this, we are going to apply cluster analysis techniques, in combination with ANOVA and determinant analysis to a sample of companies that adhere to the code of conduct. Cluster analysis reveals that there are five significant clusters. Each cluster can be interpreted as different levels of perceptions about the effects of the codes of conduct in company management.

## 1 Introduction

In recent years, the impact that E-Commerce has had on the economy has motivated many organizations to adopt codes of conduct. Likewise, the interest that a good part of companies have in improving their relationships with their clients has favored the development of structures that generate trust in the consumer and/or user. With this in mind, the companies that adhere to a conduct of trust show the corresponding seal in a visible place in their Web Page [1, 2].

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Considering the current wide-spreading of codes of conduct, we aim to analyze the effects that adhering to them have in different areas of firm management as synergy generators that are advantageous to the company. This can be a better strategic definition, an improvement in sales or of the corporative image. Similarly, we mean to localize groups of companies that maintain the same position or business behavior towards the adhering to codes of conduct, with a view to observing if companies have the same motivations when doing so in E-Commerce.

To achieve this, we are going to apply cluster analysis techniques, in combination with ANOVA and determinant analysis to a sample of companies that adhere to the code of conduct. The objective is twofold. Firstly, to attain the number of groups that has a well-differentiated behavior amongst them towards the codes of conduct from a sample of companies that adhere to them. Secondly, to determine the perceptions of these groups of companies towards four variables related to the main effects that the codes of conduct cause in company management.

A brief background on codes of conduct is presented in Sect. 2. In addition, the research methodology and the data analysis are analyzed in the successive sections (Sects. 3 and 4). Lastly, conclusions are suggested (Sect. 5).

## 2 Background

The convenience of publicly showing that a company is adhering to or is compromised with a specific code of conduct determines that it is necessary to work out a distinctive sign that serves to identify or delimit the business collective susceptible of showing it in their Web Pages [3–5].

Such signs are designed, and later exhibited, with the aim of causing certain effects in the receiver's beliefs, behaviors and attitudes. The function of this distinctive sign contributes guarantee or quality signs, as the consumers perceive that the business person is meeting the quality standards specified in the code of conduct endorsed [6–8]. The entity in charge of the system of self-regulation in matters of E-Commerce thus guarantees that the activities carried out by the business figure adhered to are fulfilled, as well as the prevailing norm in matters of E-Commerce [9].

Therefore, the reason of the code of conduct is to serve as a distinctive feature of trust in such a way that the consumers or users who identify their presence in a specific Web Site will be able to have enough elements of judgment to not distrust the company that has signed the seal in question [10–18].

Some research clearly shows that the systems that promote trust in matters of E-Commerce are generally efficient at increasing sales [2, 19, 20]. Authors such as [21] or [22] state that the use of quality seals (accrediting the adherence to a code of conduct) is, from the commercial point of view, the best strategy that can help the growth of small companies and business entities emerging in the digital economy area.

**Table 1** Variables

| Variables | Description |
|---|---|
| 1 | Adhering to the code of conduct has increased visits to their Web Site |
| 2 | Adhering to the code has increased the attracting of new clients |
| 3 | Adhering to the code has improved their corporative image |
| 4 | Adhering to the code has increased Internet sales |

To sum up, trust or quality seals incorporated into the Web Sites allow consumers to opt between those who have a public compromise with the best business practices and those who lack such a compromise [23]. Only the former offer a bonus or added value to the product or service commercialized.

## 3 Research Methodology

The aim of this study has been to get to know the opinion of the majority of service providers of the information society that, carrying out E-Commerce B2C, currently adhere to some of the systems of self-regulation in the matter of E-Commerce in Spain. It is worth highlighting that there is no official list of companies who adhere to a code of conduct. This is why we have been obliged to resort to Web Sites dedicated to defining self-regulation systems, such as Agace, Confianza Online or Iqua. These show a list of adherent companies.

With this information we have identified a total of 130 service provider companies who are affiliated to some code of conduct.127 of these companies make up our study. The three remaining companies did not wish to take part. These organizations are from different industries, such as consultant, electrical, technological and manufacturing.

We designed a questionnaire to obtain the data. This questionnaire was validated by five professional experts in the matter from companies promoting codes of conduct and two researchers who have published about codes of conduct in journals of renowned prestige.

Once the questionnaire had been validated, we carried out the personal interviews of information society service providers. The respondents in these interviews were mostly those in charge of Information Systems and, when this was not possible, the person in the company in charge of Marketing. The interview period was from the second half of 2008 to the first quarter of 2009.

The variables used are showed in the Table 1. A three point Likert-type scale was used in the questionnaire from (1) “strongly disagree” to (3) “strongly agree”.

The authors have applied multivariate analysis, essentially cluster analysis, for data analysis. Cluster analysis is designed to detect hidden “groups” or “clusters” in a set of objects which are described by numerical linguistic or structural data such that the members of each cluster behave similarly to each other [24]. This analysis is frequently used in Information Systems studies as an analytical tool

[25–27] due to it allowing the containing of the cases analyzed based on the identification of a behavior tendency or a similar characteristic. Also, the authors have considered ANOVA and discriminant analysis (also known as discriminant function analysis) as the complementary techniques to the cluster analysis for assuring the significance of the groups reached. Discriminant analysis is a descriptive and classificatory technique to (1) describe characteristics that are specific to distinct groups and (2) classify cases into pre-existing groups based on similarities between that case and the other cases belonging to the groups [28].

# 4 Data Analysis

Based on the research methodology, we applied, first, the hierarchical cluster analysis determined for defining the suitable numbers of clusters, second, the ANOVA analysis for observing significant differences among clusters, third, the discriminant analysis for confirming the correct alternative of the numbers of clusters, and, finally, the k-means cluster analysis to define the cluster composition.

## *4.1 Determination of the Suitable Number of Clusters*

Hierarchical classifications are broadly used in applications in order to get a stratified structure of classes at various heterogeneity levels and to visualize the mutual similarities between classes [24]. The hierarchical cluster analysis is used to determine the suitable number of clusters that the researchers finally considered in the study. Of all the possible applicable algorithms, Ward's method was selected [29, 30]. In general, Ward's method is the most successful in finding the correct classification [29].

Hierarchical cluster analysis usually produces a dendrogram, or other type of tree diagrams, as a final output. Each association level of the dendrogram represents a partitioning of the data set into a specific number of clusters [31]. In order to determine the number of suitable clusters, the authors considered the dendrogram obtained from the application of the hierarchical cluster analysis [32].

This technique completes the analysis by applying a hierarchical analysis with property clusters [29] to support this decision making. This allows for (1) the specification of the number of clusters, and also (2) the comparing of the mean values that each one of the analysis variables reaches in the situations.

The results identify the alternatives with five clusters as being more suitable. In spite of this affirmation, this method does not allow the obtaining of the number of clusters with a suitable certainty. So, in order to confirm the suitable alternative, the authors next apply ANOVA and discriminant analysis.

**Table 2** Anova Analysis

| Variables | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Between groups (Combined) | 14.561 | 4 | 3.640 | 14.284 | 0.000 |
| | Within groups | 31.092 | 122 | 0.255 | | |
| | Total | 45.654 | 126 | | | |
| 2 | Between groups (Combined) | 16.848 | 4 | 4.212 | 21.119 | 0.000 |
| | Within groups | 24.333 | 122 | 0.199 | | |
| | Total | 41.181 | 126 | | | |
| 3 | Between groups (Combined) | 34.770 | 4 | 8.692 | 31.481 | 0.000 |
| | Within groups | 33.687 | 122 | 0.276 | | |
| | Total | 68.457 | 126 | | | |
| 4 | Between groups (Combined) | 9.322 | 4 | 2.330 | 35.957 | 0.000 |
| | Within groups | 7.907 | 122 | 0.065 | | |
| | Total | 17.228 | 126 | | | |

### 4.2 Significant Differences Among Clusters

ANOVA results indicating group differences in single variables and factor analysis results indicating underlying factors among sets of variables are additional kinds of empirical evidence that can be consulted in selecting discriminator variables [28]. The authors applied ANOVA analysis in order to observe the presence of any significant differences among clusters [29, 30]. This analysis tests (Table 2) the differences of the mean values that the variables take in each one of the alternatives [33]. With this objective, the F statistical is used at a critical level of 0.05 ($p < 0.05$) to verify that all the variables included in the analysis take different values for each one of the five groups formed. The F statistic comprises the ratio of the variance between groups and the variance within groups as follows: When the source of variance between groups (reflecting the strength of the treatment) is larger than the source of the variance within groups (reflecting individual variability), then the F value increases and approaches statistical significance [34].

ANOVA analysis shows that all the items are significant for $p < 0.05$, and, thus, these results confirm the correct item selection process. In order to assure the appropriateness of this alternative with five clusters, the authors applied a discriminant analysis whose development and results are shown in the following section.

### 4.3 Correct Alternatives

One of the objectives of discriminant analysis is to determine the discriminant functions, which in turn define, explain and interpret the differences among the groups [29, 30]. However, before obtaining the estimation of these functions, it will be necessary to verify that the variables considered in this study are

**Table 3** Discriminant analysis: Wilk's lambda

| Step | Number of Variables | Lambda | df1 | df2 | df3 | Statistic | df1 | df2 | Sig. | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.459 | 1 | 4 | 122 | 35.957 | 4 | 122.000 | 0.000 | Exact |
| 2 | 2 | 0.228 | 2 | 4 | 122 | 33.110 | 8 | 242.000 | 0.000 | F-value |
| 3 | 3 | 0.154 | 3 | 4 | 122 | 27.194 | 12 | 317.782 | 0.000 | Approximate |
| 4 | 4 | 0.136 | 4 | 4 | 122 | 20.983 | 16 | 364.189 | 0.000 | F-value |

independent (which is why Wilks' lambda has been applied). Wilks' lambda is an inverse measure of the importance of the functions [28]. Values close to 1 indicate that almost all of the variability in the discriminator variables is due to within-group differences (differences between cases in each group). Values close to 0 indicate that almost all of the variability in the discriminator variables is due to group differences.

Also, with this in mind, an F statistical associated with Wilks' lambda at a 0.05 level has been constructed (Table 3). As can be observed, the variables do not surpass this level, affirming their independence and discriminatory capacity.

Finally, it is critical to cross-validate the results of a discriminant analysis. The cross validation analysis shows that 93.9 % of the cases have been classified correctly and allows the affirming of the high explanatory power of a model with five clusters. The next section exposes the k-means cluster analysis, through which the characteristics of the five clusters defined will be obtained.

## 4.4 Cluster Composition

The objective of the k-means cluster analysis is to determine which companies will comprise each one of the clusters [29, 30]. k-Means is a typical clustering algorithm. It is attractive in practice, because it is simple and it is generally very fast. It partitions the input dataset into k clusters [35], k being the exact number of clusters pre-assigned by the researchers. This analysis obtained values (centroid) that take the final variables for each one of the clusters. These values will help to determine the perception of the effects of the codes of conduct in each cluster (Table 4).

## 4.5 Discussion and Findings

Cluster analysis reveals that there are five significant clusters (Table 4). Each cluster can be interpreted as different levels of perceptions about the effects of the codes of conduct in company management.

As a first result, we highlight how perception, represented by cluster 3, is the one most followed by the sample of companies analyzed: 37.01 %. The companies

**Table 4** Cluster composition

| Variables | Cluster | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1 | 1 | 1 | 2 | 2 | 1 |
| 2 | 2 | 1 | 2 | 2 | 1 |
| 3 | 2 | 2 | 1 | 3 | 2 |
| 4 | 3 | 2 | 3 | 3 | 3 |
| Number of cases | 13 | 7 | 47 | 30 | 30 |
| % | 10.24 | 5.51 | 37.01 | 23.62 | 23.62 |

that make up this cluster, as also occurs in the rest of the clusters with the exception of number 2, consider that adhering to codes of conduct has increased Internet sales. On the other hand, they are not companies that do not perceive that the codes of conduct improve the corporative image, nor do they have a clear perception of how the codes of conduct have increased web site visits and have made it possible to attract new clients.

The second result that we highlight is how companies that comprise cluster 4 are those that have a more favorable perception in relation to the effects of codes of conduct on the four variables analyzed. They have, then, a very clear perception that adhering to codes of conduct has improved their corporative image and a moderately positive perception that these have increased visits to their Web Site and the attracting of new clients. It is worth remembering that this group makes up 23.62 % of the total.

Thirdly, we have been able to observe that few companies do not perceive, or do so only moderately, the effects of adhering to codes of conduct analyzed. We are here referring to cluster 2 (5.51 % of the total).

On the other hand, we observe how clusters 1 and 5 have the same perception in all the variables with the exception of the capacity of attracting new clients, where both groups consider that adhering to codes of conduct have not increased the visits to the company's Web Site.

It is worth highlighting how variable 1 has been the one that has obtained the lowest perception in the majority of clusters. Variable 4, however, is the one that has the greatest perception in all the clusters.

## 5 Conclusions

Codes of conduct have a great potential to improve the management capacities of a company with regards to E-Commerce, especially B2C. A first contribution of this article has thus been to attain evidence in this sense. We have been able to check how organizations generally positively perceive the impact of codes of conduct in the improvement of specific aspects related to their activities. This conclusion is amply significant as the companies analyzed cover 97.69 % of the study's sample. This is a percentage that very few studies have been able to achieve.

Another relevant contribution of the article has been to attain a classification of companies with respect to their perceptions about the effects of codes of conducts on specific variables of company management. This classification has allowed us to determine how important codes of conduct are for companies, as well as to get to know the true motivations that lead these organizations to adhere to therm. We have therefore been able to observe with clarity how organizations consider that they have increased their Internet sales.

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# Playing with Numbers: Development Issues and Evaluation Results of a Computer Game for Primary School Students

**Chris T. Panagiotakopoulos, M. E. Sarris and E. G. Koleza**

**Abstract** Development and evaluation issues of a computer game, named "PwN", are presented in this study. PwN application aims to enhance students' mathematical thinking, as well as to examine their problem solving strategies when confronted with simple mathematical tasks such as addition and multiplication. The application operates with random numbers that fall in a "box". Individual scores are calculated when the appropriate computation is achieved. PwN development was based on the linear model using prototypes with continuous formative evaluation. Summative evaluation results indicate that the application improved the children's skills both in addition and multiplication tasks.

## 1 Introduction

In recent years there is a growing bulk of research evidence arguing for the value of ICT and multimedia applications embedded in mainstream teaching practice [1, 2]. Relevant studies provide comprehensive analysis on the use of new technologies in typical classroom settings [3, 4]. The arguments for the implementation of ITC are framed in terms of motivational aspects, skill development and knowledge acquisition [5–7].

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Students' motivation and attitude towards learning is a determinant factor of both performance and knowledge acquisition. In modern educational contexts however, teachers report a dissonance between formal education and digital learning environments that students experience outside school [8–10]. Yet, the disengagement and lukewarm interest in curricular contents that students often exhibit [11] may be tackled by building-up a more interactive framework that incorporates games as an educational tool. Computer games are particularly appealing to children as most of them are regular domestic game players [3, 12]. The notion of using games as a "mediator" in the learning process is not new and originates from Vygotsky's theory. Educational games integrate several pedagogical approaches, such as learning by doing, goal-oriented learning and constructivist learning [5]. Further support for the positive effect of educational computer games can be drawn from numerous studies [3], which hold the view that such games may enhance students' performance in mathematics, science etc.

The role of primary education in developing students' mathematical skills is important since this is a transitional phase for the growth of students' mathematical thinking [13]. In general, these skills are considered to be crucial not only for academic success but also for daily living [14]. Multiplication and addition tasks are often considered by students as stumbling blocks in their mathematical progress. In a non-computer assisted teaching method, children try to reinforce their multiplication skills using recitation techniques or complete practical set of exercises [15]. Such traditional methods lack immediate feedback and reduce pupils' interest in learning instruction [16].

The use of computer games, as alternatives to the afore mentioned practices, is rather appealing [17–21]. An interesting buzzword in educational research using ICTs is *edutainment*, which refers to the convergence of education and entertainment. The rationale behind this form of entertainment is to exploit technology for developing interactive interfaces that encompass educational objectives into a digital learning environment [1].

In this paper we describe the operation of an educational computer game named "Playing with Numbers" (PwN). We also analyse the operation of the application, describe its structure, illustrate the parameters affecting its operation and present some initial results of its final evaluation. The sample consisted of students from primary education and the results have been found very encouraging regarding the improvement of their computational skills.

## 2 PwN Application: Identification

### *2.1 Description*

The PwN application was developed during 2010 in the Computers and Educational Technology Laboratory of the Department of Primary Education—University of Patras (www.cetl.elemedu.upatras.gr).

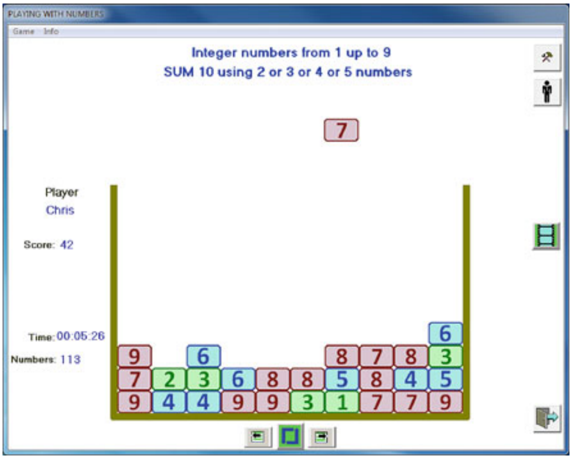


**Fig. 1** An actual screenshot of PwN regarding the operation of addition

The target group of the developed application is primary education students. The application works using square blocks of numbers instead of multi-shaped blocks. Random numbers continuously fall from random positions from the top of a window, accumulating in a "box". During their fall the user can move them only to the right or left.

When the user manages to create predefined sums (or products) from the falling numbers (which act either as addends or factors) vertically at one of the ten stacks, the score raises. The numbers then disappear and the space they occupied is freed. Figure 1 shows a screenshot of the developed application, featuring the game in the numerical operation of addition.

While designing and developing this interface the effort was put on making it as simple as possible, using pale colours and avoiding any misleading features. The aim was to keep the focus of the user on the specific task that has to be performed.

The "box" where the numbers accumulate, while they fall from the top of the window, is depicted in the middle of Fig. 1. Over the "box", there exist labels showing the bounds of the falling numbers as well as the sum that has to be achieved. The player's name, current score, elapsed time and total numbers used, are provided on the left side of the screen. The right side of the screen hosts four buttons which are used to configure/customise the user settings, enter username, start the game and exit the game. Under the "box", there exist three buttons. The left and the right ones are used to horizontally relocate the falling numbers, while the middle one is used for pausing/restarting the game. Although the horizontal relocation of the falling numbers may be also performed through the arrow buttons of the keyboard, including these two buttons was considered necessary for being able to operate the application with a smartboard.

The application is susceptible of configuration regarding various groups of numbers (e.g. positive or negative numbers) and operations. The only limitation is to integrate the appropriate pictures of the numbers into the application.

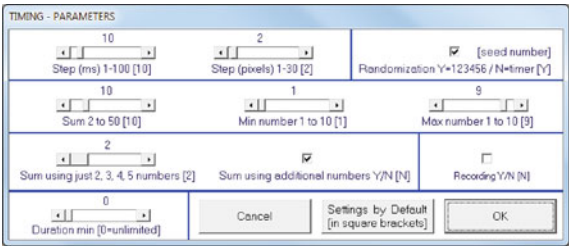


**Fig. 2** Configuration panel of the application's operational features in the numerical operation of addition

In its current form, the pilot application model used for this research and tested in practice, consists of three parts:

(a) Addition of integers with addends' value ranging from 1 to 10 and amount from 2 to 5, giving a total sum from 2 to 50.
(b) Addition of decimals with addends' value ranging from 0.1 to 1.0 and amount from 2 to 5, giving a total sum from 0.2 to 5.
(c) Multiplication of integers with factors' value ranging from 1 to 10 and amount from 2 to 5, giving a total product from 1 to 100,000.

### 2.1.1 Operational Features

The administrator is able to configure/customise the application's operational features through an appropriate panel. Figure 2 demonstrates this window, which includes all the timing settings, random number emergence and other features regarding the execution of the numerical operation of addition.

Through the configuration panel the following features can be modified:

(1) The speed with which the numbers fall. This is achieved through two parameters: (a) movement step, and (b) elapsed time between movement steps. Both parameters are determined by the administrator.
(2) The sequence of random numbers through seed number, may remain the same (or not) for different computers. This was considered necessary for research purposes. When multiple users operate with the same sequence is possible to consider several other factors that might affect students' performance.
(3) The requested sum or product that has to be achieved.
(4) The numbers' range (from smallest to biggest).
(5) The amount of addends or factors that will be used to achieve the requested sum or product.
(6) Whether the amount of addends or factors that can be used will be exactly predefined or extended (up to 5).
(7) Whether zero, in the multiplication tasks, will be included in the sequence of the falling numbers and how often.
(8) Whether the full set of user's moves or only basic information regarding user's performance will be recorded.

(9) The duration time (which can be unlimited or predefined, e.g. 15 min) varies according to research needs.

In its current form, the application does not include a time-dependent accelerating feature, unlike traditional computer games. Our desire was to let the user have an invariable period of time (even a small one) to think, each time a new number was falling into the "box".

Access to the application, from the user's perspective, is personalised. As mentioned above, each time the user manages to place a group of numbers at a vertical stack achieving the required sum or product, the score raises. The successful effort is accompanied by a characteristic sound. Meanwhile, with a view to raising competitiveness and motivation, a window presents the highest score, the username that achieves it as well as the elapsed time for it.

The administrator has the capability to activate a user action tracer that records all user-computer interaction in detail. A screenshot capturing mechanism is enabled through triggering events. Suchlike events are mouse click, mouse move, keypress etc. that relocate the falling numbers on the stacks.

Additionally, the developed application is designed to record basic data regarding usage information. This allows the researcher to gain access on the complete list of users that have accessed the application regarding their performance, the elapsed time of the completed tasks and the values of the operational features (range of numbers, sums or products etc.). These data may either be simply presented on the screen or exported to a Microsoft Excel file for further statistical analysis.

The combined information (e.g. user-computer interaction records, timing settings, performance scores, problem solving strategies, etc.) gives the opportunity to draw a number of conclusions regarding thought processes (modeling) in mathematical computation tasks.

## *2.2 Design and Development Issues*

The application operates in Microsoft Windows using a typical microcomputer without any special specifications. Its development was based on the linear model with prototype creation [22] and the programming language used is Microsoft Visual Basic 6.0.

The basic programming structure of the application is illustrated in Fig. 3, and some important points which were given particular attention during PwN's design and development are discussed below.

The "box" is designed to fit a total of one hundred numbers—"blocks" (10 numbers at width and 10 at height). The game stops (under normal circumstances) when the "box" is filled with numbers. In the case that 10 numbers are already placed on any given stack and a new number appears on its top, the user has to move the block either to the right or left of the stack. The first and the last stack (on

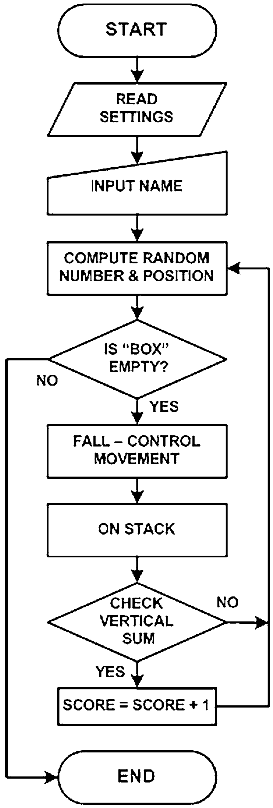


**Fig. 3** The general flowchart of the application (module of addition)

the left and right sides of the "box") are excluded from this operation and the movement is limited to the right or to the left respectively.

The value shown at the picture of each falling number is randomly assigned. For the production of random integer numbers the *RND* function of Visual Basic was used, which creates random numbers from *DownValue* to *UpValue* starting with the command<*RANDOMIZE*>and through the command [23]:

$$\mathrm{x} = \mathrm{Int}((\mathrm{UpValue} - \mathrm{DownValue} + 1) * \mathrm{Rnd}) + \mathrm{DownValue}$$

where:

- x the produced random number,
- Int the integer part,
- UpValue the upper bound and,
- DownValue the lower bound of the group of numbers.

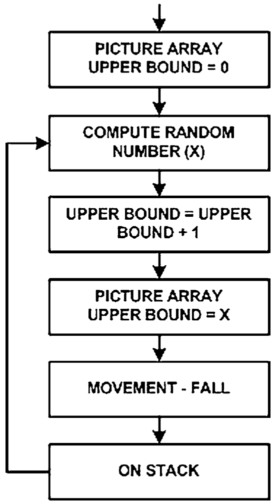


**Fig. 4** The flowchart of the continuous production of pictures subroutine

Using this command to continuously produce random numbers, within a specific range, ensures the long-term normal distribution of numbers within the predefined range [24, 25]. Furthermore, two timers control the speed and time duration parameters, while during the execution time various timers control the rest of the game's features (such as score and amount of used numbers).

The numbers appear randomly at the top of the "box" before the user could be able to move them either left or right. When the falling block is positioned on a stack a subroutine proceeds to performing a continuous micrometric repositioning and position check, in order to overcome any optical problems.

Another issue that had to be taken under consideration during development was the creation and control of the falling blocks. The sequence should essentially be infinitive. The solution to this issue was given through an appropriate subroutine. This subroutine performs, during run time, a dynamic increase in the argument of the simple precision array that holds the block of the randomly produced number (re-dimensioning) [26]. The implemented process is depicted in the flowchart of Fig. 4, in detail.

Finally, it should be mentioned that development was performed through continuous formative evaluation from the members of the research group of the Computers and Educational Technology Laboratory. A small sample of four primary education students was also used, which excluded from the final evaluation. Thus, gradually implementing portions of the predefined requirements produced several prototypes. Each prototype was thoroughly examined for the detection of strong and weak points, until the application was finalised [27].

# 3 Final Evaluation' Results

## 3.1 Methodology

Overall, 30 children attending the fifth grade of elementary school were selected for the study. The children were tested individually in a quiet room within the school setting. One experimenter collected the data in order to control variations in testing. Before the main experimental procedure a pilot test was conducted. Results led to revisions on both software calibration functions and the experimental tasks.

For the needs of this research a desktop personal computer with a microprocessor P4/2.8 GHz/2 GB RAM and a LCD/TFT display 17'' was used. The operating system was Microsoft Windows 7 and the screen resolution 1024 × 768 pixels with a refresh rate of 85 Hz.

A pre-test was employed for assessing children's simple mathematical calculation abilities. Participants were asked to calculate an array of 15 simple addition (of decimal and integer numbers) and multiplications tasks. Visual stimuli were presented on a whiteboard, using a video projector, preceded by a fixation point (1 s) and children were asked to report their results on a separate answer sheet. Stimuli disappeared after 30 s.

The main experimental procedure involved three successive sessions for each experiment (addition of integer and decimal numbers as well as multiplication of integer numbers). Each session was set to last 5 min, and children had to reach the target sums or products as set by the researcher for each experiment. Thus, for the addition of integers participants were asked to achieve a predefined sum of 15, for the addition of decimals the target sum was 1.2 and, finally, for the multiplication task the target product was 18. Total scores were calculated for each participant. The completion of the main experimental procedure was followed by a post test that involved the same set of mathematical tasks used in the pre-test. A three-week interval between pre and post-test evaluation was selected for controlling presumable warm-up effects.

## 3.2 Results

Table 1 presents the mean performance scores for each experimental task across the three testing sessions. It is important to note that scores seem to improve across testing for all tasks. Yet, a minor deviation from the general pattern may be observed in the multiplication data. The multiplication of integers was found to pose some difficulties to children and, as the table illustrates, improvement in scores was only recorded in the last testing session.

Results for all three main experimental tasks were analysed using one-way analysis of variance (ANOVA), repeated-measures design, with *Testing Session*

**Table 1** Mean performance scores across testing points

| Mathematical operation | Testing session 1 | Testing session 2 | Testing session 3 |
|---|---|---|---|
| Addition of integers | 17.87 (3.08)[a] | 20.33 (3.61) | 21.80 (3.47) |
| Addition of decimals | 19.80 (3.93) | 20.33 (3.85) | 23.07 (4.46) |
| Multiplication of integers | 5.67 (2.12) | 5.87 (2.9) | 8.27 (2.82) |

[a] Standard Deviation is given in the parentheses

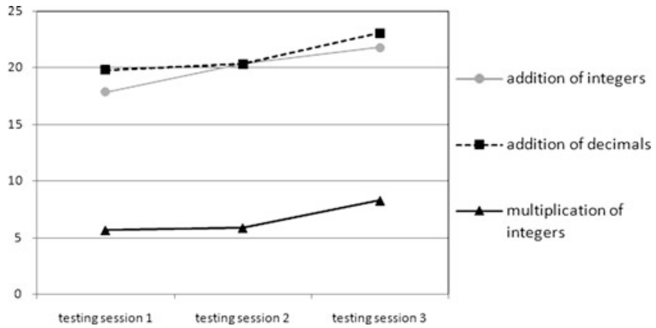


**Fig. 5** Mean performance scores across testing points for each experimental task

as the within-subjects factor. The post hoc multiple comparisons were conducted applying a Bonferroni correction ($p < 0.05$). The data analysis for the addition of integers revealed that there was a significant effect of *Testing Session*: $F_{(2,\ 58)} = 15.7$; $p < 0.001$; $\eta^2 = 0.35$. Post hoc comparisons unveil significant differences between sessions 1 and 2 ($p < 0.05$), as well as between sessions 2 and 3 ($p < 0.001$).

In Fig. 5 is illustrated the mean performance scores across testing points for each experimental task.

The analysis of the addition of decimals, alike the above mentioned results, also revealed a significant effect of *Testing Session*: $F_{(2,\ 58)} = 9.62$; $p < 0.001$; $\eta^2 = 0.25$. Post hoc multiple comparisons revealed significant differences between sessions 1 and 3 ($p < 0.005$), as well as between sessions 2 and 3 ($p < 0.001$). Yet, no statistically significant differences were observed between sessions 1 and 2 ($p > 0.05$). The multiplication of integers, as mentioned before, was found to be more difficult for young students. Despite that fact, the effect of *Testing Session* was still found to be significant [$F_{(2,\ 58)} = 14.86$; $p < 0.001$; $\eta^2 = 0.34$]. The relative scores, though, reached statistical significance only after the completion of two successive sessions. Post hoc comparisons demonstrated significant differences between sessions 1 and 3 ($p < 0.001$), as well as between sessions 2 and 3 ($p < 0.05$). The delaying effect observed in the multiplication performance may be attributed to the fact that the subjects had fewer alternative options at their disposal for reaching the predefined product.

As it is mentioned in the introduction, one of the main objectives of the presented software was to evaluate its potential, if any, in enhancing children's

**Table 2** Mean accuracy scores in the pre and post-test

| Mathematical operation | Pre-test | Post-test |
|---|---|---|
| Addition of integers | 34.22 (15.03)[a] | 37.78 (13.71) |
| Addition of decimals | 19.56 (14.11) | 31.11 (13.71) |
| Multiplication of integers | 16.44 (13.53) | 23.56 (15.44) |

[a] Standard Deviation is given in the parentheses

computational skills. Table 2 illustrates the mean accuracy scores in the pre and post-test assessment.

As Fig. 6 depicts, children achieved higher scores in the post-test evaluation for all three tasks. Mean differences were calculated using separate paired-samples t-test. For both the addition of integers and decimals tasks the analysis revealed significant differences [$t(29) = -2.19$; $p < 0.05$] and [$t(29) = -4.79$; $p < 0.001$], respectively. Similar results were obtained for the multiplication of integers task [$t(29) = -4.86$; $p < 0.001$].

## 4 Discussion

This study reports the development and evaluation of an educational computer game named PwN. Our main focus was to produce an appealing computer game that exploits an interactive interface and puts emphasis on educational objectives.

The application described so far, comprised of three separate modules. Each module addressed a simple mathematical computation task. Thus, addition of integers and decimals, as well as multiplication operations, was under the scope of the interface used. The design of the software allows the integration of a number of different modules. For example, fractions or signed numbers could easily be added with minor modifications in the application's code.

Several programming features were taken into account during the development of the application (e.g. usability, aesthetics, motivational aspects and game data recording). The children participated in this study, despite being novice computer users, did not face any particular usability issues with the specific application. The fact that they could operate PwN using either a mouse or the keyboard's arrow keys was proved to be especially helpful for them as reported by the students. The pale colours, the simplicity of the Graphical User Interface (GUI) and the sound warnings were proven to be especially appealing.

PwN's resemblance to a well-known computer game and the mix of motivational features (e.g. personal performance score and duration time score) had a positive effect on children's attitudes towards mathematical learning instruction. Another important aspect addressed by the application reflects its potential to offer some insights of the cognitive processes and strategies used by schoolchildren in computation tasks.

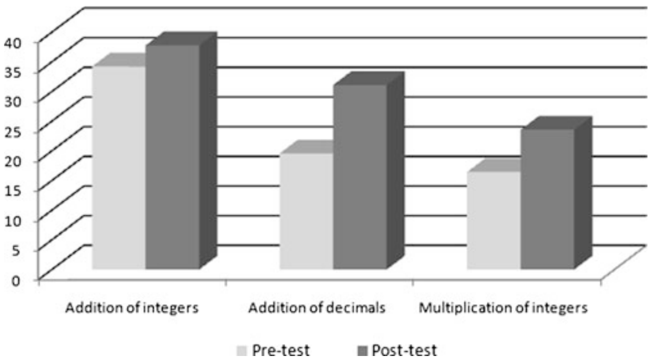


**Fig. 6** Mean performance scores for pre and post-test assessment

For evaluation purposes we examined the performance of thirty primary school children on three sets of simple computational tasks. The assessment comprised of a pre and post-test evaluation of simple addition (both integers and decimals) and multiplication tasks. Between assessments, the participants completed three successive practice sessions. Individual scores for each experimental task were recorded. Data analysis revealed a substantial increase in performance scores for all the trials. It is important to note at this point that the computational gains at the end of session 3 were over 22 % for the addition of integers and over 15 % for the addition of decimals. A profound 46 % difference between the initial and the final tryout was observed in the multiplication condition.

In an effort to further examine the effect of the PwN application in improving children's computational skills, we carried on analysing the pre and post-test data. Results indicate that in the post-test assessment mean accuracy scores were significantly higher than those achieved in the initial testing.

This study reports a preliminary evaluation of the PwN application. Our data support the view that the observed differences may be attributed, at least to some extent, to the effect of the software used.

Even though the focus of this study is the development and evaluation of an educational computer game, its motivational aspects should not be overlooked. Apart from the potential benefits that PwN application may offer in enhancing computational skills, an important issue that should be stressed is the fact that students' motivation was surprisingly higher than expected.

## 5 Conclusions

In this paper the development and evaluation of a computer game, named PwN, aiming to enhance students' mathematical reasoning is reported. The interface comprised of three modules that deal with simple addition and multiplication tasks.

PwN development was based on the linear model using prototypes with continuous formative evaluation.

The administrator can easily adjust the settings enabling the selection of different game conditions and operational functions dictated by the educational objectives to be met.

Data analysis unveiled encouraging results suggesting that using educational games in mainstream teaching practice may be an appealing alternative for effective learning. Results indicate that performance scores were improved significantly in all the experimental procedures. Moreover, an important issue that it should be noted is the fact that students' motivation was surprisingly higher than expected.

Finally, future and further research may focus on strategies applied by users during mathematical computation.

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# Reverse Auctions: How Electronic Auctions Can Aid Governments in Significantly Cutting Their Procurement Spending and Introduce Greater Competition in Public Sector Contracting

**David C. Wyld**

**Abstract** This article examines the pressures affecting procurement practices in the federal government and how reverse auctioning represents a significant change in the way acquisition will be carried out going forward. Specifically, the article describes how a major federal agency has made use of a reverse auction-centered online marketplace to revamp its procurement processes. The researcher analyzed the agency's spending data over the past four fiscal years, finding that the public–private partnership has mirrored results found across the public and private sectors. With the increased competition to be found by tapping into the power of the power of the competitive online marketplace with an ever-expanding network of suppliers, the agency has been able to achieve both significantly less reliance on sole sourced contracts and heightened participation of small and disadvantaged businesses. The agency has also seen significant improvements in its procurement processes and in the ability to better communicate and work with internal customers and suppliers. The implications of this shift are discussed.

## 1 Introduction

### *1.1 The Push for $40 Billion Savings in Federal Procurement*

In mid-September 2010, President Barrack Obama added a great deal of specifics—and specific goals and priorities—to his previously-announced Accountable Government Initiative that seeks to cut operating costs by $40 billion annually in

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FY2011. President Obama has established "reforming contracting" as one of the six primary goals of this effort. Jeff Zients, who is the Federal Chief Performance Officer, has specifically pinpointed competitive bidding as one of the primary ways that federal agencies will strive to achieve this goal, stating: "Agencies identified $19 billion in savings from contracting for FY 2010, and we remain on track to achieve this savings through a combination of program terminations and reductions, new and stronger applications of strategic sourcing, and continued implementation of innovative procurement methods, such as the use of web-based electronic reverse auctions" [1, 2].

Yet, this focus on the role that competitive bidding can—and has—played in changing the way the federal government executes the over $1 trillion in procurement spending for goods and services on an annual basis is not new. In fact a decade ago, former Speaker of the House Newt Gingrich predicted that one day the federal government will be "buying weapons systems via the Internet with an open bidding process that everyone can see" [3]. And back in 2000 as well, this author produced one of the first academic research studies looking at the potential role that reverse auctions could play a pivotal role in saving money, increasing competition, and improving transparency in governmental procurement. In this report, *The Auction Model: How the Public Sector Can Leverage the Power of E-Commerce through Dynamic Pricing*, this author predicted that: "Adopting dynamic pricing concepts and the auction model in some form…may well become the 'norm' in governmental operations" [4].

## 1.2 Reverse Auctions Come to the Forefront

This author was among those at the time who foresaw much of what would transpire over the next decade, as the then hype of the early e-business era (remember the dot-com frenzy?) waned as we would progress through what Gartner has labeled the "hype cycle" of new technologies [5].

In 1999, Stewart Alsop predicted that: "The 'e' in e-business will soon be irrelevant…. In the next wave, in other words, businesses will make "e" such a core part of their business that the difference between "e" and everything else will be nonexistent. Or they won't be businesses anymore" [6]. Thus, what was largely theory and hype in 2000 is becoming actuality in 2010. Indeed, as we are in the maturity stage of the e-business era—the "plateau of profitability" as Gartner would characterize it—we are seeing many of the e-commerce concepts introduced by the new technology triggers of the late 1990's-early 2000's period become mainstream—simply the best way to do business—all business—across both the private and public sectors.

Now, a decade later, after many stops and starts along the way, we are seeing one of these new-old technologies—reverse auctions—take center stage—moving to the forefront of procurement reform efforts at the highest level of the federal government. In Fig. 1 (Forward vs. Reverse Auctions), the difference between forward

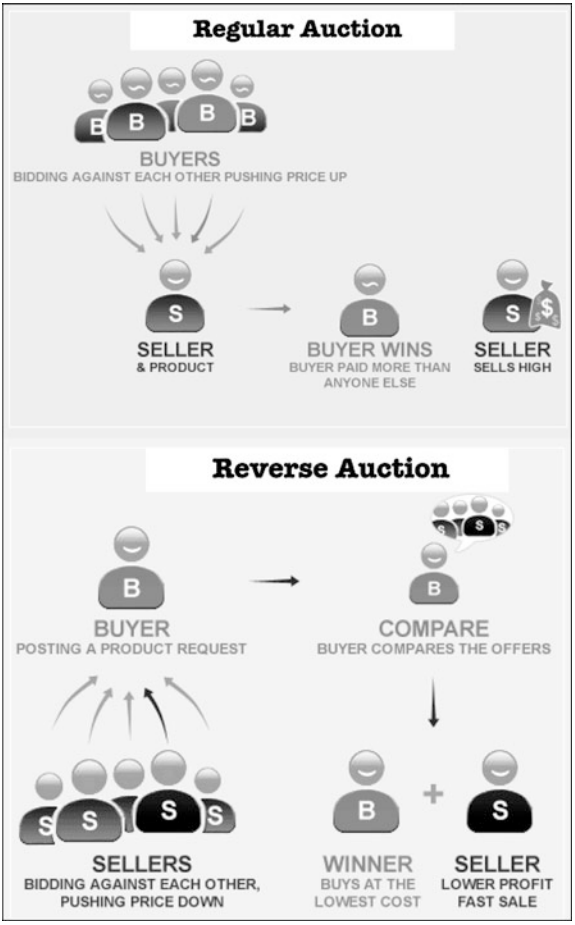
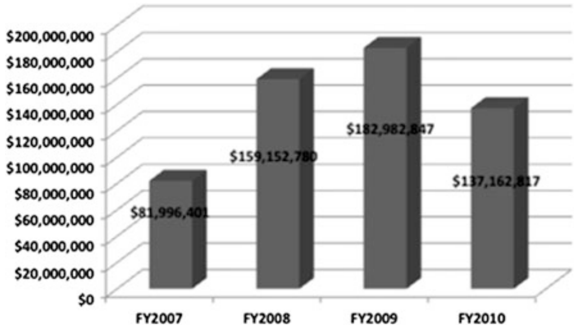



**Fig. 1** Forward versus. reverse auctions

auctions (*used for selling items*) and reverse auctions (*used for procurement*) is proven vehicle through which government agencies can take strategic actions toward saving money, increasing competition, and improving transparency in their procurement operations.

And certainly part of the reason why we are seeing the push for procurement reform and efficiencies is the simple fact that these are certainly difficult times in the public sector world today. Today at all levels, government executives are being challenged each and every day to—as Ashton B. Carter the Under Secretary of Defense for Acquisition, Technology, and Logistics bluntly put it recently—to "do more without more" (Shalal-Esa, 2010, n.p.). Budgets are being tightened, positions are being eliminated (or simply not filled), and yet, across the board, agencies and their personnel are being tasked with bigger and more important missions than ever before.

**Fig. 2** Total annual spend volume




## *1.3 The Present Study*

What level of savings can be achieved through reverse auctioning in federal governmental procurement through the employment of electronic reverse auctions? This article looks to project the level of savings that could be achieved annually based on this switch in acquisition practices. For this purpose, the researcher was afforded access to procurements made by a single sample agency over the four most recent fiscal years for the federal government (2007–2010). The present analysis shows that the target agency has made increasing—and increasingly effective—utilization of reverse auctions over time. Since FY2007, the agency has shifted a major portion of its procurement spend to a competitive bidding environment, administered by a private sector partner. This is changing—in a major way—the agency's overall acquisition strategy and practices. Thus, the agency is a good case study of the level of acquisition savings that can be achieved through increased utilization of reverse auctions in procurement operations.

# 2 Analysis of First Order Savings

## *2.1 Overall Assessment*

Over the past four fiscal years, the growing use of reverse auctions by the agency can be seen in the volume of their procurement dollars that have been shifted to competitive bidding. As can be seen in Fig. 2 (Total Annual Spend Volume), the dollar amount of procurement spending being conducted by the agency via reverse auctioning significantly increased over time. Indeed, the total amount of procurement that the agency has subjected to competitive bidding today stands at over half a billion dollars. As more agency procurements have been shifted to the competitive bidding environment, the savings of taxpayer dollars achieved through the cooperative efforts of the agency and its private sector partner have grown significantly. As can be seen in Fig. 3 (Total Savings Achieved), the annual

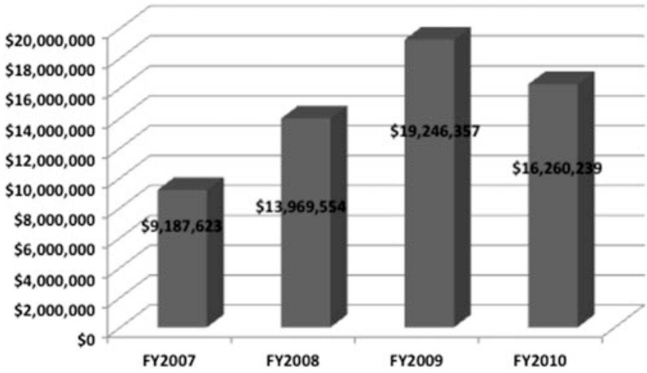
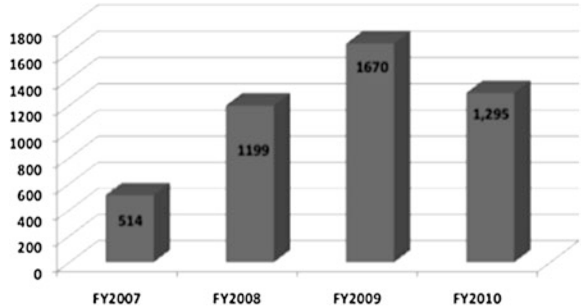



**Fig. 3** Total savings achieved

**Fig. 4** Number of Events




savings achieved through this partnership have already doubled—from over $9 million in FY2007 to in excess of $19 million in FY 2009.

## *2.2 A Look Behind the Savings*

How did the agency's procurement leadership and staff achieve this level of savings? First and foremost, it was a simple matter of mathematics, as with an average cost savings achieved through competitive bidding of 10.31 %, the more of the agency's purchasing spending that is directed through competitive bidding, the higher the savings potential will be. Indeed, as Fig. 4 (Number of Events) shows, the agency's contracting personnel have increasingly made use of reverse auctioning with increasing frequency over the past four years. A review of the four years of procurement data shows that the size of the procurement is not determinative of the potential savings percentage that can be garnered on individual buys. Thus, greater utilization of the reverse auction-based methodology translates into more opportunities to produce savings, regardless of whether it involves procurements for several thousands or several millions of dollars.

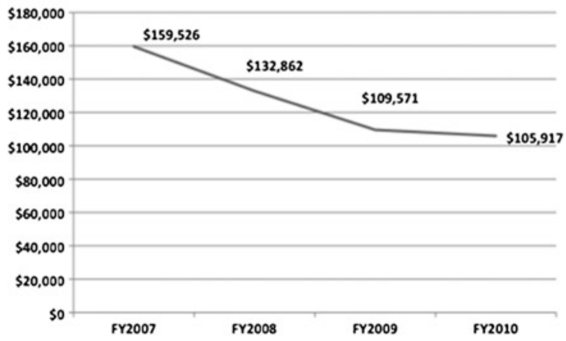



**Fig. 5** Wider utilization means increasing savings for the agency, even while the average dollar volume of events declines

And yet, larger procurements can translate into larger dollar savings. Indeed, the agency's procurement specialists have begun to make use of the online marketplace for some of their agency's largest purchases, making multimillion dollar purchases that have produced multimillion savings. Yet, as Fig. 5 (Wider Utilization Means Increasing Savings for the Agency, Even While the Average Dollar Volume of Events Declines) demonstrates, as utilization of reverse auctioning grew, the average dollar volume for individual purchases declined. You can see that even as the average size of procurements has steadily declined, the total amount of savings for the agency (as was shown in Fig. 3) has grown significantly—surpassing over $55 million dollars to date.

Thus, it is important to remember the simple mathematics of all of this—the more procurements that are competed through the online marketplace among the agency's contracting staff to encompass more and varied dollar amount procurements, the greater the savings will be for the agency, the government as a whole, and most importantly, for the taxpayer.

## *2.3 Analyzing the Internal Auction Metrics on Competition*

When looking at the internal metrics behind the reverse auctions held for the agency, the dynamics of competitive bidding are a major reason behind the top-level cost savings that have been produced by the online marketplace. Looking at the key "internals" for the events held for the agency (shown in Table 1—Reverse Auction Metrics on Agency Buys), one can see that in each successive year, there were—on average—more bidders for each reverse auction and the number of bids submitted. As has been shown in countless academic studies on auctions of all varieties, more competitors and more competition means better pricing. And in this case, the beneficiary will be the taxpayers, as a result of the millions of dollars to be saved through reverse auctions driving down procurement costs (remember, there is an average of 10.31 % savings, based on the multi-year CBP experience).

**Table 1** Reverse auction metrics on agency buys

| Process Metric | FY2007 | FY2008 | FY2009 | FY2010 | Average |
|---|---|---|---|---|---|
| Average Number of Bidders/Event | 3.89 | 4.35 | 4.82 | 3.67 | 4.18 |
| Average Number of Bids/Event | 7.93 | 10.32 | 11.1 | 7.57 | 9.23 |
| Average Number of No Bids/Event | 35.39 | 51.7 | 61.93 | 63.61 | 53.16 |
| Largest Number of No Bids/Event | 280 | 248 | 450 | 476 | 364 |
| Total Number of No Bids in Fiscal Year | 18,191 | 61,986 | 103,419 | 82,381 | 66,494 |

An internal dynamic that should not be overlooked is the growth in the number of "no bids." Contrary to what one might think, no bids are actually a positive when it comes to reverse auctions in federal procurement. This is because when a solicitation is issued for any procurement using the online marketplace, a notice is electronically forwarded to all potential interested and qualified suppliers in the auction provider's database for federal procurement opportunities, as well as being placed in FedBizOpps (the federal government's central opportunity notification database) when applicable. Thus, while thousands of potential suppliers may know about a particular event, to register a "no bid," the supplier actually has to go in and reply to the solicitation—and by that reply, that means they have actually read and considered—to some degree—actually participating in the reverse auction. And with the emphasis on reaching small and disadvantaged businesses and including them in federal contracting opportunities, an increasing level of no bids means that more and more potential suppliers are not just being considered for contracting opportunities, but actually making decisions on whether or not to participate in reverse auctions. In the future, the data on no bids that is can perhaps be used by buyers to better target suppliers with contracting opportunities based on their record of participation and non-participation in reverse auctions.

### *2.4 Moving Away from Sole Sourcing*

An especially important consideration found by delving into the agency's procurement data is in regards to changing both the mindset and practice of purchasing when it comes to items that had formerly been considered to be "sole source" (able to be delivered by only a single supplier). The utility of the online marketplace to find viable rival suppliers for goods and services that had been sole sourced in the past was quite remarkable.

The average value of a procurement that was turned from a sole source to a competitive bidding event was in excess of $300,000—meaning that each time this happens, on average the government can expect to save over $30,000—and in some cases far more than that given the fact that in several instances, these involved formerly sole sourced items on contracts that were at the multi-million dollar level. Thus, one of the principal benefits of making use of the online marketplace is testing the waters on sole sourced items to find potential competitive—and qualified—suppliers and introduce competition into areas that had heretofore been considered non-competitive. This not only works to save money and increase competition, but to restore confidence in government's stakeholders—the taxpayers—that every dollar expended on goods and services is being spent in the best—most competitive and most transparent—manner possible.

## *2.5 Increased Opportunities for Small and Disadvantaged Businesses*

Finally, it is important to take a look at the fact that the gains—in savings and in competition as well—made through the use of the online marketplace have benefitted small and disadvantaged businesses across the country, all of which have gained newfound access to compete for the agency's procurement spending dollars. Thanks to the network of potential suppliers for government contracts that the marketplace provider constantly works to enlarge and update, the agency has achieved having the lion's share of its procurement spend being directed to small and disadvantaged businesses—well in excess of 90 % of the total for each of the years since the agency began using the online marketplace. Especially because much of this agency's work and spending occurs the Washington, DC area, the nature and location of this spending has a tremendous impact on small firms throughout the country—but especially in the border areas of the Southwest. One example of this was the agency staffer who was able to quickly use the reverse auction procurement method to complete what for him was the smallest purchase made to date through the online marketplace—a transmission for a Dodge truck, advertised nationally through the online marketplace—with the winning bid coming from a local Dodge dealership in Tucson, Arizona. In the harsh economic times the country faces today, the importance of providing an opportunity for small and disadvantaged businesses to compete in—and win—government contracts through the online marketplace cannot be understated.

## *2.6* Conclusion—Why It Works?

Finally, what was striking to this researcher in working closely with the agency's procurement executives and staffers in conducting this research was the difference between using the online marketplace and other reverse auction tools that have been offered in the marketplace to date. In short, when an acquisition professional taps into the online marketplace system, they are accessing just that—a complete system. In the present model, reverse auctions are not just an add-on option as part of an e-procurement suite that may—or may not—be used on a case-by-case basis. Neither are they treated as a stand-alone, self-service event that must be uniquely created each time an auction is chosen as the procurement vehicle. Instead, when making use of the online marketplace, an agency's acquisition staff is able to enter into a true marketplace—one that is active 24/7/365 and is constantly growing with an expanding network of tens of thousands of suppliers. Instead of having to carry out all of the steps necessary to recruit and target interested suppliers and organize a unique reverse auction event on each occasion, contracting officers and specialists can simply post their particular buy on the online marketplace. By doing so, they can take advantage of not just the increased price-based competition between qualified suppliers that federal buyers find when using the online marketplace, but they can do so on far smaller (down to $3,000) buys for not just commodities, but all kinds of goods and services. And they can tap into a very active online marketplace, where the seller community is constantly engaged because of the opportunity they have to easily, quickly, and affordably access significant federal buying opportunities in their area.

# 3 Analysis of Second Order Savings

## *3.1 Second Order Savings*

One of the primary goals of this research effort was to go beyond looking at the "bottom-line" savings and procurement metrics to "look behind the curtain" as to the process savings that can be attributed to the use of reverse auctions. Based on anecdotal evidence, this is one of the often-overlooked benefits of using an acquisition tool such as the online marketplace. For while we rightly concentrate on the "first-order" savings—the actual bottom-line savings achieved through reverse auctions (and as documented in the preceding section, this number is in the tens of millions of dollars thus far for the agency), there are added, "second-order" savings springing from the process improvements in the acquisition process. These savings can be considerable—and they need to be taken into account to grasp the whole story on the benefits of more use of competitive bidding processes in procurement operations. In fact, quantifiable gains to be made in a number of process areas, including:

- Integrating reverse auctions as a preferred way of conducting acquisitions,
- Dramatically shortening procurement cycle times,
- Enabling better, higher-order use of procurement professionals' time,
- Fostering improved service for the agency's internal customers.

It is believed that in time, these process efficiencies will be significant for federal agencies, as it will enable them to better pursue their mission and face the new normal to "do more without more."

## 3.2 Analysis

In order to gain insight into the documentable process savings arising from the use of the online marketplace, the researcher gathered an expert panel, consisting of the senior leadership of the agency's procurement operation. Together, we developed a list of all the necessary tasks that contracting officers and specialists need to carry out an acquisition—from the determination of what the buyer needs at the inception of the procurement through the complete cycle—all the way through handling post-award inquiries and any bid protests that might occur. This list then became the focus of our efforts to examine the process improvements that can be accomplished through using the reverse auction model over traditional procurement practices.

The participating contracting professionals were first asked to review the task list and rate whether they believed they were spending less time conducting each phase in the procurement process when using reverse auctioning versus the time they spent carrying-out the step in a traditional procurement environment. The contracting staff indicated that using the online marketplace saved them time across the entire procurement operation. In most of these areas, a vast majority of the survey participants indicated that they were spending significantly less time carrying out these tasks.

Then, they were asked to actually look back at their own experience and estimate the amount of time they would spend—on average—on each of these tasks in the procurement process, first when conducting a "traditional" procurement and then, when carrying-out a procurement through the online marketplace. The contracting officers and specialists taking part in this study clearly indicated that the use of the reverse auction-based procurement method took far less time than using traditional federal procurement techniques. And in many instances, as can be seen in Table 2 (Time Savings: Steps in the Procurement Process That Now Take Less than an Hour), the time requirements for each step in the acquisition process was reduced from multiple hours—even multiple days—to less than an hour. Thus, utilizing the online marketplace meant that overall, procurement professionals took far less time to execute procurements than in a traditional procurement process, all with full compliance to federal contracting laws and procedures "baked in" to the system.

Again, working with the same expert panel, the researcher developed a list of activities of how contracting staff would be able to use the time that was saved through the use of the reverse auction-based system. The participants were asked if they have indeed found that since using the online marketplace, they had more time available for various activities that would aid customers, suppliers, and even themselves.

As can be seen in Table 3 (Impact on Time for the Procurement Professional), in all cases, the contacting personnel reported that since beginning to use the online marketplace, they did in fact have more time for these outreach and support efforts. Additionally, the staff members reported that not only did their use of reverse auctioning create more time for them to engage in these activities, but they

**Table 2** Time savings: steps in the procurement process that now take less than an hour

| Task | Less Time (%) | Same Amount of Time (%) |
|---|---|---|
| Determining buyer needs | 34.30 | 62.90 |
| Specifying the items/services to be procured | 42.80 | 54.30 |
| Soliciting qualified sellers based on specifications and designated acquisition scenario | 80.00 | 17.10 |
| Amending specifications and reissuing solicitation to qualified sellers | 82.90 | 11.40 |
| Revising acquisition scenario and reissuing solicitation to qualified sellers | 80.00 | 11.40 |
| Fielding, managing, and responding to seller questions | 80.00 | 17.10 |
| Collecting and organizing bids | 91.40 | 5.70 |
| Evaluating bids | 77.10 | 17.10 |
| Performing due diligence | 54.30 | 42.90 |
| Making award decisions | 62.80 | 34.30 |
| Making award notification to both successful and unsuccessful bidders | 71.40 | 25.70 |
| Documenting the procurement process | 71.40 | 25.70 |
| Handling post-award inquiries | 57.20 | 34.30 |
| Resolving bid protest actions | 22.90 | 37.10 |
| Ensuring compliance with FAR and other applicable regulations | 51.40 | 42.90 |

**Table 3** Impact on time for the procurement professional

| Activity | More (%) | Same (%) | Less (%) |
|---|---|---|---|
| Working/communicating with customers | 51.50 | 42.90 | 5.70 |
| Working/communicating with sellers | 82.90 | 17.10 | 0.00 |
| Focusing on complex requirements/contracts | 48.50 | 37.10 | 14.30 |
| Providing pre-award support | 57.20 | 40.00 | 2.90 |
| Providing post-award support | 65.70 | 25.70 | 8.60 |
| Handling delivery issues and/or contract administration issues | 45.70 | 48.60 | 5.80 |
| Providing other administrative support | 34.30 | 60.00 | 5.70 |
| Engaging in professional development activities | 34.30 | 57.10 | 8.60 |

also expressed a strong belief that their customers receive a higher level of service from them due to the time that had been freed-up through the use of the online marketplace. Thus, the use of the reverse auction based procurement method not only enables the agency's acquisition professionals to engage in more "higher level" tasks on the job and spend less time doing some of the routine tasks associated with standard procurement protocols. While not able to be tested here in this non-longitudinal study, over time, greater use of the online marketplace should lead to not just increased job satisfaction amongst these contracting professionals, but enhance the ability of the agency to retain and to attract these individuals an the important skills—and knowledge—they posses.

## 4 Conclusion

Through the strategic use of electronic competitive bidding, this agency has demonstrated that reverse auctioning can interject increased competition into governmental contracting. This has created new opportunities for small and disadvantaged firms to succeed at winning federal business. With tens of millions of dollars in documented, hard-dollar savings on acquisition costs, plus the value created by freeing-up time for procurement professionals to carry-out more complex and more valuable tasks, the partnership forged between the agency and its private sector partner stands as a model for how procurement reform efforts should be conducted. In the end, this agency's experience shows that through the proper design and implementation of the latest e-procurement methods, greater collaboration can be facilitated between public sector agencies and private sector suppliers, making it a significant Government to Business (G2B) success story. As the conversation begins on how to reform the cumbersome, confusing, and complex web of federal procurement, this is a case study of which all in the acquisition community and public sector should take note. This is due to the documented first and second order savings found in this research reviewing the most recent four-year time span, during which the agency has made increasing use of reverse auctions and an increasing commitment to using best practices in e-procurement through the online marketplace.

We thus stand at an important crossroads. Pressure is mounting on all in government to indeed "do more without more." And yet, here we have a proven business concept—with a decade's worth of evidence, not hype—that can go a long way towards making federal procurement better, faster, cheaper—and more accountable and transparent in the process. There will undoubtedly be fits and starts along the way. And yes, changing the way procurement is conducted is nothing less than a major organizational change effort. It is one which Steve Kelman, who is a Harvard University Professor and the former head of the Office of Federal Procurement Policy, characterized as needing committed leaders and procurement professionals to be a part of the "change vanguard" to shift the focus of procurement from one emphasizing process to one creating value—and saving money in the process [7]. However, it is clear—armed with both guidance from the President and evidence from agencies such as the one reviewed in the present research—the time to move to reverse auctions in a major, major way is now in order to produce solid savings through innovative use of e-commerce applications to procurement.

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# Models for Some Smart Toys and Extensions

**Dan Ciulin**

**Abstract** Toys based on a Top (which is a simple gyroscope) reveals some interesting property of a gyroscope to be able to dynamically keep the direction of its spinning axis in space and also, to dynamically stand up on its end. Some smart toys had extended these properties. As example: (1) in Pumped Top, by compensating electrically the losses of its energy and then, allowing the Top to stand up the time that is pumping. (2) in Power Ball, where well synchronized mechanical external torques allows the Top to increase its spin speed and then, to display much stronger external torques. (3) in Levitron, where a special Top equipped with a permanent magnet can fly even in steady state. Analyzing these Tops lead to the fact that a gyroscope, when external torques are applied, develop a lifting force. This lifting force correspond to the reunion of the gyroscopic torque pulses during a precession period that try to restore the initial angles in space of its spinning axe. Some interesting extensions lead to a gravitational aerial, gravitational-electromagnetic resonator and to a gravitational motor. More, some (maybe naive) models for atomic particles and inertia are also presented. All these may leads to an other approach of the associated wave and inertia.

## 1 Introduction

In the following, some smart toys based on a gyroscope will be presented.

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### 1.1 Pumped Top

A Top can spin vertically on its end only if it's inside kinetic energy is enough. As it looses its energy by friction, after a time, the Top falls down on the ground and stops to spin.

Professor P. Cornu from the Ecole des Metiers d'Yverdon, in Switzerland, has had the idea to add a magnet to a Top and to consider it as a rotor of an electrical motor. Adding an equivalent stator under the table on which the Top spin will allows it to spin as much time as is electrically pumped. In this case, the magnet added to the Top was polarized horizontally, similarly to the magnet of an equivalent electrical motor. This modified Top spins on a plastic box that had a flat horizontal surface boarded circularly by a small wall that limit the space where it can spin. Inside this box are placed a battery and an equivalent stator. This stator imply a magnetic field Hall sensor to sense the phase/frequency of the Top spin. The obtained electrical signal is then numerically processed and, after amplification, sends to a coil as electrical impulses. This will compensate the loss of energy due, mainly, to the mechanical friction of the Top end then keeps it spin as much time as it is electrically pumped. It may be remarked that this system keeps (approximately) the same spin of the Top and then, keeps nearly constant its inside energy.

### 1.2 Power Ball

Another smart toy that uses gyroscopes is the Power Ball or Wrist Roller. This consists of a plastic transparent and colored ball inside which is placed a (mechanical) well-balanced gyroscope with a single gimbals. The ring of the gimbals is made of some kind of (harder) plastic and fit inside the ball but can also rotate. At the beginning, the gimbals are placed into an initial position using a kind of pawl. First, we had to spin the gyroscope fast enough and then, to apply a convenient time sequence of external torques while keeping the Power Ball in hand. These applied torques will leads to a precession movement and the gimbals will start to rotate inside the ball. A right time-sequence of the applied external torques will leads to a precession movement into a single direction and also, to increase of the spin of the Top (gyroscope). It is like as the applied external torques pump mechanical energy into the gyroscope. To keep the same direction of the precession, the actual frequency of the applied torques has to be well synchronized (matched) with the resulting torques produced by the gyroscope. Otherwise, the direction of the precession movement will change and/or even, energy will be pumped off. That means that an ill-synchronized sequence of applied external torques may leads to a stop of the gyroscope spin. Contrary, a well-synchronized sequence of torques will increase the energy of the gyroscope and then we have to increase also the value of the applied external torques to keep the action going on. This situation will nearly cease when, at a given spin value, the gyroscope will

**Fig. 1** Some aspects of a power ball

began to vibrate and the mechanical frictions will compensate the energy brings by the external torques. This maximal spin value depends on the used technology for a given Power Ball.

To add fun, an electrical generator has been also built inside and, at a given spin value, it lit some LEDs that spin with the gyroscope. The visual effect is reinforced because of the double rotation of the gyroscope and of its precession. It may be observed that the Power Ball has same analogies with an electrical rectifier: it converts mechanical oscillatory signals (the applied external torques) into a direct movement (the increase of the spin speed). It may be also remember that a kind of energy transfer from the spin of the rotor of a helicopter to its lifting force is used to land a helicopter which engine had failed. Some models of the Power Ball had also a digital display of the obtained spin value.

This toy represents an improvement in comparison with the Pumped Top because it allows more energy to be transferred to the spin of the gyroscope. Figure 1 shows some aspects of a Power Ball.

## *1.3 The Levitron*

The Levitron is another smart toy where a Top can fly. It uses a well-balanced Top that had also a magnet on it but, this time, it is vertically polarized. A strong magnetic field given by a repelling magnetic base realize a lift of this Top because, due of its gyroscopic properties, the Top, when its spin is high enough, cannot be rotated by 180° so that the magnetic field will becomes attractive. To satisfy the Earnshaw theorem [1], the magnetic base has a kind of hole through the center of its magnetic field. The Top is magnetized with North Pole to its end and the base also with North Pole to its up surface so that the Top will be repelled. All the used

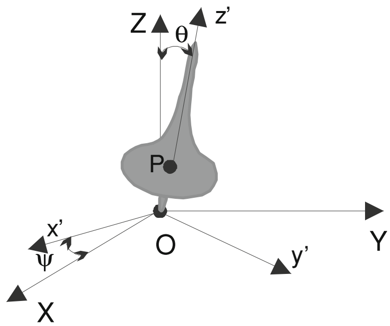


**Fig. 2** An ordinary top

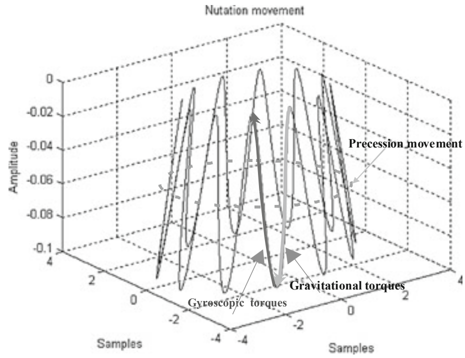


**Fig. 3** Nutation movements of an ordinary top

magnets are ceramic (and not metallic) to avoid losses by circular currents due to the spin of the Top.

An ordinary Top must be based on a strong point with its end. In this manner, the vertically gravitational force can be transformed into torques applied to the Top that spins (approximately vertically) like in the Fig. 2.

Due to this torques, the Top will begin to fall down but, due to its gyrator properties, it results also an orthogonal movement, the precession. Then, the upper point of the Top will follow a complex movement called nutation. A (possible) example of this kind of movement in steady state is shown in the Fig. 3. The speed of the nutation movement increases due to the gravitational torques and, starting from a given speed, it results an orthogonal gyroscopic torques that try to restore the initial angle value of the Top. As the energy of the torque which try to restore the initial angle value of the Top is (mainly) borrowed from the energy stored during the fall down of the Top, the angle of the Top will be restored to its initial value only in the absence of any loses. Otherwise, it will arrive near to this value. At that point, all the stored energy of the forced precession movement is vanished and then, the preview described process will starts once more again. If the end of the Top is based on a surface that has also acoustical properties of resonance, the pulses of the torques that try to restore the initial angle value can be hear too. We can observe that the nutation movement is periodic only in the ideal case of steady

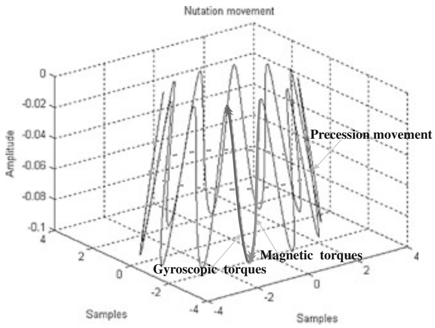


**Fig. 4** An ideal example nutation movement of the Levitron

state where all the system is symmetric and no others torques except those resulted from the gravitational field are applied. When others forces/torques are applied, the movement is modified to insure that the axis of the Top will keep (approximately) its direction in space. It may be remarked that, during a precession period, the reunion of all the gyroscopic pulses torques that restore the initial angle value are equivalent to a lifting force that maintain dynamically up the spinning Top (gyroscope). This force is a mechanical force and then, equivalent to a gravitational force. As the Top is based on a strong point with its end, its weight is (statically) compensated. Then, in steady state, this lifting force has a zero mean value over a precession period and, the altitude of the Top and its energy (in the ideal case of no looses) are conserved.

In the case of the Levitron, the torques needed for its nutation movement results from the interaction between the 2 magnetic fields: the magnetic field created by the magnetic base and those created by a magnet built on the Top. In this way, the Top does not need to be based on a strong point. It is known that for a small magnetic object that interact with a magnetic field produced by a much bigger magnetic object, the magnetic field of the small object will push mainly this object to rotate so that it will be attracted by the magnetic field of the bigger object. Due to this magnetic torques, a precession and nutation movements will results for the Top, creating orthogonal gyroscopic torques that will try to restore its initial direction in space. This is shown in the Fig. 4 for a (possible) exemple of a steady state Top. Then, as for an ordinary Top, the reunion of all the gyroscopic torques that try to restore the initial angle value, over a precession period, will generate a lifting force that is added to the repelling force generated by the magnetic base and Top magnet. It may be observed that, during the orthogonal gyroscopic torques that try to restore the initial angle value of the Top, the magnet built on the Top will restore also the magnetic energy borrowed during the bending phase.

At the beginning, the Top spin is started on a plastic cover superposed on the repelling base. After, this cover is lifted up with the Top on it and then, when the Top is flying correctly, this cover is pushed down and ejected laterally. Lifting the Top increase its total energy and then, the Top will fly on this new altitude because it try to conserve its internal energy. That is in accord with the fact that practically, the Top may fly at a higher altitude that that which results from the static repelling between the magnetic base and its own magnet. Of course, the Top cannot fly at a higher altitude than those where the magnetic repelling field is not strong enough to insure the necessary magnetic torques. Then, the resulting lifting force, which is of gravitational nature, may have, in steady state, over a precession period, a non-zero zero mean value. This force will compensate the static gravitational field. As in mean, the position in space is kept over a precession period, the energy of the Top and of the static magnetic field will be conserved.

When the Top goes out from the central zone of the magnetic base, due to the magnetic field of the magnetic base, the applied magnetic torques on a precession period will be not symmetric and the Top will be ejected laterally. Outside of the magnetic base, the magnetic torques and the repelling magnetic force will diminish. As results, the Top will land some part outside the magnetic base. It may be remarked also that the Levitron instructions precise that the base must be well horizontal to insure a good stability of the flying Top. More, this stability exist only inside an upper and lower spin speeds [2] and that is also connected with the Top weight and the force developed by the interaction of the magnetic fields. As the temperature may change the magnetic force, it represents also a parameter that influences the stability. Anyhow, in steady state, the Top is flying only inside the zone where the static magnetic revulsion fields compensate (approximately) the gravitational field and keeps its position in space during the time interval where its parameters are correct.

## 2 Mathematical Model of a Top

A mathematical model for the rigid body in movement uses generally moving axis that have their origin on the point around which the rigid body rotate. In pure rotation, the linear speed $\vec{v}$ is replaced by the the angular speed $\vec{\omega}$:

$$\vec{\mathbf{v}} = \vec{\omega} \times \vec{\mathbf{r}};. \tag{1}$$

where $\mathbf{r}$ is the rotation radius. The momentum $\mathbf{m}.\vec{v}$ is then replaced by the angular momentum $\vec{M}$ defined using the moment of inertia $\vec{I}$ and the angular speed $\vec{\omega}$:

$$\begin{cases} \vec{\mathbf{I}} = \mathbf{I}_{xx}.\vec{\mathbf{i}} + \mathbf{I}_{yy}.\vec{\mathbf{j}} + \mathbf{I}_{zz}.\vec{\mathbf{k}} \\ \vec{\omega} = \omega_x.\vec{\mathbf{i}} + \omega_y.\vec{\mathbf{j}} + \omega_{\mathbf{z}}.\vec{\mathbf{k}}; \\ \vec{\mathbf{M}} = \mathbf{I}_{xx}.\omega_x.\vec{\mathbf{i}} + \mathbf{I}_{yy}.\omega_y.\vec{\mathbf{j}} + \mathbf{I}_{zz}.\omega_z.\vec{\mathbf{k}}; \end{cases} \tag{2}$$

where $\vec{i},\vec{j},\vec{k}$ stands for unit vectors [14]. The torques $\vec{}$ may be obtained as:

$$\begin{aligned} \vec{\mathbf{L}} &= \frac{\mathbf{d}\vec{\mathbf{M}}}{\mathbf{dt}} = \mathbf{I_{xx}}.\frac{\mathbf{d}\omega_x}{\mathbf{dt}}.\vec{\mathbf{i}} + \mathbf{I_{yy}}.\frac{\mathbf{d}\omega_y}{\mathbf{dt}}.\vec{\mathbf{j}} + \mathbf{I_{zz}}.\frac{\mathbf{d}\omega_\mathbf{z}}{\mathbf{dt}}.\vec{\mathbf{k}} + \vec{\omega} \times \vec{\mathbf{M}} \\ &= \mathbf{I_{xx}}.\vec{\xi}_\mathbf{x}.\vec{\mathbf{i}} + \mathbf{I_{yy}}.\vec{\xi}_\mathbf{y}.\vec{\mathbf{j}} + \mathbf{I_{zz}}.\vec{\xi}_\mathbf{z}.\vec{\mathbf{k}} + \vec{\omega} \times \vec{\mathbf{M}}; \end{aligned} \tag{3}$$

where $\vec{\xi}$ is the angular acceleration. This last relation corresponds to Euler equations of a rigid body with one fixed point.

For an ordinary Top as in the Fig. 2, it results:

$$\begin{cases} \omega_x = \frac{\partial\theta}{\partial \mathbf{t}} = \dot{\theta}; \\ \omega_y = \frac{\partial\psi}{\partial \mathbf{t}}.\mathbf{Sin}(\theta) = \dot{\psi}.\mathbf{Sin}(\theta); \\ \omega_z = \frac{\partial\psi}{\partial \mathbf{t}}.\mathbf{Cos}(\theta) = \dot{\psi}.\mathbf{Cos}(\theta); \end{cases} \tag{4}$$

and:

$$\begin{cases} \mathrm{I_{xx}}.\underline{\omega}_{\mathrm{x}} + (\mathrm{I_{zz}} - \mathrm{I_{yy}}).\omega_{\mathrm{y}}.\omega_{\mathrm{z}} + \mathrm{I_{zz}}.\omega_{\mathrm{y}}.\mathrm{s} = \mathrm{m.g.l.Sin}(\theta); \\ \mathrm{I_{xx}}.\underline{\omega}_{\mathrm{y}} + (\mathrm{I_{xx}} - \mathrm{I_{zz}}).\omega_{\mathrm{x}}.\omega_{\mathrm{z}} - \mathrm{I_{zz}}.\omega_{\mathrm{x}}.\mathrm{s} = 0; \\ \mathrm{I_{zz}}.(\dot{\omega}_{\mathrm{z}}. + \dot{\mathrm{S}}) = 0; \end{cases} \tag{5}$$

where **m** is the mass of the Top, **g** the gravitational acceleration and **l** the distance between the end of the Top and its mass center. It can be observed that the angle $\theta$ is connected with the nutation movement and the angle $\psi$ with the precession movement. If $\omega_z + s = S$, the Eq. 5) becomes:

$$\begin{cases} \mathrm{I_{xx}}.\underline{\omega}_{\mathrm{x}} - \mathrm{I_{xx}}.\omega_{\mathrm{z}} + \mathrm{S.I_{zz}}.\omega_{\mathrm{y}} = \mathrm{m.g.l.Sin}(\theta); \\ \mathrm{I_{xx}}.\underline{\omega}_{\mathrm{y}} + \mathrm{I_{xx}}.\omega_{\mathrm{x}}.\omega_{\mathrm{z}} - \mathrm{S.I_{zz}}.\omega_{\mathrm{x}} = 0; \\ \mathrm{I_{zz}}..\dot{\mathrm{S}} = 0; \end{cases} \tag{5'}$$

From here we can compute the (total) energy E of the Top:

$$\frac{1}{2}.[\mathrm{I_{xx.}}_{(}\omega_{\mathrm{x}}^2 + \omega_{\mathrm{y}}^2) + \mathrm{I_{zz}}.\mathrm{S}^2] + \mathrm{m.g.l.Cos}(\theta) = \mathrm{E}; \tag{6}$$

The terms $\frac{1}{2}.[\mathrm{I_{xx.}}_{(}\omega_{\mathrm{x}}^2 + \omega_{\mathrm{y}}^2) + \mathrm{I_{zz}}.\mathrm{S}^2]$ represent the internal energy of the Top and the term $\mathrm{m.g.l.Cos}(\theta)$ the external applied energy.

Taking into account (4) and (6) results:

$$\dot{\theta}^2 + \dot{\psi}^2.\mathrm{Sin}^2(\theta) = \frac{2.\mathrm{E} - 2.\mathrm{m.g.l.Cos}(\theta) - \mathrm{I_{zz}}.\mathrm{S}^2}{\mathrm{I_{xx}}}; \tag{7}$$

Further, it can be observed that the torque about the Z axis is zero. Then:

$$I_{zz}.\mathrm{S.Cos}(\theta) + \mathrm{I_{xx}}.\omega_{\mathrm{y}}.\mathrm{Sin}(\theta) = \mathrm{A} = \mathrm{cons\,tan\,t}; \tag{8}$$

which can also be written as:

$$\dot{\psi} = \frac{\mathrm{A} - \mathrm{I_{zz}}.\mathrm{S.Cos}(\theta)}{\mathrm{I_{xx}}.\mathrm{Sin}^2(\theta)}; \tag{9}$$

To simplify the relations we note by:

$$\begin{cases} \alpha = \frac{A}{I_{xx}}; \\ \beta = \frac{I_{zz}.S}{I_{xx}}; \\ a = \frac{2.E - -I_{zz}.S^2}{I_{xx}}; \\ b = \frac{2.m.g.l}{I_{xx}}; \end{cases} \tag{10}$$

With these notations, the relations (7) and (9) become:

$$\begin{cases} \dot{\psi} = \frac{\alpha - \beta.\mathrm{Cos}(\theta)}{\mathrm{Sin}^2(\theta)} \\ \dot{\theta}^2 + \dot{\psi}^2.\mathrm{Sin}^2(\theta) = a - b.\mathrm{Cos}(\theta); \end{cases} \tag{11}$$

By eliminating $\dot{\psi}$ it results:

$$\dot{\theta}^2 = -\frac{(\alpha - \beta.\mathrm{Cos}(\theta))^2}{\mathrm{Sin}^2(\theta)} + a - b.\mathrm{Cos}(\theta); \tag{12}$$

If $u = \mathrm{Cos}(\theta)$it results:

$$\begin{cases} \dot{u}^2 = (a - b.u).(1 - u^2) - (\alpha - \beta.u)^2 = \\ r_3.u^3 + r_2.u^2 + r_1.u + r_0 = f(u); \end{cases} \tag{13}$$

This polynomial may be bring to the Weierstrass $\wp$ elliptical function form:

$$f(v) = C.(4.v^3 - g_2.v - g_3); \tag{14}$$

by putting $v = u - \zeta$ with a convenient constant factor$\zeta$. In fact, $\zeta$ is the mean value of the roots of the f(u) and C is an other constant coefficient. By observing that $\frac{dv}{dt} = \frac{du}{dt}$, the relation (13) becomes:

$$\dot{v}^2(t) = C.(4.v^3(t) - g_2.v(t) - g_3); \tag{15}$$

where t is the time. This differential equation may be solved if we remark that by replacing $t \to t'.\sqrt{C}$, the constant C appears also in the left member and can be simplified. Then, the solution of the differential equation 15) is the Weierstrass $\wp$ elliptical function:

$$v(t) = \wp[\sqrt{C}.t,\ g_2,\ g_3]; \tag{16}$$

The half periods of this Weierstrass $\wp$ function are connected with the roots of the polynomial in v:

$$\begin{cases} \wp[\sqrt{C}.\frac{T_r}{2}, g_2, g_3] = v_1; \\ \wp[\sqrt{C}.(\frac{T_r}{2} + j.\frac{T_j}{2}), g_2, g_3] = v_2; \Rightarrow j = \sqrt[2]{-1}; \\ \wp[\sqrt{C}.\frac{j.T_j}{2}, g_2, g_3] = v_3; \end{cases} \tag{17}$$

and this relation is fulfilled only by the fundamental lattice of this Weierstrass $\wp$ function. Then, the physical solution of the differential equation (15) is $v(t) = \wp[t, g_2, g_3]$. From here we can compute the function $u(t) = v(t) + \varsigma = \wp[t, g_2, g_3] + \varsigma$. It can be observed that this function verify also the condition (17) but for the roots $u_1$,$u_2$,$u_3$. Then:

$$\theta(t) = \mathrm{ArcCos}[v(t) + \varsigma] = \mathrm{ArcCos}[\wp[t, g_2, g_3] + \varsigma]; \tag{18}$$

Now, using this solution and the relation (11), the precession angular speed $\dot{\psi}(t)$ can be easily computed.

It may also be remarked a given analogy with the solutions of the differential equation $m.x + k.x = 0$corresponding to the mechanical resonator mass-spring and/or to its electrical equivalent coil-condenser.

## 2.1 *Ordinary Top*

The Levitron Top can be used also as an ordinary Top outside of any magnetical field and its parameters are [2]:

$$\begin{cases} \mathbf{m = 0.02135.kg;} \\ \mathbf{I_{zz} = 2.20.10^{-6}.kg.m^2;} \\ \mathbf{I_{xx} = 1.32.10^{-6}.kg.m^2;} \\ \mathbf{S = \ 251\ rad;} \end{cases} \tag{19}$$

To compute the energy E [14] we need to known also $\omega_x, \omega_y$and the maximal value of $\theta$. We suppose that :

$$\begin{cases} \theta_m = 0.0872665 \text{ rad}; \\ \omega_x = 125.5 \text{ rad/s}; \\ \omega_y = 12.55 \text{ rad/s}; \end{cases} \tag{20}$$

Then, the polynom $\mathbf{f(u)}$ becomes:

$$f(u) = -163525. + 354334.\ u - 194388.\ u^2 + 3490.73\ u^3; \tag{21}$$

with the roots:

$$\begin{cases} u_1 = 0.873736; \\ u_2 = 0.996248; \\ u_3 = 53.817; \end{cases} \tag{22}$$

With these data we find the maximal excursion of the angle of nutation:

$$\Delta\theta = \left|\mathrm{ArcCos}[u_1] - \mathrm{ArcCos}[u_2]\right| = 0.421313 \text{ radians}; \tag{23}$$

From the relations (14) to (15) we gets:

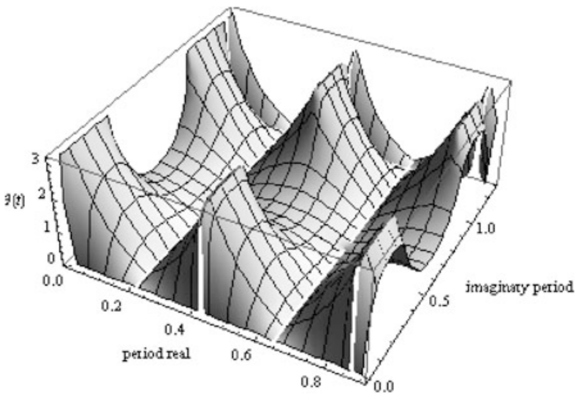


**Fig. 5** Real part of the function $\theta(t)$ with complex time

$$\begin{cases} g_2 = 3728.69166606034; \\ g_3 = 43817.23403766148; \end{cases} \tag{24}$$

and then we can compute the function $\theta(t)$. The real part of this function of complex time argument is shown in the Fig. 5 and a detail of the real part of the variation in time of the angle of nutation in the Fig. 6. The imaginary part of the variation in time of the angle of nutation is shown in the Fig. 7.

Using the period of the nutation, the nutation angular speed results as $\omega_x = 14.544$ rad/s and using the first root $u_1$, the precession angular speed results as $\omega_y = 4.20919$ rad/s. These values are different from our initial supposition. As the ratio between $\omega_x$ and $\omega_y$ is not entire, the position of the nutation torque pulses will move continuosly over the precession period.

Based on the relation (11) the real part of the variation in time of the precession angular speed is presented in the Fig. 8 for complex time and in the Fig. 9 for real time.

On this figure it can be observed also the variations due to the nutation movements.

A more advanced investigation implies the relation between the energy E and the equivalent elliptic modulus. To increase virtually the external energy we had consider the behavior of the Top on planets with an increased gravitational field. The results are shown in the Fig. 10 for g = 9.81 to 100.

To increase virtually the internal energy we had increase its spin S. The results are shown in the Fig. 11 for S = 251 to 1,000.

It can be observed that nearly only the $u_3$ root change: it decrease when g increase and increase when S increase. May we consider the elliptic modulus as a charge parameter?

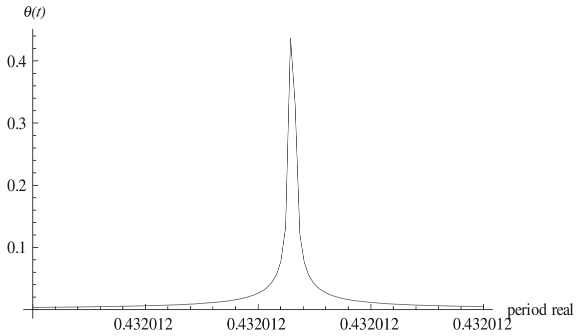


**Fig. 6** Detail of the real part of variation in time of the angle of nutation

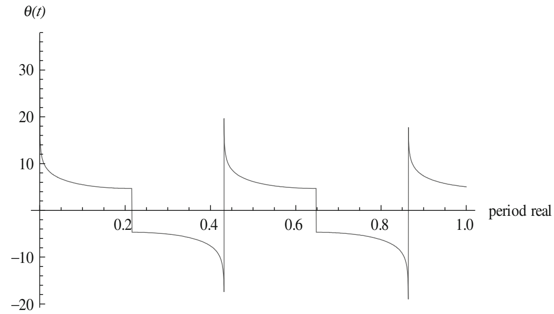


**Fig. 7** Imaginary part of the variation in time of the angle of nutation

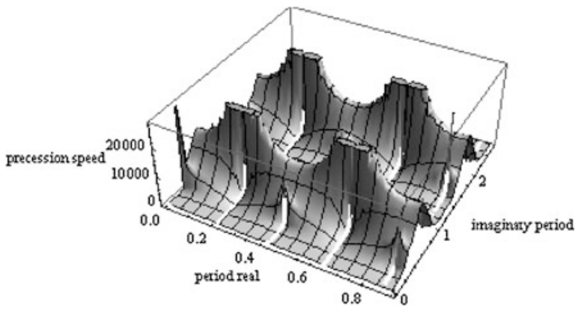


**Fig. 8** Real part of the variation in time of the precession angular speed for a complex time argument

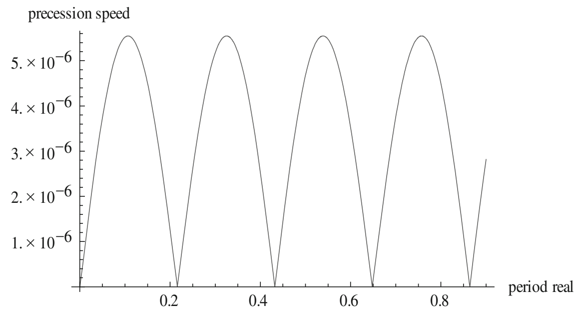


**Fig. 9** Real part of the variation in time of the precession angular speed for a real time argument

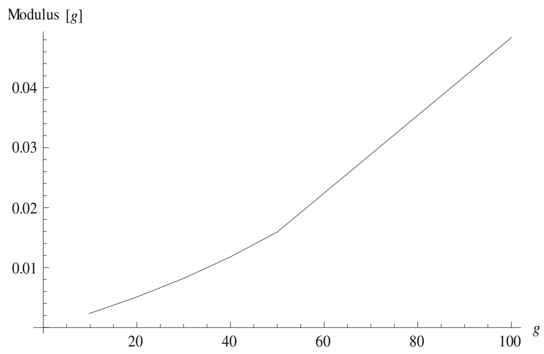


**Fig. 10** Elliptic modulus function of the gravitational acceleration g

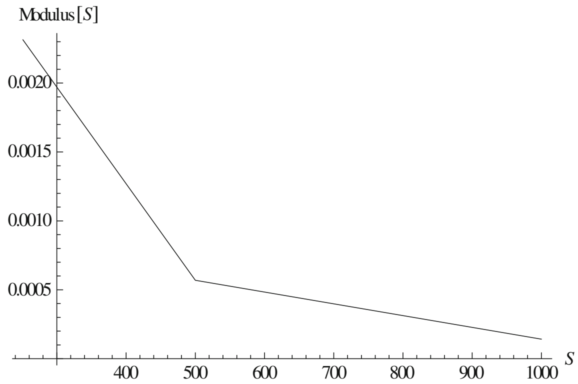


**Fig. 11** Elliptic modulus function of the spin S

### 2.1.1 Remarks

1. An ordinary Top (and/or a gyroscope) may be considered as a second order oscillator because it change the gravitational energy into mechanical oscillations having 2 periods (corresponding to the nutation and precession movements). By analogy, the mass-spring and/or its electrical equivalent coil-condenser oscillators are first order oscillators having a single period.
2. Any oscillator implies a resonator which store the energy of the considered signal. By analogy and based also on its gyrator properties, a Top may accumulate and/or restitute mechanical energy. Of course, correct phase/frequency signals are needed. Power Ball constitutes an example of this kind of transfer. In that case, due to the low precession frequency, it is easy enough to find out the correct parameters.
3. An other possibility is to transfer energy using the nutation frequency but in that case the correct values of the necessary parameters (amplitude/frequency/phases) will be more difficult to be established because the frequency of the external applied torques may be variable and much higher than the frequency corresponding to the precession movement but depending also on the actual position and direction of the Top in space.

4. When the spin is high enough, the nutation (or even the precession) movements may not be observed (the Top sleeps) [14].

## 2.2 Levitron Top

In this case, the applied torques results by the interaction between 2 magnetic fields: the magnetic base and the own magnetic field of the Levitron Top. Then, a strong point is no more needed. For this reason, the Levitron Top can fly. Following [2], the magnetic torque is given by:

$$\frac{\mathrm{d}\mu}{\mathrm{dt}} = \frac{\mu}{\mathrm{I_{zz}.S}}.\vec{\mu} \times \vec{\mathrm{B}}; \tag{25}$$

where $\mu$ is the magnetic moment and $\mu = |\vec{\mu}|$ is constant. This (magnetic) torque will replace the gravitational torque m.g.l. As the Levitron Top will reach a given height $\Delta$hafter it spin is set up, we have to consider also the corresponding energy $E_\mathrm{h}$. Then, $\mathrm{E_h} = \int \mathrm{m.g.dh}; \mathrm{E}_\mu = \int \frac{\mathrm{d}\mu}{\mathrm{dt}}.\mathrm{d}\theta$ where $\theta$ is the nutation angle. With these considerations, the precedent mathematical model may be uses even in this case.

### 2.2.1 Remarks:

1. An ordinary Top is able only to dynamically keep the height of its mass center in space but the Levitron Top can fly and then is equivalent to a system which use the energy of the gravitational and magnetic field to create a lifting force that can (theoretically) even lift off the system.
2. A Levitron Top may be electrically pumped using the spin frequency [2]. More interesting is an electrical pumping using its nutation frequency. In that case, changing conveniently the parameters (amplitude/frequency/phase) of the electrical signal, the position and/or direction in space of the Top may also be changed or, as for the Power Ball, the spin of the Top may be increased and/or decreased. Of course, relations between the position and/or direction in space of the Top and the parameters of the pumping electrical signal needs to be established to insure a simple and correct control. As for the Pumped Top, a Hall sensor may be used to sense the actual parameters (amplitude/phase/frequency) of the nutation movement. May we consider the electromagnetic nuatation equivalent frequency waves as a traction ray able to move a Levitron Top without any direct mechanical contact? Anyhow, some optical manipulation of some small particles are presented in [15, 16].
3. It may be observed that an electrical pumped kind of Levitron Top using the the nuatation frequency may fly at a higher level than a Levitron Top which is repelled by a (static) magnetic field. In that case, the electromagnetic field must

also generate the necessary energy for the bending torques that will produce a high enough lifting force to compensate the weight of the Top.

4. A mechanical system able to create a gravitational force and based on the (mechanical) interaction between 2 gyroscopes was presented in [3, 4]. Theoretically, a Levitron Top may be also considered as a system able to generate a mechanical (gravitational) force and this force may be modulated by changing some parameters of the system. In spite of the method presented in [3, 4], it uses a single gyroscope but on which a magnet is fixed and the force is generated by electrically pumping this gyroscope on its nutation frequency. This method seems to be more convenient than the method presented in [3, 4] as it follows the natural behavior of a gyroscope and also that over a precession period much more forces pulses may results.

## 3 Some (Possible) extensions

### *3.1 Gravitational aerial*

Pumping electrically a Levitron Top using its nutation frequency may be an easy manner to control its parameters. Then, in this case, the magnetic base is not at all necessary. Let's now consider a kind of Levitron Top with 2 (or even 3) gimbals where the external gimbals is fixed on the ground. When this Top will spin and will be pumped electrically using its nutation frequency, a gravitational force will results but the Top, being fixed on its gimbals, will remain on the ground.

It may be observed that a convenient change of the parametrers of the pumped electrical signal may invert the direction of this resulting gravitational force and/or change its direction. Modulating this force, for example with a sine signal, may then create a gravitational sine wave in the same manner in which modulating a static magnetic and/or electric field with a sine signal create a sine electromagnetic wave. Here, the equivalent Levitron Top may be considered as an electromagnetic to gravitational waves converter. For that reason, this kind of system may be considered as an asymmetric active gravitational wave aerial. It may be observed that the spin of the Top can be also independently electrically pumped because the electrical frequency corresponding to the spin differs from the frequencies of the nutation movement. In this way we can keep (about) constant the energy of the system. This gravitational aerial may send gravitational waves but also receive it in the same manner in which an active electromagnetic aerial may receive signals by using some internal feedbacks.

### 3.2 Gravitational-Electromagnetic resonator

Let's now suppose a kind of Levitron Top that may fly in steady state, without the repelling base, by being electrically pumped on its nutation frequency. In that case, the corresponding electrical signal will be (theoretically) periodic and the energy of the electromagnetic wave corresponding to the nutation movements generated by the Top magnet have to be compensated by the pumped electrical signal to keep the system going on. If we remember that in this case the electromagnetic wave generated by the Top is also periodic, it may be used, with a convenient delay, to bend it again on its next nutation period. Then, theoretically, if we do not consider the inherent looses, an electromagnetic resonator may be used in conjunction with a kind of Levitron Top to store this electromagnetic wave energy and return it conveniently to the Top. This kind of system may then be considered as a gravitational-electromagnetic resonator.

### 3.3 Gravitational motor

Let's now consider again a kind of Levitron Top with 2 (or even 3) gimbals. We may fix the external gimbals of 2 such equivalent Levitron Tops on a platform because two such systems with opposite spin may be necessary to minimize the common torques on their external gimbals. On this platform, we can fix also an electrical energy source, a control system equipped with sensors and two electromagnetic wave senders which may generate the necessary nutation pumping signal. Such kind of system may generate a gravitational force which parameters (intensity, direction) may be controlled by the embarked control system. The electromagnetic waves with the nutation frequencies may be considered as a traction ray because it fix the parameters of the resulting force. It may be also remarked that in this case, the necessary energy of the electromagnetic wave embarked sender will be smaller than for the case of a sender placed outside of the platform. If the resulting gravitational force will be bigger than the weight of this system, it may be consider as a gravitational motor and lift off the system.

An analogy may be remarked with the platform presented in [3, 4]. As for a helicopter, where before the lift off, the motor must pump energy to the main rotor, each electromagnetic sender must pump energy to the Tops before the lifting force will be enough to lift off the system.

Some other extensions to the atomic particles and mass inertia may be envisaged as a possible (and may be naïve) models. These extensions may results as a direct analogy between a Levitron Top and some atomic particles like electron, proton, etc.

### 3.4 Atomic particles

An electron, proton, etc., may be considered as a gyroscope having also a magnetic moment [19]. When such a particle is pushed by an external force to change its position in space, by considering that the external electromagnetic field can be neglected, it must interact with the gravitational field. Let now suppose that even a (may be slight) unbalance exist for the mass of such particle. Then, torques will result too. Due to the gyroscope properties of the particle, this torques will produce a nutation movement and, due to the magnetic moment, electromagnetic wave. This may explain the associated wave of a particle [23]. As for the Levitron Top, a gravitational lift off force may results and it will interact with the external (gravitational) force. Then, more energy will be pumped inside the particle. Further, it may be observed that to minimize the energy of this interaction, the spin of the particle have to be (about) parallel with the direction of its trajectory and, probably, these interaction torques will realize that in time.

### 3.5 Mass inertia

Let's now consider a given atom of a body where its nucleus has a spin and a magnetic moment. We suppose that this atom will be pushed in movement by an external force and that the axis of the atomic nucleus spin differs from the axis of the external force. It is known that the atomic nucleus lie inside an electron cloud [19] and that this cloud may be considered as a kind of electromagnetic cavity for some electromagnetic wave frequencies [22]. It is also known that the mass of the nucleus is much higher than the mass of all electrons of the atom [21]. One may suppose that:

1. As any atomic particle, this nucleus, pushed by an external force, may be (slightly) unbalanced and due to the interaction with the gravitational field, torques will result. This torques will generate a nutation movement and then, electromagnetic waves. As presented before, a gravitational lift off force will results and it will interact also with the external (gravitational) force.
2. If the frequencies of these electromagnetic waves will be reflected by the atomic cloud and if the equivalent introduced delay is convenient to maintain the nutation movement, the space between the nucleus and the atomic cloud may be considered as an electromagnetic cavity and then, the atom may be consider as an gravitational-electromagnetic resonator where the equivalent quality factor may be very high. Then, as for the Levitron Top, a gravitational force in the direction of the spin of the nucleus may results. It is like as this excited atom where polarized gravitationally. The resulting force will depends evidently on the energy stocked during this process of interaction, inside the nucleus (and/or atom). Due to the atomic fields, this force will be transmitted to

the whole mass of the body in movement and then, an acceleration of the whole body will results.

3. It is known that the spins of the atomic nucleus of a body must have an uniform spherical distribution so that the matter does not have a spin [18]. Then, the gravitationally polarized atoms where the spin of the nucleus is nearly parallel with the direction of the movement will generate, by addition, a bigger gravitational force but the gravitational force generated by the other atoms will cancel statistically. As a convenient shift of the phase of the electromagnetic waves may invert the generated gravitational force, the nucleus which spin point in the direction contrary to the movement may generate also a force that point in the direction of the movement. May we consider the inertia of a mass as the results of the gravitational polarization of its atoms?
4. It may be remarked that the energy stocked in the gravitationally polarized atoms results from the accelerations in the gravitational field. After acceleration, the speed of the body is maintained due to its internal gravitational polarization. It may be said that the speed is dynamically maintained by the fact that now, the equivalent lifting force of nucleus has a zero mean value. When the body is again accelerated, a bigger number of atoms will be gravitationally polarized (and/or the stocked energy in each atom will increase) and the speed will increase too. This may explain why gravitational forces appear only during the acceleration..

As the speed of the body approach the speed of the light, delays will results in the propagations of the electromagnetic waves inside the atomic cavity. Then, the energy transferred to the nucleus will begin to be less or even canceled. By analogy with the Power Ball, incorrect parameters of the externally applied torques through the electromagnetic waves may change essentially the behavior of the nucleus and then the energy stocked inside the atom as inertia may be canceled and/or transferred to other modes. A very simple calculus concerning the associated electromagnetic wave where $\mathrm{t}, \mathrm{T}, \mathrm{x}, \lambda, \mathrm{v}, \mathrm{c}$ are respectively the time, the electromagnetic wave period in time, the wave position in space, the wavelength (in space), the velocity of the associated particle and the (theoretical) speed of the light gives:

$$\begin{cases} \mathrm{U}[\mathrm{x},\mathrm{t}] = \mathrm{Cos}[2.\pi.(\frac{\mathrm{t}}{\mathrm{T}} - \frac{\mathrm{x}}{\lambda})] = \mathrm{Cos}[\frac{2.\pi.\mathrm{t}}{\mathrm{T}}.(1 - \frac{\mathrm{v}}{\mathrm{c}})] = \\ \qquad \mathrm{Cos}[\kappa\frac{2.\pi.\mathrm{t}}{\mathrm{T}}] = \mathrm{Cos}[\kappa.\omega.\mathrm{t}]; \end{cases} \tag{26}$$

The multiplying factor $\kappa$ may be considered as $\sim 1$ for velocities of the particle much less than c. Then, the resulting phase delay may be neglected. For relativistic velocities, $\kappa$approach to 0 and even change of the wave frequencies results. For $\mathrm{v} \equiv \mathrm{c} \Rightarrow \kappa \equiv 0 \Rightarrow \mathrm{U}[\mathrm{x},\mathrm{t}] = \mathrm{Cos}[0] \equiv 1$ and no associated wave results.

This may explain why at relativistic speeds, more and more energy is needed to accelerate a given mass. As according to the Einstein relation $\mathrm{E} = \mathrm{m.c}^2$, the mass may be considered as equivalent to the energy, the mass of the body seems to increase at relativistic speeds.

5. As the speed of a body increase, more and more of its nucleus will (probably) have their spin parallel to the body trajectory. That may explain why a body keep its trajectory direction in space. As statistically, the number of the gravitationally polarized atoms which spin point in the direction of the movement will be (nearly) equal to the gravitationally polarized atoms which spin point in the contrary direction of the movement, a spin of the whole body is, generally, not observed.

These extensions where presented in a crude qualitative mode. More work will be needed to check up and fix all the details. Anyhow, it represents same idea that (may be) will permit to simply realize a gravitational motor, a (small dimensions) gravitational waves aerial and also, to better understand the gravitational field.

## 4 Conclusions

Some smart toys based on a Top had permitted to better understand some special behavior of a gyroscope and an intelligent interpretation of the Earnshaw theorem [1] had lead to the Levitron Top that can even fly in steady state. A Levitron toy may be also electrically pumped to keep constant its energy [2]. Probably, an electrical pumping using the nutations movement frequencies may be used to control also the position and direction in space of such kind of Top. The mathematical model developed for the Top leads to Weierstrass $\wp$ functions which may be considered as a 3-D extension of the trigonometric functions used, for example, to represents the electromagnetic waves.

All this may leads to the ideas of some possible extensions like a (relatively simple and small) gravitational aerial, a gravitational-electromagnetic resonator and a gravitational motor. Based on a (direct and simple) analogy, these concepts may be (perhaps) extended to the atomic particles, atoms and matter. This may lead to a simple interpretation of the associated electromagnetic wave of a given atomic particle and (may be) to give a (classical) physical interpretation of inertia.

These extensions have been presented in a crude and (may be naïve) qualitative manner. We remark that an extension of the possibility to create a traction ray able to move objects without a direct mechanical contact is not straightforward. Find out electromagnetic waves able to pump many nucleus nutation frequencies so to obtain a given strong enough gravitational force implies more statistical knowledge and tricks. Anyhow, more works are needed to achieve the goals presented in these extensions, to correctly understand and fix all the details and also to realize the necessary technology. Giving their importance, I hope that this will be realized soon.

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# Matrix-Based Methods for Supporting Logic Planning of IT Projects

**Zsolt Tibor Kosztyán and Judit Kiss**

**Abstract** In case of using methodology of project planning, in the first step we had to create a "good" logic network. We had to determine the successors and predecessors of the tasks. However, usually successors and predecessors proceed from the technology, sometimes (especially in case of IT and innovation projects) these relations between tasks are not explicit. In case of projects especially IT and innovation projects; one of the most critical points of views is the phase of logic planning. In spite of the fact that it is a very important phase, it is hardly supported by any kind of project management tools. Our goal was to support the logic planning phase. In our study a new planning method, namely Project Expert Matrix (PEM) is introduced. The PEM method can determine all feasible solutions with the help of stochastic variables and can also take into consideration all the possible precedents. The parameters of logic relations can be changed if the impacts on the project change. With this method the most probable project scenario can be determined taking into account time, cost, and resource demands.

## 1 Introduction

Nowadays the notion of 'project' is often used, however, it is important to make a difference between projects. In the followings we make a distinction between two groups. In the first group there are those projects (e.g. construction projects) that follow the same technological order and consist of the same tasks according to a fixed order. In the second group there are projects requiring a more complex

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planning (e.g. product development or software development projects). As the order of tasks can be handled in a more flexible way the technological order is less fixed. In some cases the realisation of some functions/tasks can become uncertain due to time and/or resource constraint(s).

## 2 Project Scheduling Methods

Network planning methods are mainly used for planning and scheduling projects [1]. However, Critical Path Method [2] and Metra Potential Method (or Precedence Diagramming Method) [3] can only handle tasks with given duration, the Program (or Project) Evaluation and Review Technique can handle stochastic durations [4], while Graphical Evaluation and Review Technique can also handle decision events [5]. These methods were developed for the scheduling of traditional projects, so at product or software development projects they can only be used partially or not at all, because these network planning methods cannot handle the specialities of these projects.

### *2.1 The Principles of Matrix-Based Methods*

The beginning of the development of network planning methods dates back to the 1950 s, while matrix methods came to exist in the 1980s due to the work of Donald V. Steward. His Design/Dependency Structure Matrix (DSM) can be applied in different areas from system modelling to project scheduling; the practical application possibilities were primarily proven to be effective in case of product development projects [6]. The rows and columns of the matrix show project tasks in the same order, and the marks in the matrix cells (with black or 'X') refer to the precedence relations between tasks. Initially only the evidence of the strict relations was marked with the help of DSM, but they did not provide any special information about the relation [7].

### *2.2 Improved Matrix-Based Methods*

In case of the Numerical DSM (NDSM) the precedence relations are not just signed but also weighted according to different viewpoints. These relation/dependency weights could fall to different categories or in some cases (e.g. dependency strength) the weights are represented with numbers between 0 and 1. The bigger the value, the stronger the relation is. Primarily this method was developed for supporting system ana-lyses or product development processes, later it was used for analysing and planning of projects as well [7].

During a research at the University of Pannonia a new method was developed, namely Stochastic Network Planning Method (SNPM), which is independent from the NDSM. It is similar in appearance but different in semantics. In the SNPM the importance of a relation is represented with a value between 0 and 1. 0 shows a total independence, 1 shows certain relation, and the value between 0 and 1 shows uncertain or possible relation between tasks. If the values of cells are probabilities of the relation instead of the importance, it is signed with $p_{(\mathbf{A},\ \mathbf{B})} \in [0, 1]$ in case of tasks **A** and **B**; then $1 - p_{(\mathbf{A},\ \mathbf{B})}$ shows the probability that there is no relation between the two tasks. If $1 - p_{(\mathbf{A},\ \mathbf{B})} = p_{(\mathbf{A},\ \mathbf{B})}$=0, 5, then the relation between these two tasks is indifferent, so the realisation of the tasks can be sequential and parallel with the same probability [8].

Relations between tasks can be treated as probability if there are some a'priori information about possible technological order of similar projects which were realised previously (in this case they are objective probabilities); or rather possible technological relations can be formed based on the opinions of different experts (in this case they are subjective probabilities). The diagonal does not play a role, so the values in the diagonal cells can be signed with 0 or with empty cells as well [8].

Since the relations are weighted according to their importance, it can be assumed that different graphs can be depicted from the matrix as a result. According to the importance of the relations it can be decided whether the realisation or the omission of the possible relation is more practical. Prior experience of similar projects, the constraints, the objective function (e.g. the most occurrence project scenario, minimal lead time, the least resource using, or combination of multiple objective functions) can influence this decision.

## *2.3 Specialities and Application Possibilities of PEM*

SNPM can be used in many cases; however, this method cannot help to solve all the problems. For example in IT projects, especially in case of software development it is possible that the order of some tasks can be reversed or tasks can be left out or replaced with other tasks [9]. These cases cannot be represented in SNPM, because this method can "only" handle the possible relations. We enhanced the SNPM and created the Project Expert Matrix (PEM). With PEM the possible occurrence of task realizations can be handled as well, because the importance/probability of the task realisations can be represented in the diagonal of the matrix. Mark 'X' or 1 shows the certain tasks, the value between 0 and 1 shows the uncertain or possible tasks.

If the values in the PEM diagonal show the (relative) priority/importance of the realisation and information about the cost, time and resource need are given, then the following exercise can be defined: A project scenario has to be determined that includes the most tasks within the given time, cost and resource limit. This process can be interesting in case of the so-called agile project planning that is used


**Fig. 1** Connection between uncertainty of task realization (used in PEM) and prioritising task realizations with MoSCoW analysis

primarily at IT development projects [10]. In this paper we propose a solution to this problem.

The agile project planning technique used at IT projects puts the concept of project management up-side-down. At the traditional project planning the goal of the realisation and the tasks are given, so the challenge is to determine the project scenario with the smallest cost, resource and time need. At agile projects the constraints are the time, the cost and the resources, while the goal is to realise as much tasks as possible [11].

The agile project planning lacks a comprehensive support methodology as well as software support. It is difficult to use the traditional network planning methods, because they cannot handle the possible tasks. However, PEM can help the project experts to set the importance of the task realisations and to determine the omissible tasks (Fig. 1).

In the analysing phase of IT software development projects the so-called MoSCoW Analysis is a frequently applied method [12]. With MoSCoW Analysis those tasks/functions are defined that

- have to be realised certainly, because it is the condition of the contract (Must have);
- are not parts of the conditions of the contract, but they can be realized with a later modification, or can contain useful functions (Should have);
- can although be realized, but they require either too high costs/resources or too much time (Could have).

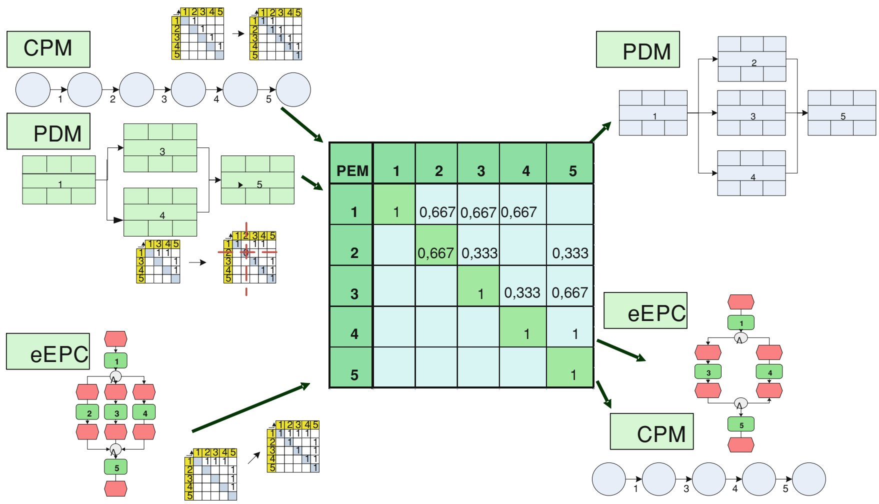


**Fig. 2** Prior project plans and its DSM matrices; PEM matrix contains the relative frequencies of the occurrence of the tasks and their relations; Generated possible project networks. (*CPM* Critical Path Method, *PDM* Precedence Diagramming Method, *eEPC* extended Event-driven Process Chain)

This analysis includes not only the tasks above (marked with M, S and C), but also those tasks, that will not realise in this project (Won't have). Value 1 shows the certain tasks, value above 0.5 shows the tasks which have to be realized practically, value below 0.5 shows the omissible tasks and 0 shows the not-realising tasks in this project (Won't have). It is possible to rank the tasks according to their importance.

The values of PEM can be calculated with taking into account logic plans of previous similar projects or experts' opinions. If tasks are determined based on prior projects, then the occurrence probabilities of tasks are objective; and if the occurrence of tasks are determined based on the experts' opinions, then the occurrence probabilities of tasks are subjective. At summarization of the different plans into PEM matrix it is practical to use the geometric mean instead of the arithmetic mean because of the independence of these opinions and experience (see Fig. 2).

Diagonal values of PEM can be determined using votes employed in complex group decision making methods. These votes can be derived from the opinions of experts inside or outside of the company or from the stakeholders of prior projects as well. The votes can be calculated with equal or with different weights depending on various viewpoints (e.g. constraints or objective functions). Votes can be summarized with the help of complex group decision making methods, like Analytic Hierarchy Process (AHP).

## 2.4 Determining Possible Logic Plans from the PEM

A two-step algorithm was developed to determine all possible deterministic solutions represented by the DSM matrices or in graphs which stem from the PEM that includes stochastic tasks and relations. The uncertainty of the PEM derives from the possibility of some tasks and relations, because a possible task and relation between tasks can be either realised, or not. If it is realised, then the occurrence probability of the project scenario is calculated with the value in the matrix ($p$); and if not, then the occurrence probability is calculated with the complement $(1 - p)$.

Firstly the PEM is regarded on the level of the tasks so all possible solutions have to be determined focusing on the values in the diagonal of the matrix. All possible combinations have to be created from the PEM, where each possible task can be realised (1) or not (0). This way SNPM matrices or project scenarios can be determined.

Secondly SNPM matrices are regarded on the level of the precedence relations of which values are in the off-diagonal cells of the matrix. All possible combinations have to be created to each SNPM matrix to determine the case whether there is relation between two tasks (1) or not (0). These possible combinations can be represented with DSM matrices and/or representation graphs as well. This way DSM matrices or project structures are determined.

When determining the project scenarios it is necessary to define the tasks that have to be realised within a given time, cost and resource limit. It is the answer to the following question: **WHAT** are those tasks which have to be realized in the course of the project. If the project scenario is determined, another question occurs: **HOW**, in what kind of logic order has the project be realised.

## 2.5 Selection Methods

Some algorithms were developed for ranking the possible solutions and choosing the best one. The Project Scenario/Structure Selection Method (PSSM) begins with the definition of tasks, and then they can be ranked according to their importance/probabilities in descending order. Since the tasks signed with 1 are the certain ones and the tasks with priority/probability 0 will not be realised, these tasks do not influence the number of possible project scenarios. It depends on the number of the uncertain/possible tasks (S and C). If it is $k$, then $2^k$ is the number of possible project scenarios. The selecting process of the best project structure from the project scenarios is the same process as at PSSM.

PEM can be extended, so more data can be depicted simultaneously assigning to the tasks (importance/probability, duration, resource and cost needs) and to the relations (importance, possible delay). If the exercise is to determine the logic plan with the highest priority/probability within a given time and resource limit, then

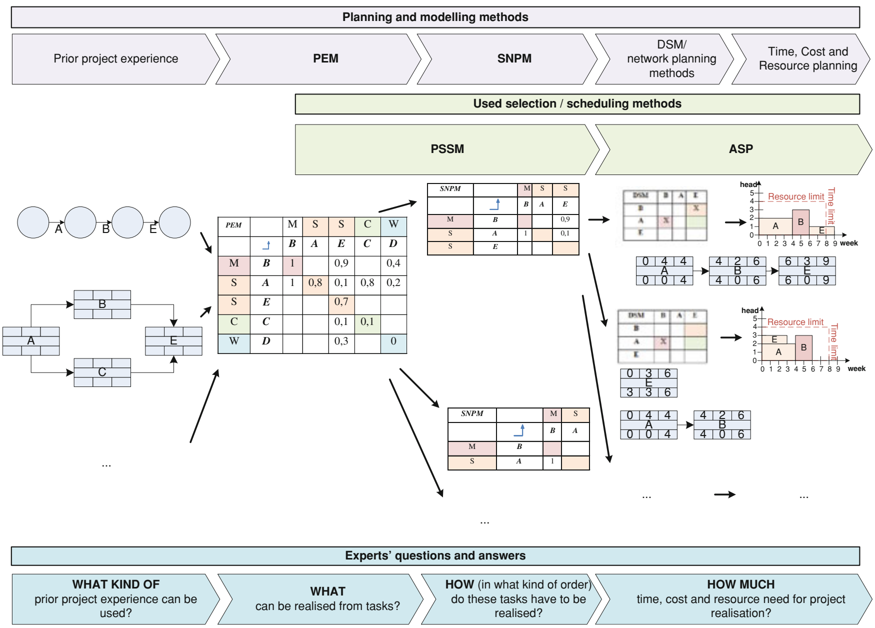


**Fig. 3** The summary of our methods

time and resource needs are the constraints. The primary objective function is the determining of the project structure with the maximal (relative) priority/probability. The secondary objective function is selecting the project structure with the maximal (relative) priority within the time and resource constraints. The possible project scenario/project structure is determined with the help of PSSM method. A new agile project scheduling method (APS—Agile Project Scheduling) can take into account multiple objective functions at the same time, so it can determine the (optimal) resource allocation within time, cost and resource constraints.

# 3 Summary

In this paper a new matrix-based approach of project planning techniques was introduced. PEM can model the previous network planning procedures; however, the real advantage of applying this method for projects is that there are tasks with flexible/possible technological order. These are the IT (especially software development) and innovation projects. The introduced algorithms can be very useful for planning and tracking these projects. These project scenarios and project structures can be ranked according to their priorities. PEM is a useful tool for project managers to handle the possible and omissible tasks; moreover it can determine the ways of the realisation of tasks. This method can (re)use the prior successful project scenarios as a part of a project expert system. It could give valuable information to project managers how to solve a given problem. The Fig. 3 shows a summary of the introduced procedures.

A program using genetic algorithms was developed at the University of Pannonia for supporting the procedures with computer. This program can handle project structures in case of high number tasks as well [13].

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# From Three Dimensional Document Circulation Diagram into UML Diagrams

**Ilona Bluemke and Stanislaw Jerzy Niepostyn**

**Abstract** In most projects UML models are systematically modified and refined in the software development process. Existing software development methodologies are not explicitly describing transitions between different views, models, and appropriate elements of models. The three dimensional Document Circulation Diagram (3D DCD) enables to design the functionality, structure and even the behavior of an application. From the 3D DCD model, consistent and complete UML diagrams may be automatically generated. In this paper a modeler, named Dodocum, automatically generating UML models from 3D DCD model is also presented.

## 1 Introduction

The "4+1" View Model of Software Architecture proposed by Philippe Kruchten [1] is a well-known architectural model and it is often used in the software development process. This model contains five views, each one consists of one or more UML models. In most projects, models are artifacts systematically representing software architecture in these views. They are modified and refined in the development process. Unfortunately, no current development software methodology explicitly describes the transition between the different views, models, and

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even appropriate model's elements. This is evident in the transition from the scenarios view to the logical view. The transition rules between different views, models, and elements depend on the knowledge and experience of engineers [2]. The "4+1" view model uses four views to describe the design: logical, process, implementation and deployment. The scenarios (use-cases view) may be seen as a coordinator of these four views.

The Rational Unified Process (RUP) [3] proposes to design the software architecture using the concept of 4 + 1 views. This method uses UML models (artifacts) to systematically represent a software architecture. The UML models are modified and refined in the development process. The RUP process does not explicitly describe the transitions between the different views and models. UML diagrams may be categorized as structural, behavioral and functional (use-case) diagrams [4]. In the RUP development process conflicts might arise within UML models and these conflicts may drive to an inconsistency and incompleteness in the whole system.

In this paper some improvements in the development process based on "4+1 Views" of architecture in scenarios and design (logical) views are presented. The "Three dimensional Document Circulation Diagram" (denoted as 3D DCD) was introduced in [5]. The 3D DCD diagram (described in Sect. 3) consists of several UML diagrams describing system behavior (state diagrams), structure (class diagrams), and functionality (use-case diagrams). With 3D DCD diagram the consistence between all necessary diagrams, describing software architecture in the scenarios and logical views, can be effortlessly obtained.

The organization of this paper is as follows: in Sect. 2 the term "dimensions" of the software architecture view is defined and in Sect. 3 the three dimensional DCD model is presented. The rationale of applying the 3D DCD model in the design (logical) view of the software architecture to derive the complete and consistent UML model is also given. Next the Dodocum modeler generating UML diagrams from 3D DCD and an example is described. Some conclusions are given in Sect. 5.

This paper significantly differs from ours previous work [5]. DCD metamodel, presented in Sect. 4, was build and DCDocum modeler was implemented. With this modeler completely new examples, part of an industrial projects, were prepared (Figs. 2, 4, 5, 6, 7, 8 and 10).

## 2 Dimensions of the Software Architecture View

In the majority of projects using UML diagrams, use case diagrams are prepared in the beginning of software development to show the main functions of the system. Next, class diagrams are designed to show the main objects in the system, and state machine diagrams are built to show the behavior of system's elements [6, 7]. The most commonly used diagram for modeling a scenario is an activity diagram. Activity diagram visualizes scenario and associates some elements from others

UML diagrams. Other diagrams, such as sequence diagram or collaboration diagram can be also used to achieve the same goal.

The above mentioned approach requires an experience and appropriate heuristics from the software architects to derive complete and consistent UML model representing the design (logical) view of the software architecture. The design of a software can be seen in three dimensions:

- Functional,
- Structural,
- Behavioral.

In this paper use case diagrams represent the dimension of functionality, state diagram the dimension of behavior, and class diagram are used in the dimension of a structure. These three dimensions are orthogonal (Fig. 1) and enable to derive use case realization diagram. A model, which properly integrates these diagrams, would enable to keep the consistency and the completeness of the whole system. Moreover, any change in one dimension will affect automatic changes in the others dimensions, thus keeping the consistency and completeness in UML models.

## 3 3D DCD Model

To introduce the 3D DCD model some explanations about DCD diagram should be given.

### *3.1 DCD Diagram*

Document Circulation Diagram (DCD) is used to show the flow of documents in the information systems. DCD model is intuitive and easy to understand for both business and IT people and thus it can be used to bridge the gap between them. In Fig. 2 an example of an auction process is showed. DCD diagram was described in details in [7].

The header of the diagram contains the DCD objects and first column shows DCD actors. In the next columns the DCD operations are given, each one is performed by appropriate DCD actor. There are several kinds of DCD operations: `Creating`, `Copying`, `Checking`, `Archiving`, `Approving` and `Other`. These operations are performed on the instances of the DCD objects (grouped into the DCD Document). The example, presented in Fig. 2, visualizes an auction process (basic path). `Seller` sets up an `Auction` (02), then a `Buyer` who `Bids` (06) the highest price wins the auction (08). The closed auction is archived (10) and then `Seller` creates financial `Transaction` (12), which is approved by the `Buyer` (14). In Fig. 3 few specific DCD elements are shown.

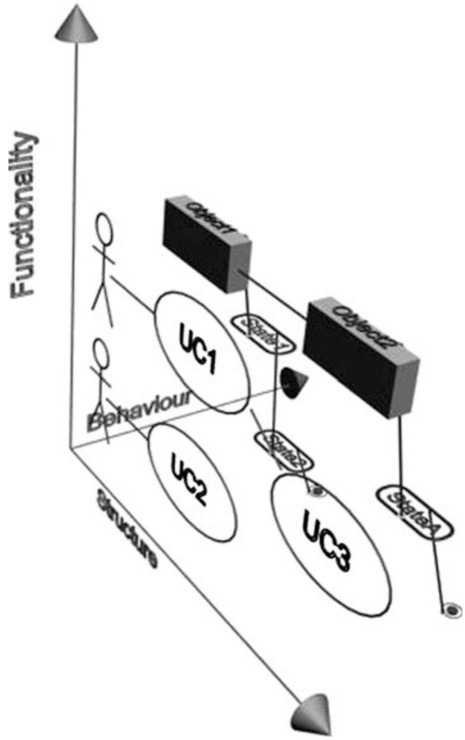



**Fig. 1** Three dimensions of software architecture view [5]

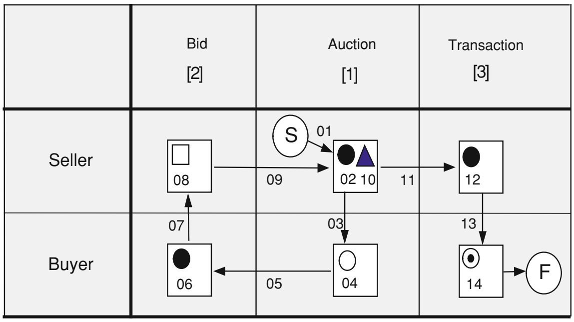
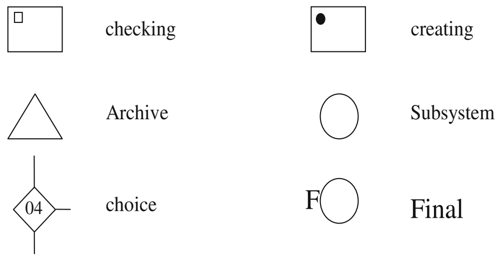



**Fig. 2** The Document Circulation Diagram (DCD) diagram

## 3.2 3D DCD Model

In Fig. 4 the mappings between DCD model and UML diagrams are shown. These diagrams describe the design view of the software architecture. The DCD model has simple and unambiguous relationships with class diagram (structure), state diagram (behavior), and use case diagram (functionality). Each element in the header of the DCD model corresponds to only one object (class) from object (class) diagram. The associations between objects (classes) are derived from the

**Fig. 3** The DCD elements




edges of data flow (horizontal edges) representing the flow of data between instances of DCD objects (a document—element of DCD model). Moreover, each DCD object has simple and unambiguous state diagram derived from the DCD operations. Each DCD operation corresponds to only one state from state diagram, which is used to describe the DCD object's behavior. The number of types of DCD operations is limited, so their names may be used to entitle appropriate states from state diagram (e.g. the DCD operation of type 'Creating' with the '02' label corresponds to the state labeled 'Creating 02'). In a similar way the DCD operations can be mapped into use case diagram.

The transitions between states are derived from the edges of control flow (vertical edges) representing the flow of control between DCD operations. Thus names of these edges may be used to label appropriate transitions in the state diagram. Each use case is identified as a DCD operation, and each use case is associated with an actor, which performs particular DCD operation. The name of a use case contains the corresponding DCD operation (e.g. 'Creating') and its number (e.g. '06'). In order to better visualize the mapping method between DCD model and UML diagrams the three dimensional DCD model is presented in Fig. 5. Appropriate views (projections) of this model correspond to the adequate UML diagram.

## *3.3 Use Case Realization Diagram: DCD Diagram*

The front view of the three dimensional DCD model is simply the DCD diagram (Fig. 6). DCD diagram, described in details in [7] represents the business use case. In DCD ("flat" diagram) edges connect documents, where in 3D DCD model, edges connect operations. In Fig. 6 (3D DCD) operations are connected and in Fig. 2 the connections between documents, on which these operations are performed, can be seen. Typically, an UML project starts with business use case analysis. Details of business use case is often called as "scenario". The most common diagram for scenario is an activity diagram. DCD diagram may be integrated with UML diagrams and such feature is not possible in an activity diagram.

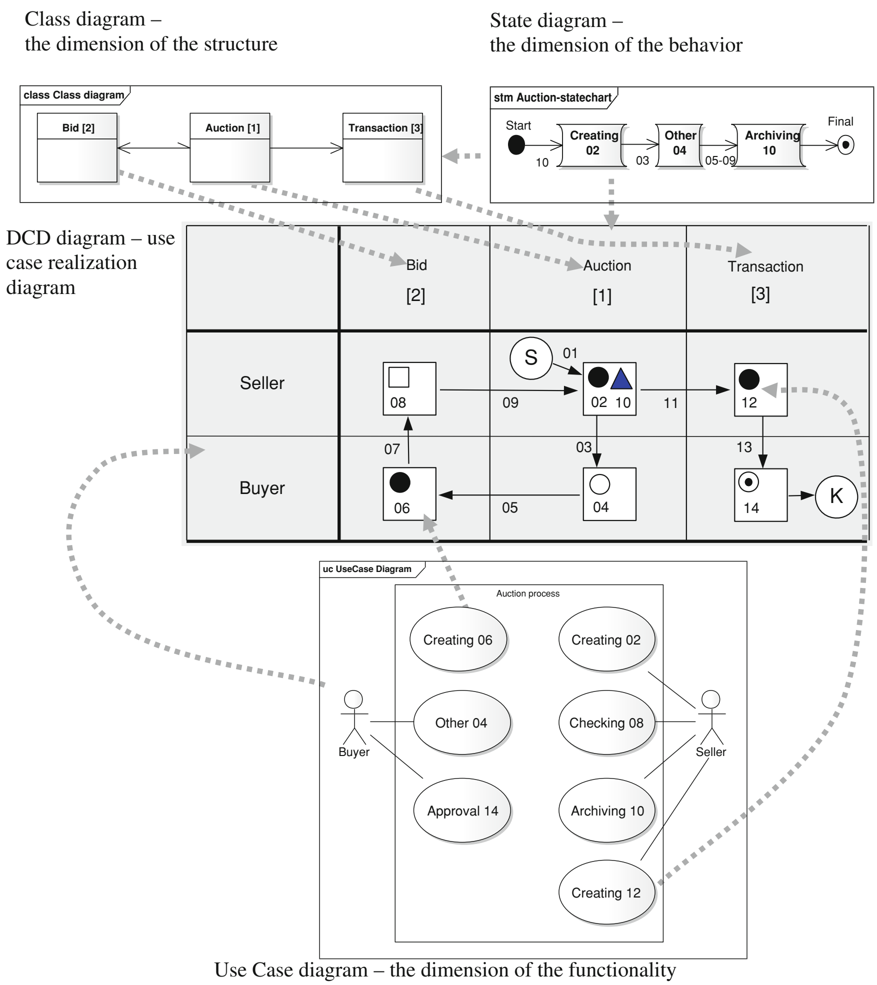



**Fig. 4** The mappings method between DCD model and UML diagrams

If we would like to interpret this DCD diagram as a system use case model, we may disregard the edges between DCD operations and assume particular association between these operations and UML actors, which correspond to the DCD horizontal partitions. The system use case diagram (dimension of functionality) is derived in unambiguous way from the front view of 3D DCD model.

In next sections subsequent views of 3D DCD model are described. They correspond to particular UML diagrams integrated with 3D DCD model. Furthermore, these UML diagrams may be refined by e.g. by software architects, developers, programmers, analysts without rising inconsistency and incompleteness in the model.

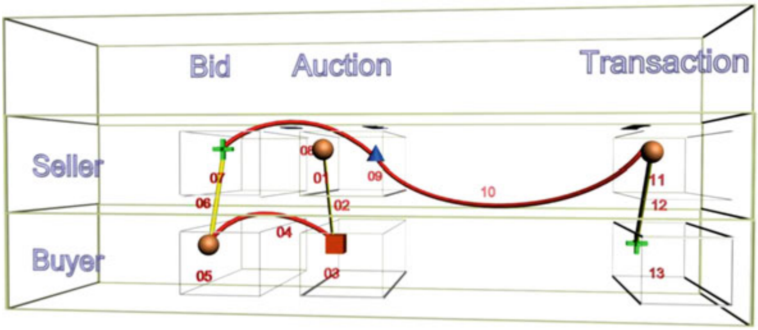
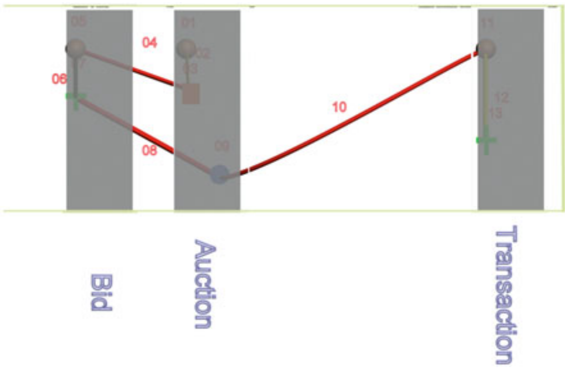



**Fig. 5** Three dimensional DCD model

**Fig. 6** DCD Diagram—use case realization diagram


**Fig. 7** The *top view* of three dimensional DCD model—class diagram




## *3.4 The Dimension of Structure: Class (Object) Diagram*

Overlapping some parts of the projection from the top of the three dimensional DCD model and uncovering others, we can interpret this projection as a class (object) diagram (Fig. 7).

We may consider only edges between DCD documents (as associations between classes)—the associations between objects (classes) are derived from the edges of data flow (horizontal edges) representing the flow of data between

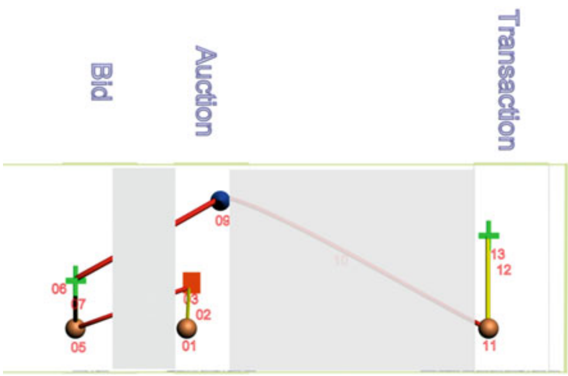



**Fig. 8** The *bottom view* of three dimensional DCD model—system-wide state machine

instances of DCD objects. Moreover, the DCD operations can be mapped into methods of particular classes (objects). Attributes of the objects can be defined from the header of 3D DCD diagram, which is another advantage of the three dimensional DCD model.

## *3.5 The Dimension of Behavior: State Machine Diagram*

The projection from the bottom of three dimensional DCD model, can be interpreted as a system-wide state diagram (Fig. 8). At horizontal axes there are the DCD objects, and at vertical axes are states of this objects. There are only few types of DCD operations in the DCD diagram, so it is easy to identify the states of a particular object from the DCD operations. The transitions between states are derived from the edges of control flow (vertical edges) representing the flow of control between DCD operations. The state diagram describes the behavior of the object, thus the "bottom view" (projection) of three dimensional DCD model describes the dimension of system's behavior.

## *3.6 3D DCD Model: Other Diagrams*

The views (projections) of the three dimensional DCD model presented in the above sections show, that the integration of this model with appropriate UML diagrams is simple and leads to a software architecture which can be better understood and easily managed. Three dimensional presentation offers the possibility to combine relevant, chosen aspects and information for a stakeholder and form an holistic context. The transformations from DCD model to UML models are unambiguous. Moreover, there are others views (projections) of the three dimensional DCD model, which can be interpreted on other diagrams commonly used to describe information system (e.g. sequence diagram, actors activities diagram etc.).

Considering the others views of “4+1” model it can be noticed, that similar mapping can be applied to others views of the software architecture. In the use case view the dimension of the structure can be interpreted as the associations between actors. The dimension of behavior can be interpreted as the activities performed by actors. The dimension of functionality of the use case view is use case diagram.

## 4 Dodocum Modeler and Example

DCDocum modeler is an application for modeling business process with the DCD model, implemented in Topcased environment [9] (Toolkit in OPen-source for Critical Applications & SystEms Development) at the Institute of Computer Science Warsaw University of Technology. Currently the DCDocum modeler can be freely downloaded from www.project-media.com.pl. The Topcased project [9] aims at developing an open source CASE tool for safety critical applications. It offers meta-level tools helping in the implementation of model driven environments. The Topcased environment is using eclipse platform [10] especially Eclipse Modeling Framework (EMF) and Graphical Editing Framework (GEF). Metamodels and editors are provided by TOPCASED for well known modeling languages, such as UML and SysML.

In Fig. 9 the DCD metamodel is shown. Dodocum modeler contains also a few transformations from DCD model to UML models. These transformations (Model-To-Model) enable to generate appropriate UML models from DCD model based on the three dimensional DCD model and its projections. The auction process with alternate paths is presented in Fig. 10. The DCD elements are displayed by using icons.

## 5 Conclusions

The three dimensional DCD model presented in this paper enables to keep consistency and completeness in the description of the software architecture in the design view. This model can provide automatic relationships between UML diagrams. It can be pointed out, that any change in one dimension of the model will influence automatic changes in the others dimensions, thus the consistency and completeness in UML models will be kept. Furthermore, the three dimensional DCD model is easy to read and is not “overloaded” with redundant information elements. We may say that the three dimensional DCD model is “what remains when you cannot take away any more things and still understand the system and explain how it works”—Kruchten [3]. The three dimensional model has others advantages, which can be used in the others views of the software architecture. Applying this model in the others views we can expect an

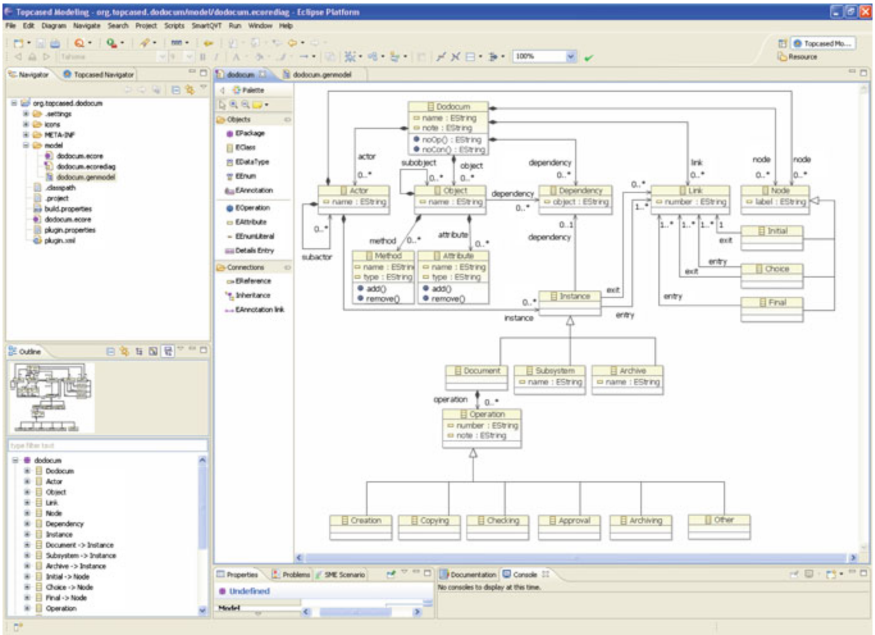



Fig. 9 DCD metamodel in Topcased environment

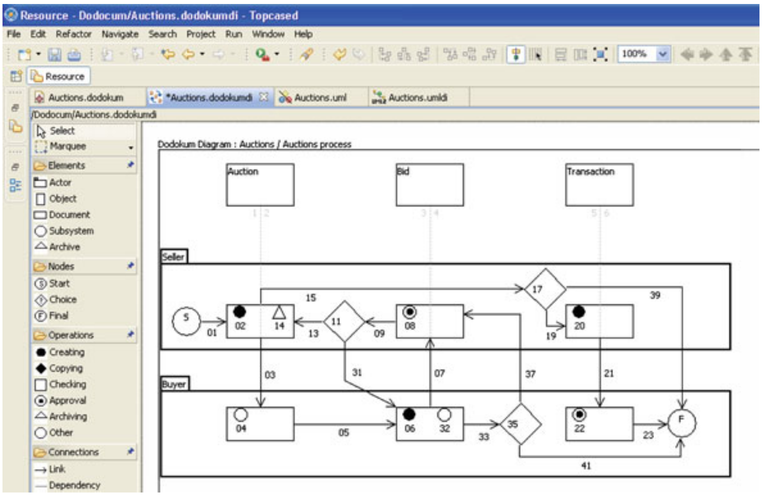



Fig. 10 The auction process in Dodocum modeler

extended model for information systems, in which "a huge gap between the client's requirements and the implementation-oriented models" [11] would be filled.

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# Operating System for Wireless Embedded Systems Powered by Energy Harvesters

**Attila Strba and Tibor Krajčovič**

**Abstract** This paper discusses the requirements, architecture and implementation of an operating system designed for wireless embedded systems powered by energy harvesters (WESPEH). First part of the paper introduces WESPEH and gives an overview of existing thin resource operating systems. It is explained why there is a need for a new operating system. The second part of the paper deals with the new operating system called DolphinAPI which is the first operating system running on the EO3000I HW platform and implementing the EnOcean Radio Protocol Stack. To prove the feasibility of the new operating system TinyOS was also ported to the EO3000I platform. The EnOcean Radio Protocol Stack as a new component was created in TinyOS. The last part of the paper presents the evaluation results comparing the performance of TinyOS to DolphinAPI.

## 1 Introduction

Wireless embedded system powered by energy harvesters (WESPEH) are energy autonomous, self-sustaining, maintenance free devices equipped with wireless interfaces that do not depend on battery or line power. Enough energy can be harvested from a 5 N force generated by pressing a button, a 5 K temperature differential, or 400-lux luminance from a light source to power these devices. The architecture of a generic WESPEH system is shown on Fig. 1. The device includes

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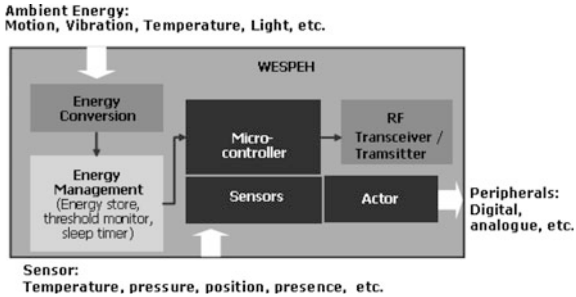



**Fig. 1** Architecture of wireless embedded system powered by energy harvester

an energy conversion component, in which an energy harvester transforms ambient energy to electricity.

The energy management block feeds the converted electrical energy to long-term energy storage like a gold cap capacitor that powers the rest of the system. The microcontroller is the central processing unit of the WESPEH system. It controls all peripheral devices, interacts with the environment through the sensor and actor interfaces and handles the radio communication with the RF interface.

In an energy harvesting system, the RF interface consumes the major part of energy. To minimize the system energy consumption a strongly optimized radio protocol with minimum energy demand, low data collision probability and high transmission reliability is required. There are several short-range wireless standards available as showed in Table 1. Most of these wireless standards have too complex architecture and high-energy demand. The most energy efficient protocol from the listed wireless standard is the EnOcean Radio Protocol. It has extremely short messages and high data rate. The protocol uses ASK modulation which enables possibility of reducing energy need by switching the RF oscillator off at every "zero" bit transmission. Using the 315 and 868 MHz band ensures the best ratio of the indoor transmission range to the energy consumption Another important factor in the WESPEH design is the microcontroller selection.

The microcontroller (MCU) platform choice is usually dictated by the interfaces and performance requirements. For a WESPEH application, the major criteria of the MCU selection is the power consumption, power features and the availability of RF interface. Only few IC exist that integrates complete RF interface and are capable of ASK modulation on 868, 315 MHz frequency bands with 125 kbs data rate. CC1020 is such an IC from Texas Instrument. The CC1020 is an RF transceiver without integrated microcontroller, operates at min. 2.1 voltage. An external MCU can be connected through the SPI interface. EO3000I is another IC from EnOcean that integrates an 8-bit 8051 CPU core with an RF transceiver, 32kB Flash and 2kB RAM and an advanced ultra-low power management module. For our research, we have decided to take the integrated solution because it minimizes the complexity of the HW system and has better assumption for lower power consumption.

The objective of our work is to design an operating system that runs on wireless embedded system powered by energy harvester; abstracts the WESPEH HW, utilize the HW resources in an energy efficient manner; is thin resourced, capable to run on

**Table 1** Summarization of short-range wireless standards

| | EnOcean | Zigbee | Z-wave | Bluetooth | WLAN |
|---|---|---|---|---|---|
| Frequency | 315/ 868 MHz | 2.4 GHz | 868/ 915 MHz | 2.4 GHz | 2.4 GHz |
| Modulation | ASK | GSK DQPSK | BFSK | GFSK | DSSS, FHSS, OFDM |
| Packet length (minimum) | 0.6 ms | 4 ms | 20 ms | 0.7 ms | – |
| Data rate | 125 kbs | 250 kbs | 40 kbs | 720 kbs | 1–150 Mbs |
| Interference risk | Extremely low | Very high | Medium | Low | Low |
| Approximate outdoor range (maximum) (m) | 300 | 75 | 100 | 100 | 250 |
| Approximate indoor range (maximum) (m) | 100 | 10 | 30 | 30 | 70 |
| Power requirement | Low | Moderate | Moderate | High | Very high |

constrained HW with an 8bit 8051 CPU, 32kB Flash and 2kB RAM; has a direct support of EnOcean Radio Protocol Stack; or the architecture of the operating system makes the implementation of the EnOcean protocol stack possible.

The rest of the paper is structured as follows. We present an overview of existing thin resource operating systems in Sect. 2. Section 2.2 describes the design of a new WESPEH OS called DolphinAPI implemented on the EO3000I HW platform. The brief overview of TinyOS porting to the EO3000I platform is described in Sect. 3. The preliminary evaluation results are described in Sect. 3.2.

## 2 Operating System for Wireless Embedded Systems Powered by Energy Harvesters

### *2.1 Existing OS Analysis*

Several operating systems targeting low power applications have already been implemented for both embedded systems and wireless sensor networks. We have done a comprehensive analysis in order to find a system that fulfills our requirements. The first group of analyzed operating systems where embedded operating systems supporting the 8051 architecture. The second analyzed group are sensor network OS. The result of analysis is summarized in Table 2. From the embedded operating system group all analyzed systems were directly supporting the 8051 platform. Most of the analyzed operating systems task scheduler is based on cooperative task switching.

Implementing the EnOcean RT timing requirement is very hard to realize. The secondary problem of the analyzed systems was the closed library architecture.

**Table 2** Overview of embedded operating system and wireless sensor operating systems

| | Embedded operating system | | | Wireless sensor operating systems | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FreeRTOS | RTX51 | Salvo | TinyOS 2.x | SOS | Contiki | LiteOS | Nano-RK | Mantis | VROS |
| Analyzed HW platform | Generic | 8051 | 8051 | ATMega 128L | ATMega 128L | MSP430 | ATMega 128L | ATmega 128L | ATmega 128L | ATm ega 128L |
| Multitasking architecture | Preemptive or cooperative | Cooperative or preemptive | Cooperative | Event driven and cooperative | Cooperative | Event driven and preemptive | Preemptive | Preemptive | Preemptive | Message queue |
| Tasks specification | No priority limit/no task limit | 1 Priority level, maximum 16 tasks | 16 Priority level, task 255 memory limit | No priority | High and low priority tasks | Not specified | Priority | Priority | 5 Priority levels | Messages |
| Task switching latency (CPU cycles) | Not specified | 100–700 | Not specified | 80 | 310 | Not specified | Not specified | 360 | 400 | 189 static 312 dynamic messages |
| Approximate RAM requirement + RAM per each task (bytes) | 236 (+64/task) | 7 (+3/task) | 23 (+6/task) | 226 | 1163 | 2024 (+20/task) | 1.6k | 2k | 500 | 1083 |
| Approximate ROM requirement (kBytes) | 4k | 0.9–9k | 1k | 3.5k | 19k | 40k | 30k | 16k | 14k | 5kB |
| Power management support | No | No | No | Yes, integrated to scheduler | No | No, application layer | No | Yes | Partial. application layer | No |
| Dynamic code | No | No | No | No | Yes | Yes | Yes | No | No | No |
| Dynamic memory management | No | Yes | No | Partially (through TirryAlloc) | Yes | Yes | Yes | No | No | Not specified |
| Distribution | Source code | Library | Library | Source code | Source code | Source code | Source code | Source code | Source code | Not specified |
| License | GPL | Single user | Single user | Open source | Open source | Open source | Open source | GPL | Open source | Not specified |
| Development status | Active | Active | Active | Active | Inactive | Active | Inactive | Inactive | Inactive | Inactive |

This made it impossible to adopt the system effectively to support EO3000I HW resources. Radio Protocol Stack on such a system in a way that radio tasks runs parallel to the application and it fulfills the 1 ms hard. Among the wireless sensor network operating systems, neither the operating systems had a direct support of the 8051 processor architecture. Contiki [1] combines the properties of event driven operating system with preemptive multitasking. Its high ROM and RAM requirements make it unusable for the EO3000i platform. LiteOS [2] showed that it is possible to implement Unix like features as a shell and file system on a low resource device. Such features are good for experimental purpose or in line powered devices but in a real WESPEH application are wasting of system resources. Mantis [3] has followed the implementation of classical Unix based preemptive architecture with kernel and user space, which led to high RAM and ROM resource needs, again not usable for the EO3000i HW platform. SOS [4] main feature dynamic loading possibility enables remote update of an application. Such feature is very useful for wireless sensor networks but unnecessary for a WESPEH device where the same application runs for the whole lifetime of the device. Nano-RK [5] showed an interesting power management method using which the battery lifetime can be prolonged by setting limits of the task execution however; its memory footprint was too high for the EO3000I platform. From all the operating systems, the TinyOS was the best candidate to fit all the defined requirements. However, TinyOS is still not ideal for our needs due to lack of direct support of the 8051 architecture and its cooperative scheduler.

The analysis showed that neither of the analyzed systems fulfills all the requirements. Most of the analyzed OS has no power management support. They are also not designed to run on energy autonomous devices and have no support of the 8051 HW platform. For this reasons we have decided to implement a new operating system.

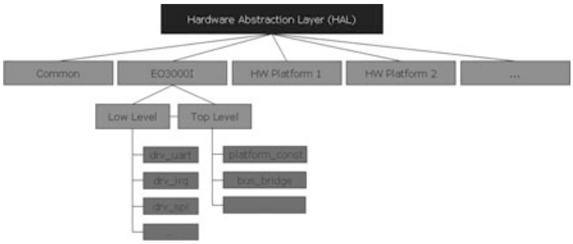
## *2.2 DolphinAPI*

The OS architecture is shown on Fig. 3. It is implemented in ANSI-C and assembler using the Keil C51 compiler. We have also attempted to port the code to the SDCC compiler although this experiment has showed a significant slow down and increase of the OS footprint. The OS has a modular and layered structure. It is constructed of the following layers (bottom up): Hardware Abstraction Layer, ESSL Layer, and Application Layer.

### 2.2.1 Hardware Abstraction Layer

The Hardware Abstraction Layer (HAL) is the bottom layer of the OS that interacts directly with the underlying hardware. The HAL layer abstracts the EO3000I HW platform.

Fig. 2 HAL layer structure




With the help of this abstraction, the OS components are HW independent. This layer enables the migration of the OS to other HW platforms. The structure of the HAL is composed of several modules: common-, platform specific-, low level- and top level- modules as showed on Fig. 2. The Common module defines all supported HW platform properties like bus width, register width, C variable types and compiler specific defines. Top-level and low-level modules are HW platform specific. The top-level layer contains HW platform constants and registry definitions, bus bridges, and memory addresses. The low-level layer implements the drivers—the abstraction of hardware components. There are three different driver types: bus drivers, memory drivers, and peripheral drivers. Most of the drivers are passive drivers. They do not allocate memory or use the CPU for performing operations. These passive drivers are constructed from C defines. The active drivers are implemented in assembler and they realize for instance a bus communication.

### 2.2.2 ESSL Layer

The ESSL layer contains the implementation of the scheduler, power management, network stack and peripheral components. DolphinAPI does not implement classical kernel architecture. Operating system libraries are linked to the application upon compilation time thus; there is no kernel and user space separation. The structure of the ESSL is modular. Most of the modules are independent. Modules interacting together are shown as horizontal boxes on Fig. 3. Modules that are directly accessible from the application has a configuration and function interface. In the next section the details of the ESSL layer is described in more detail.

#### Modules Configuration

The configuration interface of the module activates the module (by linking it to the application), allocates memory for the module variables, passes memory resource pointers allocated by the application, configures the HW resources, and activates interrupts. If the configuration interface is not called the module will not be linked to the application, thus it will not use any ROM, RAM or HW resources. Configuring *radio_mod* or *io_mod* requires various combinations of dependent

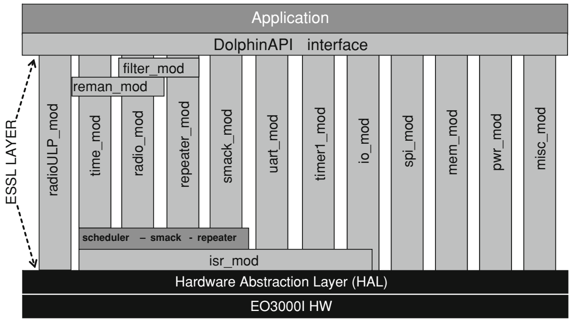



**Fig. 3** DolphinAPI architecture

parameters. For instance to configure the RF front-end the modulation frequency has to be set, PLL and various filters has to be configured. To perform such an operation on a C level several configuration interfaces would be needed. Each call to the OS requires time and energy. This problem is solved in DolphinAPI by moving the parameter logic out of the OS to a configuration SW running on a desktop computer. We have implemented a configuration SW called *Dolphin-Studio*. It offers a comfortable GUI interface to select the appropriate configuration. The selected configuration is generated to an array that is passed to the module configuration interface. The array parameters are directly translated by the OS to the low-level drivers.

## Memory Management

There is no memory management in the OS; the memory is assigned statically to the objects during compilation. Each module has its own static RAM allocation. Some actions, like the *radio* module implementing the radio protocol stack or the *mem* module implementing the flash memory storage require a great deal of memory resources. For instance, the *radio* module needs buffer allocation for packets and the *mem* module needs a shadow memory for flash processing. These memory resources are allocated by the application and transferred to the module through the configuration interface. The advantage of this technique is that the application has a direct control of the amount of the memory the OS uses and no extra resources are needed for memory management. Another advantage of this method is that the application can share memory resources among modules that are not executing parallel tasks. For example, the shadow buffer of the *mem* buffer can be used by the application for analog values sampling until a function of the *mem* module is called.

## Scheduler

DolphinAPI realizes a unique preemptive priority scheduler on system level. We differentiate between two types of tasks: single application and several system tasks. System tasks run preemptive to the application task but concurrent to other system tasks thus a system task can always interrupt the application task. System tasks always run to completion. One of the system tasks can be assigned a high priority. Such system task can also preempt other system tasks. There is only one application task; thus, no parallel application task can be executed. The OS implements no message handling. System tasks can execute application code using static callbacks.

System tasks are divided into synchronous tasks and asynchronous tasks. Most of the synchronous system tasks provide the function of the radio protocol stack. To execute the synchronous system task a scheduler is used using the HW timer interrupt. The scheduler runs on a round robin basis and every task has 1 ms timer slice. Every millisecond the execution of the application is interrupted and one of the system tasks takes over the CPU. Synchronous system tasks are executed sequentially according their priority and demand. Some of the synchronous tasks can be triggered by events from asynchronous tasks. Asynchronous system tasks are HW module dependent and are connected to HW interrupts. The structure of the scheduler is modular. There are several different scheduler configurations in the OS. It is possible to change the scheduler module by invoking other init function of the *time* module. With this method, the OS can be configured to support other synchronous system task configurations. For instance, we can introduce a new system task supporting a routing or repeating process. An example of a typical scheduler configuration is showed in Table 3. The scheduler configuration is done using DolphinStudio.

The scheduler also provides a system tick for the application. Using these system ticks the *time_mod* implements SW timer interface. Applications without receiver capability powered by short energy burst can avoid using the scheduler and synchronous system tasks. Instead, these applications can use ULP routines that offer interfaces to access synchronous system task functionality. The execution of the ULP functions without a scheduler is significantly faster therefore requiring less energy. On the other hand, the application code is more complex and requires that the application implement its own timing mechanism.

### Power Management

The OS implements an application driven power management model. The OS abstracts the power management features of the HW and provides interfaces to the application to control power domains.

The application can select different CPU clock sources and can put the HW into different power modes. A summarization of the power modes and the power management module features of the OS are shown in Table 4. The power management module in the OS ensures smooth transitions between the power modes selected by the application. Prior to entering sleep mode the power management module of the OS makes sure that all pending task run to competition, all interrupts are switched off, the scheduler is stopped, radio communication is powered down safely and the HW buffers are cleared. The low power timers and wake up events that trigger the power

**Table 3** Typical scheduler configuration in Dolphinapi

| Synch task execution | Synch task description | Asynch task execution | Asynch task description |
|---|---|---|---|
| SynchTaskl always | *System timer increment*—increments a counter representing the system clock counter | Prio high: AsynchTask1 event based | *Uart Rx/Tx interrupt*—process uart byte arid put to the ring buffer |
| SynchTask2 always | *Radio buffer update*—Processes Radio SW buffer, subtelegram timings. If there is a telegram that has to be transmitted, it is placed to the Radio HW buffer | AsynchTask2 event based | *Radio Rx interrupt*—process incoming subtelegram |
| SynchTask3 event based | *Telegram decoding*—decodes only one received telegram and stores it in a free radio buffer | AsynchTask3 event based | *Radio Tx interrupt*—finishes telegram transmission, stops ongoing HW state machine |
| SynchTask4 event based | *Telegram converting*—converts all UxS/TxS telegrams to RPS | AsynchTask4 event based | *Timerl*—processes timer1 interrupt and calls the application callback function |
| SynchTask5 event based | *Telegram compressing*—processes received subtelegrams. It is checked If the same subtelegram exists. If the telegram is new the repeating option is proved | AsynchTask5 event based | *10*—processes gpio interrupt and calls the application callback function |

mode transition are controlled by the application. After the wakeup, the OS informs the application about the last power mode and provides the event information that triggered the power mode transition. Such a power management scheme gives the application great flexibility to control the power consumption of the whole system. The reason why the OS does not implements dynamic power management (DMP) is partially that DMP needs lot of system overhead. In addition, different type of WESPEH application has different power lifecycles. Creating an optimal DPM solution would in WESPEH application not be as optimal as application driven power management. More details about this problematic can the reader find in the paper [6].

## Remote Management

One of the OS unique features is the integrated support of remote management. Using the remote management module the application or parts of the OS can be easily configured through the radio interface. Using remote management messages the device automatically responds to ping or query messages with the radio strength information. This is useful to localize the WESPEH deployed device in an

**Table 4** Dolphinapi power modes

| Power mode | Current | Wakeup event | Startup | Startup state | Description |
|---|---|---|---|---|---|
| Deep sleep | 220 nA | Watchdog timeout, wake pins | Reset vector | RAMO retained. XTAL off, running on CRCO | Used for weak ambient energy powered, event triggered TX applications |
| Flywheel sleep | 720 nA | Watchdog timeout Flywheel timeout, wake pins | Reset vector | RAMO retained XTAL off, running on CRCO | Used for high precision system timing, lowest duty-cycle synchronous network |
| ShortTerm sleep | 10 nA | ShortTerm timeout, watchdog timeout, flywheel timeout, wake pins | Continue in application | All RAM retained except radio configuration XTAL off, running on CRCO | Used for short periods which are significantly longer than the XTAL startup time (e.g. between subtelegrams) |
| Standby | 1.4 nA | TimerO, wake pins. external pin, Radio Rx telegram | Continue in application | CPU inclusive all RAM retained | Used for waiting for an event |

unknown environment. The module implements a security mechanism to protect the system from attacks or unwanted configuration.

### 2.2.3 Conclusion

We have successfully implemented several energy autonomous applications on the DolphinAPI to prove the functionality of the operating system. The next step in our research was to evaluate the performance of the operating system and compare it to other systems.

This step requires that another benchmarked operating system run on the EO3000I HW platform. Our analysis in the previous chapter showed that the best OS candidate for WESPEH systems was TinyOS. TinyOS has several similarities to the DolphinAPI: the TinyOS architecture is modular, has small footprint and has static memory allocation. We decided to port the TinyOS to the EO3000I platform and implement components that support the EnOcean Protocol Stack.

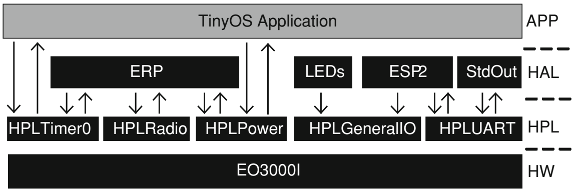



**Fig. 4** TinyOS architecture ported on EO3000i

# 3 Evaluation

## 3.1 Porting TinyOS 2.x to the EO3000I Platform

The porting was not a straight forward procedure. The EO3000I chip is based on the 8051 Intel architecture and the original TinyOS 2.x source code has no 8051 support. Several attempts where made to introduce the TinyOS 2.x port on the 8051 architecture. From these attempts, the best-documented, most popular solution is a TinyOS 2.x port provided by the team of Leopold Martin [7]. We have based the porting of the EO3000I on the work of Leopold Martin. We had to adjust the mangle script to support the enhanced 8051 structure of the EO3000I HW. In order to provide benchmark measurements between TinyOS and DolphinAPI, the minimum requirement was to implement in TinyOS the radio, power-, io-, timer-, and for debugging purposes, the uart module. The simplified architecture of the ported TinyOS is shown on Fig. 4. Several modules from DolphinAPI had to be redesigned. We did not port the scheduler architecture from DolphinAPI; instead, we used the cooperative TinyOS scheduler. The porting was successful and we were able to run the TinyOS on the EO3000I platform to transmit and receive telegrams. As the next step in our research we will do performance measurements between DolphinAPI and TinyOS.

## 3.2 Performance Measurements

We have evaluated the performance of DolphinAPI using both macro- and micro-benchmarks. The evaluations of the system are still ongoing. Therefore, we present only partial results. The first measurements where focusing on stress testing of the system through the radio interface. The aim of the evaluation was to prove the feasibility of the DolphinAPI scheduler design and to point out the problem of the TinyOS cooperative scheduler.

We have implemented an application where several radio telegrams are exchanged between two WESPEH devices. To simplify the test setup, the devices where line powered during the measurement. The reception and transmission was controlled through the UART interface using a desktop computer. In the first test case 100 telegrams with one subtelegram in different time ranges where

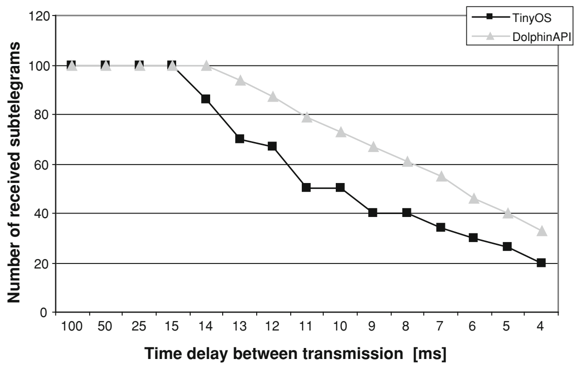



**Fig. 5** Telegram reception rate (100x subtelegrams)

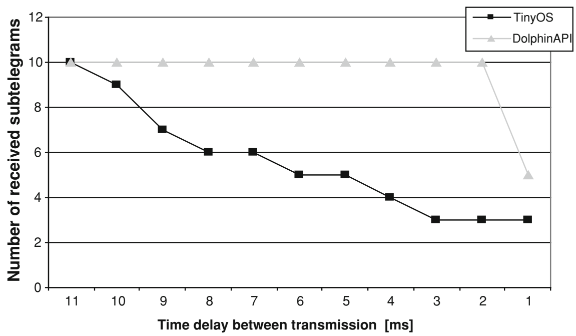



**Fig. 6** Telegram reception rate (10x subtelegram)

transmitted. We monitored the test setup using a spectrum analyzer to make sure the data are correctly transmitted. Application on both OS had 10 radio buffers and a 14 bytes serial ring buffer. The results are showed on Fig. 5. In the second measurement 10 subtelegrams where sent with a very short delay between transmissions. The results are showed on Fig. 6. In the third measurement pin control code was injected in different low level drives to both OS. Using logic analyzer a trace log was created from which the latency of telegram processing was measured. The results are showed on Fig. 7. From all the measurements, we have observed that DolphinAPI performance for the evaluated application is better as of TinyOS. This can be explained by the scheduler overhead and the cooperative scheduler architecture of TinyOS. By analyzing measurement data it is clear that TinyOS task keeps monopolizing the system. Thus the radio telegram processing gets delayed. In DolphinAPI the preemptive scheduler and task priorities avoids such situation.

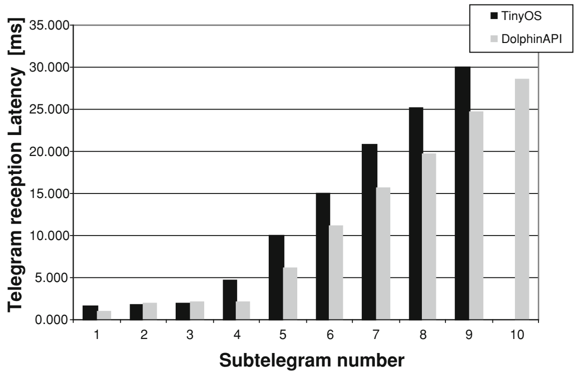



**Fig. 7** Subtelegram processing latency

## 4 Conclusion and Further Work

In this paper, we presented a new operating system DolphinAPI that is intended to be used for WESPEH devices. The contributions of this paper are twofold. First, we have introduced WESPEH and presented a comprehensive summary of existing thin resourced operating systems. Our second contribution is presenting a new operating system for WESPEH. The novelty of the OS is the unique scheduler, implementation of EnOcean Radio Protocol stack, support of remote management and capability to run on extremely thin resourced HW. This is the first OS supporting the EO3000I platform. We have ported TinyOS on the EO3000I platform in order to make benchmarking measurements. We have implemented the EnOcean protocol stack component to TinyOS. From the initial measurements, we can see that DolphinAPI architecture shows a better performance as of TinyOS. In the next research phase, we plan to continue our work in the evaluation. Also we plan to port DolphinAPI to new HW platforms.

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# Data Transformation and Data Transitive Techniques for Protecting Sensitive Data in Privacy Preserving Data Mining

**S. Vijayarani and A. Tamilarasi**

**Abstract** Privacy Preserving Data mining is a new research area in the field of data mining. It greatly deals with the side effects of the data mining techniques. With the help of data mining techniques people can analyze and extract the hidden patterns from the large data set. In many situations, the retrieved hidden knowledge provides the confidential information. This confidential information may be misused for variety of purposes. This situation raises the need for privacy and security issues. The main objective of privacy preserving data mining is, extracting the knowledge available in the data; at the same time the individual's privacy should be protected. It also protects the data owner against mishandling or disclosure of the data. Several techniques and algorithms are required for maintaining the secrecy of data in order to limit the extraction of confidential patterns. There are many techniques are available for protecting the sensitive data in the database. Some of them are statistical, cryptographic, randomization methods, k-anonymity model, l-diversity and etc [2–5, 7]. In this research work, we have developed two new perturbative masking techniques known as data transformation technique and data transitive technique. These techniques are used for protecting sensitive data in the form of modifying the sensitive data. In order to find the best technique, we have compared the two techniques with the existing technique micro aggregation. Experimental result shows that the data transformation technique gives the better result.

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## 1 Introduction

The growth of computing technologies, internet, and development in databases, a huge quantity of individual data can be incorporated and investigated. This situation has elevated the worldwide alarm about protecting the individual's privacy. The major goal of the privacy preserving data mining research is, the researchers would develop new algorithms and techniques for modifying the sensitive data, so that the confidential data and confidential knowledge remain confidential even after the mining process also [15].

The necessities for defending statistical data from disclose has increased considerable significance in recent years. Government organizations which release data have always been interested in this problem. However, with the increase in the ability of organizations to gather, store, analyze, disseminate, and share data, there has also been a growing demand for commercial organizations to secure sensitive data from disclosure. Recent legislation worldwide has made this an important issue for all organizations that gather and store any sensitive information.

The progress of information technologies has allowed different organizations (e.g., census agencies, hospitals) to gather huge quantity of sensitive personal data (e.g., census data, medical records) [8, 11–14]. Due to the great research value of such data, it is often released for public benefit purposes, which, however, poses a risk to individual privacy. A typical solution to this problem is to anonymize the data before releasing it to the public. In particular, the anonymization should be conducting in a vigilant way such that the published data not only prevents an opponent from inferring sensitive information, but also remains useful for data analysis.

Most of the privacy preserving computation methods applies various type of transformation on the data in order to perform the privacy preservation. A host of techniques are available for protecting numerical data from disclosure. These include rounding or coarsening, perturbation, additive noise, micro-aggregation, data swapping, and more recently, data shuffling.

The rest of this paper is organized as follows. In Sect. 2, reviews of related work are discussed. In Sect. 3, we present an overview of micro data and masking techniques in statistical disclosure control. In Sect. 4 we discuss about the problem formulation and the proposed solution. Section 5 gives the experimental results of data transformation, data transitive and additive noise. Conclusions are given in Sect. 6.

## 2 Review of Literature

The safety of governmental databases has received considerable attention in the literature in recent years. This can be attributed to a simultaneous increase in the amount of data being stored in databases, the analysis of such data, and the desire to protect confidential data. Data perturbation methods are often used to protect confidential, numerical data from unauthorized queries while providing maximum access and accurate information to legitimate queries. To provide accurate information, it is desirable that perturbation does not result in a change in relationships between attributes. In the presence of non confidential attributes, existing methods will result in such a change.

Most methods for privacy calculations use some form of transformation on the data in order to execute the privacy preservation. Typically, such methods decrease the granularity of demonstration in order to lessen the privacy. This reduction in granularity results in some loss of effectiveness of data management or mining algorithms. This is the natural trade-off between information loss and privacy. A host of techniques are available for protecting numerical data from disclosure. These include sampling, local suppression, random noise, rounding, micro-aggregation and etc.

Ruth Brand [9] described micro data protection by adding noise. Several algorithms were developed that have different characteristics. The simplest algorithm consists of adding white noise to the data. More sophisticated methods use more or less complex transformations of the data and more complex error-matrices to improve the results. He gives an overview of different algorithms and discusses their properties in terms of analytical validity and level of protection.

Domingo Ferror et al. [1] discussed micro aggregation, a technique for statistical confidentiality that uses aggregation operators. They described the goals of statistical confidentiality and its application to continuous and categorical data. They showed the application of the method to a small publicly available data set.

Krishnamurthy Muralidhar et al. [6], described a new method (General Additive Data Perturbation) that does not change relationships between attributes. All existing methods of additive data perturbation are shown to be special cases of this method. When the database has a multivariate normal distribution, the new method provides maximum security and minimum bias. For non normal databases, the new method provides better security and bias performance than the multiplicative data perturbation method.

Muralidhar and Sarathy [10] provide a comprehensive discussion of the different techniques for protecting numerical data. With the exception of swapping and shuffling, most other data masking techniques involve the modification of the original values of the confidential variables. Many users find such modification of values to be objectionable and hence are less likely to use the modified data. By contrast, by transforming the original values leaves the original data unmodified. Hence, this type of transformation techniques are more likely to be accepted by users who find “data modification” objectionable.

## 3 Statistical Disclosure Control

Statistical data protection is also known as inference control in statistical databases, also known as Statistical Disclosure Control (SDC) or Statistical Disclosure Limitation (SDL). Statistical disclosure control seeks to protect statistical data in such a way that they can be publicly released and mined without giving away private information that can be linked to specific individuals or entities.

### *3.1 Micro Data*

A micro data is a collection of records holding a data of individuals being considered who can be persons, business companies, etc. Micro data file contains the individual records of a micro data set. The data vector Vj contains individual record j, and it is formed by many variables or attributes. Attributes of the micro data table are classified as, [15].

1. Identifiers—This type of attributes are used for identifying a particular person directly. Name of a person, employee identification number are some of the examples of this type.
2. Quasi-identifiers—The combination of attributes that can be connected with external information to re-identify, all or some of the respondents to whom information refers or reduce the uncertainty over their identities. For instance, attributes DOB, ZIP, and SEX are quasi-identifiers: they can be linked to external public information to reveal the name and address of the corresponding respondents or to reduce the uncertainty to a specific set of respondents.
3. Confidential attributes—In micro data table, the attributes which contain the confidential information are called confidential attributes. For instance, in an employee data set the attribute salary and account number are to be considered as confidential.

### *3.2 Classification of Micro Data Disclosure Protection*

There are two types of micro data protection technique. (i) Masking Techniques (ii) Synthetic Techniques

(1) Masking techniques
 The data items found in the confidential attribute are modified to produce new data items. These newly arrived data items are valid for statistical analysis and also preserve the confidentiality of respondents. There are two types of masking techniques (i) Non-perturbative (ii) Perturbative.

 1.1 Non-perturbative—All the data items found in the confidential attribute are not modified, only a portion of the data are suppressed or removed.

It eliminates some details from the original data. Examples of this type are sampling, local suppression, global recoding, top-coding, bottom coding and generalization.

1.2 Perturbative—All the data items found in the confidential attributes are modified in some way. Modifications can formulate distinctive mixtures of values in the original table disappear as well as establish new combinations. Examples of this type are resampling, lossy compression, rounding, PRAM, MASSC, additive noise, Swapping, Rank swapping and Micro-aggregation.

(2) Synthetic data generation techniques

A new set of tuples are generated and it can be replaced with the original tuples in a micro data table. It also preserves the statistical properties of the original data. There are two types of synthetic data generation. (i) Fully synthetic and (ii) Partially synthetic

# 4 Problem Formulation and Proposed Solution

## *4.1 Objective of the Problem*

Consider a database D consists of T tuples $D = \{t_1,t_2,\ldots t_n\}$. Each tuple T has set of attributes ($T = A_1,A_2,\ldots A_m$) where $A_i \in T$ and $T_i \in D$. The sensitive attribute $SA_R$ can be selected from the database D and it can be modified by a data transformation and data transitive masking techniques. After modification, the modified database D' can be released to data mining researchers or any agency or firm for data analysis i.e. applying the data mining techniques such as clustering, classification, etc. in D' and ensure that the results are same as the original database D. In this work, we have applied k-means clustering algorithm to the modified data D' and verified the result.

## *4.2 Proposed Solution*

The steps involved in this work are,

1. Sensitive Attribute Selection
2. Proposed Masking Techniques

   2.1 Data Transformation Technique
   2.2 Data Transitive Technique

3. Existing Masking Technique

3.1 Micro aggregation

4. Applying k-means algorithm for original and the modified data for all the proposed and existing techniques
5. Comparing the results based on the performance factors

## *4.3 Sensitive Attribute Selection*

Identify the sensitive numeric data item in the micro data table. For example, the attributes of an employee database are employee number, employee name, date of birth, salary, account no, qualification, designation and etc.. From these attributes, we have considered the salary and account number are sensitive attributes.

## *4.4 Proposed Masking Techniques*

(1) Data Transformation Technique
The sensitive data items of the micro data table are modified using the data transformation approach.

1. Consider a database D consists of T tuples. $D = \{t_1,t_2,\ldots t_n\}$. Each tuple in T consists of set of attributes $T = \{A_1,A_2,\ldots A_p\}$ where $A_i \in T$ and $T_i \in D$
2. Identify the sensitive or confidential numeric attribute $SA_R$
3. Consider the sensitive attribute $SA_R$, find out the maximum number of digits, $maxD \in SA_R$ and minimum number of digits, $minD \in SA_R$
4. For grouping the same number of digits, find out the number of groups
5. Verify if (maxD = mind) then assign r as 1
   Arrange the entire sensitive data item $\in$ r group only
   Go to step 7
6. Compute $r = (maxD - minD) + 1$
   Arrange all the sensitive data item $\in X_k$ $(k = 1,2,\ldots r)$ groups, according to the number of digits. Check if $(minD \le r \le maxD)$
7. Find the number of items $K_l(l = 1,2,\ldots m)$ in $\forall X_k$ group
   $\forall X_k$ group $(k = 1,2,\ldots r)$
   If number of items $k_l \in X_k = 1$ then no modification
8. Otherwise, if number of items $k_l \in X_k = 2$
   Then transform the value of $k_l$ to T, $k_m$ to $k_{l;}$ and T to $k_m$
   else
9. Assign the value of $k_1$ to T
10. Repeat (for $l = 1$ to m)
    begin
    Assign the value of $k_{l+1}$ to k

end
until ($l > m$)
11. Assign the value of T to $k_m$

(2) Data Transitive Technique
The sensitive data items of the micro data table are modified using the data transitive approach.

1. Consider a database D consists of T tuples. $D = \{T_1, T_2, \ldots T_n\}$. Each tuple in T consists of set of attributes $T = \{A_1, A_2, \ldots A_p\}$ where $A = \{A_1, A_2, \ldots A_p\}$, $A \in T$ and $T \in D$
2. Identify the sensitive or confidential numeric attribute $SA_R . \forall\ SA_R \in A$.
3. Repeat
4. Calculate the length L of all the data items in the sensitive attribute $SA_R$
5. Check if ($SA_{R(i)} = 0$) then

(i) ignore the current data item and select the next data
(ii) go to step 3

6. else calculate the Transitive Value $TR_i$ for all the sensitive data items $SA_{R(i)}$
7 $TR_i = (SA_{R(i)}/L(i))*2$
8. Replace $SA_{R(i)}$ with $TR_i$
9. Increment the value of i
10. until ($i >= n$)
11. End

## 4.5 Existing Masking Technique

(1) Micro Aggregation Technique
Micro aggregation is a statistical disclosure control technique for micro data. In micro aggregation, the sensitive data items are grouped and forms a small clusters. Each cluster should contain at least k records to avoid exposé of individual information. The average values of each cluster are calculated and this average value is the new or modified value of all the data items available in the clusters. Micro aggregation is one of the statistical disclosure control technique for protecting the micro data, so it belongs to the data modification category. The basic concept of micro aggregation is that confidentiality rules in use permit publication of micro data sets if the data items correspond to groups of *k* or more individuals, where no individual controls the group and *k* is a threshold value. Strict application of such secrecy rules guides to changing individual values with values computed on small aggregates (micro aggregates) prior to publication. This is the basic principle of micro aggregation [1].

To obtain micro aggregates in a micro data set with *n* data vectors, these are combined to form *g* groups of size at least *k*. For each variable, the average value over each group is computed and is used to replace each of the original averaged values. Groups are formed using a criterion of maximal similarity. Once the procedure has been completed, the resulting (modified) data vectors can be published [9].

1. Consider a database D consists of T tuples. $D = \{T_1, T_2, \ldots T_n\}$. Each tuple in T consists of set of attributes $T = \{A_1, A_2, \ldots A_p\}$ where $A = \{A_1, A_2, \ldots A_p\}$, $A \in T$ and $T \in D$.
2 Identify the sensitive or confidential numeric attribute $SA_R . \forall\ SA_R \in A$.
3. Get the number of clusters K. where $K = \{k_1, k_2 .. k_n\}$
4. Group the sensitive items in k clusters based on some condition
5. Do
6 Find out the data items in cluster $K_i$ (where $i = 1,2 \ldots n$)
7. Calculate the mean value of all the clusters
8. Replace the mean value with the original data
9. While $(i > = n)$
10. End

## 4.6 K-means Clustering Algorithm

The k-means algorithm for partitioning, where each cluster's center is represented by the mean value of the objects in the cluster Input

- K : the number of clusters
- D : a data set containing n objects

Output: Set of k clusters
Method

(1) arbitrarily choose k objects from D as the initial cluster centers;
(2) Repeat
(3) (re)assign each object to the cluster to which the object is the most similar, based on the mean value of the objects in the cluster
(4) Update the cluster means, i.e. calculate the mean value of the objects for each cluster
(5) Until no change

Apply the k-means clustering for both original and modified data set to get the clusters.

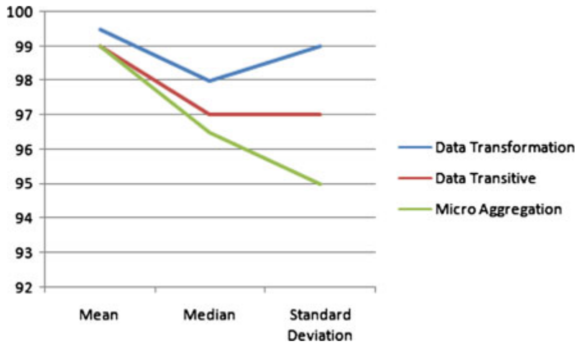



**Fig. 1** Statistical performances

### 4.7 *Comparing the Results*

The performances of the masking techniques data transformation, data transitive and micro aggregation are compared based on the following factors.

(i) Statistical properties
(ii) Privacy protection
(iii) Clustering accuracy.

All these factors are compared with the original and the modified data (from data transformation, data transitive and micro aggregation).

## 5 Experimental Results

In order to conduct the experiments, synthetic employee dataset can be created with 1,000 records. From this dataset, we have selected the sensitive numeric attribute as 'income'. Data transformation, data transitive and micro aggregation perturbative masking techniques are used to modify this sensitive attribute.

### 5.1 *Statistical Performance of the Original Data and Modified Data*

The statistical properties used for calculation are mean, median and standard deviation. These are calculated for both the original as well as the modified data. The sensitive data is modified using all the masking techniques. Comparing the results of statistical properties, the data transformation technique has produced more accurate results than other techniques. This is illustrated in the chart. We have applied different size of data sets for verification (Fig. 1).

**Fig. 2** Privacy protection

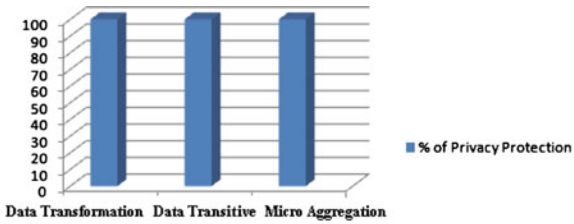
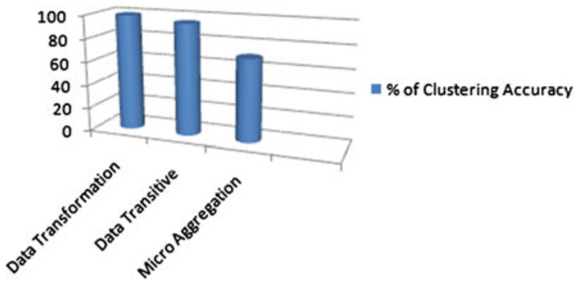



**Fig. 3** Accuracy of clustering algorithm




### *5.2 Privacy Protection*

To perform the privacy protection, we have verified whether all the original data items are modified using the techniques of data transformation, data transitive and micro aggregation or not. From the chart, we have identified that, all the data items are modified and all the three techniques have given 100 % privacy protection (Fig. 2).

### *5.3 Accuracy of k-means Clustering Algorithm*

The percentage of clustering accuracy obtained from the data transformation, data transitive and micro aggregation is given in the chart. From the results, we have noticed that the data items found in the original data item clusters are same as the data item clusters formed by the data transformation approach. Comparing the performance of clustering accuracy, the data-transformation clustering accuracy is better than data transitive and micro aggregation (Fig. 3).

## 6 Conclusion And Future Work

Sensitive data protection and knowledge extraction are very complicated tasks in privacy preserving data mining. In this research work we have used two new techniques data transformation and data transitive. These two techniques are compared with the existing micro aggregation technique. Based on the experimental results, data transformation technique is a good technique for protecting and modifying the sensitive data. After modification, the modified data can be used for mining purposes also. In this work, we have considered for protecting only numerical attributes. In future, we will concentrate on developing new masking techniques for protecting categorical attributes and also applying other data mining techniques.

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# Handling Maintenance Projects with Matrix-Based Methods

**Zsolt T. Kosztyán, Csaba Hegedűs, Judit Kiss and Anikó Németh**

**Abstract** Creating a maintenance plan for production and service processes can be handled as a special area of project planning, because the order of the tasks are negotiable in most cases, but the order of the operations within the tasks are fixed. In this paper we present an expert system which is capable of finding the optimal maintenance plan by applying risk based ranking of the tasks with consideration of time and resource constraints. Estimating reliabilities, theory of stochastic process and expression of measurement uncertainty are also applied and improved in order to handle decision errors and their consequences. The expert system determines when a given task should be accomplished and the time, cost and resource demands of the realization.

## 1 Introduction

In the case of a high number of devices the planning and scheduling of maintenance tasks are very difficult. The reliability of the devices or the risk of its failure must be considered as well as the time, cost and resource constraints.

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In this paper an expert system is introduced that uses the measurement results of the observed characteristics of the processes or devices as input and determines the priority of maintenance tasks. It specifies which operations should be realized in different kinds of maintenance tasks, what maintenance tasks should be realized, how to realize these tasks, how long does the realization take and how many resources these tasks require.

# 2 Background

## *2.1 Reliability- and Risk-Based Ranking of Maintenance Tasks*

According to Reliability-Centered Maintenance (RCM) [1] the maintenance tasks are ranked by the probability of the device failure in the time interval of the maintenance planning. Those devices that have higher failure rates and therefore have lower operating time between failures are given priority and their maintenance tasks are completed first. The order of priority can be more exact if the costs and required time of the inspection and preventive maintenance are compared to the costs and required time of the corrective maintenance and both the material and immaterial loss of the failures. The severity of the failures consequences are weighted by the probability of the failure so the classification and decisions are carried out on a risk base (*RBM* Risk-Based Maintenance) [2].

However, in the measurement of the observed characteristic of a device measurement error must be taken into consideration. A number of our previous papers [3–5] deal with the consideration of uncertainty resulting from the measurement and sampling. The consideration of measurement uncertainty is necessary to make a proper decision. The decision errors result from sampling and measurement uncertainty in the case of the inspection of the degradation of a device.

The costs of decision errors must also be determined. If maintenance is performed before it is required some parts of the productivity will not be fully utilized. The extent and therefore the cost of the unutilized productivity decrease with time. On the other hand if the maintenance is not performed and the device failure occurs beside the breakdown additional costs (health, environmental, economic) might appear. These additional costs are independent from the time of the failure. Therefore there are time dependent and independent costs. The control limit belonging to the minimal total risk can be determined from these costs and probabilities for every point of the time. For the specification of the curve of minimal total risk simulations and analytic calculations have been used.

The process of the observed characteristic can be treated as time series and after the decomposition the next values of the characteristic can be predicted with linear stochastic models. These models predict the next value based on actual and previous values of real process and prediction error. However, this prediction can also contain uncertainty so the lower and upper bound of confidence interval appears below and above the time series. After the validation of the stochastic model it can be used for forecasting. The further ahead we try to forecast the higher the uncertainty will be.

With a given time interval of the maintenance planning we calculate (or determine with simulation) the confidence level for each device with its observed value which just reaches the curve of minimal total risk. With our approach probabilities can be assigned to the devices. These probabilities can be the probabilities of the operation in the time interval of the maintenance planning, or just the opposite, the probability of the failure within this interval. With the consideration of these probabilities (and the costs of consequences) the maintenance plan can be optimized.

## 2.2 Planning and Organizing Maintenance Projects

Realization of maintenance tasks can be regarded as a special maintenance project. However, traditional network planning methods have several deficiencies and throw difficulties in the way of using project planning methods in maintenance. The first shortcoming of network planning methods is the handling of circles. A frequently occurring problem is to realize a task more than once in a project (i.e. diagnose and revise a part of equipment until it works). In spite of the fact that GERT method [6] can handle circles for detecting and managing circles the matrix-based methods give better alternatives.

The other problem is to determine the sequences of the maintenance task. Traditional logic planning methods are hard to use for these projects, because on the one hand the sequence of the operations of a maintenance task can be described with a deterministic logic plan (network plan, Gantt chart etc.). On the other hand, most sequences of maintenance tasks (e.g. repairing different kind of equipments) are independent from each other. This means that the sequence of maintenance tasks can be reversed, or can be ranked by their values of reliability or risk. Since network planning methods cannot be used for ranking maintenance tasks, hereinafter matrix-based methods are introduced. These methods can handle circles and also can be used for ranking maintenance task sequences.

## 2.3 Matrix-Based Project Planning Methods

In case of scheduling production development projects mainly matrix-based methods are used for planning and scheduling. These matrix methods are based on Design Structure Matrix/Dependency Structure Matrix (DSM) methods published by Steward [7]. Tasks of the project are represented in the rows and columns of a matrix. This method can handle the iterations between two tasks, as well. Iterative relation between task *A* and *B* means that the sequence of task *A* and task *B* has to be realized more than once. This relation is the simplest cyclic dependency. The cyclic dependencies are called "Circuits" or "Cycles". Cycles can contain more than two tasks. Detecting cycles is very important in project management, because the iteration can cause the increase of project duration. When using matrix-based methods for project planning one of the most important functions is to determine the sequence of the tasks. If the project plan does not contain cycles the matrix of the project plan can be reordered into an upper triangular matrix and the activity-on-node graph of the project plan can be topologically ordered. This method is called sequencing [8, 9].

Formerly introduced methods show how to use matrix-based methods for project planning. However, DSM matrices can also be used for scheduling [10] and resource allocation [11] or in addition this method can be used for reorganizing the projects [12, 13]. This way duration, cost or resource demands of tasks can be represented in the diagonal or an additional column. Numbers in the off-diagonal cells can show the lags of successors/predecessors [14].

## 3 Methods

Yassine [15] and Tang [16] showed that in case of project planning there could be uncertain relations between two tasks. They introduced a new method called numerical DSM (NDSM), which handle the strength of the relations between two tasks. When using NDSM matrices the level of the dependency of relations between two tasks can be represented. Numbers instead of "X" in NDSM can be used to represent [17] i.e. Dependency Strength. This can be a measure between 0 and 1, where 1 represents an extremely strong dependency. The matrix can now be partitioned by minimizing the sum of the dependency strengths below the diagonal.

Despite the fact that these methods handle the uncertain relations they cannot handle the realization priority of the tasks. Authors have formerly published a Stochastic Network Planning Method (SNPM) [18] for generating all possible project networks. The acronym SNPM alludes to uncertain project networks. Enhanced method of SNPM called Project Expert Matrix (PEM) can handle the uncertain realization of the tasks, as well [19, 20]. Similarly to uncertain relations the uncertain realizations of the tasks can refer to (1) the probability of task realizations; (2) or the otherwise relative importance of task realizations. The uncertainty of the task realizations can be notated in the diagonal of the PEM matrix (see Table 1). The certain task realizations denoted as 1 or "X" in the PEM matrix.

### *3.1 Applying Matrix-Based Project Planning Methods for Organizing Maintenance Projects*

In this chapter we show how to apply previously introduced matrix-based methods for planning and organizing maintenance projects. Maintenance operations (i.e.

**Table 1** Evaluating the project expert matrix

| PEM | NDSM/SNPM | DSM | AoN Network |
|---|---|---|---|
| ↥ A B<br>A X ?<br>B ? | ↥ A B<br>A ?<br>B | ↥ A B<br>A X<br>B | A → B |
| | | ↥ A B<br>A<br>B | A<br>B |
| | ↥ A<br>A | | A |

servicing equipment, evaluating results of diagnostics etc.) usually can be described as a deterministic logic plan (using a task list, Gantt chart etc.). In this case the operations have to be realized in a sequence following the task list. These operations can be represented by a DSM matrix or can be contracted into a maintenance task. However, realization order of maintenance tasks can be determined considering the values of reliabilities and risks. Duration, costs, resources can be assigned to the maintenance tasks.

We developed a method called Maintenance Project Planning and Scheduling (MPPS): Values of risks or reliabilities of equipment can be represented in the diagonal of Project Expert Matrix. These values can be determined as introduced in "Information Security Measurement Roles and Responsibilities." Realized maintenance tasks are categorized by level of risk or reliability. Maintenance tasks with low level risk or low level reliability can be realized within a succeeding project. If the level of risk of a maintenance task is high the probability of realization of this task is also high. This probability is marked as $p$. (In this case $1 - p$ is the probability of leaving out this task from the project. If $p$ is the importance of realization of the task, then $1 - p$ is the value of ignorance). The probable project scenarios can be ranked by their probabilities. The Probability of a project scenario is the geometric average of the probability of realizations (of realized tasks) and probability of ignorance (of non realized tasks). Using a PEM matrix maintenance tasks will be ranked by their realization probabilities.

Similarly, the probability of a project structure can be defined. If two maintenance tasks can be realized both parallelly and in a sequence and the sequential and parallel realization is indifferent, the probability of relation between two tasks can be notated as 0.5. If sequential realization is preferred, probability of relation between two tasks are higher than 0.5 otherwise lower than 0.5. The objective function is to select the most probable project scenario according to the project budget, and the most probable project structure according to the time and resource constraints.

When constructing an aggregated PEM matrix (aPEM) the plan of operations of a maintenance task is an input data and can be described with a DSM matrix or a network plan. These operations can be contracted into different kind of maintenance tasks. The probabilities of task realizations can be determined from the values of reliabilities or level of risks and are represented in the diagonal of the aPEM matrix (see Fig. 1 and Appendix). Maintenance tasks should be ordered by their probabilities of realizations. Preferred sequential and parallel realization can be expressed by the strength of relation between two tasks. According to the budget feasible project scenarios are specified and ranked by the probability of project scenarios. Project scenarios are represented by an SNPM or an NDSM matrix. In this phase we can answer *WHAT* maintenance tasks should be realized in agreement with the project budget. According to the time and resource constraints feasible project structures can be specified and can be ranked depending on the probabilities. In this phase we can answer *HOW* to realize the maintenance tasks. The logic plan of project structures can be represented by a DSM matrix. Duration and resource demands can be represented by a resource sheet. At the end we can also answer *HOW LONG* the maintenance tasks take, *HOW MUCH* are the cost and resource demands.

A project plan is *infeasible* if (time, cost, resource) demands are higher than the project constraints. The optimal project plan is the feasible project plan that possesses the highest probability.

## 3.2 Use of Genetic Algorithms

For determining feasible project scenarios and feasible project structures genetic algorithms can be used in order to decrease the need of computation resources. Genetic algorithms can be used for NP complete or NP hard problems [21] and when optimal solution is determined from the large set of probable/feasible solutions. When using genetic algorithms for project scheduling, the initial population will be the set of probable project scenarios and project structures of a project scenario represented by DSM matrices. Evolution operators (selection, mutation, recombination, etc.) are executed on the entities of the population. In the course of recombination (or crossover) the DSM matrix of the parent entities are split along the antidiagonal and the child entity inherits one half of the fathers DSM and the other half of the mothers DSM. There is an other case of recombination with the probability of 30 %, the child inherit each cell of the parents DSM with equal chance. The mutation operator changes the value of a DSM cell from 0 to 1 or from 1 to 0. The selection is realized by a tournament selector. Every entity has a fitness value. To increase effectiveness, and decrease computation time the fitness value is the combination of probability/importance within the project scenario, resource and time constraints. If the project scenario or project structure is infeasible, the fitness value is 0. Effectiveness of genetic algorithms can be improved if we use distributive architectures (CPUs or computers). For handling the numerous probable solutions and computations we used a promising distributive technology called Compute Unified Device Architecture (CUDA) [22], which distributes computation tasks amongst the Graphical Process Units (GPUs).

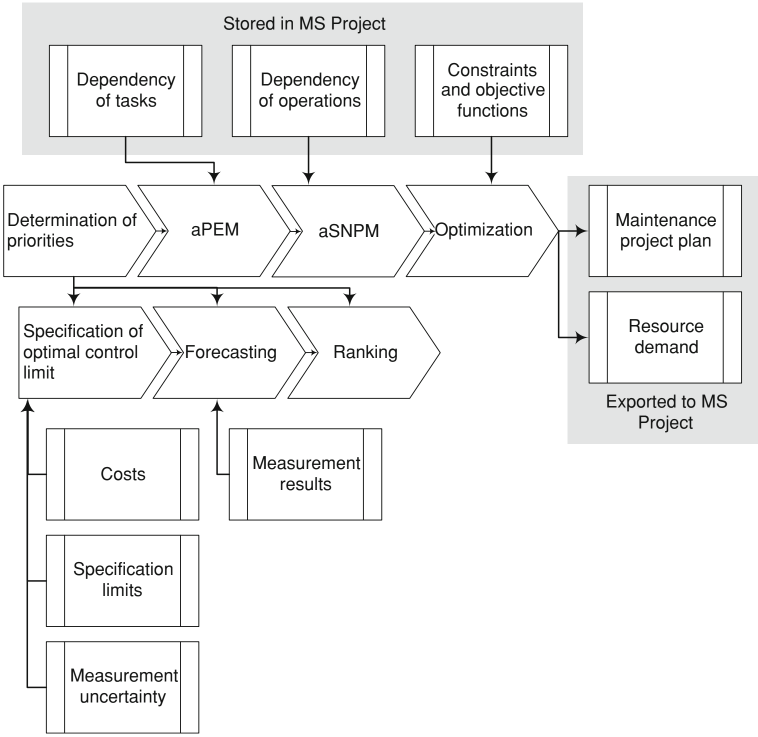



**Fig. 1** The logical structure of the expert system

Genetic algorithms do not surely find the optimal solution however with the help of appropriate fitness function and evolution operators the optimal solution can be approximated. In order to compare various genetic algorithms all possible project scenarios and all possible project structures are ranked, and the most important/the most probable feasible project structures are selected for the test projects. Henceforth, the formerly introduced MPPS method referred to as the naive MPPS method. Using genetic algorithms for this problem is called genetic MPPS method, and using distributed genetic algorithm (applying CUDA) for this problem is called distributive genetic algorithm for Maintenance Project Planning and Scheduling.

During the course of developing we had to write some interface programs between maintenance diagnostic systems and MPPS as well as between MS Project (where the operations of maintenance tasks are) and MPPS. After the genetic algorithm framework finds and ranks the possible project scenarios and structures the interface program exports the optimal project structure to MS Project.

**Table 2** Comparing various maintenance project planning and scheduling methods

| Size of PEM matrices | Runtime of full evaluating algorithm | Runtime of genetic algorithm | Runtime of distributive genetic algorithm |
|---|---|---|---|
| 10 × 10 | 62 ms | 42 ms | 38 ms |
| 20 × 20 | 2.1 h | 493 ms | 451 ms |
| 50 × 50 | 12.2 h | 48 s | 37 s |

## 4 Results

To compare different kinds of methods, different sizes of random PEM matrices are generated, where the number of uncertain tasks and number of uncertain relations can be defined as a percentage of all tasks and possible relations. Duration of the tasks, project budget and 3 different kinds of resource demands of the tasks are generated randomly. In the comparison test the time constraint was specified. This time constraint was the half of the project duration, when all uncertain relation specified to 1. In this case all uncertain relations between tasks were considered as certain dependencies. The resource constraints were half of maximal resource demands, when all uncertain relations are considered as a certain independency and the tasks scheduled for earliest start time. The percentage of uncertain task realizations was 80 of all probable tasks. The percentage of uncertain relations between two tasks was 20 of all possible relations. And the time budget was 15 % lower than all tasks were realized.

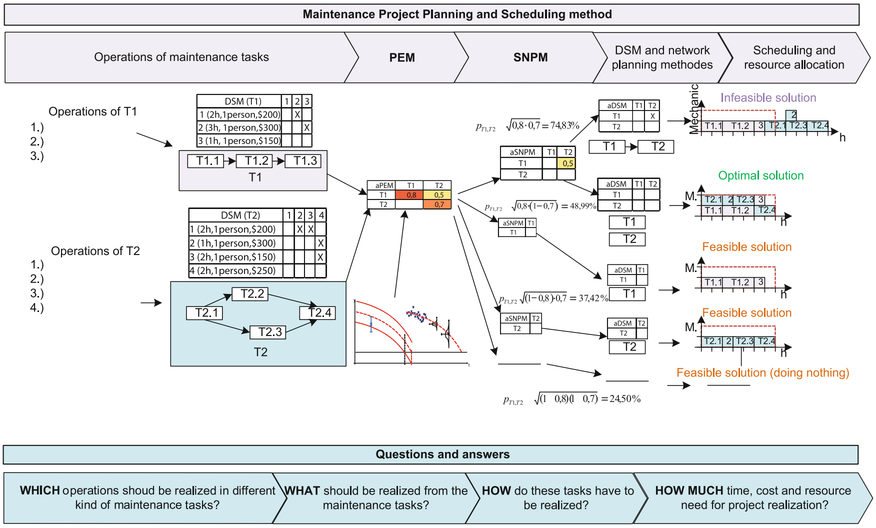
For the comparison of the run time of different kinds of methods it needs to be emphasised that all methods were run in the same computer architecture, which was a Pentium PC, with Intel Core i7-720QM CPU, 6GB RAM, 320 GB HDD. The GPU was the 1GB NVidia GeForce GT 230M. For the implementing distributive genetic algorithms, the CUDA technology was applied. Table 2 shows specifications and the efficiencies of different kind of MPPS methods.

Using genetic algorithms the computation time can be extensively decreased. When the number of tasks is more than 300 naive MPPS cannot be used because the computation time is more than a week. Nevertheless, using genetic algorithms for Maintenance Project Planning and Scheduling, the computation time is less than an hour for 300 tasks (the formerly specified constraints are taken into account).

## 5 Summary

The introduced methods are the results of a four-year research. Taking measurement uncertainty into consideration in maintenance related decision and forecasting is one of the basic concepts of our model. This way maintenance can be planned. With our forecasting method the degradation can be predicted more accurately considering incorrect decision consequences. Using this model the probability of maintenance task realization can be specified and can be used for project planning. The other main concept is using PEM matrix for project planning and scheduling. Since finding the optimal project plan (considering the project constraints) is a combinatorial problem, using genetic algorithms can be applied to decrease computation time extensively. The introduced expert system can interact with project planning applications (like MS Project) and other diagnostic applications.

# Appendix

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# Computer Aided Diagnostic Methods to Forecast Condition-Based Maintenance Tasks

Zsolt Tibor Kosztyán and Csaba Hegedűs

**Abstract** Nowadays, production and service processes rely heavily on computerized supervision. The data provided by these supervisory systems are also crucial for decision-making, involving maintenance and revision. However, these data can include various measurement and sampling errors. Taking measurement uncertainty into consideration the loss can be decreased. In our model the realized (or lost) revenue is treated along with the occurred costs, in order to maximize the profit with the help of analytic calculation and simulations. This paper presents that by treating measurement results as a time series the time of probable failure can be predicted at a given confidence level. The uncertainty of measurement and uncertainty of forecasting can be treated in the same model.

## 1 Introduction

Every measurement has uncertainty that must be defined and expressed in order to make the measurement results explicit [1]. The Guide to the Expression of Uncertainty in Measurement (GUM) proposes methods to evaluate and express this uncertainty in a uniform way. However, GUM does not give any suggestions, how to decide about the conformity of a product or a process on the basis of uncertainty. Following the GUM many studies discussing this problem have been published. Forbes [2] approaches the conformance assessment as a Bayesian-decision, where the costs of wrong decisions are taken into account. Pendrill [3]

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emphasizes that the impact of decisions should be kept to the fore at the specification of maximum permissible errors. To have correct risk calculation the measurement uncertainty must be treated in a probabilistic approach [4]. According to our research and previous studies the consideration of measurement uncertainty has advantages not only in the case when this uncertainty is high [5] but also in cases when the consequences of a decision error (type I or type II) are significant [6]. Treating measurement uncertainty has vital importance in the area of maintenance where the failure of a device can cause the halt of the whole production or service [7].

The studies dealing with measurement uncertainty take only the costs into account and try to minimize them. They oppose the producer's risk and the customer's risk. In our previous paper [8] it has already been shown, with taking revenues into consideration that the two points of view can be integrated, and the producer's profit can be maximized. These revenues also depend on the decisions.

In preventive maintenance based on actual measured values a conclusion is drawn to the future: What will be the next value of the observed characteristic? When will the failure occur? These questions cannot be answered when using fundamental conformity control. Since the measured values are not independent of the previous ones the future values are predictable with the use of time series [9, 10]. However, in the use of time series the measurement uncertainty is not taken into account or it is not separated from the uncertainty, rather treated as part of the white noise.

## 2 Background

According to the methods proposed by the GUM, the uncertainty can be expressed in two ways. On the one hand the measurement uncertainty can be expressed as a probability distribution of measurement results described by the value of standard deviation (standard uncertainty). If the measurement result is obtained from the values of a number of other quantities the standard deviation called combined standard uncertainty. On the other hand, the uncertainty can be described as an interval. The length of the interval calculated as a multiplication of the combined standard uncertainty and a $k$ coverage factor. The value of $k$ determined by the confidence level and the type of the probability distribution function, but it is often specified as 2 or 3 [1, 4]. This approach assumes the symmetry of the probability distribution, but this assumption is not valid in every case. This is why in our model [5, 11] a $k_{\mathrm{LSL}}$ lower and a $k_{\mathrm{USL}}$ upper values were used instead of $k$ and these new altered coverage factors were determined not by the reliability but by the risk of decisions (Fig. 1). In this way instead of measuring points, measuring intervals are taken into consideration between the specification limits. It is an equivalent solution if instead of using intervals new limits (critical values) are set for the decision (Fig. 1). Since the alteration of limits depends on not only standard deviation of measurement uncertainty but also the type of the probability

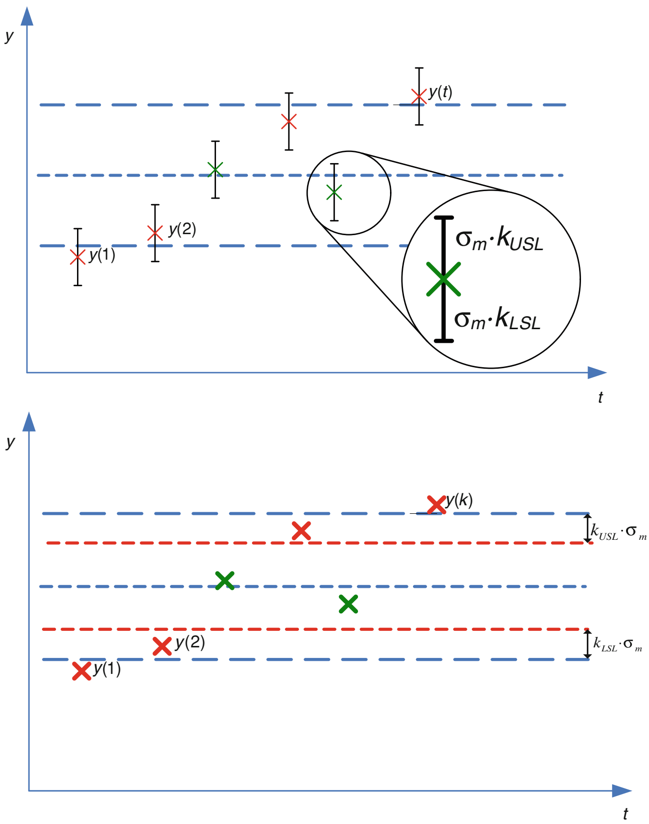


**Fig. 1** Decision-making of adequacy based on measuring intervals instead of measuring points, and the alteration of limits as an equivalent solution

distribution and the consequence of decisions the $K_{\text{LSL}}$ and $K_{\text{USL}}$ correction factors are used subsequently. These factors give the total length and direction of the offset of specifications limits.

The change of the observed characteristic can be analysed in several ways. It can be treated as a sequence of various states identified by artificial neural networks [12] and the probability of transition between two states can be calculated. The actual state of the process of characteristic can be specified based on the measured values of the characteristic and the previous observations. The time interval in the process is in this state and the most probable state into which it switches after that can be determined from the probability of the transitions. If the actual or the most probable subsequent state of the characteristic threats the operation of device or process maintenance is necessary.

There is another way to handle the change of characteristic. Its values are treated as a time series and can be studied in time-domain or frequency-domain. The stationary or quasi-stationary time series can be described with an autoregressive integrated moving average (ARIMA) model [10, 13]. This is the model we combine with the consideration of measurement uncertainty. The ARIMA model is the generalisation of autoregressive moving average (ARMA) model for $d$ ordered integrated process. AR($p$) is the $p$ ordered autoregressive and MA($q$) is the $q$ ordered moving average process. ARMA($p$,$q$) is the combination of AR($p$) and MA($q$) process (see Eqs. 1, 2).

$$A\left(p^{-1}\right)y(k) = C\left(q^{-1}\right)e(k) \tag{1}$$

$$\begin{aligned} &a_0y(k) + a_1y(k-1) + \cdots + a_py(k-p) \\ &= c_0e(k) + c_1e(k-1) + \cdots + c_qe(k-q) \end{aligned} \tag{2}$$

When estimating the orders of ARIMA process we select the simplest significant model, where the coefficients of AR and MA processes are also significant.

# 3 Methods

Monte Carlo simulations and analytical calculations will be used to determine the optimal modification of the control limits based on consideration of measurement uncertainty. Then, this model will be combined with stochastic time series models in order to forecast the future values of the observed characteristic, expected (point of) time of the failure and the risk of failure.

## *3.1 Simulations*

In case of simulation it is assumed, that the probability distribution (with its parameters) of $x$ real value of observed characteristic and probability distribution of $m$ measurement error from the calibration report are known. The decision on the conformity of process, device or product based on $y = x + m$ measured value as a sum of the real value and measurement error. The process is considered as conform if the observed value is between the LSL lower and USL upper specification limit, LSL $\leq y \leq$ USL. If there is only one specification limit, the other limit can be ignored in the model. The process is conforming if the $x$ real value of observed characteristic is between the specification limits, LSL $\leq x \leq$ USL.

Because of the measurement uncertainty four cases can be distinguished as a combination of real conformity and the decision itself (Table 1). If control or maintenance is not required, but the measured value shows the inverse, unnecessary control is done (producer's risk) and decision error type I is made. If the real value of observed characteristic is nonconforming but it is undetected because of the measurement uncertainty (customer's risk) decision error type II is made. Also

**Table 1** Profits influenced by the decisions and the facts

| Profit/loss | | Decision | |
|---|---|---|---|
| | | Maintenance/control is not performed (1) | Maintenance/control is performed (0) |
| Fact | Maintenance/control is not required (1) | $\Pi_{11} = r_{11} - c_{11}$ Appropriate acceptance | $\Pi_{10} = r_{10} - c_{10}$ Inappropriate control |
| | Maintenance/control is required (0) | $\Pi_{01} = r_{01} - c_{01}$ Inappropriate acceptance | $\Pi_{00} = r_{00} - c_{00}$ Appropriate control |

appropriate decisions can be made, if a nonconform process gets controlled or conform process is let run.

In the four cases the $c_{ij}$ costs are different. These costs depend on the number of executed measurement, the cost of production of service or product and the actions in accordance with the decisions. In order to calculate the unrealized profit an alternative decision is made the $r_{ij}$ revenues must also be taken into account beside the costs. So $\pi_{ij} = r_{ij} - c_{ij}$ proportional profits are used to calculate the $\Sigma\Pi$ total profit in reference to decisions:

$$\sum \Pi = q_{11} \times \pi_{11} + q_{10} \times \pi_{10} + q_{01} \times \pi_{01} + q_{00} \times \pi_{00} \tag{3}$$

The $q_{ij}$ number of elements belongs to certain cases calculated in the simulation.

To maximize the expected profit let the decision rules be modified: the process will be treated as conform if $\mathrm{LSL} + K_{\mathrm{LSL}} \leq y \leq \mathrm{USL} - K_{\mathrm{USL}}$ where $K_{\mathrm{LSL}}$ and $K_{\mathrm{USL}}$ the correction factors belong to the LSL and USL. The value of correction factors are calculated in the simulation. These correction factors are not coefficients; they give directly the extent of the alteration of specification limits. If the risk of decision error type II is low the value of correction factor can be negative. In this case the control limits do not become stricter rather wider. Our Monte Carlo simulation searches the value of $K_{\mathrm{LSL}}$ and $K_{\mathrm{USL}}$ that determine the maximum of total profit in reference to decisions.

$$\begin{aligned}\sum \Pi(K_{LSL}, K_{USL}) = {} & q_{11}(K_{LSL}, K_{USL}) \times \pi_{11} + q_{10}(K_{LSL}, K_{USL}) \times \pi_{10} \\ & + q_{01}(K_{LSL}, K_{USL}) \times \pi_{01} + q_{00}(K_{LSL}, K_{USL}) \times \pi_{00} \rightarrow \max\end{aligned} \tag{4}$$

In the maintenance of a device the revenue cannot be interpreted in every case, that is why only costs are used to express consequences. The costs can include the costs of inspection, control and failure or the loss of unutilized productivity. This modification does not alter the structure of model but the value of $r_{ij}$ revenues will be zero.

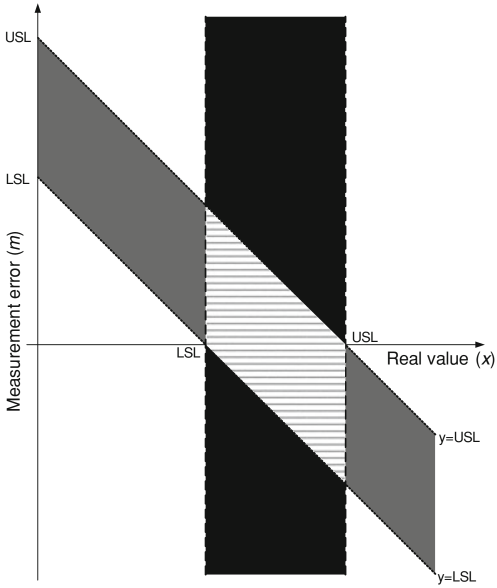


**Fig. 2** The four regions of decision outputs

### 3.2 Analytic Calculation of Risks

Let us assume the probability density function of $x$ real values is $f(x)$, and the probability density function of $m$ measurement error is $g(m)$. Let us assume these two distributions are independent of each other, and the common distribution is calculated as their multiplication. On Fig. 2 the four cases of Table 1 can be seen: the striped parallelogram in the middle is the region of appropriate acceptance bounded by the $y = \mathrm{LSL}$, $y = \mathrm{USL}$, $x = \mathrm{LSL}$ and $x = \mathrm{USL}$ lines. Above and below this parallelogram are the regions of decision error type I (marked with black), on the left and the right side between the $y = \mathrm{LSL}$ and $y = \mathrm{USL}$ lines are the regions of decision error type II (marked with grey). The uncoloured regions belong to the appropriate control.

The control limits and decisions must be modified in order to maximize the profit similarly to the simulation. For the sake of simplicity let the $K_{LSL} = K_{USL} = K$ that is the lower and upper limits are modified to the same extent. If the profits belonging to certain cases are weighted with the probability of occurrence, the profit maximizing objective function is the following:

$$\Pi(K) = \Pi(0) + \Delta\Pi(K) \rightarrow \max \tag{5}$$

The $\Pi(0)$ is the expected profit without any modification ($K = 0$) and the $\Delta\Pi(K)$ is the increase (or decrease) of the expected profit as a function of $K$. The $\Pi(K)$ is similar to risk, because a probability is multiplied with consequence in terms of money. Because of the negative implications of risk, we use the term of

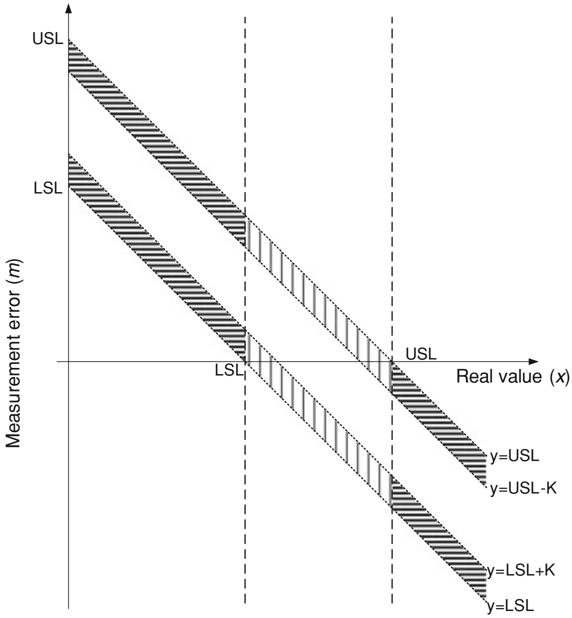


**Fig. 3** The modification of the specification limits. The vertically striped regions are the increase of decision error type I and the horizontally striped regions are the decrease of decision error type II if the value of $K$ is positive

expected profit. To maximize the expected profit it is sufficient to maximize $\Delta\Pi(K)$ (Fig. 3):

$$
\begin{aligned}
\Delta\Pi(k) = (\pi_{00} - \pi_{01}) \int_{-\infty}^{LSL} \left[ \int_{LSL-x}^{LSL+K-x} f(x)g(m)dm + \int_{USL-K-x}^{USL-x} f(x)g(m)dm \right] dx \\
+ (\pi_{10} - \pi_{11}) \int_{LSL}^{USL} \left[ \int_{LSL-x}^{LSL+K-x} f(x)g(m)dm + \int_{USL-K-x}^{USL-x} f(x)g(m)dm \right] dx \\
+ (\pi_{00} - \pi_{01}) \int_{USL}^{\infty} \left[ \int_{LSL-x}^{LSL+K-x} f(x)g(m)dm + \int_{USL-K-x}^{USL-x} f(x)g(m)dm \right] dx \to \max
\end{aligned}
\tag{6}
$$

At those devices, where degradation appears and there is a trend in the observed characteristic it is sufficient to take into consideration only the specification limit to the trend tends. In those cases when the observed characteristic must not exceed the limit of one minimum or one maximum value, this limit must be taken into consideration in the course of decision making. If there is only LSL the regions belong to $\Delta\Pi(K)$ are similar to the region in Fig. 4.

All the points above the $y = \text{LSL} + K$ line are in the accepting region but only the points right to the $x = \text{LSL}$ vertical line are actually conform. Under the $y = \text{LSL} + K$ line the maintenance is executed, but it should be done only if $x < \text{LSL}$. The increase of profit is calculated with the (7).

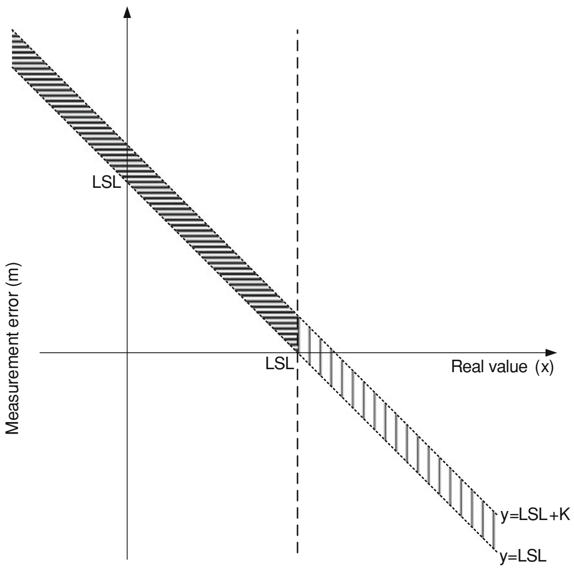


**Fig. 4** The region of $\Delta\Pi(K)$ in case of only LSL exists

$$\Delta\Pi(k) = (\pi_{00} - \pi_{01}) \int_{-\infty}^{LSL} \int_{LSL-x}^{LSL+K-x} f(x)g(m)dmdx + (\pi_{10} - \pi_{11}) \int_{LSL}^{\infty} \int_{LSL-x}^{LSL+K-x} f(x)g(m)dmdx \to \max \tag{7}$$

## 3.3 Forecasting

If degradation occurs at a device the process of observed characteristic of the device has a trend. In case of trend it is suitable to handle the process as a time series. In order to treat the time series of observed characteristic with linear stochastic models the time series must be decomposed. The trend shows the expected value of the characteristic. The uncertainty of this forecast derived from the random variation of real value, the frequency of sampling, the sample size and the time interval of forecast. If the intervals between the samplings are equal the width of the confidence interval of the trend is constant. The lower and upper bound of confidence interval parallel to the trend. At a given confidence level the width of confidence interval can be decreased if the sampling frequency is increased when the trend come closer to the LSL. Increasing the frequency of sampling the length of the confidence interval of forecasting will decrease. The length of the confidence interval (for a given significance level $\alpha$) can be calculated as follows:

$$INT_{1-\alpha} = \bar{y} \pm t_{1-\alpha/2} \times \frac{\sigma}{\sqrt{n}} \times \sqrt{1 - \frac{n}{N}} \tag{8}$$

where $n$ is the size of the sample, $N$ is the number of the elements of the whole population, $\sigma$ is the uncertainty expressed as a standard deviation and $t$ is the value of Student-$t$ distribution that belongs to the confidence level of $1 - \alpha/2$

After the decomposition we identify the stochastic process best fitting to the real process. Once we have identified a particular model we need to estimate the parameters and assess how well the model fits. After the validation of the stochastic model it can be used for forecasting. This model predicts the next value on the basis of actual and previous values of real process and prediction error. The further we try to forecast the higher the uncertainty will be.

We simulate or estimate the optimal control limit with the methods showed in Sects. 2.1 and 2.2. This limit is not a constant it changes with the time. If maintenance is performed before it is required (decision error type I) some parts of the productivity will not get utilized. The extent and therefore the cost of the unutilized productivity decrease with time. On the other hand, if the maintenance is not performed and device failure occurs beside the breakdown additional costs (health, environmental, economic) might appear. These additional costs are independent from the time of the failure. Therefore there are time dependent and independent costs. The control limit belonging to the minimal total risk can be determined from these costs and probabilities for every point in time. For the specification of the curve of minimal total risk simulations and analytic calculations have been used.

The following measurement must be performed there, where the confidence interval of forecast intersects the control limit (belonging to minimal total risk) ($t_{M1}$) (see Fig. 5). Until this point failure will not occur in the process with the confidence level of forecast. With the new measurement result the decomposition, identification, estimation of parameters and forecast will be executed again. These steps are performed iteratively ($t_{M2}$, $t_{M3}$) until the cost of the next measurement exceeds the profit earned from the utilisation of productivity between the two measurements. At this point maintenance is required as opposed to measurement.

In all the three cases—simulations, analytical calculations and forecast—the required data can be obtained from the general processes of a production system. The measurement results can be imported from the diagnostic system, the probability density function of measurement uncertainty come from or can be calculated from the calibration data or from the repeatability and reproducibility inspection. The cost and revenues of the four decision outcomes derived from the controlling or ERP system. After our application specifies the optimal control limits with numerical analysis or Monte Carlo simulation and the identification of the time series, the control limits and the time of the next sampling can be exported to the production planning or control system.

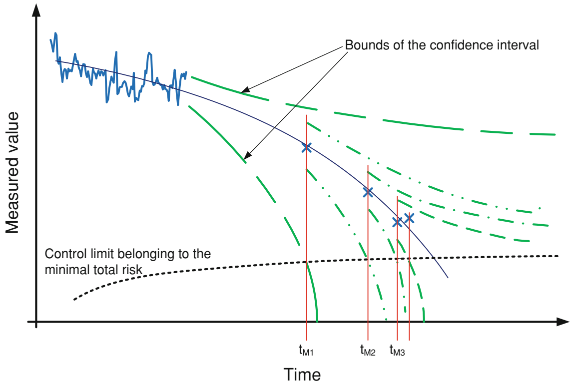


**Fig. 5** The intersections of confidence intervals and curve of minimal total risk determine the time of measurements

## 4 Results

We did the simulations and calculations to different types of distributions: like continuous uniform, triangle and normal distributions (Table 2). There was only a lower specification limit; LSL = 52. Two cases were considered: in the first case the loss of decision error type II $(\pi_{01} - \pi_{00})$ was much (15 times) higher than the loss of decision error type I $(\pi_{10} - \pi_{11})$. In the second case, the loss of decision error type II was only twice as high as the loss of decision error type I. (If the rate of these losses are below 1 then the corrective maintenance is more efficient than the preventive maintenance.) Two relative costs were calculated:

$$c_{sim}\left(K_{opt}^{sim}\right) = \frac{C_{sim}\left(K_{opt}^{sim}\right)}{C_{sim}(0)} \times 100 \tag{9}$$

$$c_{calc}\left(K_{opt}^{calc}\right) = \frac{C_{calc}\left(K_{opt}^{calc}\right)}{C_{calc}(0)} \times 100 \tag{10}$$

The $K_{opt}^{sim}$ is the optimal correction factor determined by simulations; the $C_{\mathrm{sim}}(K_{opt}^{sim})$ is the total cost in $K_{opt}^{sim}$. The $K_{opt}^{calc}$ and $C_{\mathrm{calc}}(K_{opt}^{calc})$ the optimal correction factor and minimal total cost calculated analytically.

In the case of forecast the curve of minimal total risk in reference to decisions was determined by simulations. The time series of the process could be decomposed to a trend and random effects according to the initial measurement. The trend decreased exponentially. The $y_{\mathrm{T}}$ was the value of the trend at the $t$th measurement without random effect.

$$y_T = 2810 - 233.58 \times \exp(0.0021 \times t) \tag{11}$$

The ARIMA(1,1,1) process was the identificated stochastic process that described the random effect in the real process. The parameters of ARIMA(1,1,1) are in Table 3.

**Table 2** The results of the simulations and analytical calculations

| Distribution of real values | Distribution of measurement uncertainty | $\frac{\pi_{01}-\pi_{00}}{\pi_{10}-\pi_{11}}$ | $K_{opt}^{sim}$ | $K_{opt}^{calc}$ | $c_{\text{sim}}(K_{opt}^{sim})$ (%) | $c_{\text{calc}}(K_{opt}^{calc})$ (%) |
|---|---|---|---|---|---|---|
| uniform (50,70) | uniform (−3,3) | 15 | 2.6250 | 2.6393 | 26.08 | 26.14 |
| | | 2 | 0.9798 | 0.9986 | 95.93 | 95.96 |
| Triangle (50,60,70) | Uniform (−3,3) | 15 | 1.9693 | 2.1890 | 68.21 | 68.01 |
| | | 2 | −1.6469 | −1.4563 | 79.09 | 78.39 |
| Normal (60,4.0825) | Uniform (−3,3) | 15 | 1.9745 | 1.8341 | 66.34 | 66.28 |
| | | 2 | −1.1109 | −0.9758 | 90.24 | 89.46 |
| Uniform (50,70) | Triangle (−3,0,3) | 15 | 1.9484 | 1.9425 | 29.81 | 29.81 |
| | | 2 | 0.4468 | 0.5038 | 93.14 | 93.00 |
| Triangle (50,60,70) | Triangle (−3,0,3) | 15 | 1.3543 | 1.4005 | 58.89 | 58.15 |
| | | 2 | −0.3438 | −0.2383 | 97.68 | 96.55 |
| Normal (60,4.0825) | Triangle (−3,0,3) | 15 | 1.3264 | 1.2106 | 57.72 | 57.27 |
| | | 2 | −0.1441 | −0.1947 | 98.95 | 97.19 |
| Uniform (50,70) | Normal (0,1.2247) | 15 | 1.8698 | 1.8870 | 32.44 | 32.32 |
| | | 2 | 0.5182 | 0.4801 | 93.20 | 93.19 |
| Triangle (50,60,70) | Normal (0,1.2247) | 15 | 1.3016 | 1.1185 | 58.79 | 55.21 |
| | | 2 | −0.2738 | −0.3504 | 97.83 | 97.70 |
| Normal (60,4.0825) | Normal (0,1.2247) | 15 | 1.2436 | 1.2546 | 58.18 | 58.08 |
| | | 2 | −0.1438 | −0.1770 | 99.21 | 98.96 |

**Table 3** The parameters of ARIMA model

| Parameters | | Estimate | SE | t | Significance |
|---|---|---|---|---|---|
| Constant | | 0.043 | 0.302 | 0.141 | 0.888 |
| AR | Lag 1 | 0.682 | 0.043 | 15.994 | 0.000 |
| Difference | | 1 | | | |
| MA | Lag 1 | 0.903 | 0.025 | 35.828 | 0.000 |

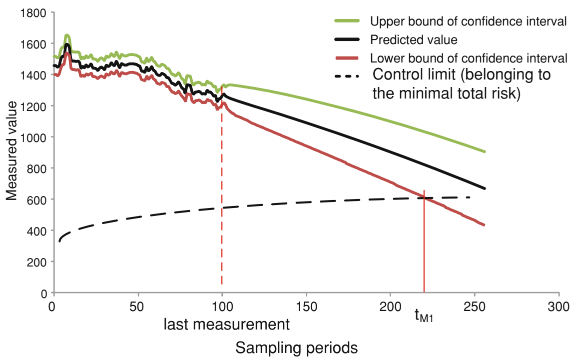


**Fig. 6** Forecast of the time of the next measurement

The confidence interval of forecast intersects the curve of minimal risk in the $t_M$ point (Fig. 6). This is the latest point in time the measurement must be performed. The interval between the last measured point and $t_M$ corresponds to 120 measurement interval.

## 5 Summary

In this paper a uniform model that treats the customer's risk along with the producer's risk was presented. This model gives the optimal control limit of the process that minimizes the total risk associated with the decisions and maximizes the related profits. It can treat both kinds of the processes that have either only one or two specification limits. The optimal control limit influenced by the risks can be determined by Monte Carlo simulation or analytical calculation. If the process can be forecasted our model gives the latest time when the next measurement must be performed, to minimize the cost of measurement but avoid threatening the operation of the device or production process. Until this time control is not necessary at a given level of confidence.

The further goal of our research is to develop this model to give the optimal control limit and time of linked devices on the basis of joint reliability and total cost of consequences.

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# On Numerical Approach to Stochastic Systems Modelling

**Eimutis Valakevicius and Mindaugas Snipas**

**Abstract** The paper considers the problem of representing non-Markovian systems that evolve stochastically over time. It is often necessary to use approximations in the case the system is non-Markovian. Phase type distribution is by now indispensable tool in creation of stochastic system models. In the paper is suggested a method and software for evaluating stochastic systems approximations by Markov chains with continuous time and countable state space. The performance of a system is described in the event language is used for generating the set of states and transition matrix between them. The example of a numerical model is presented.

## 1 Introduction

A problem in system modeling having a wide range of important practical applications arises when the system is inherently stochastic and complete statistical description is not known. In order to evaluate system performance a mathematical model must be developed. As the system is random in nature, a statistically based model is required.

Stochastic system models are often based on continuous-time Markov processes. Markov chains are commonly used for stochastic systems modeling.

However, some important aspects of system behavior cannot be easily captured in a Markov model. Very often some, the life-times distributions connected with a system are simply not exponential. For example, electronic component failure

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times often approximately follow a Weibul or lognormal distribution [1]. When an exponential distribution is both unrealistic and unsatisfactory for representing life-time distribution then the usual approach is to use the "method of (exponential) stages" [2–6]. This method is both general and compatible with definition of Markov processes. It is general in what we can represent arbitrary distributions arbitrary closely. It is compatible with Markov processes because the only memory introduced is the distribution stage to accommodate this additional memory we merely refine our state definition.

It is known that creation of analytical models requires large efforts. Use of numerical methods permits to create models for a wider class of systems. The process of creating numerical models for systems described by Markov chains consists of the following stages: (1) definition of the state of a system; (2) definition of the set of events that can occur in the system; (3) generating the states of the system and infinitesimal generator matrix; (4) creating equations describing Markov chain; (5) computation of stationary probabilities of Markov chain; (6) computation of the performance measures of the system. The most difficult stages are obtaining the set of all the possible states of a system and transition matrix between them. In the paper is used a method for automatic construction of numerical models for systems described by Markov chains with a countable space of states and continuous time.

To construct a model we need to describe the performance of a stochastic system in the event language [7–9]. It allows automating some stages of the model. The created software in C++ generates the set of possible states, the matrix of transitions among states, constructs and solves equilibrium equations to find steady state probabilities.

## 2 Description of the Behavior of a Stochastic System by Markov Processes

Consider a stochastic system with a random state vector at time *t*.

$$Y(t) = (Y_1(t),\ Y_2(t), \ldots, Y_m(t)),$$

where $Y_i(t)$, $i = \overline{1, m}$ are discrete random variables. Assume that the system can change a state at any time. If all the life-times connected with a system have exponential distribution, the process is Markovian and standard methods yield a set of ordinary linear differential equations to determine the behavior of the process and a set of simple linear equations to determine the equilibrium distribution, if one exists. Examples of life-times are the service-times in a queue, the intervals between the arrivals of successive customers in a queue, the division times of bacteria, and so on. Markov modelling is a common approach to analyzing the performance of various stochastic systems.

Thus, many real world systems can be modeled by Markov chain $\{Y(t), \quad t \geq 0\}$ with countable space of states and continuous time. Let us denote by$B = \{S_j, \quad j \geq 1\}$, where $S_j = (y_{1j}, y_{2j}, \ldots, y_{mj})$ the state space and by $P\{Y = S_j\} = \pi_j, \quad j \geq 1$ the probability of $j$-th state. The steady state probabilities can be calculated by solving the following system of equations

$$v_j \pi_j = \sum_{k \neq j} \pi_k \lambda_{kj}, \quad S_j \in B$$

where $\sum_{S_j \in B} \pi_j = 1$, $\lambda_{kj}$ is a transition rate from state $k$ to state $j$ and $v_i = \sum_{j \neq i} \lambda_{ij}, \quad S_i \in B$. Based on the calculated probabilities, we can compute a wide range of relevant performance characteristics of system under investigation.

Formally a system can be depicted by the relation $S = \{X, R\}$, where $X = \{X_1, X_2, \ldots, X_n\}$ is the set of input elements into the system; $R$ -describes the behavior of the system, restrictions and control. To describe the performance of the system we need know the mechanism of input-output. In other words, for given $X$ and $R$ we need to find the vector$Y = \{Y_1, Y_2, \ldots, Y_m\}$, i.e., to know the depiction$f : \{X, R\} \to Y$, i.e., for given $\{X, R\}$ it is possible to calculate$Y$, if the depiction $f$ is known. In such a way we can describe as deterministic as stochastic systems. For deterministic systems given$X$, $R$ and $f$ the output vector $Y$ is obtained with probability one. For stochastic systems the output vector $Y$ is a random value with distribution $P(Y = (y_{1j}, y_{2j}, \ldots, y_{mj}) | X, R, f) = \pi_j, j = 1, 2, \ldots$, if the random value $Y$ is discrete.

Assume, that a system works in stationary mode and states of the system change by influence of $n$ events stream. The interval $X_i$ between two successive events is a random variable with distribution function $G_i(x), \quad i = 1, n$. So the set of input elements $X = (X_1, X_2, \ldots, X_n)$ consists of random variables. The output is a system state $Y = (Y_1, Y_2, \ldots, Y_m)$. We now turn our attention to systems with non-Markovian event processes. In the absence of the memoryless property, we must also "remember" the residual lifetimes of all events. Let the observed current state be $Y$, with a feasible event set $E(Y)$. Each event $e_j \in E(Y)$ has a clock value (residual lifetime)$Z_j$. Then, the probability that the triggering event is some $e_j$ is given by the probability that event has the smallest clock value among all events in $E(Y)$:

$$P(e_j) = P\left[Z_j = \min_{e_i \in E(Y)} \{Z_i\}\right].$$

To determine this probability, we generally need information on the random variables$Z_j$. It is only in the case of Markov chains the memoryless property allowed us to obtain:

$$P(e_j) = \frac{\lambda_j}{\Lambda(Y)},$$

where $\lambda_j$ is the exponential rate of event $e_j$ and

$$\Lambda(Y) = \sum\nolimits_{e_i \in E(Y)} \lambda_i$$

In this case, no information on the random variables $Z_j$ is needed.

Let $e_1, e_2, \ldots, e_k$ be collection of exponential events with a common fixed rate, which we intend to use as "building blocks". Then, we may define a new event $e$, as occurring only after all events $e_1, e_2, \ldots, e_k$ have occurred in series, one immediately following the other. By adjusting the number $k$ of building blocks used, we can expect to generate a variety of events $e$ with different lifetime characteristics. Alternatively, we may define $e$ as occurring only after some event $e_i$, $i = 1, \ldots, k$, has occurred, where $e_i$ is chosen randomly with probability$p_i$. Again, by adjusting the probabilities $p_i$ and the number $k$, we should be able to generate different event processes. In this way, we decompose an event $e$ into stages, each stage represented by Building block event $e_i$. The idea here is to preserve the basic Markovian structure (since all building-block events are Markovian). At the expense of larger state space (since we will be forced to keep track of the stage the system is in, in order to be able to tell when $e$ does in fact occur). The suggested method of constructing distribution is called the phase-type distribution or a mixture of exponential distributions.

A popular approach in mapping a general probability distribution, $G$, into a phase type (PH) distribution, $P$, is to choose $P$ such that some moments of $P$ and $G$ agree. To obtain accurate results, it is desirable to match as more as possible moments of the input distribution $G$ by $P$. Matching more moments may be possible if we are allowed to use many exponential distributions (phases). However, the use of many phases in the PH increases the complexity of the Markov chain, and makes its analysis hard. Matching many moments using a small number of phases may be possible if we are allowed to use unbounded computational resources or if we limit the class of input distributions. However, these limitations are not desirable. Achieving all the four desirable properties is the challenge in designing a moment matching algorithm [3]:

1. It is desirable that more moments of the input distribution, G, and matching PH distribution, P, agree.
2. It is desirable that P have a small number of phases.
3. It is desirable that the algorithm be defined for a broad class of input distributions.
4. It is desirable that algorithm have short running time.

The general approach in designing moment matching algorithms in the literature is to start by defining a subset $S$ of PH distributions, and then map each input distribution into a distribution in $S$.

Let us given $m$ non-intersected sets (building blocks)

$$A_k = \left\{ p_i^{(k)},\ \ \mu_i^{(k)} e^{-\mu_i^{(k)} x},\ \ i = \overline{1, n_k} \right\},$$
$$\sum_{i=1}^{n_k} p_i^{(k)} = 1, \quad k = \overline{1, l}\ ,$$

where $\mu_i^{(k)} e^{-\mu_i^{(k)} x}$- exponential probability distribution. From the sets $A_k$ , $k = \overline{1, l}$ we can construct the desired structure of exponential stages. The Laplace transform gives some function $F(s)$. It is shown that the poles of the function may be complex numbers. Since $F(s)$ is always real then the complex poles must be present in conjugated pairs and real parts of the poles must be negative. Then despite of the fact that $\{\mu_i\}$ are complex, it may be formally possible to investigate the process as Markovian [10].

To find the unknown parameters of exponential stages we need to solve the system of equations. Equating the first initial moments $v_i$ of the original $G(x)$ and the approximating density

$$v_i = (-1)^i F^{(i)}(s)|_{s=0} \ \ , i = 1, 2, \ldots, j.$$

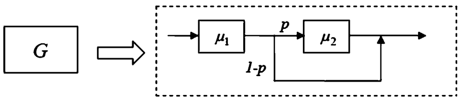
and adding the condition of the zero initial moments equality to 1, we receive a system of nonlinear algebraic equations for the unknown parameters determination; $j$ is the number of unknown parameters.

Let us that life-time $T$ has a general probability distribution function $G$ $(t)$. Useful approximation can be obtained by the mixture of exponential (phase-type) distributions [9]. Suppose that $ET = m$ and $DT = \sigma^2$. The function $G$ $(t)$ approximate by the distribution of a random variable represented as

$$X = \begin{cases} X_1 + X_2 & \text{with probability} \quad p, \\ \mathrm{X}_1 \quad \text{with probability} & 1 - p, \end{cases}$$

where $X_1$ and $X_2$ are independent random variables having exponential distributions with respective means $1/\mu_1$ and $1/\mu_2$.In words, the life-time $X$ first goes through an exponential phase$X_1$ and next it goes through a second exponential phase $X_2$ with probability $p$ or it goes out with probability 1-$p$.

Approximation of general distribution $G$ using phase-type distribution is depicted in figure below




The distribution function of variable $X$ is given by

$$F(x) = 1 - e^{-\mu_1 x} + \frac{p\mu_1}{\mu_2 - \mu_1}(e^{-\mu_2 x} - e^{-\mu_1 x}),$$

where

$$\mu_{1,2} = \frac{1}{(v^2+1)m} \pm \frac{\sqrt{2v^2+1}}{(v^2+1)m} \cdot i, p = 1,\ i^2 = -1,\ v^2 = \frac{\sigma^2}{m^2},\ \text{if } v^2 < \frac{1}{2}$$

and

$$\mu_1 = \frac{2}{m},\ \mu_2 = \frac{1}{mv^2},\ p = \frac{1}{2v^2},\ \text{if } v^2 \geq \frac{1}{2}.$$

After approximation we get a new system, isomorphic to the original system. So we can expand the class of stochastic systems which are possible to model by Markov chains.

It is known that creation of analytical models requires large efforts. Use of numerical methods permits to create models for a wider class of systems. The process of creating numerical models for systems described by Markov chains consists of the following stages: (1) definition of the state vector $Y = (Y_1, Y_2, \ldots, Y_m)$; (2) the set of events $E = (e_1, e_2, \ldots, e_k)$ which may occur in the system; (3) creating equations describing Markov chain; (4) computation of stationary probabilities of Markov chain; (5) computation characteristics of the system performance. The most difficult stages are obtaining the set of all the possible states of a system and transition matrix between them.

## 3 Example

Apply the described technique to construct a model of a queuing system with priorities.

Consider the system $S = \{X, R\}$ with the depiction

$$\begin{aligned}
&f : \{X, R\} \to Y,\\
&X = (X_{1j};\quad X_{2j},\ j = \overline{1,k});\\
&R = \left(NPRP;\ Q \leq l_j,\ j = \overline{1,k};\ FCFS\right);\\
&Y = (Y_1, \cdots, Y_{k+2}),
\end{aligned}$$

where the random variables $X_{1j}$ describe the input flows of customers with preemptive priorities and $X_{2j}$–respective service times.

The stochastic system is the queuing system with only one service node. The waiting rooms in queues $Q_j$ are restricted by numbers$l_j$. The inputs of customers are Poisson $M(\lambda_j)$ with rates $\lambda_j,\ j = \overline{1,k}$ and respective service times are distributed by the following deterministic distribution functions

$$D_j(x) = \begin{cases} 0, & x \leq d_j, \\ 1, & x > d_j. \end{cases}$$

The service strategy is *FCFS* (first come first service)

Approximate the distribution functions $D_j(x)$ by the functions

$$G_j(x) = 1 - e^{\mu_1^{(j)}x} + \frac{p\mu_1^{(j)}}{\mu_2^{(j)} - \mu_1^{(j)}}\left(e^{\mu_2^{(j)}x} - e^{\mu_1^{(j)}x}\right).$$

where

$$p = 1; \quad \mu_1^{(j)} = \frac{1}{d_i} + \frac{1}{d_i}\cdot i; \quad \mu_2^{(j)} = \frac{1}{d_i} - \frac{1}{d_i}\cdot i, \quad i^2 = -1.$$

The performance of the queuing system can be described by Markov process with countable state space and continuous time.

The set of possible events in the system is the following:

$$E = \left\{e_{1j}, j = \overline{1,k},\ e_2,\ e_3\right\},$$

where

$e_{1j}$ arrived the a customer from $j$th flow, $j = \overline{1,k}$;
$e_2$ a customer is served in the first phase;
$e_3$ a customer is served in the second phase

The state of system is

$$Y = \left\{Y_j, j = \overline{1,k}, Y_{k+1}, Y_{k+2}\right\},$$

where$Y_j$- the number of customers from $j$th flow;

$$Y_{k+1} = \begin{cases} 0, & \text{if the system is empty,} \\ \text{j}, & \text{if the customer is served from the jth flow,} \end{cases}$$

$$Y_{k+2} = \begin{cases} 0, & \text{if the system is emty,} \\ 1, & \text{if the customer is served in the first phase,} \\ 2, & \text{if the customer is served in the second phase;} \end{cases}$$

The number $N$ of all the possible states in the system is equal to

$$N = 2k\prod_{i=1}^{k}(l_i + 1) + 1.$$

Denote by $\pi_i$ , $i = \overline{1,N}$ the steady state probabilities of the states; $L_q^{(j)}$ the average number of customers in $j$th queue; $W_q^{(j)}$ the average waiting time in $j$th queue. The denoted performance characteristics of the system are calculated by the formulas:

$$L_q^{(j)} = \sum_{y_j=1}^{l_j} \sum_{y_1,\ldots,y_{k+2}} y_j \pi\big(y_1,\ldots,y_j,\ldots,y_k,y_{k+1},y_{k+2}\big),$$
$$W_q^{(j)} = L_q^{(j)}/\lambda_j, \quad j = \overline{1,k},$$

If the waiting rooms are not bounded then the same characteristics may be computed analytically by the formulas [7]:

$$W_q^{(j)} = \frac{\sum_{m=1}^{k} \lambda_m \big(E_m^2(t) + \sigma_m^2(t)\big)}{2(1 - S_{j-1})(1 - S_j)};$$

$$L_q^{(j)} = \lambda_j W_q^{(j)},$$

$$S_0 \equiv 0, \quad S_j = \sum_{i=1}^{j} \rho_i < 1, \quad \rho_i = \lambda_i E_i(t), \quad j = \overline{1,k}.$$

$E_j(t)$ and $\sigma_j^2(t)$ are the service time means and dispersions.

The system was modeled with the following parameters:

$$k = 2, \quad \lambda_1 = 4, \quad \lambda_2 = 3,$$
$$d_1 = 10^{-1}, \quad d_2 = 9^{-1}, \quad l_1 = 7, \quad l_2 = 11.$$

For computing the performance characteristics the complex probabilities were used.

The results of numerical model are the following:

$$L_q^{(1)} = 0{,}25674, \quad L_q^{(2)} = 0{,}72127,$$
$$W_q^{(1)} = 0{,}064185, \quad W_q^{(2)} = 0{,}2404233.$$

The results of analytical model are such:

$$L_q^{(1)} = 0{,}25679, \quad L_q^{(2)} = 0{,}72132,$$
$$W_q^{(1)} = 0{,}0641975, \quad W_q^{(2)} = 0{,}24044.$$

## 4 Summary

The results showed that a non-Markovian queuing system with infinite number of states can be approximated by Markovian model with finite number of states with required accuracy. The complex probabilities may be used.

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# An Advanced DSS for Classification of Multiple-Sclerosis Lesions in MR Images

**I. De Falco, M. Esposito and G. De Pietro**

**Abstract** The use of Magnetic Resonance as a supporting tool in the diagnosis and monitoring of Multiple Sclerosis and in the assessment of treatment effects requires the accurate classification of cerebral white matter lesions. In order to support neuroradiologists in this task, this paper presents an advanced Decision Support System devised to: (i) encode the expert's medical knowledge in terms of linguistic variables, linguistic values, and fuzzy rules; (ii) implement a fuzzy inference technique able to best fit the expert's decision-making process to identify MS lesions; (iii) employ an adaptive fuzzy technique to tune the shapes of the membership functions for each linguistic variable involved in the rules. The performance of the DSS is quantitatively evaluated on 120 patients affected by MS.

## 1 Introduction

Multiple Sclerosis (MS) is an autoimmune inflammatory disease of the central nervous system, and it is characterized by multiple demyelinated lesions involving the brain and spinal cord, that interrupt communications between the nerves and the rest of the body. Recently, magnetic resonance imaging (MRI) has been

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applied as supporting tool in MS diagnosis, enabling the visualization of cerebral MS lesions and as monitoring tool both in the course of MS and in the assessment of treatment effects. The use of MR images as MS marker requires the expert's knowledge and intervention to classify MS lesions; nevertheless, manual classification is a very thorny and time-consuming task due to the huge amount of MR images to be examined and the variable number, size, and spatial distribution of MS lesions per image.

In this respect, Fuzzy Logic [1] has widely demonstrated its capability for classification in different medical problems, such as the classification of benign and malignant nuclei in cytological images [2], the classification of risk for aspiration [3] and cardiac arrhythmia [4], the diagnosis of myocardial infarction [5], and so on. Such a popularity is due to the fact that Fuzzy Logic represents a formalism suitable to deal with the imprecision intrinsic to many medical problems, so as to offer a more realistic and acceptable interpretation for the medical inference.

This paper proposes an advanced decision support system (DSS) devised to automatically support neuroradiologists in the classification of a type of MS lesion, i.e. white matter lesion (WML). Such a DSS is aimed at: (i) encoding the medical knowledge elicited from clinical experts in terms of linguistic variables, linguistic values, and fuzzy rules; (ii) defining a fuzzy inference technique to best fit the expert's decision-making process to identify WMLs; (iii) defining an adaptive fuzzy technique to tune the shapes of the membership functions for the variables involved in the rules. The performance of the DSS is quantitatively evaluated on 120 patients affected by MS.

The rest of the paper is organized as follows: Sect. 2 discusses some motivations and related works. Section 3 describes the proposed approach while in Sect. 4 the experimental evaluation is reported. Finally, Sect. 5 concludes the work.

## 2 Related Work

In the last two decades, operator-assisted techniques, such as local thresholding, have been successfully employed to classify MS [6], but they are time-consuming and require operator intervention since they are monoparametric, i.e. based only on MR signal intensity data. Recently, successful methods assessing multiple parameters have been developed, in which automated classification of MS lesions is characterized by high specificity and sensitivity [7–11].

Although all these methods obtain very good classification performance, they suffer from two important limitations. First, the most part of them does not reproduce the expert's decision-making process, but implements algorithms that are often too complex to be understood by a non-technical audience. As a result, they are considered by physicians as black boxes that simply generate answers with no further explanation. Second, a lot of them rely on mathematical models based on thresholding to classify MS lesions. Hence, they neither take into account the fuzziness of input data nor reproduce the expert's decision-making process applied in a vague-laden domain such as medicine. As a matter of fact, the decision-making model the physicians have in mind to classify MS lesions is often fuzzy in nature, and the introduction of crisp mathematical models can represent an unrealistic oversimplification of reality, leading to possible wrong interpretations when compared to a direct observation.

As a result, an intelligent system able to support physicians in the detection of MS lesions by handling fuzziness and providing interpretation for the classification outputs would be of great clinical value. To the best of our knowledge, none of existing classification methods proposed in literature adopts an adaptive fuzzy approach to classify MS lesions, neither DSSs appear to have been developed in that direction.

## 3 The Proposed Approach

The construction of DSS for the classification of MS lesions has required respectively: (i) the encoding of the clinical experts' knowledge in terms of linguistic variables, linguistic values, and fuzzy rules; (ii) an inference fuzzy technique to best fit the expert's decision-making process to identify WMLs; (iii) an algorithm to tune the formalized knowledge by optimizing the shapes of the membership functions for each linguistic variable involved in the rules. These issues are described in detail in the following sections.

### *3.1 Dataset and Knowledge Representation*

The dataset used in this work includes MR brain images of 120 patients with clinically definite MS. Their age range is between 20 and 63 years. These clinical data, opportunely anonymized, were collected at the Department of Bio-Morphological and Functional Sciences of the University of Naples "Federico II". Starting from MR images, the multiparametric segmentation procedure proposed in [12] is applied to the whole dataset in order to identify normal brain tissues or clusters of potentially abnormal white matter voxels, labeled as White Matter Potential Lesions (WMPLs). For each WMPL, the following features represent the actual input data for the DSS:

- *Volume*: it estimates the lesion volume in terms of the number of voxels.
  - Unit: Voxel; Range: 3–10522
- *Sphericity*: it evaluates how spherical a lesion is. The more elongated the lesion is and the more it deviates from a sphere, the lower the sphericity will be.
  - Unit: dimensionless; Range: 0.01–1.23

- *Compactness*: it evaluates how compact a lesion is. For a given shape, compactness is high either in the case where the volume is large or in the case where the enclosing surface is small, i.e. the object is strongly compact.
  – Unit: dimensionless; Range: 0.31–1.98
- *Tissue Contrast*: it indicates the minimum color contrast to detect a WML in the multiparametric space.
  – Unit: percentage; Range: 0.56–1.0
- *Surrounding WM:* it estimates the amount of WM enclosing a lesion.
  – Unit: percentage; Range: 0.32–1.0

Starting from these features, the medical knowledge necessary to classify WMLs has been defined in cooperation with the team of physicians and can be synthesized, in natural language, as follows. The tissue composing a WMPL is abnormal in the case where the lesion is somewhat surrounded by WM, characterized by a strong compactness and greatly contrasted in the multiparametric space. The sphericity is moderate or high in small lesions, whereas, as their volume increases, the sphericity starts decreasing progressively. Finally, as volume increases and sphericity starts lessening, a lesion can be surrounded by gradually decreasing WM and its compactness still remains high.

Starting from this knowledge, the following linguistic variables and values have been identified:

- *Volume* - > *{Small, Medium, Large}*
- *Sphericity* - > *{Low, Moderate, High}*
- *SurroundingWhiteMatter* - > *{Bit, Partially, AlmostCompletely, Completely}*
- *Compactness* - > *{Weak, Strong}*
- *TissueContrast* - > *{Little, Great}*
- *TissueStructure* - > *{Normal, Abnormal}*

Successively, these linguistic variables and values have been used to formulate the "if–then" rules described in Fig. 1, aimed at identifying only the positive cases, i.e. when a potential lesion is an actual one.

## 3.2 The Fuzzy Inference Technique

The definition of a specific fuzzy inference technique for classifying WMLs is driven by a set of considerations about the elicited medical knowledge.

This knowledge is represented by means of incomplete rules, since the formalized rules collect only all the positive evidence, looking for those manifestations that could be sufficient to establish a positive conclusion.

Furthermore, in the reported rules, conjunction and disjunction operators should be modeled. Nevertheless, for instance, the disjunction of two contiguous and

*1)* ***IF*** *[Sphericity is (Moderate* ***OR*** *High)]* ***AND*** *[Compactness is Strong]* ***AND*** *[Volume is Small]* ***AND*** *[TissueContrast is Great]* ***AND*** *[SurroundingWhiteMatter is Completely]*
***THEN*** *[TissueStructure is Abnormal]*

*2)* ***IF*** *[Sphericity is Moderate]* ***AND*** *[Compactness is Strong]* ***AND*** *[Volume is Medium]* ***AND*** *[TissueContrast is Great]* ***AND*** *[SurroundingWhiteMatter is (AlmostCompletely* ***OR*** *Completely)]*
***THEN*** *[TissueStructure is Abnormal]*

*3)* ***IF*** *[Compactness is Strong]* ***AND*** *[Volume is Large]* ***AND*** *[TissueContrast is Great]* ***AND*** *[SurroundingWhiteMatter is (Partially* ***OR*** *AlmostCompletely* ***OR*** *Completely)]*
***THEN*** *[TissueStructure is Abnormal]*

**Fig. 1** If-then rules for identifying actual lesions

orthogonal fuzzy sets, modeled as union, could generate a scarcely intuitive behavior. Indeed, in the area in which the two fuzzy sets are partially overlapping, the uncertainty is the greatest between the corresponding values of the two fuzzy sets. Differently, in accordance with the expert's opinion, the disjunction in the overlapping area should have an additive behavior, i.e. the values of uncertainty of both the fuzzy sets in that area should be summed.

To overcome these issues, we introduce a fuzzy inference technique resembling the FIRE method proposed in [13] to filter images. Such a technique also applies Lukasiewicz norms as aggregation operators and defines ad-hoc operators of implication, accumulation, and defuzzification coherently with the Lukasiewicz Logic [14]. In the following, the basic knowledge about the proposed technique is described.

**Definition 1** Given $M$ fuzzy rules, $N$ continuous input variables $v_1, v_2, \ldots, v_N$ and one discrete output variable $s$, the formulation of the fuzzy rules is defined as follows:

$$\begin{gathered} IF\ (v_1, A_{11})\ AND/OR\ (v_2, A_{12})\ldots(v_N, A_{1N})\ THEN\ (s, B_1) \\ IF\ (v_1, A_{21})\ AND/OR\ (v_2, A_{22})\cdots(v_N, A_{2N})\ THEN\ (s, B_2) \\ \ldots\ldots \\ IF\ (v_1, A_{M1})AND/OR\ (v_2, A_{M2})\cdots(v_N, A_{MN})THEN\ (s, B_M) \\ ELSE(s, B_E) \\ A_{ij} = \ (a_{ij})\ AND/OR\ (b_{ij})\cdots AND/OR\ (z_{ij}) \end{gathered} \tag{1}$$

where $A_{ij}$ is a logical expression associated to each rule $i$ and calculated for the variable $j$ in accordance with its linguistic values $a_{ij}$, $b_{ij}$, … $z_{ij}$ and $B_i$ and $B_E$ are the linguistic values associated respectively to rule $i$ and to the *ELSE* rule calculated for the output variable s.

This formulation models a disjunctive system of rules where at least one rule must be satisfied. The *ELSE* rule is activated when the other rules are weakly satisfied or not satisfied at all. In particular, in this work, the *ELSE* rule allows determining all the potential abnormal cases that are not actual lesions.

**Definition 2** The strength level $\lambda$ of the rule $i$ is calculated in terms of the degrees of membership for the antecedent clause. Lukasiewicz t-norm and s-norm are used as aggregation operators since they verify the laws of contradiction and excluded middle. As a result, when the antecedents are connected by the *AND* operator, the strength level is formulated as:

$$\lambda_i = \max\left\{0, \sum_{j=1}^{N} \mu_{A_{ij}}(v_{ij}) - (N-1)\right\} \tag{2}$$

whereas, when the antecedents are connected by the *OR* operator, it is defined as:

$$\lambda_i = \min\left\{1, \sum_{j=1}^{N} \mu_{A_{ij}}(v_{ij})\right\} \tag{3}$$

The logical expression $A_{ij}$ associated to each rule $i$ is calculated for the variable $j$ in terms of the degrees of membership for its linguistic values $a_{ij}$, $b_{ij}$, … ,$z_{ij}$ in the antecedent clause. In particular, when the linguistic values of the variable in the antecedent clause are connected respectively by the *AND* operator and the *OR* operator, the logical expression $A_{ij}$ is calculated by applying the Lukasiewicz t-norm and s-norm too.

**Definition 3** The strength level $\lambda_E$ of the *ELSE* rule is calculated by applying a *NOT* operator to the strength levels $\lambda_i$ of the other rules, since the *ELSE* rule is activated when all the other ones are partially or completely unsatisfied. Moreover, since the if-then rules are connected by *OR* connectives, the results obtained by applying the *NOT* operator to the strength levels $\lambda_i$ are combined by means of *AND* connectives. Summarizing, the strength level $\lambda_E$ is defined as:

$$\lambda_E = \max\left\{0, \sum_{i=1}^{M} \lambda_i - (M-1)\right\} \tag{4}$$

**Definition 4** The operator of implication is defined as a t-norm implication where the Lukasiewicz t-norm has been applied, as reported in (5):

$$x \rightarrow y = \max\{0, x + y - 1\} \tag{5}$$

**Definition 5** The operations of accumulation and defuzzification are calculated as a center of gravity of the strength levels, previously accumulated with respect to the singleton spikes defined in the output universe:

$$COG(s) = \frac{\sum_{l=1}^{P} \min\left\{1, \sum_{k=1}^{Q_l} \lambda_k * x_{B_k}\right\}}{\sum_{l=1}^{P} \min\left\{1, \sum_{k=1}^{Q_l} \lambda_k\right\}} \tag{6}$$

$$x_{B_k} = x_l \quad k = 1, 2, \ldots, Q_1$$

where $P$ is the number of singleton spikes defined in the output universe, $Q_l$ is the number of rules with the same singleton spike as output value and the accumulation operator used for each singleton spike is the Lukasiewicz s-norm.

**Definition 6** The output of the center of gravity is a continuous appraisal value. The final discrete output is produced by simply identifying the singleton spike whose numerical value is the nearest to the appraisal value with respect to a fixed threshold value. Summarizing, the final discrete output is defined below:

$$\begin{array}{r} if\ (|COG(s) - x_{Bi}| < threshold)s = B_i;\ i = 1, 2, \ldots, M \\ if\ (|COG(s) - x_{BE}| < threshold)s = B_E \end{array} \tag{7}$$

## *3.3 The Adaptive Fuzzy Technique*

After formalizing the expert's knowledge under the form of linguistic variables, linguistic values, and fuzzy rules, the shape and location of membership functions for all the values related to all the linguistic variables involved in the rules have to be opportunely defined. It is well known that whereas fuzzy rules are relatively easy to derive from human experts, the membership functions are difficult to obtain and their tuning is a time-consuming and often frustrating exercise.

To overcome these difficulties, we propose an adaptive fuzzy technique based on differential evolution (DE) [15]. DE is a stochastic and reliable evolutionary optimization strategy which presents noticeable performance in optimizing a wide variety of multidimensional and multimodal objective functions in terms of final accuracy and robustness, and overcomes many of the already existing stochastic and direct search global optimization techniques [16, 17].

The proposed adaptive fuzzy technique uses the *DE/rand/1/bin* version of DE. In particular, given the multiple sclerosis dataset and the set of fuzzy rules elicited from the experts, we make use of this version to find the best set of the membership functions for the declared variables so that the highest correct classification rate can be achieved on the input dataset.

It is worth noting that we have chosen the shape of the membership functions for the input variables as trapezoidal in order to verify the orthogonality. As a result, each membership function can be represented by an ordered set of four real values $\{a_1, a_2, a_3, a_4\}$, where the first represents the starting value of the leading

```
Algorithm
begin
    randomly initialize population of solutions X = (x_1,…, x_Npop)

    evaluate fitness Φ for all the individuals x_i
    while (maximal number of generations Gen is not reached) do
    begin
        for i = 1 to N_pop do
        begin
            choose three integers r_1, r_2 and r_3 in [1, N_pop],
            with r_1 ≠ r_2 ≠ r_3 ≠ i
            choose an integer number s in [1, q]
            for j = 1 to q do
            begin
                choose a random real number ρ in [0.0 – 1.0]
                if ((ρ < CR) OR (j = s))
                    x_ij'= x_r3j + F * (x_r1j - x_r2j )
                else
                    x_ij'= x_ij
            end
            evaluate Φ (x_i')
            if Φ (x_i') > Φ(x_i)
                insert x_i' in the new population
            else
                insert x_i in the new population
        end
    end
end
```

**Fig. 2** The DE/rand/1/bin algorithm

edge, the second its ending value, the third the starting value of the trailing edge, and the fourth its final value.

Therefore, the trapezoid will be delimited by the four points $\{(a_1, 0); (a_2, 1); (a_3, 1); (a_4, 0)\}$. Of course, a trapezoid can be reduced to a triangle by optimization. The membership function for the output variable *Tissue Structure* is defined by two singleton spikes respectively in 1 for the value *Normal* and in 2 for the value *Abnormal*.

In order to tune the trapezoidal membership functions in accordance with the orthogonality, the shapes of any couple of adjacent fuzzy values cross at a level of 0.5, and, more importantly, $a_3$ and $a_4$ for the first fuzzy value of a variable coincide with $a_1$ and $a_2$ of next value of the same variable, and so on.

Furthermore, for the first (respectively, the last) value of each linguistic variable, the two first (two last) points coincide. These two latter considerations imply that the number of real values representing the membership functions for the $F_v$ values of each variable is lower than $4 * F_v$: in general it is given by $2 * (F_v - 1) + 2$.

The *DE/rand/1/bin* algorithm is used to optimize this set of real values in Fig. 2.

We have decided to set the parameters as follows: population size equal to 100, number of generations equal to 50, CR = 0.8, and F = 0.5. Each solution in the population is a vector of real numbers encoding, for each linguistic variable, the control points for the trapezoidal membership function of any value associated to the variable. The vector has a length equal to $\sum_{i=1}^{N_{\mathrm{var}}} 2 \cdot \left(N_{val}^{i} - 1\right) + 2$where $N_{var}$ is the number of linguistic variables and $N_{val}^{i}$ is the number of values associated to the generic *i*th variable.

As fitness function of any solution, we have taken into account the percentage of correctly classified examples in the training sets.

For the learning mechanism, an $N_f$-fold cross-validation has been carried out. This means that the dataset is divided into $N_f$ subsets, and $N_f$ training sessions are effected: in the generic *i*th session, the *i*th subset is kept for testing and the algorithm is shown the items contained in the remaining $N_f - 1$ folds.

The best solution found in each training session is then evaluated on the testing set.

Finally, the average results of these $N_f$ classifiers are computed, and the best among them in terms of highest generalization ability is considered as the best solution to the problem, and the shapes for the membership functions represented by this solution are taken into account in the final system.

## 4 Experimental Evaluation

In the absence of histological confirmation, the true WMLs are not known. Therefore, the expertise of a team of neuroradiologists involved in this work has been utilized in order to establish the true lesions among the identified WMPLs. In particular, only 1,905 out of 2,844 detected WMPLs have been classified as proven lesions by the team of neuroradiologists. This result is considered as the gold standard in the work.

Binary classifications of WMLs were produced by applying a threshold in order to obtain discrete outputs from the continuous appraisal values generated by the fuzzy inference technique. These classifications were compared with the gold standard and accuracy, sensitivity, and specificity were calculated for the threshold equal to 1.5.

As soon as the system starts the adaptive phase for each fold, better and better solutions in terms of higher accuracy values are found: while in the initial generation good solutions have percentages of correct classification of around 30−35 %, as the number of generations increases these values get rapidly better, up to around 85−90 % at the end of the run. We show in Table 1 the average results achieved over the ten folds, and those for the best fold in terms of the highest percentage of accuracy on the test set. The results are arranged in terms of percentage of accuracy on the training set $\%T_r$ and on the test set $\%T_e$, sensitivity $S_e$, and specificity $S_p$.

The run corresponding to the fold 7 shows the highest generalization ability, so it is the most suitable to be chosen in a real situation where new cases arrive and should be classified. The related solution classifies correctly 89.13 % of all the

**Table 1** Results of our system

| Average results over the ten folds | | | |
|---|---|---|---|
| $\%T_r$ | $\%T_e$ | $S_e$ | $S_p$ |
| 89.10 | 88.79 | 0.88 | 0.88 |
| Results for the best fold in terms of $\%T_e$ | | | |
| $\%T_r$ | $\%T_e$ | $S_e$ | $S_p$ |
| 88.71 | 92.93 | 0.96 | 0.84 |

**Table 2** Values for the shapes of the trapezoids

| Variables | Values | | | | | |
|---|---|---|---|---|---|---|
| Surrounding | 0.31 | 0.33 | 0.38 | 0.40 | 0.41 | 0.46 |
| White matter | | | | | | |
| | 0.95 | 1.00 | | | | |
| Compactness | 0.31 | 0.36 | 0.74 | 1.98 | | |
| Tissue contrast | 0.56 | 0.61 | 0.92 | 1.00 | | |
| Volume | 3 | 3,177 | 3,529 | 7,051 | 7,697 | 10,522 |
| Sphericity | 0.01 | 0.03 | 0.10 | 1.02 | 1.03 | 1.23 |

**Table 3** Ten-fold classification accuracy

| | Our system | Bayes net | MLP | RBF | K-star |
|---|---|---|---|---|---|
| Accuracy | **88.79** | 78.09 | 88.04 | 82.20 | 85.90 |
| | Bagging | Ada boost | NB tree | Ridor | VFI |
| Accuracy | 87.86 | 82.34 | 86.81 | 86.91 | 72.39 |

dataset. The shapes for the membership functions for the linguistic values taken on by the five variables are reported in Table 2.

To evaluate the effectiveness of our system, we have decided to compare these results against those provided by a set of widely used machine learning classifiers.

Namely, we have made reference to the Waikato Environment for Knowledge Analysis (WEKA) system release 3.6.2 [18] which contains a large number of such techniques, divided into groups such as Bayesian, based on functions, lazy, meta-techniques, tree-based, rule-based, others. From each group, we have chosen some representatives. They are: the Bayes Net from the Bayesian methods, the Multi-Layer Perceptron Artificial Neural Network (MLP) and the Radial Basis Function Artificial Neural Network (RBF) from the function-based, the K-Star from the lazy, the Bagging and the AdaBoost from the meta-techniques, the Naive Bayes Tree (NBTree) from the tree-based ones, the Ripple Down Rule (Ridor) from the rule-based ones and the Voting Feature Interval (VFI) from the category 'other'.

Parameter values used for any technique are those set as default in WEKA. As a result, Table 3 reports the comparison among the results achieved by our system and by the other classifiers on the basis of ten-fold classification accuracy.

As a general comment, the lack of a simple insight as to how the machine learning classification methods work and scarce interpretability of the classification results make them too complex to be understood by a non-technical audience and, as a result, scarcely appealing and trustworthy by the physicians.

Differently, not only has our system shown the capability to obtain very good results, but also it has resulted extremely simple and intuitive to be understood also by the physicians, thanks to the presence of the fuzzy rules expressing expert's knowledge.

## 5 Conclusions and Future work

The presented DSS offers an innovative and valuable way to perform automated WML classification. The results given by the experimental evaluation suggest that the system could be proficiently utilized with the remarkable aim of supporting diagnosis and monitoring for patients affected by MS. Because the knowledge representation model, the fuzzy inference method, and the adaptive technique have a general basis, in the future, the system could be undoubtedly used in other classification problems in MR brain images, such as classification of gray matter or cerebrospinal fluid.

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# E-Learning Software for Students with Autism

**Soly Mathew Biju, Catherine Todd, Latif Tchantchane and Bushra Yakoob**

**Abstract** This project is intended to design and provide an educational software to help autistic students to learn computer skills and daily life skills. It also monitors the progress of the student and maintains it in a database. It also provides an interface for the teacher to modify the material used. It is fundamentally an e-learning software for students with autism designed in collaboration with the Dubai Autism Centre. There are specific modules in the project which emphasizes on three-dimensional graphics and high user interactivity.

## 1 Introduction

Autism is a spectrum disorder and as such, there are varying degrees of autism [1], although there are general symptoms that are prevalent throughout the spectrum. This prevalence has resulted in typical teaching methods which try to counter the learning disabilities of students with autism. The most common teaching method used is that of repetition of a task, dividing it into a series of steps, to make it easier

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to perform [2]. Most teaching methods require individual attention to each student, since students with autism are more prone to distraction, lack of motivation and other behavioural difficulties than students who do not have autism [3]. Notebook activity schedules are used to foster independent behaviour among students with autism; they are used by most educators to teach self-reliance to students with autism [4]. The books used at the Centre usually consist of pictures and text that serve as a walkthrough for activities which keeps the student sufficiently occupied for long periods, without direct supervision of a tutor or parent [4]. Dubai Autism Centre (DAC), a non-profit organization in the United Arab Emirates, applies these educational techniques to encourage independent learning and development among their students.

Interactive VEs and VRs have been successfully used to teach students with autism. According to a study by Moore and Calver [5, 6], the use of computers increased the student's ability to learn vocabulary, by increasing their motivation and interest. Further, students with autism have considerable difficulties in social situations which, according to the research, can be aided with computer-based learning. In a study conducted by Mitchell, Parsons and Leonard [7], a VE representing a café was developed to teach participants about social judgments and mannerisms. It was concluded that the students showed significant improvement within the set social scenes after completing the tasks in the environment [7]. VEs offer great potential in the field of teaching students with developmental disorders such as autism. The surroundings of the VE can be tailored to the user's preference [8] and offer a safe, controlled environment in which to participate and interact.

This study focuses on the design of an interactive software application which could be used as an assistive tool in the education and overall development of students with autism; extending current practices at DAC to include interactive, three-dimensional VR environments. This software has been designed and deployed for use students at the Dubai Autism Centre. This study was conducted in close collaboration with teachers at the Centre and was based on their requirements specification and requirement analysis conducted based on various analysis methods.

## 2 Design Specifications

The software design specifically addressed the needs of students with autism. Table 1 shows the Challenges face and the design solution developed to tackle these issues.

## 3 Implementation

The research and development of this project work followed the agile programming approach.

**Table 1** Challenges faced by autistic student and corresponding design solution

| Challenges faced by autistic students | Design solution |
|---|---|
| Difficulty in manual dexterity and using mouse | Games and activities specifically designed to teach mouse control and keyboard usage |
| The students prefer a quiet and calm environment while performing their tasks | Sound could be set to mute for all the modules designed |
| Students with autism respond more favourably to visual information than to only textual information [10] | The Graphical user Interface was designed with a bright colours wherever applicable |
| Students with autism are attracted to inanimate objects and tend to focus on the minor details [10] | The user interface was designed to be simple and without any cluttering of visual cues |
| Students with autism tend to exhibit repetitive behaviour and in addition, prefer predictable events [11] | Special consideration was given in introducing new concepts at a slower pace slowly. All the educational games introduced this application progressed in a sequential manner |
| Students with autism do not respond well to negative feedback [12] | Messages and responses displayed were very positive and encouraging |
| Autism is a spectrum disorder and as such, people with autism experience different degrees of the disability [13] | The tasks in the VR environment have varying levels of complexity helping students improve their motor control, computer and communication skills gradually |
| Students with autism have difficulty with social interaction | A key issue which is addressed within the daily life module of the software [14].The social setting within the VR environment enables the user to customize their clothes and skin colour to reflect their own style and ethnicity and helped them interact within the virtual world |

Teachers at the Autism Centre were involved in every iteration of the software application allowing incorporation of any feedback request at any stage of the application development. This e-learning software is divided into two modules. The first module is Computer Assessment Module and the second module is Daily Life skills Module.

## *3.1 Modules Implemented*

1. Computer Assessment Module—The Computer Assessment Module has been designed to improve manual dexterity and basic knowledge about using a computer. The sections within this module address the different skills required by the student: teaching use of a computer mouse, relation of cause and effect, testing visual tracking to assess their ability to visually follow a moving object in 3D space at different speeds and providing an interest level game to add a fun

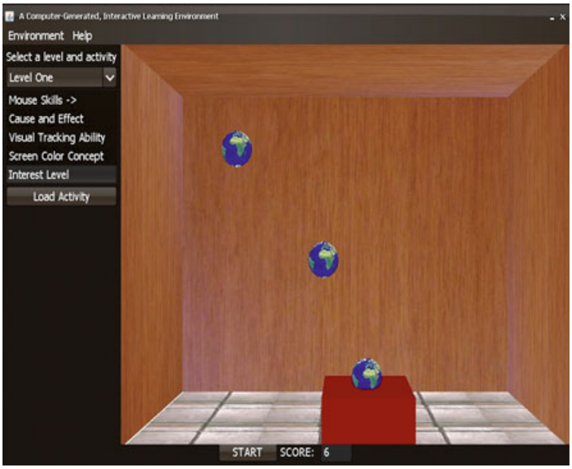



**Fig. 1** Output of level 1 of the Interest Level module. The falling objects are to be caught by the student using the *red basket* and the score is displayed in the *bottom panel*

element to the e-learning activity. The module also enables assessment of the student's ability to differentiate among colours within a scene, develop awareness of computer components, text editing and typing skills. Every section is divided into three difficulty levels and are based on current teaching practices of the Dubai Autism Centre.

The sections are as follows Mouse Skills, Cause and Effect Visual Tracking Ability, Interest Level, Screen Colour Concept, Computer Component Recognition and Typing and Text Editing Skills (Fig. 1).

2. Daily Life Skills Module—The Daily Life Skills Module is the second module available in the e-learning software. In this model various real life scenarios are modelled to provide the students a platform to interact with virtual character within the virtual environment to accomplish the given task as well as to allow them to communicate with other users. This module is aimed at helping the students acquire social skills.

It records the student performance based on the extent to which the student has accomplished the given task with respect to time and accuracy with which the task was performed.

There are three different modes within this virtual world, which allow the student to participate individually or with peers. The three modes are Animation, Interaction and Collaboration.

(a) Animation Mode—In Animation mode, the student must complete the tasks in the virtual world using only mouse clicks. The tasks involve greeting the teacher, queuing inside the classroom, counting the number of students in the classroom, determining the means of transport to be used to travel to the supermarket (Fig. 2), entering the supermarket, picking a basket, picking items from the shelf according to the shopping list displayed, paying the cashier and completing a questionnaire at the end of the task.


**Fig. 2** The figure shows the output of the animation mode within the Daily Life Skills module. The user has to click the correct answer to move to the next task

(b) Interaction Mode—In Interaction mode, the user who is represented using an avatar in the virtual environment is required to use the arrow keys on the keyboard to move the avatar (refer Fig. 2 for the output of this mode) in the required direction. The movements of the avatar in this mode is completely controlled by the user.

(c) Collaboration Mode—The Collaboration mode is intended to provide the users with a platform which they could use to freely interact with other users without any restrictions within the virtual environment. User located at different Pc's can interact with each other using an avatar (a virtual character) representing themselves. These avatars could be made to walk around the virtual classrooms and also chat with each other.

## *3.2 User Interface*

The user interface of this module is designed to be simple and complete with all the functionalities and options required by the users, both students and teachers (administrative). The students will be using an interface that is colourful and simple to understand. The interface is different for teachers than for students, as shown in Figs. 3 and 4; teachers have authorization to change various functionalities and settings of the virtual simulation.

## *3.3 Resources and Tools Used*

This section details all the software tools and techniques used to create the e-software application.

**Fig. 3** Student's menu

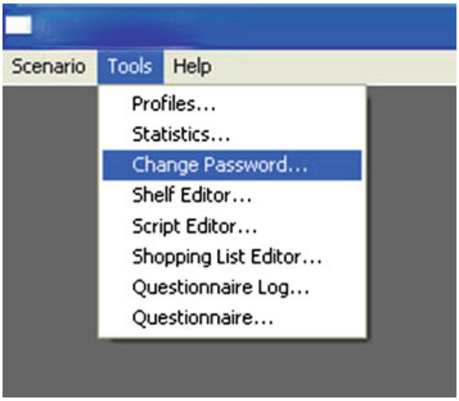
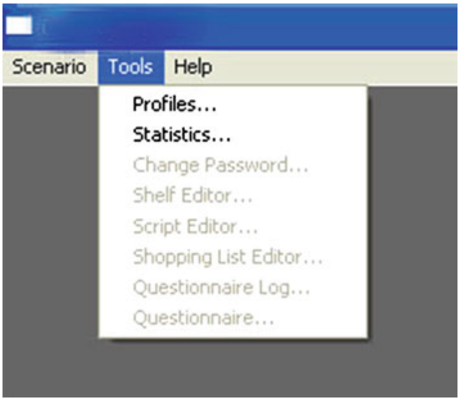



**Fig. 4** Teacher's menu




Java 3D Scene Graph API was chosen to render the 3D models. Java3D API enables the development of three-dimensional graphics applications and offers high-level abstractions of 3D graphics that allow rapid development of VEs [9]. Java3D has functionality for graphics, audio and collision detection (Java3D) which was used for all tasks within module.

MySQL was the relational database management system selected for this project as it is an open source and is reliable for maintaining a small database.

The architecture of this application is a compile time static pluggable architecture which separates the scene logic from the environment dynamics that handle the interface, which takes care of what scene to load. The 3D objects are created and transformed within the environment using the Java3D constructs for manipulating and rendering 3D geometry.

3D modelling suite Blender was used for animating avatars. Graphical User Interface (GUI) was created using wxPython and wxGlade libraries. The programming library used was Panda3D.

A high level protocol was also written which would dictate how the client–server connects within the network. As a scene selected from the GUI was loaded, the Panda3D game engine loaded the corresponding screen and character, giving options either to simulate the whole game or to play it in an interactive or collaborative mode.

## 4 Conclusion

The research project has help in accomplishing the following objectives:

Create a user friendly, interactive, three-dimensional graphical user interface designed for students with autism. Two modules were created one focused on helping student improve their motor control and computer skills. And other focuses on helping students acquire daily life skills. Each sub-module in the first module has three levels of complexity helping students to gradually refine their skills.

The Daily life skill modules had three specific modes

- Single user with different scenarios within the same VR environment. Each scenario would comprise a set of tasks for the user to complete, which would be focused on the improvement of their social skills.
- A collaborative (networked) VR environment where the users can simultaneously share the same virtual world. The students would be able to navigate around the environment and chat with other students within the same environment.
- An assistive environment for the teacher to assess the level of skill acquired by the student and monitors his/her development.

Results from this facility may then be used for research and statistical purposes, to analyze and study the impact on of the e-learning software on their ability to learn the skills each module aims to help acquire.

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# Steganography and Steganalysis: Current Status and Future Directions

**Eman Abdelfattah and Ausif Mahmood**

**Abstract** Steganography is the art of hiding a secret object in a cover media, while Steganalysis is the art of discovering the secret object from the cover media. With the increased emphasis in security, both steganography and steganalysis have recently drawn great research attention. While it is relatively easy to embed a secret message in a media such as an image, audio or video, the detection of an embedded message i.e., steganalysis is challenging because of the many different methods used in steganography and the continuous evolution of new steganography algorithms. In this paper we discuss the different techniques of steganography and steganalysis used in popular cover types i.e., images and audio. We also present an overview of some of the state-of-the-art tools used in this field. Our goal is to provide this as a survey paper identifying the current state of research, and possible future directions in this field.

## 1 Introduction

Steganography has been defined as the art of invisible communication, while steganalysis is the art of discovering hidden data in stego objects [1]. The stego object i.e., the object that contains the hidden information is created by modifying the original object with an embedding algorithm. The original object is often referred to as the cover object in steganography terminology. An extraction algorithm that is the opposite of the embedding algorithm is employed to recover the embedded information from a stego object. Figure 1 shows a general model for steganography [2].

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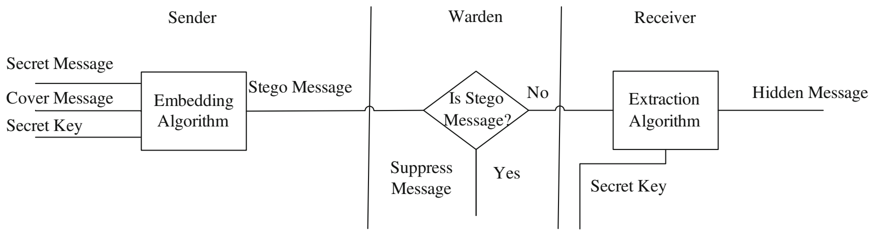


**Fig. 1** A general model for steganography [2]

Steganography is generally considered to be secure, if the set of stego objects has the same statistical properties as the set of cover-objects. As described later in this paper, one of the popular steganalysis techniques employed is to see if the statistical properties such as distribution of DCT coefficients in the stego object (in case of images) differ from the original cover object. Having similar statistical features in the cover and stego makes it extremely difficult to know if the object contains any hidden information.

There are three kinds of steganography approaches; pure steganography, private key steganography and public key steganography. The technique for embedding the message in pure steganography is unknown to warden and shared as a secret between the sender and receiver. Thus, this technique relies on the secrecy of the algorithm itself which is not a good practice as the security is compromised once the algorithm is known. Secure steganograhy systems depend on the secrecy of the key. In private key steganography both the sender and the receiver share a secret key which is used to embed the message. The warden has no knowledge about the secret key. However, he/she is aware of the algorithm that they could be employing for embedding messages. In public key steganography, both the sender and the receiver have private–public key pairs and know each other's public key.

The purpose of steganalysis is to identify if a carrier (image, text, audio or video) has been manipulated by embedding a secret message using some embedding technique. These two factors; different carrier types and many possible embedding techniques, introduce a great complexity in designing a reliable steganalyzer.

The steganalysis techniques are classified under two categories; specific and universal steganalysis. The specific steganalysis techniques are designed for a targeted embedding technique. Thus, they yield very accurate decisions when they are used against the particular steganographic technique. In universal techniques, dependency on the behavior of the individual embedding techniques is removed by determining and collecting a set of distinguishing statistics that are sensitive to a wide variety of embedding operations. As an example, universal steganalyzers dealing with images are composed of two important components; feature extraction and feature classification. In feature extraction, a set of distinguishing statistics (e.g., DCT coefficients) are obtained from a data set of images by observing general image features that exhibit a strong variation under embedding.

Feature classification uses the distinguishing statistics from both cover and stego images to train a classifier. Then, the trained classifier is used to classify an input image as either cover or a stego in the test process.

The remainder of the paper is organized as follows. In Sect. 2, we discuss the steganography and steganalysis approaches used for images. In Sect. 3, we describe the methods used for audio embedding and its detection. Then, in Sect. 4 we report the methods employed for other media types. Finally, we introduce some steganography and steganalysis tools in Sect. 5, and the paper is concluded in Sect. 6 along with comments on some possible future directions in this field.

## 2 Image Steganography and Steganalysis

With the wide availability of digital images, and the high degree of redundancy present in them (despite compression), digital images have drawn great attention as cover-objects for the purpose of steganography [3]. Most reported steganography techniques dealing with images embed a secret message in the spatial domain, or the transform domain. While some methods such as the least significant bit (LSB) modification approaches embed in the spatial domain, other techniques such as Discrete Cosine Transform (DCT) methods and Discrete Wavelet Transform (DWT) embed in the transform domain.

The goal, in general, in all universal steganalysis approaches is extracting reliable distinguishable features between the cover and the stego object. The extracted features in current image steganalysis techniques belong to the following categories: binary similarity measures (BSMs), wavelet-based (WB), or feature-based (FB). Once the distinguishing features corresponding to an image have been obtained, then these features are used to train a classifier. Researchers select a classifier from the different classifiers that can be employed for classification such as Fisher's linear discriminate (FLD), support vector machines (SVM), Neural Networks (NN). In this section, we present a brief summary for some of the existing steganalysis techniques.

Fridrich et al., discuss Feature-Based Steganalysis (FBS) where JPEG images are first decompressed, and then crop the spatial representation by four lines of pixels in both horizontal and vertical directions to estimate statistics of the original image, before embedding [1]. Then, the image is JPEG recompressed with the original quantization table. The difference between statistics obtained from the given JPEG image and its original estimated version are obtained through a set of functions that operate on both spatial and DCT domains. According to authors "techniques (such as FBS) that rely on DCT based statistical features are expected to perform better than binary similarity measures (BSM) and Wavelet-Based Steganalysis (WBS)".

Lyu et al., used Wavelet-Based Steganalysis (WBS) to build a model for natural images by using higher order statistics and then show that images with messages embedded in them deviate from this model [4, 5]. Quadratic mirror filters (QMFs) are used to decompose the image into the wavelet domain, after which statistics such as mean, variance, skewness, and kurtosis are calculated for each sub-band. Additionally the same statistics are calculated for the error obtained from a linear predictor of the coefficient magnitudes of each sub-band, as the second part of the feature set. The images are decompressed before being fed into the steganalyzer because this technique operates on spatial domain. The authors conclude that their approach scores reasonable accuracy results. However, if a small message is embedded, this leads to poor performance detection.

Martín investigated the effect of embedding a secret message into a natural image on the statistics of the image to examine the possibility of the detection of the presence of this secret message [6]. The three different embedding algorithms that are used in the experiments are: Jsteg [7], MHPDM [8], and one of the algorithms in S-Tools [9]. JSTEG is one of the early embedding tools that was publically available. MHPDM is a modified version of Histogram-Preserving Data Mapping (HPDM) which embeds into DCT coefficients. S-tools hides files in both BMP and GIF files. The following five different statistical models of natural images are used: Areas of Connected Components Model [10, 11], Adjacent Pixel Values Model [12–14], Laplacian Distribution Model [15], Wavelet Coefficients Model and DCT Coefficients Model. They concluded that the effect is insignificant to the natural images when the analysis is independent of the steganograhy algorithms. However, if a prior knowledge of the embedding algorithm is known, a better classification can be obtained.

Avcibas et al. used binary Similarity Measures (BSMs) to calculate three types of features; computed similarity differences, histogram and entropy related features, and a set of measures based on a neighborhood-weighting mask by looking at the seventh and the eighth bit planes of an image [16, 17]. The images are decompressed before being fed into the steganalyzer because this technique operates on spatial domain. The authors conclude that their technique demonstrates comparable results to the results obtained by Farid's scheme [18].

Goljan et al. present a method that calculates the features in the wavelet domain as higher-order absolute moments of the noise residual [19]. The advantage of calculating the features from the noise residual is that it increases the features' sensitivity to embedding. Therefore, this method outperforms a previously proposed method by Holotyak et al. [20]. A classifier using Fisher Linear Discriminant (FLD) is constructed and it is called WAM classifier. Also, WAM classifier is used to examine the security of three steganographic schemes: pseudo-random $\pm 1$ embedding using ternary matrix embedding, adaptive ternary $\pm 1$ embedding, and perturbed quantization. The authors conclude that perturbed quantization steganography technique is the most secure because it is the least detectable approach. Moreover, the adaptive ternary $\pm 1$ embedding scheme is more secure compared to pseudo-random $\pm 1$ embedding scheme.

Kharrazi et al. study the performance of three distinct blind steganalysis techniques against four different steganographic embedding techniques: Outguess [21], F5 [22], Model-Based [23] and perturbed quantization PQ [24]. The used cover media is JPEG images. The collected data set is categorized with respect to size, quality, and texture to find out their impact on steganalysis performance. Blind steganalysis is composed of two components: feature extraction and feature classification. The three techniques used for feature extraction are binary similarity measures (BSMs), wavelet-based steganalysis (WBS) and feature-based steganalysis (FBS). A linear support vector machine (SVM) is employed to avoid high computational power if nonlinear kernel SVM is employed. The authors conclude that FBS achieves superior performance because the used data set is compressed JPEG images. Moreover, PQ steganography embedding technique is the best one because it is the least detectable technique. As the quality factor of images increases, the distinguishability between the cover and stego images decreases. Recompression of JPEG images makes the distinguishability between the cover and stego images harder where the recompressed cover images are obtained by recompressing the original images using their estimated quality factor [25].

Ella conducted a survey of the methodology of information hiding and describes some techniques used in steganography and steganalysis [26]. An experiment is conducted on a set of images from Wikipedia by downloading them using the program Wikix. The program StegAlyzerSS [27] is used to scan the images. The results show that some images were found to have appended information. But, this result is not enough evidence for the existence of stego images because this appended information can be a result of manipulating images by some programs or information left from cameras. However, the author concludes that there were no confirmed instances of steganography found in the scans which makes blind steganalysis not an easy problem.

## 3 Audio Steganography and Steganalysis

Although significant research efforts are reported in the domain of image steganalysis, fewer efforts are reported in the field of audio steganalysis. This might be attributed to the different nature of audio from image which introduces challenges in obtaining the statistical features of audio. In this section we present an overview of some the advanced audio steganography and steganalysis techniques.

Tian et al. propose an m-sequence based Steganography technique for Voice over IP [28]. The technique succeeds to achieve good security, sufficient capacity and low latency by using least-significant-bits (LSB) substitution method. Moreover, m-sequence encryption approach is used to eliminate the correlation among secret messages so that the statistical steganalysis algorithm can hardly detect stego-speech. Also, a synchronization mechanism is suggested to guarantee the accurate restoration of secret messages at the receiver side. A technique for the transmission of synchronization patterns (SPs) is proposed that allows online distribution of some important parameters by distributing the SPs among some fields in the IP header that are available for steganography. Thus, it is possible to construct the covert communication in real time.

Tian et al. introduce an adaptive Steganography scheme for Voice over IP (VoIP) [29]. An evaluation for the proposed method is conducted. The evaluation is based on designing five different steganography modes. Two modes are based on the traditional LSBs substitution method and the other three modes are based on the suggested adaptive Steganography scheme. They conclude that the adaptive Steganography approach outperforms the traditional LSBs substitution method since it enhances the embedding transparency by taking into account the similarity between Least Significant Bits (LSBs) and the embedded messages.

Liu et al. present two methods: the statistics of the high-frequency spectrum and the Mel-cepstrum coefficients of the second-order derivative are extracted for audio steganalysis, and a wavelet-based spectrum and Mel-cepstrum audio steganalysis [30]. A support vector machine is applied to the extracted features. A comparison among these two methods and the signal-based Mel-cepstrum audio steganalysis method is conducted. The proposed methods outperform the signal-based Mel-cepstrum approach. Moreover, the derivative-based approach outperforms the wavelet-based approach.

Liu et al. suggest a stream data mining approach for audio steganalysis based on second order derivative of audio streams by extracting Mel-cepstrum coefficients and Markov transition features on the second order derivative [31]. Signal complexity has been taken into consideration as an important parameter for evaluating the performance of audio steganalysis. A support vector machine is applied to the extracted features. Both techniques that apply second order derivative improve the detection performance compared to signal based Mel-cepstrum audio steganalysis. Moreover, Markov approach based on second order derivative outperforms Mel-cepstrum approach based on second order derivative as reported by the authors.

Qiao et al. present an approach of detecting the hidden information in MP3 audio streams [32]. The moment statistical features of Generalized Gaussian Distribution (GGD) shape parameters of the Modified Discrete Cosine Transform (MDCT) sub-band coefficients, as well as the moment statistical features, neighboring joint densities, and Markov transition features of the second order derivatives are merged. Support Vector Machines (SVMs) are applied to the extracted features for detection. An accuracy detection of 94.1 % is achieved when the modification density is 16 %. Moreover, the percentage accuracy detection is increased to 95.6 % when the modification density is increased to 20 %.

## 4 Other Steganography and Steganalysis Used Media

In addition to the previously discussed carriers such as images and audios, some other digital entities can be used as cover media. For example, HTML files (hypertext markup language) have appropriate potentials for information hiding. While processing HTML files, the browser ignores spaces, tabs, certain characters and extra line breaks which could be used as locations for hiding information. Another example, unused or reserved space on a disk is a second type of media that can be used to hide information. Also, data can be hidden in unused space in file headers. Last but not least, network protocols such as TCP, UDP, and/or IP can be used for hiding the messages and transmit them through the network [33].

Li et al. suggest using torrent files, a crucial part of the BitTorrent P2P network, as host carriers for secret messages [34]. The authors used both Letter Case Change (LCC) and Field Reusage (FR) techniques to produce the stego-torrent files. Letter Case Change (LCC) was suggested based on the knowledge that some fields such as announce and announce-list fields in torrent files are case insensitive. This technique has the advantage of maintaining the size of the stego-torrent file as the original torrent file which provides a high level of transparency and security. Field Reusage method is suggested because of the redundancy of some other fields such as comment and publisher. The advantage of this method is the ability to embed data with huge capacity without rising suspicion. Moreover, FR method guarantees security by encrypting the stego-message with Data Encryption Standard (DES) technique. The detector will have no suspicion because a large portion of the torrent file already contains Secure Hash Algorithm 1 (SHA1) hashed pieces. Both an embedding algorithm and an extraction algorithm are presented to embed and extract secret messages.

## 5 Existing Tools

There are many tools reported in literature that perform steganography. In this sub-section we present some steganography tools such as Outguess, F5, Data Stash, S-tools and wbStego4. Moreover, there are few tools reported in literature that are used by steganalysists. These tools are limited in their capabilities and target one or few specific cover objects. In this sub-section we present some steganalysis tools such as Stegdetect and StegAlyzerSS.

(1) Outguess [21]: it identifies the redundant DCT coefficients that have minimal effect on the cover image, and based on this information it chooses bits in which it would embed the message. Outguess program recompresses the image with a quality factor defined by the user, and then it uses the obtained DCT coefficient to embed the message. The estimated quality factor of the image is communicated to the Outguess program in order to minimize recompression artifacts. When embedding messages in a clean image, noise is introduced in the DCT coefficient, therefore increasing the spatial discontinuities along the $8 \times 8$ jpeg blocks. Given a stego image if a message is embedded in the image again there is partial cancellation of changes made to the LSB of DCT coefficients, thus the increase in discontinuities will be smaller. This increase or lack of increase in the discontinuities is used to estimate the message size which is being carried by a stego image.

(2) F5 [22]: It embeds messages by modifying the DCT coefficients. The main operation done by F5 is matrix embedding with the goal of minimizing the

amount of changes made to the DCT coefficients. "The method takes $n$ DCT coefficients and hashes them to $k$ bits, where $k$ and $n$ are computed based on the original images as well as the secret message length. If the hash value equals the message bits, then the next $n$ coefficients are chosen, and so on. Otherwise one of the $n$ coefficients is modified and the hash is recalculated. The modifications are constrained by the fact that the resulting $n$ DCT coefficients should not have a hamming distance of more than $d_{max}$ from the original $n$ DCT coefficients. This process is repeated until the hash value matches the message bits." [25] F5 recompresses the image, with a quality factor input by the user, after which the DCT coefficients are used for embedding the message.

F5 alters the histogram of DCT coefficients. Thus, Fridrich et al. proposes a simple technique to estimate the original histogram so that the number of changes and length of the embedded message could be estimated [35]. The original histogram is simply estimated by cropping the jpeg image by 4 columns and then re-compressing the image using the same quantization table. Although no analytical proof is given for the estimation method, steganalysis based on this simple technique performs very well.

(3) Data Stash [36] is a steganographic tool that allows the user to hide secret data files within other files. The user can hide secret files into .exe,.com,.jpg,.mpg, and so on. In this tool the vault file is the cover file and the file to be stashed is the secret message that we are interested to embed it. The option restore in this tool returns the files to their original status.
(4) S-tools [37] S-Tools is a steganography tool that hides files in BMP and GIF files. We used S-tools for embedding a secret message in cover images with extensions .bmp and .gif producing stego images with the same extensions. Then, images with extension.bmp are recognized with StegAlyzerSS v3.1 tool under the LSB Analysis option as shown in Fig. 2. However, the images with extension .gif are not identified as stego images because StegAlyzerSS v3.1 recognizes only the BMP file.
(5) wbStego4 [38] is a steganography tool for Windows95/98/Me, Windows NT 4.0 and Windows 2000. It hides data in bitmap images, ASCII and ANSI text files, HTML files and Adobe Acrobat (PDF files).
(6) Stegdetect [39] performs steganalysis using statistical tests to determine if steganographic content is present. Furthermore, it tries to find the embedding technique that has been used to embed the hidden information by the following tools: jsteg, outguess, jphide, F5, appendX and camouflage, and invisible secrets.
(7) The Steganography Analyzer Signature Scanner [27] is one of the computer forensic analysis tools. It is limited to recognize only three tasks: the signature of a particular algorithm, appended information after the end-of-file character, and disturbances to the least significant bits of BMP image file. When we used StegAlyzerSS tool after embedding a secret message in cover files producing stego files, these files are recognized under Append Analysis option. However,

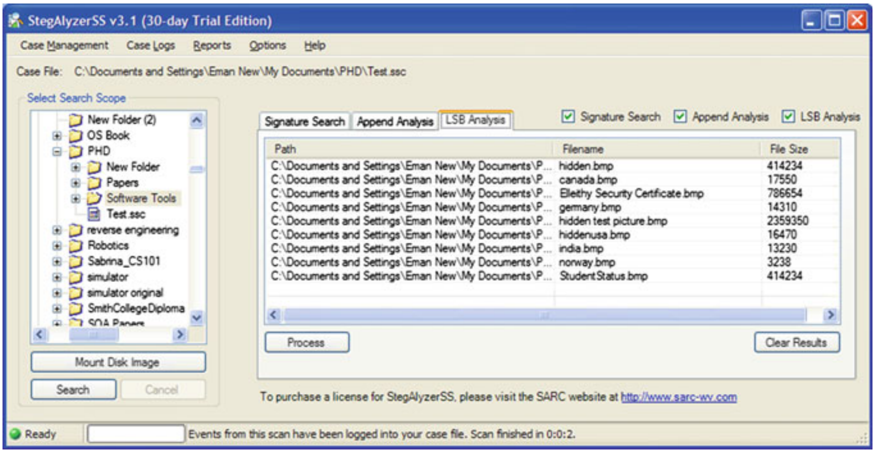


**Fig. 2** LSB analysis option in StegAlyzerSS tool

this option implies that these files contain any information appended to a file past its end-of-file marker. Files that are found to contain appended information may or may not contain steganography. Thus, Append Analysis option is not automated steganography detection algorithm. No solid conclusion can be reached about the files under investigation whether they are covers or stegos. Further analysis should be conducted to identify cover or stego file. To evaluate the performance of StegAlyzerSS v3.1, we tested it using 10 K images and it finished the scan in 2:08 min in one experiment and in 1:54 min in another experiment. When StegAlyzerSS v3.1 runs on 100 K images, scan finished in 19:52 min.

## 6 Conclusion and Future Directions

The fields of steganography and steganlaysis received increased attention in the recent years. A stego object is obtained by modifying the cover object using an embedding technique. The object might be an image, text, audio or video. However, most of the reported techniques in literature deal with images.

The main focus in steganalysis is only to detect the presence of a hidden object. Most of the reported steganalysis techniques in literature handle specific embedding techniques. Other techniques that deal with several embedding techniques are designed to handle a specific data type.

We found that existing steganalysis tools are limited in their detection capabilities and far from being considered as automated steganalyzer.

One of the fundamental challenges in steganalysis is to come up with a detection mechanism that will work on all different steganography techniques.

Since there are quite a few existing algorithms in steganography, and further since new algorithms are continuously being devised that generate similar statistical features in the stego object as the original media, a single steganalysis algorithm may not be possible. One of the approaches taken in the future may be perhaps multi- algorithms running in parallel or as a collection of web services in service-oriented architecture (SOA) that is extensible to include detection of newer steganography algorithms. Another important concern would be the steganalysis execution time reduction. With the vast amount of information being exchanged on the internet, a highly efficient real-time steganalyzer would be needed by many security organizations. So far, the researchers have not focused much on execution time reduction of steganalysis, but parallel and distributed techniques need to be developed for steganalysis for this purpose.

It is notable that different research efforts do not cross-validate new results with earlier published results. This raises the need to develop benchmarks that can be used to evaluate new techniques and see how well they perform.

Many of the reported steganalysis techniques handle specific image types such as JPEG or audio types such as WAV have reached a high degree of detection of the stego object. We envision that research groups will put more emphasis in developing new techniques that handle uncommon types.

The competition between the camp of steganography and the camp of steganalysis will continue to fuel research efforts in these fields where new algorithms and techniques are expected to be developed in the future.

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# Validation of System Architectures Against Requirements

**Andre Pflueger, Wolfgang Golubski and Stefan Queins**

**Abstract** Design decisions are based on several criteria affecting each other. The architect is responsible for ensuring that the decisions fit the system requirements. This validation process is time-consuming work which has to be repeated if the requirements change. The use of various documentation forms complicates this work. In this chapter, we describe an approach for supporting the architect in validating the architecture against the requirements. It allows an automation of the validation process and offers support for the impact analysis. It can be applied in an early as well as in an advanced project phase. For documentation, we apply the Unified Modeling Language wherever possible and reasonable in order to achieve consistent system documentation.

## 1 Introduction

There are two critical issues in system development: development time and cost. For both, estimation in an early project phase or even before project start is required. Due to the early stage, in the development process, only little information of the projected system is known. Hence experienced developers are needed in

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order to make a good approximation, which is often based on instinct rather than facts.

If the development does not primarily focus on software, the systems architecture plays an important role for the approximation. For example, in the development of embedded systems, the chosen hardware elements not only affect the resulting charges with their purchasing price but they also have a significant influence on the capability of the whole system and the used software algorithms. For instance, powerful hardware may decrease the development costs of software algorithms. A good idea of the system architecture facilitates the approximation of the required development time and therefore the budget.

In an early development stage, the state of the requirements is unstable. During requirement gathering and analysis many changes may occur in order to fit customer demands or to avoid unaccomplishable requirements. Some changes also affect the system architecture and the architect has to ensure that his first idea of the system architecture accomplishes the new requirement state. Additionally, adjustments of the architecture are not unusual in this development phase.

The architect has to validate his architecture against requirements, especially non-functional requirements. This is a time-consuming process which has to be repeated several times during system development. It is not only difficult to obtain a general idea but also not to lose track of the whole requirements and their impacts on the architecture. There are many approaches of describing ways of architecture creation and of how to deal with modifications without creating a new one. However, they do neither hint at consistent record keeping nor at how to keep the documentation consistent to the requirements [1–3].

The approach described in this paper uses the Unified Modeling Language (UML) [4] for a model-based documentation of the system development and the validation process. The UML meta model and its extension mechanisms allow adding customized information to the model without losing the ability of information extraction by specification compliant tools. The validation process consists of the following steps:

- detection of validation targets,
- creation of validation procedures,
- documentation of validation specific information,
- execution of validation procedures of every validation target, and
- improvements of the architecture if necessary.

The first three steps have to be done once for every validation target (e.g., processor load). After requirement changes only the validation step has to be repeated and optionally adjustments have to be made. If the validation can be automated, the effort for the architect is minimal. Even without automation the consistent documented validation procedures and information enable the architect to efficiently validate the target. Linking the validation targets to the corresponding requirements eases the impact analysis for the architect. This way the architect can detect the origin of side effects caused by requirement modifications and architecture adjustments. He does not only know that validation has failed in general but also which requirements in detail are involved.

The approach separates the documentation of development and validation information. Thus changes on both sides can be done without affecting each other. For example, the architect can experiment on some details without changing the development results and producing new versions for the developers. If required and desired, the necessary information can be transformed to the development results. The opposite transformation direction is possible too.

The chapter is structured as follows: Sect. 2 refers to related work. Section 3 describes in detail the documentation challenge and how UML can be used. Section 4 focuses on the validation of the system architecture against the requirements, especially the validation process. The approach is applied to an example in Sect. 5. Section 6 lists the benefits and experiences of this approach and Sect. 7 concludes the paper and states our future work.

## 2 Related Work

Approaches for the consistent documentation and validation of system architectures against the requirements using the modeling language UML are rare. Most validation approaches are targeting the software architecture or use a formal description language. According to our research, there is no approach addressing the problem of consistent documentation for system architectures and providing support for the impact analysis after requirement changes [1–3, 5, 6]. Although our approach supports simulation of system behavior to validate single validation targets, this is not our superordinate target.

The modeling and analysis of real-time and embedded systems (MARTE) profile of the OMG extends the UML and is targeting the model-driven development of real-time and embedded systems [7]. The specified elements of MARTE could be used for modeling the required information in our approach, but they are often far beyond the documentary needs.

Although modeling tools provide MARTE profiles, there are problems in practical use. The project MADES [8] deals with this problem trying to find a way to integrate MARTE into the embedded system development and achieve a usable model-driven approach for developing embedded systems, including the support of a modeling tool. The project deals with the design phase and code generation of system development and is therefore not comparable to our approach.

One example for a formal language for developing embedded hardware-software systems are the Abstract State Machines (ASM) [9]. ASMs are a method for high-level system design and analysis from requirements gathering to implementation and documentation. Models on different levels of abstraction are used to describe the system. In comparison with the UML as description language it is more accurate. However, it requires a well instructed and ASM-experienced architect to apply ASMs. Discussing results with system developer proved difficult because not every developer is capable of understanding ASMs. The introduced approach supports the architect in his developing work and in analysing the impacts of modifications. The model-based documentation with UML should also be used for discussions. Hence ASMs are not really comparable.

The CoFluent Studio [10] provides a tool to test the system architecture in a virtual environment. It uses UML models including the System Modeling Language (SysML) [11] and MARTE profiles for system documentation. These are transformed into executable SystemC transaction-level models. The concept is comparable to Executable UML [12] but has another purpose than our approach. CoFluent Studio is targeting the verification of the modeled information by simulating them in a special environment. It does not support the architect in impact analysis by identifying the violated requirements.

## 3 Documentation with UML

Due to our personal experience, a consistent documentation is missing in many projects. Information can be found in spread sheets, protocols, specifications, system development documents, e.g. UML models, or even in photos of white-boards showing the results of a meeting. These different document types handicap

- the check of consistency according to modeling rules to avoid redundant and detect missing information and
- the extraction of information for a computer aided consistency check or analysis.

One possibility to avoid the stated problems is the use of a document management system bundling prose requirements. It guarantees that every project stakeholder has access to all required documents and the respective up-to-date version. With the help of keywords or a full text search, data inside the documents can be found. However, there is no check for missing or redundant information. An automated consistency check has to be very (project) specific and complex because the analysis of prose is difficult. Adjustments for changes in the structure or the use of new document types can be very laborious.

To avoid these problems, the widespread model language UML from the Object Management Group (OMG) [4] can be used to create a domain specific documentation language which can be applied in nearly every stage of the system development. A guideline eases the use of the UML for the developer, defines the domain specific semantic of the used UML elements and, furthermore, gives some hints at how to proceed and which information may be missing. The concept of UML with its meta model and the four layer architecture [13] allows us not only to extract information from the model but also to extend the notation to include additional information.

The meta model of the UML can be extended by adding new meta model elements or by the use of the profile mechanism [14]. For our approach, we use the

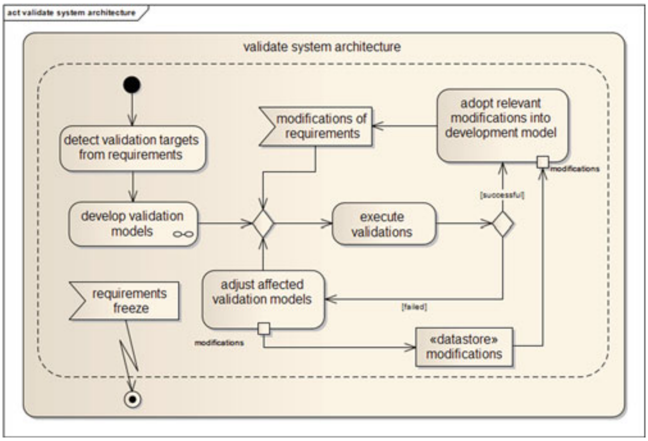



**Fig. 1** Process of system architecture validation

profile mechanism to extend the development model notation. The elements in the development model are adopted to the validation model and characterized by stereotypes. This is visualized by an additional name surrounded by Guillemets[1] and optionally some tagged values.

This specification compliant extension enables the creation of an validation process specific notation, i.e. the UML profile, and the extraction of information from the UML model by existing tools like the Eclipse Modeling Framework (EMF) [15] using the XML Metadata Interchange (XMI) format defined by UML. The effort for creating the validation process models can be reduced by automated transforming of required elements from the development to the validation model. Adopting changes from the validation to the development model in consequence of modified requirements is also possible.

## 4 Validation Process

The major goal of the system architecture is to meet the given requirements. This can be ensured by validating the architecture against every architecture specific requirement, i.e. the non-functional requirements. The overall validation process is depicted in Fig. 1 as UML activity diagram. From the non-functional requirements, the architect can deduce validation targets.

These validation targets describe the validation topic in a more abstract way than requirements and without any concrete values. They are indirectly testable by their associated requirements, and this makes them less sensitive for modifications

[1] Guillemets are the french quote signs.

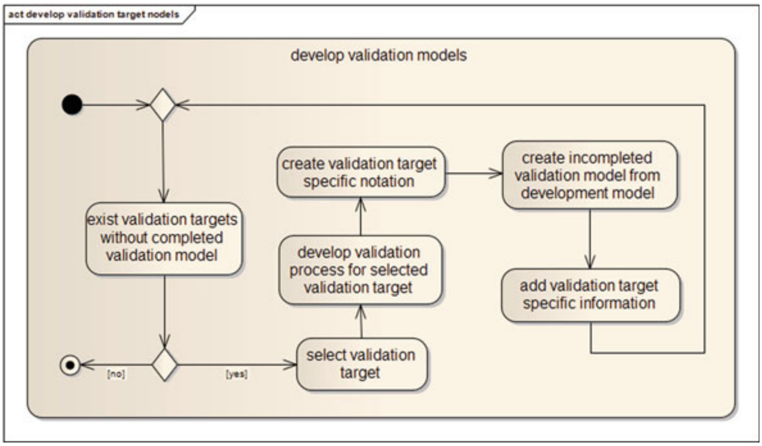



**Fig. 2** Process of creating the validation target models

than requirements. A validation target can be associated with more than one requirement. An example is the requirement "The maximum median average processor load of the system shall be 60 %." and the corresponding validation target "median average processor load" described in detail in Sect. 4.

After detecting the validation targets, the architect develops the validation models for all validation targets. If at least one validation fails, the architecture and the affected validation models have to be improved. If the validation is successful, all relevant changes are adopted to the development model. Up to project requirement freeze, the cycle of validating the system architecture is started at every modification of the considered requirements.

Figure 2 shows the refinement of the activity "develop validation models" mentioned in Fig. 1. If there is at least one validation target without a corresponding validation model, a validation target is selected, the architect develops a validation process and a validation process specific notation extending the language of the development model to add validation specific information. An uncompleted validation model is created from the development model if possible and completed with all information required for the validation process. After creating validation models for all validation targets the validation of all validation targets can be initiated.

## 5 Example

For further explanation, an example from the area of embedded systems is applied. The architect has created two UML diagrams, representing the system architecture documented in the development model (Figs. 3 and 4). Figure 3 shows the software view, Fig. 4 the assignment of software components to processing hardware

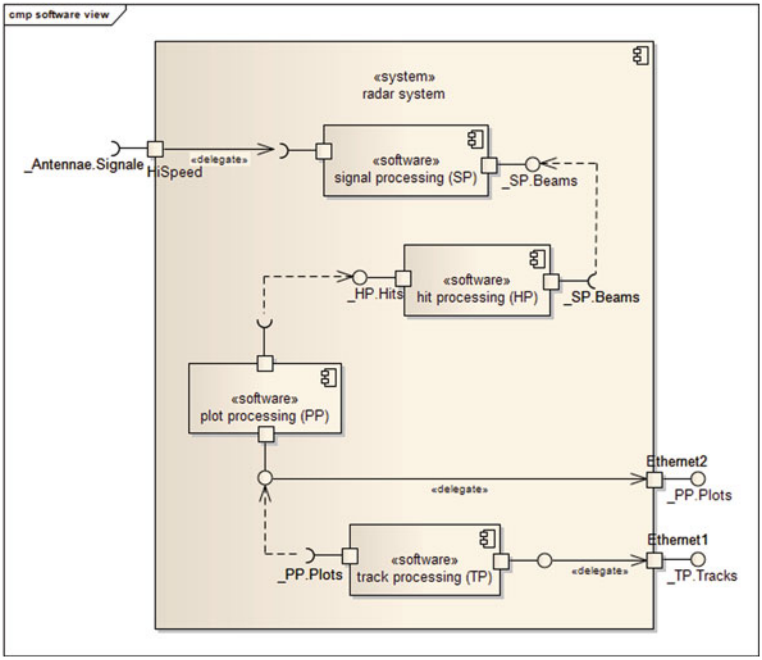



**Fig. 3** Software view of a simplified radar system

elements. The functionality of this simplified radar system will be explained with the help of the software view in Fig. 3.

During signal processing, the signals received by the antennae are digitized, filtered, e.g. the removal of rain drops, and prepared for internal processing by creating so-called beams. The reflections of real-world objects (hits) are extracted from these beams via hit processing. The remaining real-world objects are grouped, thus creating a considerable amount of objects enriched with additional information, i.e. plots. Track processing analyses these plots and links them among each other, for example, according to existing historical data. This way the progress of a tracked object can be displayed on a radar display.

These functions are represented by the four software components depicted in Fig. 3. In Fig. 4, they are assigned to processing hardware elements by using a dependency association with stereotype *executedOn*. The software components signal and hit processing are executed on a field programmable gate array (FPGA), plot and track processing on a PowerPC.

The following requirements are provided by the customer:

- The system shall process stipulated test data in 220 ms.
- The maximum median average processor load of the system shall be 60 %.

According to the validation process depicted in Fig. 2, the architect deduces the validation targets "total execution time" (vt1) and "median average processor

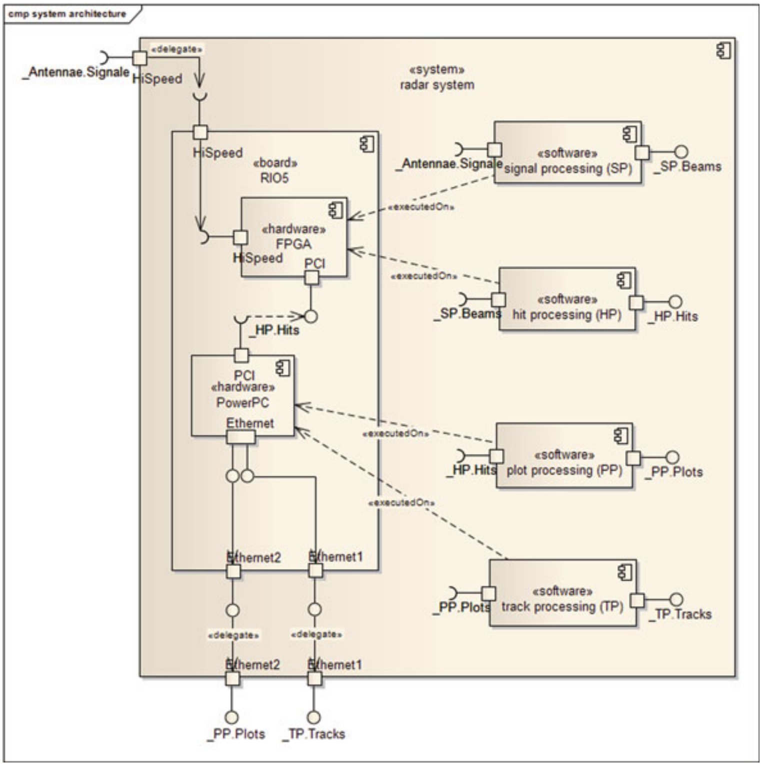



**Fig. 4** Architecture of the radar system

load" (vt2) from the two non-functional requirements listed. He also creates a link between the requirement and the corresponding validation target for traceability.

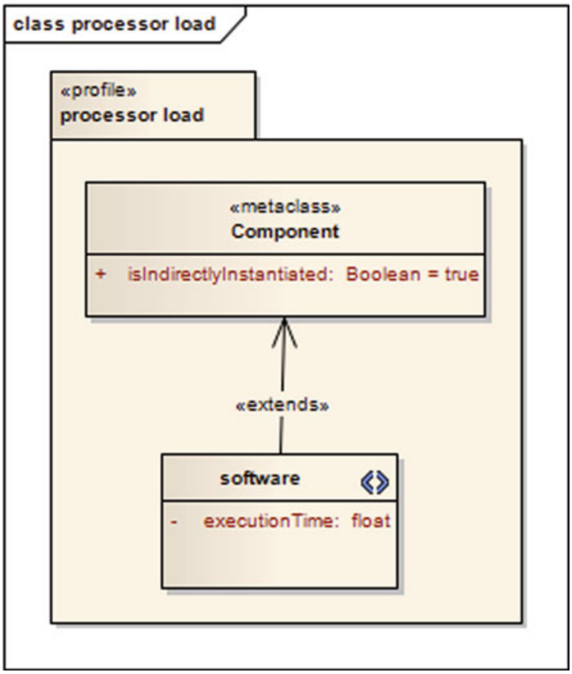
In the next step, the architect develops a validation process for the validation target *vt1*. The total execution time is calculated by the sum of the execution time of each software component *i* (see Eq. 1).

$$execution\ Time_{total} = \sum_{i=1}^{n} execution\ Time_i \quad (1)$$

In our example, the architect knows the execution time of software components on specific processor units from previous project experiences. These values can be added to the validation model by creating a new UML profile depicted in Fig. 5.[2] By applying the pictured stereotype *software* with the tagged value *executionTime* to the perspective component element, the required information for the validation process can be added to the model. For the creation of the validation model, the

[2] The presentation of the UML profile is due to the used modeling tool Enterprise architect [16]. It is not UML compliant.

**Fig. 5** Validation process specific notation for validation target vt1




architect reuses the development model. He chooses the required UML elements, transforms them to the validation model, and adds the validation process specific data to the model using the validation process specific notation, i.e. the mentioned UML profile. The validation model[3] is depicted in Fig. 6. Ports and interfaces are not necessary for the validation process of *vt1*, and therefore they have not been transformed. The work for developing the validation model of *vt1* is done, and the architect can select the next validation target.

$$processor\ Load_p = \sum_{i=1}^{n} \frac{execution\ Time_{total_i}}{n} \tag{2}$$

The processor load of a processor unit *p* is the result of the sum of the total execution time of each software component divided by the maximum of software components running on this processor unit (see Eq. 2). For the validation target *vt2*, the architect can reuse the results and validation model of *vt1* calculating the total execution time for each software component. Due to the limited space, a discussion of advantages and disadvantages of this proceeding is omitted in this chapter.

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[3] In this example the model contains only one diagram.

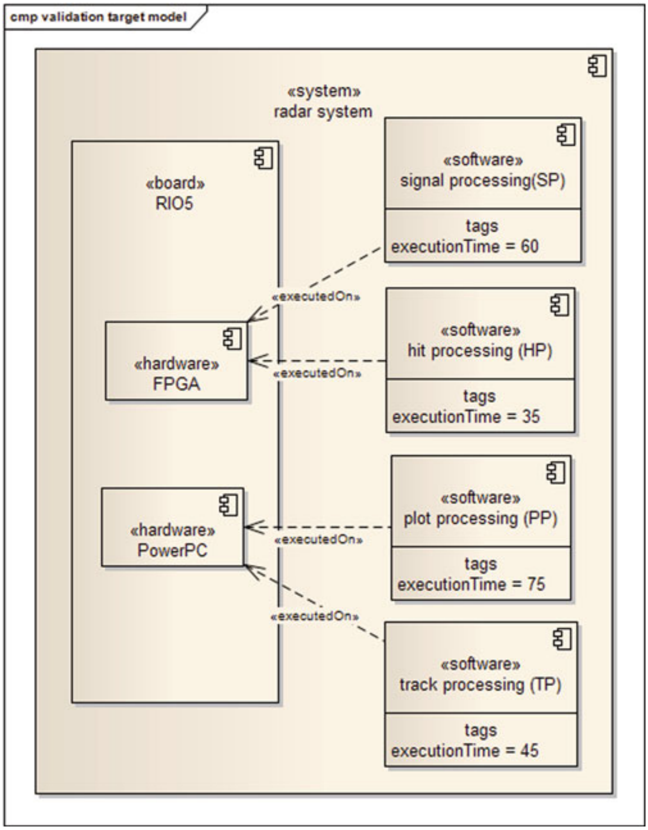


**Fig. 6** Validation model for validation target vt1

The next step in the validation process (see Fig. 2) is the validation of the validation targets with the result that the chosen allocation of the software components to the processor units fits the customer's requirements. The total execution time is 215 ms and the median average processor load is 44 % for the FPGA and 56 % for the PowerPC. Therefore, the architecture meets the requirements and no further modifications are necessary and no data have to be transformed to the development model.

Requirements change during project lifetime. These changes are often considered in the system development. The architect has to know the impacts of the changes for the system architecture. This impact analysis can be very laborious even in small or medium projects if there are many architecture specific requirements. In our example, the customer changes total execution time to 170 ms.

According to the validation process depicted in Fig. 2, the validation of all affected validation targets has to be executed. The validation of *vt1* fails because the actual allocation of software components to the processor units does not meet the changed requirement (215 ms vs. 170 ms). The architect changes the

**Table 1** Results of the validation process for vt1 after system architecture adjustment

| Software | Processor unit | Execution time (ms) |
|---|---|---|
| Signal processing | FPGA | 60 |
| Hit processing | FPGA | 35 |
| Plot processing | FPGA | 25 |
| Track processing | PowerPC | 45 |
| Total execution time (ms) | | **165** |

**Table 2** Median average processor load after system architecture adjustment

| Processor unit | Median average processor load (%) |
|---|---|
| FPGA | 73 |
| PowerPC | 27 |

allocation by drag and drop of the dependency association from the software component *plot processing* to the FPGA and reruns the validation. The required information for the calculation is extracted from the changed validation model resulting in a successful validation for *vt1* (see Table 1). However, the validation of *vt2* fails because the processor load of the FPGA is 73 % (see Table 2).

The architect has to convince the customer that there is no other allocation combination satisfying all customers' requirements, especially *vt2*. The development of better algorithms or the change of the used hardware is out of budget for which reason the customer agrees to adjust the median processor load in order to achieve the faster execution time of the radar system.

## 6 Benefits and Experiences

Our approach supports the architect in his work to ensure that the developed system architecture fits the gathered requirements. Thus it is irrelevant in which phase the development resides. It can be applied even before project start. The validation uses the available requirements and can be refined according to development progress.

Furthermore, it presents a consistent and specification compliant documentation for system architectures based on the widely-used modeling language, UML. This enables the extraction of information by tools like EMF which can be reused in the validation process. Thus, the UML model is not only for documentary purpose but also a source for data analysis. This is a good reason for convincing developers of using UML for model-based documentation. In comparison with formal languages, the UML is more intuitive and can be used as basis for discussions with other developers.

By separating the information of development and validation, an independent work in both the areas is possible. The additionally required effort can be reduced by the bidirectional adoption of development or validation data into the respective other model. Using validation target specific notations instead of new UML elements enhances readability, reduces the training period, and allows a problem specific UML extension.

By linking the validation targets with the corresponding requirements, the approach supports the architect in analysing the impacts of requirements modifications. They describe the validation topics in general which makes them insensible for value modifications in the requirements.

We have developed this approach with the help of our experiences from a real project in the area of embedded systems. It consists of more than 40 processing units and 60 software components. The goals have been worked out from customers' needs and our experiences about related problems in other projects.

## 7 Conclusion and Future Work

Submitting an approximation for the required development time and budget is difficult, especially before project start or in an early project stage. The approximation not only has to convince the customer to commission the system but also that there is enough space for achieving an equal understanding of the system and for solving unpredictable problems.

An important criterion for this approximation is the system architecture. Therefore, the architect has to prove that his idea of the system architecture satisfies the customer's requirements. In projects with numerous requirements modifications during project development, this validation of the system architecture against the requirements can be laborious and the architect has to be careful not to lose track of his design decisions. The usage of various documentation types handicaps, among other things, the detection of missing or redundant information, information searching and the extraction of information for automated analysis.

The introduced approach supports the architect in his work to create a more trustful approximation and a system architecture meeting the customer's requirements. It provides a validation process and a consistent documentation using the widely used modeling language UML. The validation process is based on validation models containing to perspective one validation target. These validation targets are a general description of architecture specific requirements so that they are not affected by requirements modifications. Setting up traceability between requirements and validation targets facilitates the impact detection after requirement or architecture modifications.

By separating the validation from the development data using different models, an independent development is guaranteed. In this manner, the architect can reproduce his design decisions even if system development has proceeded and the development model has been changed entirely.

The UML with its diagrams allows even not fully familiarized developers to use it as discussion basis. The diagrams are integrated in one model which can be searched. This avoids the existence of several documentation files and types. Due to the UML meta model, the models can be used as source for an automated data analysis. So, the documentation is not the only used for those models purpose increasing the acceptance for applying the UML and keeping them up-to-date. By using the UML profile extension mechanism, the approach guarantees that only validation specific information is part of the validation model.

In the future, we are going to concentrate on more complex simulations of the developed system to validate different validation targets affecting each other without using a virtual environment. These simulations will be capable of using less or more detailed information depending on the development stages. This is required for a more realistic usage of this approach in the customer's project.

The implementation of a tool reducing the effort of the architect to apply this approach is currently in progress. It will automate many steps, e.g. extracting information from UML model or transforming information from development model to validation models, which had to be done manually at the moment.

Another research topic will be possible data sources within the UML model and beyond if reasonable. Beside the software view, i.e. component diagrams, other elements and diagrams can be used as data source for the validation process. We plan to reuse as much information from the development model as possible increasing the user acceptance for this approach and the UML as model-based documentation.

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# A Few Reflections Regarding Assessment in an E-Learning Environment

**Jan Genci**

**Abstract** E-learning technologies are spread around the whole educational process. Knowledge assessment has become inseparable part of current e-learning technologies. Tutors give students opportunity to check their progress during study but they use assessment tests also for a midterm and final grading. The fact, that knowledge tests are not developed properly was discovered already in the 1950s. But it seems they are still not being developed with an adequate care. Testing items are not designed to reveal the reached level of knowledge—testing suites are very seldom reviewed from the point of view of their validity and items correlation. We believe that current Learning Management Systems (LMS) and their support for an assessment test design and delivering are main source of problems. This paper presents some ideas about required functionality of LMS regarding knowledge testing. Some ideas about grade semantics and misuse of modern communication technologies during assessment are also presented.

## 1 Introduction

E-learning has become a widespread technology. Knowledge assessment is inseparable part of current e-learning technologies. It can be used for students' self-assessment to give them feedback about their progress in a study or (on the opposite side) for intermediate or final grading [1, 2]. Author's experience in the area of knowledge assessment led to a belief that "plain" (un-structured) testing is

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usually used in this process. Even if developed with the adequate care, testing suites are not designed to reveal reached level of knowledge according the taxonomy of cognitive aims (if any is considered during the test development). Moreover, they are seldom reviewed from the point of view of their validity and items correlation.

Grading and its semantics constitutes "provocative" question. Despite the fact that there is a sound theory about knowledge evaluation (Item Response Theory [3, 4]), we do not meet its application in real life. In the contrary, grading is often required to be relative, without strict semantics. In such case, it is extremely difficult to say, what grade A (B, C, D) means. Moreover, we know that grade A represents different "semantics" for different classes, different schools, different years etc.

Cheating and its 'support' by modern technologies, to our opinion, becomes a problem. Mobile phones with integrated digital cameras give students possibility to take screenshots of questions presented to them during assessment. Subsequently, tools for on-line communication and social networks give them chance to spread information very quickly and anonymously. Thus, "cheated" exam does not assess level of knowledge but level of utilization of modern communication technologies, only.

## 2 Taxonomy of Educational Objectives

Taxonomy of educational objectives [5–7] is a well known classification in the pedagogical theory. According [5], educational objectives of well known Bloom's taxonomy are divided into three domains:

- Cognitive;
- Affective;
- Psychomotor.

Only the cognitive domain of the Bloom's taxonomy presents an interest for the knowledge assessment. Cognitive domain specifies six levels [8]:

- Knowledge: recognize or recall information;
- Comprehension: demonstrate that the student has sufficient understanding to organize and arrange the matter mentally;
- Application: a question that a student asks to apply previously learned information to reach an answer;
- Analysis: higher order questions that require students to think critically and in depth;
- Synthesis: higher order question that asks the student to perform original and creative thinking;
- Evaluation: a higher level question that does not have a single correct answer.

In our country (Slovakia), Niemierko's taxonomy [7] is quite often cited and sometimes stated as more suitable for building cognitive (knowledge) tests. Niemierko's taxonomy consists of four levels [9]:

- Remembering—comparable to knowledge in Bloom's taxonomy;
- Understanding—comparable to comprehension in Bloom's taxonomy;
- Specific transfer—application of acquired information to the presented patterns;
- Non-specific transfer—creative application of acquired information.

However, the taxonomy of educational objectives, although accepted and applied in educational practice, is not widely applied in the knowledge test design and implementation.

## 3 Knowledge Assessment

The term "didactic test" is often used in Slovak and Czech academic community. It usually denotes a process of examination designated for fair evaluation of level of mastering of a given study material. It seems the term "achievement test" is more appropriate (and more frequently used) in the English speaking countries.

Regardless of what term is used, this type of tests is considered as a tool of systematic measure of the results of teaching.

It is accepted, that a didactic/achievement test has to be prepared according to the rules specified by a team of specialists. We have to define what we want to measure by a test, a target group, an administration of test, a way of test evaluation and assumed conclusions according to the achieved results [10].

A test can contain closed and opened test items. The closed items are items for which several answers are prepared and participants have to decide what the right answer is (i.e. true–false, one-from-many choice, many-from-many choice, sorting, matching etc.). The opened items are items for which answers are not specified and participants are required to fill/submit the right answer.

### *3.1 Knowledge Assessment Problems*

Although the design methodology of tests (mentioned in the previous chapter) may be developed well, basic principles during the test design and implementation are usually not followed. The tests are often developed ad-hoc, without a clear specification of aims, using a basic set of testing items only (true–false, one-from-many choice, sometimes many-from-many choice). Moreover, the testing items are usually not linked with the appropriate level of the taxonomy of cognitive aims (if any taxonomy is chosen at all) and they are usually developed for specific paragraph of curriculum only.

As a result, the questions are very often targeted to the lower levels of taxonomy (knowledge/remembering and comprehension/understanding) and in such way do not evaluate participants' knowledge. Exactly in the same way, how it was discovered by Bloom fifty years ago.

The next problem represents the result processing of testing. Both a test as a whole and individual testing items should be evaluated permanently. It allows a test designer to discover possible ambiguities, to reveal correlation between items etc.

There are many reasons why we are faced with problems specified above. One of them, in our opinion, is inadequate support of methodology of knowledge assessment test development in the current learning management systems (LMS). Most of systems do not support wide range of types of assessment questions, the systems have no support to link items to the levels of taxonomy of learning objectives and items are required to be linked to specific chapter, not to appropriate, often complex, knowledge.

### 3.2 Semantics of Grading

Grading is a process which should answer students' abilities, knowledge and skills. In that way it could be used as the important source of information in the decision process of external bodies (bodies outside an educational institution). However, a grading at Slovak educational institutions is very often considered to be relative. It means it does not answer the question about student's knowledge (abilities, skills etc.) but answers her/his position in a selected (but unidentified) group of students, only.

We feel that for external bodies (next level educational institutions, employers) it is important to gain an assessment of applicant's personal abilities, knowledge and skills. In this case the relative grading according to the selected group (class, school) is inappropriate. That is the reason why external bodies in our country very often do not take into account the grades acquired at the educational institutions.

### 3.3 Technological Issues

Nowadays, the assessment tests, as usually, are performed by computer systems. The most of the computer systems are connected to the Internet without any restrictions during testing. Increasing computer literacy gives chance to participants to steal testing items and publish them on-line in a very short period of time. But even in a case of some restrictions (firewalled computer class, restrictions to use computer keyboard), students overcome them by using new technological achievements (i.e. they take a photo of computer screen by a mobile phone digital camera and publish items on-line; we even encountered some cases when students were using a mobile phone for on-line consultancy). In such way the students prove their competence in using technological achievements, but their test results do not reflect their knowledge (skills, abilities).

## 4 Mitigation of Knowledge Assessment Problems

In the previous chapter we identified several problems related to the knowledge assessment:

- Poor support of the knowledge assessment methodology by current learning management systems;
- No semantics of grades;
- Technological issues.

In this chapter we try to discuss some solutions to identified problems.

### *4.1 LMS Functionality for Assessment*

Learning Management Systems (LMS) have evolved to matured systems in the area of a course development during last 10 years. They often support some methodology for a course development and provide either integrated or external authoring tools for the course development. However, it is hard to find any methodology implemented in LMS regarding knowledge assessment. Our basic requirements for the knowledge assessment module of learning management systems regarding the implementation of assessment methodology are:

- The support of a definition of taxonomy of cognitive aims;
- The support of a definition of the cognitive structure of curriculum in addition to the ordinary structure of curriculum;
- The requirement to link each testing item to the appropriate level of the taxonomy and to the appropriate node of the cognitive structure of curriculum;
- The rich set of question item types, including open items;
- The item- and test life-cycle support;
- The functionality of tests teamwork development;
- Well developed approaches to items and test statistics.

A definition of the taxonomy of cognitive aims gives the test developers a possibility to choose an appropriate taxonomy according to their needs. LMS apart from "the flat taxonomy" (the unstructured taxonomy, which contains only one level—commonly used nowadays) should provide Niemierko's and Bloom's taxonomies at least. It seems to us wise to give an opportunity for the developers to define their own taxonomy according to their needs.

Defining the cognitive structure of curriculum we enable the specification of a composite knowledge as knowledge built on any combination of elementary and other composite knowledge. The purpose of the composite knowledge is to link a testing item to corresponding subordinated "elementary" and composite knowledge concepts stated in a curriculum.

Linking each testing item to the appropriate taxonomy level and to the node of cognitive structure of curriculum gives us wider possibilities in the production process of testing suites, including tests, which can assess the level of taxonomy reached by a student.

Rich test item types give developers chance to increase the number of possible question items for a particular knowledge node. Especially, items with an "open" answer (it means, a student have to state answer, not to choose from alternatives) can provide the solution for overcoming some problems. During the last few years, several systems for source-code assignments submitting and assessment were developed [14–16]. Such approach provides flexibility, but needs some other tools for an evaluation of submitted results (i.e. plagiarism discovery).

A test design and development is a time consuming process carried out by a team of developers. It means, that not only a whole test but the individual items should be developed, reviewed and tested by several persons. As a result, both individual items and a test as a whole have to pass several phases before the final phase is reached and items can be used in a regular testing process. These phases have to be reflected by an LMS in the item- and test life-cycle support. The system should support an item versioning. Versioning gives possibility for developers to see a history of the development of item.

To ensure the quality of assessment items, various statistics are necessary. 100 % answered items may not be useful, 0 % answered items may be incorrect, or may not reflect material presented in the curriculum. Some items can give an answer to other items—they can be correlated. All this facts (and probably many others) should be discovered by detailed statistics.

## *4.2 Application of Assessment Functionality*

Application of the functionality stated in the previous section can provide "added" value for a knowledge assessment test development. Linking testing items to the specific level of cognitive taxonomy gives a possibility to select better the corresponding items. For example, it gives a possibility to test "knowledge" of participants after lectures but before seminars. Subsequent assessment test can contain items, which can reveal comprehension of presented material. Moreover, items targeted to different levels of taxonomy can be combined for different part of curriculum. This model seems to be suitable for building some kind of adaptive test also (levels of taxonomy can define groups for selection of next bank of testing items). We can start from any level and according to the correctness or incorrectness of participant's answers we can adjust the group of items presented to the tested person.

Having links between testing items and nodes of a cognitive structure of a curriculum gives test developers a possibility to specify items for the evaluation either of an elementary or a composite knowledge. We assume that closed question items (choice from alternatives) should be suitable for elementary knowledge nodes and open question items should be more suitable for composite knowledge nodes.

A combination of presented approaches can provide a possibility to develop tests composed of different cognitive levels for different knowledge nodes.

### *4.3 Semantics of Grades*

An application of taxonomy of cognitive aims gives us an opportunity to attach semantics to grades. Let's take Bloom's taxonomy. We can attach the grade "A" to the highest level of the taxonomy and the grade "E" to the lower levels of the taxonomy (knowledge and comprehension). In such case the grades can provide valuable information for external bodies about knowledge and abilities of the evaluated person.

### *4.4 Mitigation of Technological Issues*

Mitigation of technological issues is the challenging task. Probably, it is impossible to eliminate all technological issues completely. Some of them can be eliminated by test-room organization (no use of keyboard during a test, limited duration of a test) or technologically (restricted desktop environment; use of firewalled computers etc.).

We believe that strong personalization of assessment suites (each participant receive its own not repeated copy of a test [17]) can provide some solutions. A large number of "equivalent" items (items attached to the same taxonomy level and the same node of the cognitive structure of a curriculum) required for the test personalization can eliminate problems regarding stealing of items. Alternative types of items (i.e. items with pictures) including items with open answer can mitigate on-line consultancy.

## 5 Conclusion

Presented ideas reflect the author's current experience in the area of the knowledge assessment. Based on the ideas presented in the paper and presented also in [14], we started an implementation of a knowledge evaluation system [11–13]. The system supports definition of several development roles (project leader, developer of cognitive structure of curricula, developer of cognitive taxonomy and item developer) justified with the corresponding functionality. The role of the test developer remains unimplemented for the time being because we decided to use the Moodle LMS for tests deployment at current stage of the project.

**Acknowledgments** This work is partially the result of the implementation of project "Development of the Center of Information and Communication Technologies for Knowledge Systems" (project number: 26220120030) supported by the Research & Development Operational Program funded by the ERDF.

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# Methods to Ensure Higher Variability of Knowledge Tests in the Moodle LMS Environment

**Jan Genci**

**Abstract** The phenomenon of stealing knowledge tests and their answers by students during the exams is not new for academics. Our department has considerable experience in dealing with this issue within the Cisco Networking Academy (CNA) program and many other courses. Students share "stolen" tests with their schoolmates over the Internet using popular social networks or even publish them on the Internet in order to provide them to anybody who is interested in. We analyze this issue by focusing on the increasing the variability of tests within the Moodle LMS and the results we apply in practice in the course "Operating Systems".

## 1 Introduction

One of the most widespread e-learning courses is the courses provided by the CNA [1]. They provide regular course materials and concisely developed assessment tests. Tests are intended, except final exams, for students to self-assess the level of their knowledge during the learning process. Some kind of plagiarism (steeling tests and their results) occurs during the test assessment or test review. Students just simply cut and paste knowledge items including corresponding correct answers into text document files and spread them over community using popular social network websites.

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We observe similar situations in many other courses. An increased number of students in our courses as a result of budgetary rules led to "crowded" seminar rooms. Approaches used for knowledge evaluation earlier (i.e. combination of written and oral exam) became inappropriate because of high number of students and high load of teachers. That is the reason why teachers at vaious departments concentrate on automating knowledge assessment [1–3, 5, 6]. We are fully aware that current tools supporting e-learning and the increasing popularity of open-source learning management systems (LMS) help to mitigate the above-mentioned problem. For example, one of the most popular LMS—system Moodle [4] —provides not only quite powerful set of testing methods but also supports their semi-automatic instantiation. In spite of this fact teachers spend excessively much of their time in designing, developing and evaluating knowledge tests related to their subjects. Quality of teaching and learning decreases considerably if academic community does not take appropriate measures in order to avoid this kind of plagiarism.

We present here an approach which eliminates partially the on-line assessment drawbacks discussed above. We implemented this approach in the course Operating Systems within the bachelor study program. Just to clarify terminology, we suppose that assessment test consists of assessment questions which, in turn, are chosen (generated) from corresponding assessment items.

## 2 Ways to Minimize the Effect of Stealing Tests

We tried to eliminate problem of stolen tests in the course Operating Systems by two approaches. The first one exploits the fact that students who steal tests are usually "too lazy" to post-process the stolen test. Using the LMS we usually provide several alternative testing items for every question. Let us say, we design simple test which consist of 10 questions. If we prepare only two alternatives (testing items) for each question we can get 210 = 1,024 combinations of testing items. When combined with random ordering of questions every single set of 1,024 testing items can be presented in the 10! (3628800) variants. In such case (theoretically) we are able to generate 3.715.891.200 different tests. Announcing the presented fact to students we try to persuade them that test which they publish on the Internet can be associated with the relevant person. However, in this case it is necessary to find particular stolen test on the Internet. It means we have "to penetrate" to students' social networks.

The second approach is based on the personalization of test. Our goal is to provide every student with a test which contains unique testing items (theoretically), which were not used before. We are aware that such approach is not suitable for each course, even not for all topics in a suitable course. For example, we were nor able to cover all topics of the Operating Systems course by the above-mentioned approach. We note that tests for other subjects of computer science, for example for computer programming can be designed similarly. In this case student

```
Let we have file qwe.txt, current state of which (content and file cursor) is at
the time of execution of system call read() (specified in the following fragment
of code) defined in such manner:

    File:          abcdefghijklmnopqrstuvwxyz
    Position:      00000000001111111111222222
                   01234567890123456789012345
    Cursor:                ^

    and fragment of code:
          //--------- beginning of fragment
          int fd,i;
          char buffer[80];
          ...
          fd=open("qwe.txt",O_RDONLY);
          ...
          i=read(fd,buffer,4);
          printf("%d",i);
          ...
          //--------- end of fragment

Specify sequence of characters which will be placed to buffer (program variable buffer) by
the presented code in the C language after execution of system call read(). We assume that
all system calls will be executed correctly and that variable buffer was initialized by
zeroes. (You have to specify sequence of characters exactly including the case of letters).
```

**Fig. 1** Testing item for evaluation of understanding of the *read()* system call

has to understand the code in order to "compute" correct answer. In the next paragraph we focus on this approach.

## 3 Personalisation of Tests for the Course Operating Systems

Operating System course is divided into following topics:

1. File and directory manipulation.
2. Managing devices.
3. Processes.
4. Inter-process communication.
5. Socket programming.

The file manipulation topic is the most suitable for "personalizing" of testing items. It covers several basic system calls which are related to the content of a file, content of a buffer or file cursor (current position in the file). We are able to test just single system call (i.e. read or write) or combination of several of them (i.e. open, read, write, lseek).

To test student's understanding the execution of read() system call, one of the testing item looks like that is specified on Fig. 1.

We require student to enter a correct answer in the empty field (open answer). Student has to understand semantics of the presented system call and has to be able "to compute" result (the way of presentation of testing item presented on Fig. 1 can be seen on Fig. 2). Such approach highly eliminates attempts to guess correct answer.

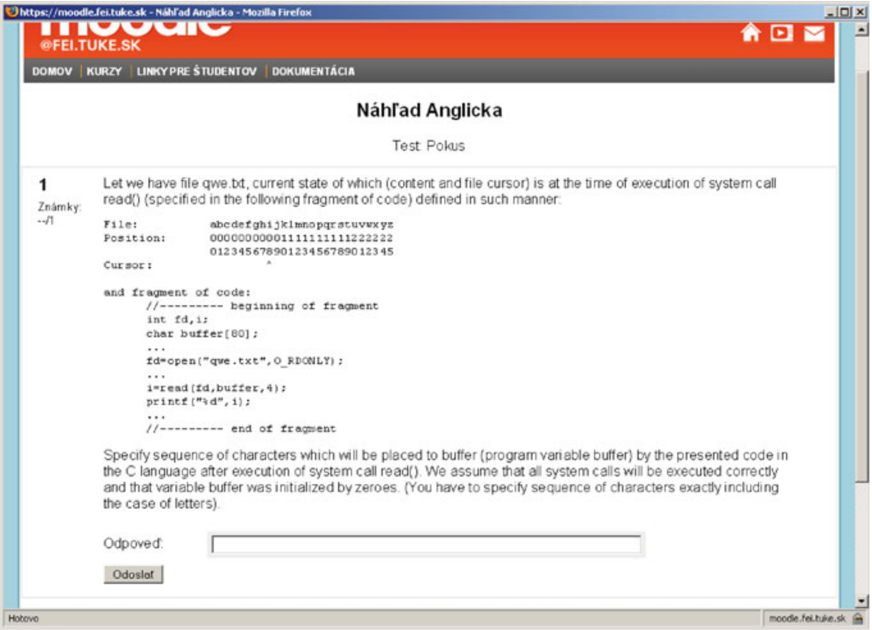


**Fig. 2** Appearance of testing item in the LMS Moodle

## 4 What Data to Personalize?

We provide "personal" version of testing item for every student by changing some fields in the testing item (yellow background on Fig. 1). We use custom random data generator which provides random strings (lower-case only, upper-case only or mixed case) of specified length and random integers (from selected interval) in the required order. Random data are generated as Comma Separated Values (CSV) file. For testing item specified on Fig. 1 we generate following random data:

- Content of the file
- Position of the file cursor in the file
- Number of characters read by read() system call specified in the corresponding line of the program.

Generated data are imported into the spreadsheet (MS Excel in our case) and, if necessary, some other computation is performed in the spreadsheet. On Fig. 3 we can see generated data for testing item presented on Fig. 1. Columns named String, P1 (file cursor position) and P2 (number of characters which should be read) are generated by random generator. Columns named Result and File cursor (will be explained later) are "computed" in the Excel environment. We instruct random data generator to produce required number of records and using MailMerge

| PC | String | P1 | P2 | Result | File cursor |
|---|---|---|---|---|---|
| 01 | oneceauugfycnbwavaokfkvvkb | 1 | 4 | nece | _^ |
| 02 | pasivwrntxialghccvctwvicaa | 4 | 4 | vwrn | ____^ |
| 03 | fqjenuiakentamxnfeiwkxlyph | 14 | 4 | xnfe | ______________^ |
| 04 | jcajfsfruxxrxrkplxwfclyfef | 16 | 5 | lxwfc | ________________^ |
| 05 | wtqfwqveledkmxabofdhmmccun | 5 | 5 | qvele | _____^ |
| 06 | afhlooswyymijekducqpfboijj | 8 | 5 | yymij | ________^ |
| 07 | pwxhfmjjpfscyjbpxjuspcufaq | 4 | 3 | fmj | ____^ |

**Fig. 3** Imported CSV data with some computed columns

functionality of text editor (MS Word) we are able to generate required number of unique testing items (hundreds or even thousands, if required).

## 5 Generating/Importing Data: Moodle Case

The first step is to prepare the required testing items. The next step is to import data to the preferred LMS. Moreover, we have to import not only testing items themselves but relevant result also. Examining Fig. 2 we can even discover that special formatting for file content and source code presentation are required. LMS Moodle (we were used for testing; version 1.8.x) provides several export/import formats, however the only Moodle XML format was able to preserve required formatting.

To ensure import of required number of testing items including correct answers and some other data we follow the following steps:

1. type a prototype single testing item to LMS Moodle
2. export a prototyped single testing item to external file in the XML Moodle format
3. import the exported content in XML format to the MS Word format (using cut&paste)
4. edit/prepare MS Word file for MailMerge (including specification of related generated data)
5. generate testing items
6. export MS Word file content to plain text XML file
7. import plain text XML file into LMS Moodle

Figure 4 illustrates exported XML file prepared for mail-merging with the corresponding data file. To save formatting in the imported testing items space characters in the ≪File_cursor≫ field have to be replaced with the underscore characters. The required transformation was done directly in the Excel file sheet in the column ≪File_cursor≫

```
<!-- question: 0  -->
  <question type="category">
    <category>
        <text>$module$/Source for Pokus/Q01-001</text>
    </category>
  </question>

<!-- question: 7884  -->
  <question type="shortanswer">
    <name><text>Q01-0«PC»</text>
</name>
    <questiontext format="html">
<text> Let we have file qwe.txt, current state of which (content and file cursor)
is at the time of execution of system call read() (specified in the following
fragment of code) defined in such manner:

&lt;pre&gt;
Chars:          «String»
Position:       00000000001111111111222222
                01234567890123456789012345
Cursor: «File_cursor»

and fragment of code:
      //--------- beginning of fragment
      int fd,i;
      char buffer[80];
      ...
      fd=open(&quot;qwe.txt&quot;,O_RDONLY);
      ...
      i=read(fd,buffer,«P2»);
      printf(&quot;%d&quot;,i);
      ...
                                   //--------- koniec fragmentu
```

**Fig. 4** Fragment of exported XML data prepared for mail merge

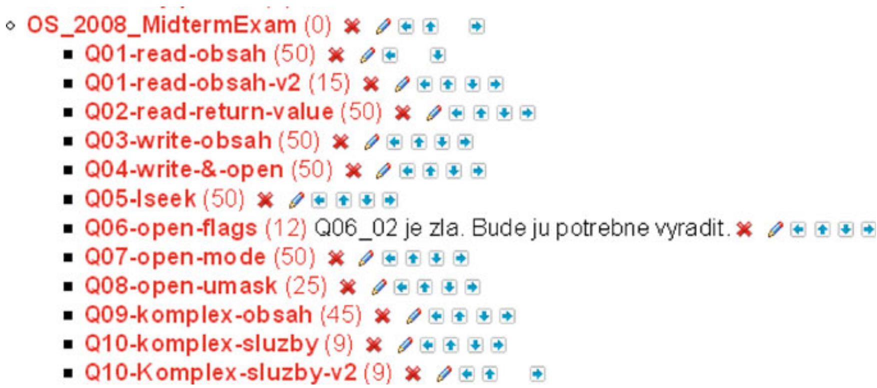


**Fig. 5** The whole test suite with corresponding number of testing items in each category

## 6 Conclusion

Presented solution enables to generate required number of testing items. During the development of tests we met just one limitation—version of Moodle we were used (1.8.x) did not accept <questiontext format = ”html”> XML tag and we were required to change every item manually after its import to correct format tag (it is required for correct presentation of item). That was the reason why we shorten number of questions to the maximum of 50 questions per testing items. But as it can be seen on Fig. 5 nearly half of the testing items have generated content with maximum number of question. It ensures high variability of test and in such way we were able to provide nearly "personalized" version of test for each student. Even in the case of "leaking" of some test to students' community they are forced to learn "semantics" of the testing item and in this way to understand hopefully the idea.

**Acknowledgments** This work is partially the result of the implementation of project "Development of the Center of Information and Communication Technologies for Knowledge Systems" (project number: 26220120030) supported by the Research & Development Operational Program funded by the ERDF

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# The Use of Virtualization and Thin Clients Within the Infrastructure of Computer Labs

**R. Mitwicki, S. Sikora and T. Danek**

**Abstract** The presented paper describes the ad hoc prepared virtualisation solution for laboratory used for short term and rapidly changing additional courses for postgraduate students. Modern computer labs in today's higher education facilities are equipped with dozens of computers and peripherals. In order to take full advantage of their potential, proper procedures in terms of management, maintenance and adaptation must be introduced. The layout of a modern computer lab for optimal use requires an appropriate selection of software and hardware. By using virtualization and thin clients, it is possible to set up very efficient and flexible computer labs, featuring an infrastructure which is oriented both towards the persons responsible for their managing and the users.

## 1 Introduction

In times of rapid development of both software and hardware, the scalability of an entire computer lab infrastructure is a very important issue that poses several difficulties: on the one hand we want to ensure the best working conditions in a computer lab, while on the other hand, available solutions are subject to numerous limitations (e.g. financial and technical problems, rapidly changing requirements etc.). Neither hardware nor software up-scaling, which is a frequent problem in case of modern computer systems, are tasks easy to deal with. This situation is influenced by numerous factors. Scaling becomes even more complicated when applied to hardware since the mere adding of another RAM unit or an additional

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hard drive is not always the best solution and, in some cases, it may even cause more unforeseen problems.

Numerous companies and research facilities attempt to resolve it through the use of servers. However, in the case of computer labs, simple desktop computers are still used instead of servers and dedicated hardware. Obviously, such desktop computers are not built to last but rather to be upgraded with costly new hardware over time—a situation profitable for the producers, but not so much for the users and/or institutions. This raises a simple question: why not use the own know-how to create an easily scalable computer lab?

Such a solution would, of course, require appropriate infrastructure and software to allow optimal use of the system.

It seems that the use of virtualization and thin clients can actually be the perfect solution to the problems mentioned above [1]. Our goal for the present study was to evaluate the applicability of above mentioned factors in the creation of a modern computer lab for higher education facilities.

## 2 Technologies Overview

During the experiment we used two technologies: The first was an open source technology based on KVM (Kernel-Base Virtual Machine) [2], a full virtualization solution for Linux on x86 hardware containing virtualization extensions (Intel VT or AMD-V). KVM was then combined with Qemu [3], a modern virtual machine solution providing numerous possibilities of creating and serving virtual machines. The second technology was a commercial solution, VMware Workstation, which is a desktop virtualization tool [4]. All data gathered during experiments were stored and visualized using Munin tool [5] (Fig. 1).

## 3 Test Environment and Applications

### *3.1 Hardware Specification*

The infrastructure used was composed of a server unit:

- Dual-Core Intel Xeon Processor 5130 (2.0 GHz 4 MB L2 1333 MHz 65w)
- Dual-channel DIMMs 16 GB
- ATI RN-50 ES1000 video controller
- LSI 1064E Serial Attached SCSI (SAS) controller
- Dual Broadcom BMC5708S Gb Ethernet controllers.

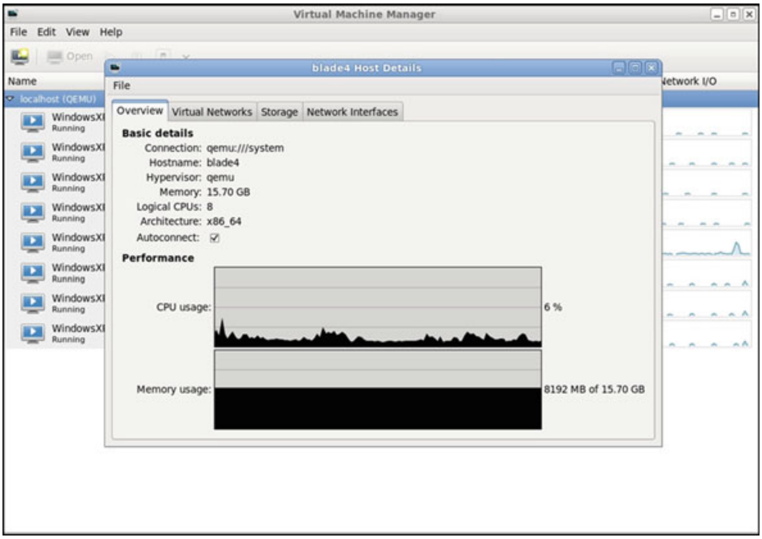


**Fig. 1** Virtual machine manager (KVM)—host details

And 25 "thin" clients(each):

– Intel Core 2 Duo 2 Ghz
– 1 Gb RAM
– Hard drive Sata 7200 rpm
– Ethernet controller 100 Mbps
– Intel® Graphics GMA3100.

### *3.2 Used Operating Systems and Component Environments*

- Server Unit:
  – Ubuntu 10.04 kernel: kernel 2.6.33
  – VMware Workstation 7.0
  – KVM Qemu
  – Munin 2.0.
- Client Unit:
  – Windows XP
  – Matlab R2007b
  – VNC Free Edition Viewer 4.1.3.

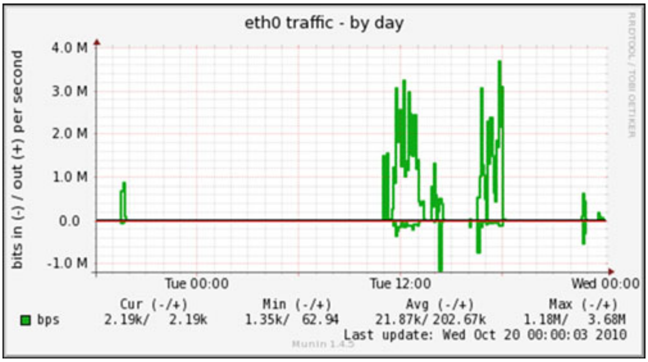


**Fig. 2** Ethernet traffic on VMware blade unit

# 4 Virtualization

In order to asses the possible use of virtualization in professional computer labs and laboratories, an experiment was conducted over the course of a week of classes devoted to image processing. The experimenting user group consisted of 25 students. During classes, the students worked under Windows XP and used special Matlab software. The application of this tool ensured that the students would use an above average percentage of each machine's computing powers.

In order to compare the virtualization solutions available on the market, we used one of the best commercial tools, VMware, as well as an alternative open solution, KVM, the leader in free solutions. Each tool provided 16 environments (8 on each blade) through integrated VNC servers. The environment included Windows XP and Matlab with additional toolboxes necessary for the classes (Fig. 2).

In total, we created 32 complete computer stations connected through a local 1 Gbit Ethernet network.

The classes lasted 6 h a day for 5 consecutive days. A main feature of the experiment was the monitoring of each element of the entire infrastructure during the study (Fig. 3).

Since all 8 machines used the same hard drive and all server machines shared the same network interface, all used elements of the infrastructure were thoroughly monitored due to the high workloads during operation. Additionally, periodic Matlab tests were run to verify the performance of individual client units. We also calculated the use of other resources, such as electricity. The results are presented below:

Assumptions:

Electricity rate—\$0.14/kWh
Energy use for the virtualization of a single blade:
Single blade—0.285 kW

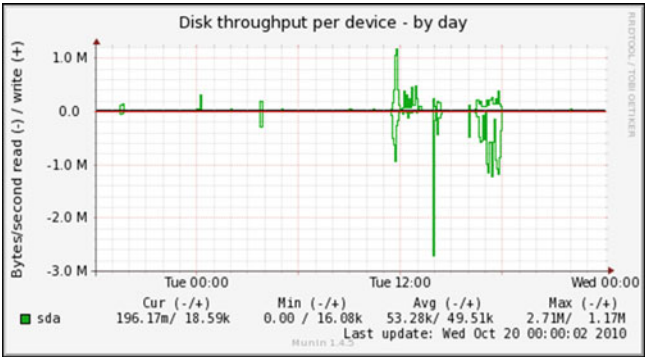


**Fig. 3** Disk usage on VMware blade unit

In 24 h: 0.285 * 24 = 6.840 kWh
Yearly (365 days) = $340.81

Energy use for the standard computers (during operation):

Single computer: 0.0778 kW
In 24 h: 1.867 kWh
Yearly (365 days): $93.03
30 computers—$2790.9 (medium size computer lab)

The estimated costs over the course of 5 years:

Virtualization: $1,704.03
Desktop computers: $4,651.75

The above calculations do not include monitors, which are used in both cases, as well as thin clients in the case of virtualization, because of the possible use of special terminals, whose energy consumption equals approx. 3 W, resulting in approx. $3.49 per year.

## 5 Discussion

While monitoring the system during 5 days of operation, we did not observe any significant issues concerning individual client units. The efficiency of both the commercial and the free solution was very satisfactory. While using virtual machines, neither the students nor the staff reported any differences compared to traditional computers. The lectures took place in a very long classroom where the lecturer used a projector to display images in one end of the room. The images were not visible to all of the students. However, students were able to connect to any machine in “read only” mode, allowing them to display images from the projector on their monitors. With this solution, each student could fully participate

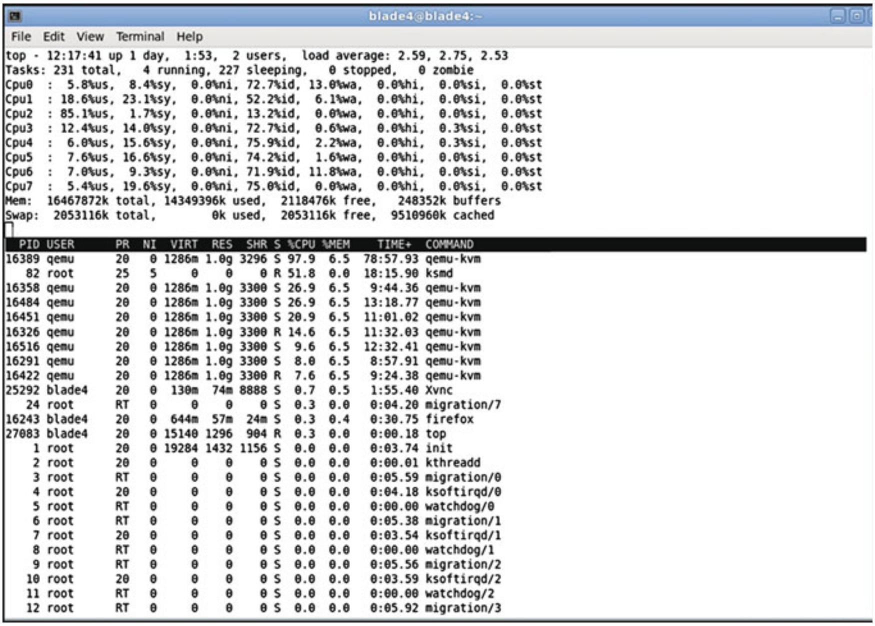


**Fig. 4** System resources utilization

in the lecture, regardless of their sit place. Both the commercial and open source solution enable monitoring and controlling individual machines in real time. This can be used by the lecturer to provide advice to particular students, as required. Additionally this technology can be used in the future to prepare multi-classroom or virtual classroom exercises.

VMware was especially useful in this field, as it incorporates an advanced application for such purposes.

Despite sufficient computing power provided by the server, some applications did not run efficiently under VMware and KVM. This problem mainly affects applications using hardware graphics card acceleration for rendering and processing images. Unfortunately, neither the solutions integrated into VMware, nor those supplied externally for Qemu proved satisfactory.

Another important advantage of virtualization is the capacity to prepare for possible break-downs. During the experiment, no major failures of the system or tools were reported. However, in case of such a scenario, it is possible to create a new working environment within minutes and recover the resources used and created by the student. This means that, just a moment after a system break-down, both the student and the lecturer can continue their work. Professional thin clients also increase working comfort, since the noise generated during operation is strongly minimized, as opposed to standard computers. This also means better energy efficiency. Compared to a standard system, energy consumption with this new approach in a single classroom can be reduced to a third. When using the standard approach, an education facility must replace its computers every several years in order to provide the good performing solutions for students. This involves incurring in high costs when purchasing components or entire computers. The use of virtualization minimizes such costs, and the scalability of servers allows for higher flexibility compared to desktop computers (Fig. 4).

## 6 Summary

Virtualization is a powerful tool, which provides numerous possibilities for creating virtual computer labs and professional laboratories. Although virtualization has been present in the world of IT for a long time, the process still requires tailoring to specific solutions and issues. The above case proves that we are able to utilise such solutions for traditional classes in higher education facilities. Further work and research will allow us to better understand the subject, eliminate the problems and optimise the tools. The solutions presented can

1. simplify the operation and management of modern research laboratories;
2. increase efficiency and working comfort;
3. save energy costs and
4. improve overall IT-budgeting.

**Acknowledgments** This work was financed by the AGH—University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection as a part of statutory project number 11.11.140.561.

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# Testing Mobile Agents on the Azul Platform

**Michał Komorowski**

**Abstract** Mobile agents are small programs that can change a place of their execution from one machine to another. Hence to this and other features this technology has a lot of advantages. Among others mobile agents can be used as a platform for multi-threaded and distributed applications. This kind of platform should be capable of cooperating with solutions like Azul which provides virtually unlimited processor and memory resources for Java and Java Enterprise Edition applications. In this paper scalability and dependability of mobile agents on the Azul platform is evaluated.

## 1 Introduction

Mobile agents (MA) are software agents that have one special feature that distinguishes them from other software agents—mobility. MA are capable of transporting their code, data and execution context from one machine to another and are able to continue execution in a new environment. Many examples of promising applications of this technology can be found in the literature [4, 6, 7, 11]. For instance application for management of heterogeneous networks or MA searching web for resources.

Mobile agents systems are naturally strongly multi-threaded because each mobile agent is usually executing in separate thread. Moreover because of mobility they are also strongly distributed. For these reasons MA can be considered as a

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platform for multi-threaded and distributed applications. In comparison to other technologies MA can be used in heterogeneous environments and provide programmers with additional services e.g. transparent communication between mobile agents.

MA could be executed on ordinary personal computers (PC), mobile devices or servers but it would be valuable if they can take advantages of virtualization solutions like the Azul platform. The goal of the Azul technology is to provide Java based applications with massive, virtually unlimited, computing resource. What is important Java applications can use these resources transparently without any code modification. For instance a mobile agent could be created on a PC or mobile device, migrate to the Azul platform in order to execute some time and memory consuming calculations and finally return to a place of an origin with results.

This research focuses on evaluation if mobile agents could be run on the Azul platform. The second goal is to examine MA scalability in comparison to traditional multi-threaded applications. MA fault tolerance on the Azul platform is also verified with a developed fault injector.

The rest of this paper is structured as follows. In the Sect. 2 mobile agents are characterized. The description of the Azul platform can be found in Sect. 3. The Sect. 4 contains the characteristic of environments in which experiments were conducted. The Sect. 5 contains description of functional tests of mobile agents on the Azul platform. The scalability of mobile agents is discussed in Sect. 6. Finally fault injection experiments are described in Sect. 7. The summary can be found in Sect. 8.

## 2 Mobile Agents

Software agent, according to [8], is a component "which is capable of acting exactingly in order to accomplish tasks on behalf of its user." Moreover it should also have two features from the set of three: being autonomous, being able to communicate and to cooperate with other agents or learn. Mobile agents fulfill these conditions because they can run without a control of a human (autonomy), send messages (ability to communicate) and change behavior based on the observation (ability to learn). Additionally mobile agents have one more feature—mobility.

Mobility is a ability to change the place of the execution from one environment to another and continue work there. The target machine does not have to know anything about migrating agent because data, code and execution context are transported with agents.

The migration is possible thanks to a special kind of software known as Mobile agents system (MAS). This software must be installed on every machine that should be available for migration. The computer that has MAS installed is called host and the running example of MAS software is called the instance of MAS.

Currently the majority of mobile agents systems is created in Java technology. In consequence execution context (registers, stack, etc.) cannot be migrated because the Java Virtual Machine (JVM) does not provide this kind of information. On the other hand popularity of Java technology allows MA to work in heterogeneous environments. Some examples of MAS are: Aglets [1], Jade [5], SeMoA [9] or Voyager [10].

Solutions based on MA are very flexible because it is always possible to create a new type of mobile agent and install it in an already working system. It is also worth mentioning that existing mobile agents can be updated easily by replacing code of MA in a repository.

Mobility allows MA to perform calculations locally, near the data storages without the need to send data though the network, so the data are more secure and the network load is lower. MA could be intercepted during migration but it is not so dangerous because they usually do not carry a lot of data. The majority of MA are small programs so they do not affect network bandwidth.

## 3 Azul Platform

The Azul platform [2, 3] consists of three main components: Compute Appliances (CAs), Azul Virtual Machine (AVM) and Compute Pool Manager (CPM).

Compute Appliance is a hardware part of the Azul platform which contains many processors optimized for virtual machine execution and large amounts of memory. Compute Appliances are responsible for performing calculations and they can be grouped in pools.

AVM is an implementation of JVM prepared to take advantages of CAs. AVM consists of two main components: Virtual Machine Proxy (VMP) and Virtual Machine Engine (VME). VMP is installed on the client side and is responsible for delegating applications for execution by VME and for mediating between file system, database, user and applications being executed. VME is running on the server side and is executing applications. Every application has its own Virtual Machine Proxy and Virtual Machine Engine.

CPM is a component which is mainly responsible for monitoring a system and for choosing the most suitable pool or CA for a particular application. CPM also provides application for administrator which allows to monitor utilization of resources. CPM is installed on every CA but only one instance is active at a particular point of time. The general overview of the Azul platform is shown on Fig. 1.

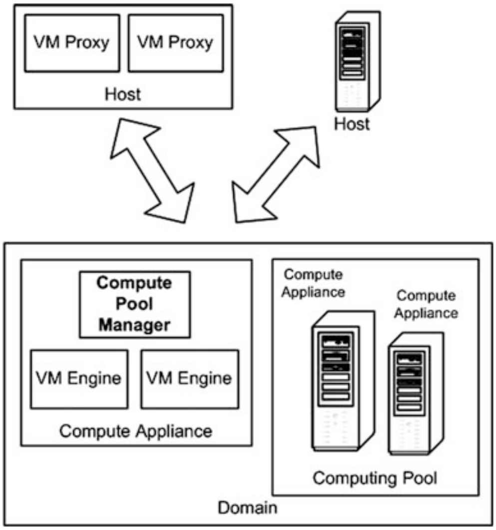


**Fig. 1** The general overview of the Azul platform

## 4 Enviroment of Experiments

The experiments were conducted on three machines: personal computer with Intel Core 2 Duo 2.53 GHz, 4 GB of memory, server brat.ii.pw.edu.pl with 16 logical CPUs 1.6 GHz, 24 GB of memory and CA (model 3840B) with the processor VEGA 1 $\sim$500 MHz with 384 cores, 96 GB of memory. However during experiments resources of CA were limited and only 183 cores and 40 GB of memory were available.

In the experiments Aglets mobile agents system was used. This system was developed in IBM laboratories but at present it is an open source project. It is easy in installation and administration.

## 5 Services of Mobile Agents System

The goal of this experiment was to validate the basic services provided by Aglets Mobile Agents System e.g. migration or communication between agents on the Azul platform. In order to conduct the experiment a new simple type of mobile agent was created. It performs two tasks. Firstly, it can ask for destination host and migrate there. Secondly, it can send messages to any local or remote mobile agent.

First part of the experiment was conducted in two configurations: two instance of MAS running on the Azul platform and two instances of MAS running on brat.ii.pw.edu.pl.

**Table 1** Efficiency comparison

| | The Azul platform | brat.ii.pw.edu.pl |
|---|---|---|
| Migration (ms) | 249 | 209 |
| Asynchronous communication (ms) | 70 | 8 |
| Synchronous communication (ms) | 57 | 7.9 |
| MAS start up (ms) | 18143 | 2065 |

The experiment showed that the MAS services are not interfered and can function properly on the Azul platform. However, the considerable differences in efficiency were noticed between the Azul platform and brat.ii.pw.edu.pl.

Average time of migration was calculated by migrating agent from one instance of MAS to another one hundred times. Before each migration current time had been stored in agent data. After arrival to a target instance difference between current time and time stored in agent data was calculated. Average time of sending message was calculated similarly. In order to get current time the Java platform method System.currentTimeMillis was used. The results are shown in the Table 1.

Despite the high processing power available for applications the results on the Azul platform are generally worse than results on brat.ii.pw.edu.pl. Only time of migration is comparable.

This observation is caused by the Virtual Machine Proxy which mediates between Virtual Machine Engine and the file system (longer start up of MAS) or network communication (longer communication or longer migration). The time of migration does not differ so much because in this case majority of time falls to the transfer of data through network. This time is the same in both environments.

It is also worth noticing that it takes a little more time to send an asynchronous message than synchronous one. This observation may seems to be in contradiction with intuition but can be explained. The experimental environment consisted of two instances of MAS running on the same host and as a result the time of transferring message through the network could be neglected. At the same time the asynchronous communication is much more complicated than the synchronous one and in consequence it takes more time to establish asynchronous connection than synchronous.

Finally the experiment was conducted in the mixed configuration in which one instance of MAS was running on the Azul platform and one on brat.ii.pw.edu.pl.

The test finished successfully and showed that migration and communication function properly in the heterogeneous environment.

## 6 Scalability of Mobile Agents

The goal of the experiment was to investigate the scalability of mobile agents on the Azul platform. For this purpose the implementation of Neighborhood Based Clustering (NBC) algorithm [12] was prepared. This data mining algorithm is used

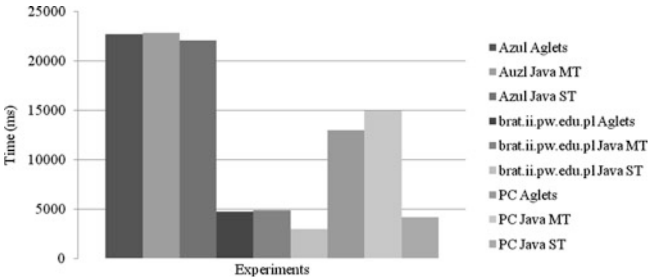


**Fig. 2** The average time of calculations for small number of agents/threads

to cluster multidimensional vectors of numbers. It utilizes a lot of computing resources and performs many operations on floating numbers.

The input data for the application are multi-dimensional vectors of numbers and the parameter K which determines the number of neighbors taking into account during calculations. In the experiment the data set with 2000 vectors was used.

The prepared application allows to specify the range of values of the parameter K e.g. from 10 to 20 with the step equal 2 and calculate clusters for each of values. The developed program has about one thousand lines of code and can be run as a agents based application, as a Single Threaded (ST) application and as a Multi-Threaded (MT) application. In case of the agents based or the MT application a new agent or a new thread is started for each value of the parameter K.

## 6.1 Experiment 1

In this experiment three environments (the Azul platform, brat.ii.pw.edu.pl and personal computer) and three types of applications (agents based, ST, MT) were used. In case of the agents based/MT application five agents/threads were created in order to perform calculations. The results are shown on Figs. 2 and 3. Figure 2 shows average calculation time for a single value of the parameter K and Fig. 3 shows how much time it took to finish calculations for all values of the parameter K.

According to the results calculations performed by the Azul platform were slower than calculations performed by brat.ii.pw.edu.pl and even by the personal computer. It is also interesting that the ST application spent the least time on calculations. The profit from the agents based/MT application is visible on Fig. 3 with total time of the calculations, however the results of the Azul platform are still the worst.

This experiment shows that the use of the complex Azul platform does not always provide a profit. It results from a few factors: the overhead of communication between VMP and VME, the fact that a single core of CA is slower than a core of brat.ii.pw.edu.pl or even a core of personal computer and because of lack of hardware Floating-point Unit (FPU) on the Azul platfrom. In the context of this

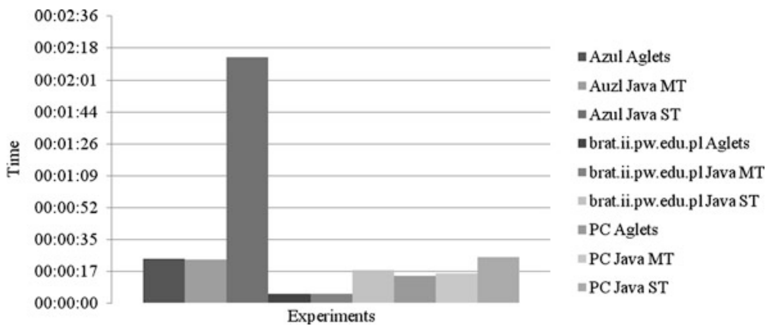


**Fig. 3** The total time of calculations for small number of agents/threads

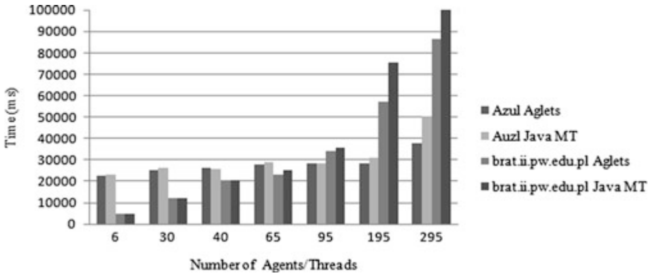


**Fig. 4** The average time of calculations for large number of agents/threads

experiment FPU is important because NBC algorithm uses floating numbers a lot of. The next experiment shows that the Azul platform should be used when the number of agents/threads is big enough.

## 6.2 *Experiment 2*

In this experiment the number of agents/threads being created during calculations was increased. The experiment was conducted on the Azul platform and brat.ii.pw.edu.pl. The results are presented on Figs. 4 and 5 which show, similarly to previous experiment, the average and total time of the calculations.

According to Fig 4 the average time of calculations increase slowly with number of agents or threads for the Azul platform. In case of brat.ii.pw.edu.pl the considerable growth is observed.

The results of the Azul platform are also better in case of total time of calculations. This shows that if the number of agents/threads in big enough the overhead of communication between VMP and VME, less speed of a single core and lack of FPU does not count so much and are balanced by the fact that each agent/thread is executed on a separated core.

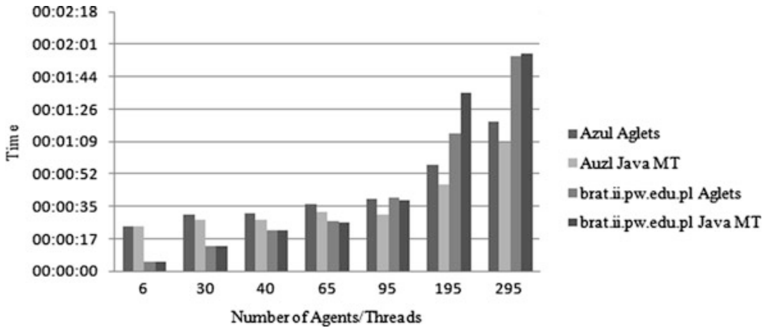


**Fig. 5** The total time of calculations for large number of agents/threads

One more thing can be noticed on the Figs. 4 and 5. The average time of calculations for the agents based application is smaller than for the multi-threaded application but at the same time the total time of calculations is bigger. The precise analysis of logs allows to explain this anomaly. Application's logs show that it takes much more time to create a single agent (dozens of seconds or more) than a single thread (less than one second). In consequence when the number of agents is big enough we have a situation in which some agents have already finished calculation while other have not been created yet. It means that the number of agents performing calculations simultaneously is limited and they do not have to compete for resources and can finish calculations faster. On the another hand it lengthens the total time of calculations.

This experiment also revealed that the Azul platform is more resistant for shortage of resources than the universal machine with Sun Java Virtual Machine installed. In order to run 65 or more agents or threads on brat.ii.pw.edu.pl the option –Xmx of JVM, which increases amount of memory available for JVM, had to be used, otherwise the OutOfMemoryException was thrown.

On the Azul platform when the number of agents or threads had exceeded one hundred the Compute Pool Manager reported shortage of memory and calculations were performed slower but the exception was not thrown. When the amount of memory available for calculations was increased the calculations were performed with normal speed.

## *6.3 Verification of Results*

The last step of the scalability evaluation was checking if results of both experiments are consistent. The evaluation was conducted separately for the agents based and MT applications.

According to the first experiment calculations performed by the agents based/MT application lasts $\sim$4.8/$\sim$4.7 times longer on the Azul platform than on the brat.ii.pw.edu.pl. If we compare number of cores on the Azul platform and on brat.ii.pw.edu.pl we will get ratio equal to ~11.4 (183 cores of CA divided by 16 logical CPUs of brat.ii.pw.edu.pl). It means that for big number of agents/threads, when all cores of CA are used, the Azul platform should be about ~2.4/~2.4 (~11.4 divided by ~4.8/~4.7) faster than brat.ii.pw.edu.pl.

The results of second experiment shows that, for the maximum number of agents/threads, calculations for a single value of the parameter K are exactly ~2.3/~2.17 faster on the Azul platform. As to total time the ratio is equal to ~1.4/~1.7.

Taking into account measurement error and the fact that machines of different architecture are compared it can be assumed that results are consistent.

## 7 Fault Injection Experiment

The goal of this experiment was to compare the dependability of mobile agents running on the Azul platform and on a traditional machine. Because no fault injector suitable for mobile agents was found a new product was developed.

The developed injector is quite simple. It works as a filter between mobile agents and a mobile agents system. It is able to monitor mobile agents' activity, for example detect when they try to migrate or send message, and inject a fault. The communication with the injector is possible through a stationary agent. This stationary agent allows to start/close the injector and to begin/end a faults injection experiment.

The faults are injected in the form of an exception. This exception is called FaultException and is derived from RuntimeException which is a base class for all unchecked exceptions. Hence to this FaultException could be throw anywhere and methods do not have to declare it.

Definitions of faults are read from a relational database. The definition of a fault consists of three elements: type of an agent, localization of a fault and probability of a fault. The type of an agent determines agents for which faults will be injected. These faults can be injected in following situations (localizations): migration of an agent, cloning of an agent and resources disposal.

The probability defines how often a fault will be injected e.g. the probability equal to 0.5 means that on average every second migration of an agent will end with FaultException. In order to check if a fault should be injected the class SecureRandom is used to generate a pseudorandom number in the range from 0 to 1. If it is lower than the probability the exception is thrown.

The injector remembers every fault injected during an experiment in order to check if a fault was handled or not. In addition every exception contains information when it was thrown so it is possible to calculate how much time it took to handle it. These results are also stored in the database. The general overview of the injector is shown on Fig. 6.

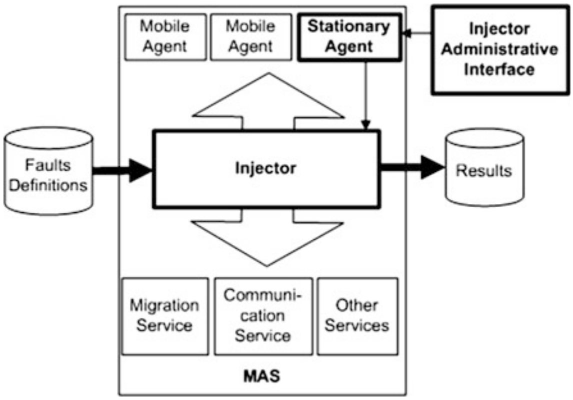


**Fig. 6** The general overview of the injector

During the experiment dozens of mobile agents were migrating and performing some very simple calculations. The faults were injected with the probability equal to 0.1 in order to allow mobile agents to run for some time.

The results of injection were similar in both enviroments. After fault had been injected a mobile agent reported the error and stopped while other MA were continuing their tasks. It is not surprising becouse implementation of exceptions in case of AVM is consisted with specification of JVM. However, it was observed that the faults were being handled considerably longer on the Azul platform (21.58 ms on average) than on brat.ii.pw.edu.pl (0.8 ms on average). It is probably becouse of the overhead of communication between VMP and VME.

## 8 Summary

The conducted experiments revealed that applications based on MA can take advantages of resources provided by the Azul platform. Particularly the basic services of MAS like migration service or communications service functions properly. In addition the agents based applications scale on the Azul platform in the same way as "normal" multi-threaded applications.

Nonetheless, when agents based application is being developed the overhead of communication between VMP and VME and the less speed of a single core of processor should be taken into account. The lack of hardware FPU is also an important factor and choice of algorithms that minimize use of floating numbers could be worth considering. However, this issue requires futures investigation e.g. preparation of experiments with algorithm which does not use FPU could help in better understating of problem.

According to the fault injection experiment there is no difference in dependability of mobile agents on the Azul platform in comparison to other machine. Though, it is necessary to elaborate more work in the future regarding this subject.

The injector used in the experiment has limitations e.g. does not allow for injection of faults into byte code or registers of JVM and is working locally in the context of one instance of MAS.

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# Support of Relational Algebra Knowledge Assessment

**Henrieta Telepovska and Matus Toth**

**Abstract** In the paper a prototype of relational algebra performance module is described. This module supports students training and automated knowledge assessment of relational algebra queries. The relational algebra is a basis of SQL queries performance. Each select statement can be written by operations of relational algebra and vice versa. It is the main idea of our solution that is described in this article. The relational algebra performance module uses a module of select statements evaluation.

## 1 Introduction

Automated knowledge assessment becomes quite popular in the last years [1]. The main idea of advanced support of relational algebra knowledge assessment is to automate the process of student training and examination [2–4]. It was developed prototype of relational algebra performance module which uses module of SQL statement processing especially SELECT statement [5]. Both modules are plug-ins to LMS Moodle. On the present Learning Management System (LMS) Moodle is used as an electronic support in education on Department of Computers and Informatics of Technical University in Kosice. It provides 69 courses in all three degrees of university study—undergraduate, graduate and postgraduate. At first the Database Systems course was developed to provide learning materials for students. Later this course was extended about verification and evaluation of students'

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knowledge. It was used a quiz module of LMS Moodle with its standard types of questions.

A quiz module is a component of LMS Moodle [6]. This module enables to develop tests consisting of various types questions. The questions and the answers are stored in database. It is possible to generate a test from database by defined requirements automatically.

LMS Moodle supports following question types—embedded answers, matching, multiple choice, calculated, random short-answer matching, short answer and true/false. It is possible to set up various test parameters or features. For example—shuffle questions, shuffle answers, permit or deny reviewing a quiz, single or multiple attempts at a quiz, review correct answers, students' responses, scores or general feedback and different grading methods.

The quiz module enables to create the categories of questions in which it is possible to distribute developed questions. One category can contain one or more thematic parts of a particular subject. The questions of Database System course are organized into two basic parts—theory and practice. The category of database system theory is a collection of database system fundamental questions. This category has 11 subcategories. The second category named Database System Examples has seven subcategories. It contains practice examples that verify student knowledge of database objects manipulation.

The examples are focused on mapping logical database schema into physical schema. The next examples are aimed at Structured Query Language (SQL) statements for database objects creation—table, triggers, and stored procedures. The very important questions are examples that verify correctness of select statement writing. The select statement examples are mainly focused on inner and outer join, subquery and usage of aggregate functions. The newest type of question is a relational algebra check that verifies correctness of query writing by the relational algebra operations.

## 2 Relational Algebra

Relational algebra, together with the relational calculus forms the mathematical basis for relational databases. Codd described it as a basis for defining the relational model [7, 8]. A relation is a fundamental concept of the relational model. In the relational DBMS it is a data structure that allows data storage in database. Relational algebra is a set of formal operations of these relations, resulting in a new relation. Relational algebra defines how we can manipulate data in tables by relational operators. Codd originally defined the eight relational operators, which he called SELECT (or RESTRICT), PROJECT, JOIN, PRODUCT, INTERSECT, UNION, DIFFERENCE a DIVIDE. The most important operators are SELECT, PROJECT and JOIN, which are mostly used in the formulation of relational algebra expressions. Relational operators are characterized by closeness property, i.e. relational algebra operators are used over existing relations (tables) and a result is new relation again. There are two types of relational operators—unary and binary. Unary operators such as SELECT and PROJECT are used only at one relation, while an operator such as JOIN is used over two relations [8–10].

There are two groups of relational algebra operations. The first one includes set operations from mathematical set theory, because each relation is defined as a set of tuples. Set operations defined in the relational algebra: union, intersection, difference and Cartesian product. The second one consists of relational operations. This includes operations such as: selection, projection and join [8–10].

## *2.1 Selection*

Relational SELECT operator, also called RESTRICT, retrieves all tuples that meet the specified criteria. SELECT is the horizontal retrieve of relation [8–10].

Syntax of select operation:

$$\sigma < \text{condition} > (< \text{relation\_name} >)$$

$\sigma$—symbol of select operation

condition—boolean expression specified over relation attributes

relation_name—name of the relation which is processed by select operation

The result is a new relation that has the same attributes as original relation defined by relation_name.

## *2.2 Projection*

Projection is vertical retrieve from relation and it selects table columns according to attribute list. Syntax of project operation:

$$\prod < \text{attribute\_list} > (< \text{relation\_name} >)$$

$\Pi$—symbol of project operation

attribute_list—list of attribute (comma separated) displayed in the result

relation_name—name of the relation which is processed by projection

The result is a new relation with attributes that is specified in the attribute list in the same order as listed. If the attribute list contains only non-key attributes of the relation, then duplicate tuples will not be displayed in the final relation.

## *2.3 Union*

Set operator UNION consolidates all tuples of two relations, eliminating duplicate records. Both relations must have the same relational scheme—degrees of relations and domains of corresponding columns must be identical then the relations are union-compatible. Syntax

$$R_3 = R_1 \cup R_2$$

U—symbol of union operation

Relations $R_1(a_1, a_2, \ldots, a_n)$ and $R_2(b_1, b_2, \ldots, b_n)$ must be union-compatible. The degree of both relations is *n*.

The result is $R_3(c_1, c_2, \ldots, c_n)$ relation with degree *n* and each tuple of $R_3$ is either from $R_1$ or $R_2$.

If two relations are not union-compatible UNION operator cannot be used. To overcome this problem, it can be used the project operator, to narrow the number of columns in each relation and the relations were union-compatible.

## 2.4 Intersect

Intersection is a binary operation. The result tuples belong to both relations. Syntax

$$R_3 = R_1 \cap R_2$$

∩—symbol of intersect

Relations $R_1(a_1, a_2, \ldots, a_n)$ a $R_2(b_1, b_2, \ldots, b_n)$ must be union-compatible. The degree of both relations is *n*. The result is $R_3(c_1, c_2, \ldots, c_n)$ relation with degree *n* and each tuple from $R_3$ is in $R_1$ and also $R_2$.

## 2.5 Difference

Difference operator returns all records from a single relation that are not in the second relation. Difference operator requires that both relations were union-compatible. Syntax:

$$R_3 = R_1 - R_2$$

Relations $R_1(a_1, a_2, \ldots, a_n)$ a $R_2(b_1, b_2, \ldots, b_m)$ must be union-compatible. The degree of both relations is *n*. The result is $R_3(c_1, c_2, \ldots, c_n)$ relation with degree *n*.

## 2.6 Cartesian Product

Syntax

$$R_3 = R_1 X R_2,$$

where

$R_1(a_1, a_2, \ldots, a_n)$ is a relation with degree *n* and the number of tuples (the cardinality of relation) is *i*.

$R_2(b_1, b_2, \ldots, b_m)$ is a relation with degree $m$ and the cardinality of relation is $j$.

The result $R_3(a_1, a_2, \ldots, a_n, b_1, b_2, \ldots, b_m)$ is a relation with degree $n + m$ and the cardinality of result relation is $i*j$.

Cartesian product combines tuples from two relations. The result contains many tuples that have no relationship between them.

## 2.7 Division

Syntax

$$R_3 = R_1 \div R_2$$

$R_1(a_1, a_2, \ldots, a_n)$ is a relation with degree $n$ and the number of tuples (the cardinality of relation) is $i$. $R_2(b_1, b_2, \ldots, b_m)$ is a relation with degree $m$ and the cardinality of relation is $j$. $R_3(c_1, c_2, \ldots, c_k)$ is a relation with degree $k = n\text{-}m$ and the cardinality of relation is $i \div j$. The result relation contains tuples from $R_1$ that a combination with each tuple from $R_2$ is in $R_1$. The result tuples has only attributes from $R_1$.

## 2.8 Join

Join operation is one of the basic operations of relational algebra. It is a binary operation that combines two relations in the prescribed manner. It is one of the most important operations in relational databases, expressing the relationship between the two relations. Join R1 and $R_2$ is a select operation applying over Cartesian product $R_1$ X $R_2$ with particular condition. Join operation is defined over corresponding attributes both relations $R_1$ and $R_2$. These attributes have the same domain and semantics. Syntax

$$R_3 = R_1 \bowtie <\text{join\_condition} > R_2$$

$\bowtie$—symbol of join operation

$R_1(a_1, a_2, \ldots, a_n)$ and $R_2(b_1, b_2, \ldots, b_m)$—relations

join_condition—boolean expression in the form <condition> AND <condition> AND … AND <condition>, where a condition has following form $A_i \ \Theta \ B_j$. $A_i$ is an attribute of $R_1$ and $B_j$ is a attribute $R_2$. Symbol $\Theta$ is one of next operators =, <, <=, >, >=, !=.

$R_3(a_1, a_2, \ldots, a_n, b_1, b_2, \ldots, b_m$—a result relation with $n + m$ attibutes

The result relation contains corresponding tuples that satisfy a join condition.

### 2.9 Aggregate Functions

Some database queries require an application of aggregate functions to collection of data records. The aggregate functions also called group functions are COUNT, SUM, AVERAGE, MAXIMUM and MINIMUM functions.

Another type of database query involves grouping the relation records according to the value of some relation attributes and subsequent use of the aggregation function independently of each group. Syntax

<group_attributes> F <function_list> (<relation_name>)

group_attributes—a list of relation attributes for grouping records

F—function symbol

function_list—a list in form <function> <attribute>, a function is one of COUNT, SUM, AVERAGE, MAXIMUM and MINIMUM functions and attribute is one of relation attributes.

relation_name—a name of relation

The result relation contains a group attribute and one attribute for each item from function_list. If no group_attribute is defined the functions are applied to all tuples of specified relation.

### 2.10 Sequences of Operations

The usage of relational algebra operations in sequence can be entered in two ways. The first way is one statement created by immersion of operations. The second one is implementation of operations in succession and storing intermediate results.

The relations which store intermediate results must be named. [8–10])

## 3 Module of Relational Algebra Performance

A query written in a relational algebra can be expressed as select statement of structured query language (SQL). Execution of select statement on the database server returns a relation. It is a way how to check the correctness of written relational algebra statements. It was developed the compiler of relational algebra statements into select statements [11].

The check correctness of a student answer is realized by execution of translated relational algebra statement on database sever. The result relation is compared with relation which is a result of correct teacher select statement. Module of relational algebra performance based on designed grammar transforms a query written by relational algebra operations into select statement of SQL. The select statement is then processed by module of SQL statement evaluation [5, 12].

### 3.1 Compiler

The lexical units of query are identified at the lexical level. On the basis of designated formal grammar rules it is checked syntax correctness of particular query [13, 14]. It was designed a special language for writing relational algebra queries for our solution. The special symbols ($\sigma$, $\prod$, $\bowtie$) which are not standard keyboard input were replaced following keywords:

$$\sigma = \text{SEL}$$
$$\pi = \text{PROJ}$$
$$\hbar = \text{JOIN}$$

The symbol of aggregate functions ‘F’ was replaced FUN keyword.

The intermediate results are written following:

MV1 = relational algebra operation

MV2 = relational algebra operation

…

V = relational algebra operation

MVi—symbol of intermediate result

V—symbol of result—resulting relation

### 3.2 Grammar

An alphabet is the foundation of every language. It is a finite set of elements called symbols [13, 14]. Alphabet of relational algebra:

- {a,b,…z}—roman letters
- {0, 1,…9}—decimal digits
- {‘.’, ‘,’, ‘(‘,’ )’, ‘+’, ‘−’, ‘*’, ‘/’, ‘<’, ‘<=’, ‘>’, ‘>=’, ‘=’, ‘!=’}—special symbols
- {‘SEL’, ‘PROJ’, ‘JOIN’, ‘FUN’, ‘SUM’, ‘AVERAGE’, ‘MAX’, ‘MIN’, ‘COUNT’, ‘AND’, ‘OR’, ‘NOT’}—keywords
- {‘MV1’, ‘MV2’, ….‘MVi’, ‘V’}—reserved words

Grammar of relational algebra language is

G = (N, T, P, S), where

**N** = {Program, Command, Select, Project, Join, JoinAF, Agreg, Conditions, Condition, Relation, Function, Query, Operation}—a finite set of nonterminal symbols

**T** = {SEL, PROJ, JOIN, FUN, AND, OR, NOT, SUM, AVER, MAX, MIN, COUNT, RESULT, DOT, POINT, LOZAT, NM, POZAT, PLUS, MINUS, MULL, DIV, LT, LE, GT, GE, EQ, NE, PART, ID, KONST}—a finite set of terminal symbols (Table 1)

**P** a set of rules

**S** = Program—start symbol

**Table 1** Terminal symbols

| Lexical unit | Terminal symbol |
|---|---|
| Lex[[SEL]] | SEL |
| Lex[[PROJ]] | PROJ |
| Lex[[JOIN]] | JOIN |
| Lex[[FUN]] | FUN |
| Lex[[AND]] | AND |
| Lex[[OR]] | OR |
| Lex[[NOT]] | NOT |
| Lex[[SUM]] | SUM |
| Lex[[AVERAGE]] | AVER |
| Lex[[MAX]] | MAX |
| Lex[[MIN]] | MIN |
| Lex[[COUNT]] | COUNT |
| Lex[[V]] | RESULT |
| Lex[[.]] | DOT |
| Lex[[,]] | POINT |
| Lex[[(]] | LOZAT |
| Lex[[)]] | POZAT |
| Lex[[+]] | PLUS |
| Lex[[−]] | MINUS |
| Lex[[*]] | MULL |
| Lex[[/]] | DIV |
| Lex[[<]] | LT |
| Lex[[<]] | LE |
| Lex[[>]] | GT |
| Lex[[>]] | GE |
| Lex[[=]] | EQ |
| Lex[[! =]] | NE |
| Lex[[MVi]] | PART |
| i → (‘0’ $\mid$.. $\mid$ ‘9’) | |
| Lex[[$j_1$ … $j_n$]] | ID |
| $j_k$ → (‘a’ $\mid$.. $\mid$ ‘z’) {(‘a’ $\mid$.. $\mid$ ‘z’)} | |
| Lex[[$c_1$ … $c_n$]] | NM |
| $c_k$ → (‘0’ $\mid$.. $\mid$ ‘9’) {(‘0’ $\mid$.. $\mid$ ‘9’)} | |
| [(‘.’ $\mid$ ‘,’) (‘0’ $\mid$.. $\mid$ ‘9’) {(‘0’ $\mid$.. $\mid$ ‘9’)}] | |
| Lex[[a$i_1$ … $i_n$a]] | KONST |
| $i_k$ → znak, a →”‘” | |

**A set of rules:**
Program → {**PART** Command} **RESULT** Command
Command → **EQ** (Select | Project | JoinAF | Agreg)
Select → **SEL** Conditions Relation
Project → **PROJ ID** {**POINT ID**} Relation
JoinAF → **ID** (Join | AF)
Join → **JOIN** Condition {**AND** Condition}

(**ID** | **PART**)
Agreg → {**POINT ID**} **FUN** Function (**ID|MUL**) {**POINT** Function (**ID|MUL**)} Relation
Relation → **LOZAT** (**ID** | **PART**) **POZAT**
Function → **SUM** | **AVER** | **MAX** | **MIN** | **COUNT**
Conditions → Condition {(**AND** | **OR**) Condition}
Condition → [**NOT**] (**ID** (**EQ|NE|GT|GE|LT|LE**)
Query | **LOZAT** Conditions **POZAT**)
Query → **ID** | **NM** | **ST** | **LOZAT** Query **POZAT**
| Query Operaction Query
Operation → **PLUS** | **MINUS** | **MUL** | **DIV**
It is a context-free grammar. The form of each grammar rule is
A → α, where A ∈ N a α ∈ N U T).
On the left side of any rule it is no terminal symbol
The grammar is LL(1) grammar, because it satisfies FIRST–FIRST a FIRST-FOLLOW conditions, i.e. for A type rules are defined:
A → α1|α2 |… | αn

- FIRST–FIRST

If $\alpha i \Rightarrow {}^{*}w,\ w \in T^{+},\ \alpha j \Rightarrow {}^{*}u,\ u \in T^{+}$,
then $FIRST_1(\alpha i) \cap FIRST_1(\alpha j) = \varnothing$ pre $1 \leq i, j \leq n,\ i \neq j$.

- FIRST-FOLOW

If $\alpha i \Rightarrow {}^{*}e$,t.j. $e \in FIRST_1(\alpha i)$ for i,
then $FIRST_1(\alpha j) \cap FOLLOW_1(A) = \varnothing$ pre $1 \leq j \leq n,\ i \neq j$

## 4 Implementation

On Fig. 1 the scenario of the relational algebra performance is displayed. SQL_RA_Module controls the whole process of RA_queries and select statements treating. Compiler checks RA_query syntax and if any errors occur in parsing SQL_RA_module finishes its evaluation. RA_query is classified as incorrect. Otherwise, a module returns select1_statement which corresponds with student relational algebra query [11].

The select1_statement is executed on database server [5, 12]. The result relations of select1 and select2 statements are compared. If they are equal a student RA_query is correct else it is incorrect. The module displayed error message if an error occurs in any step of performance.

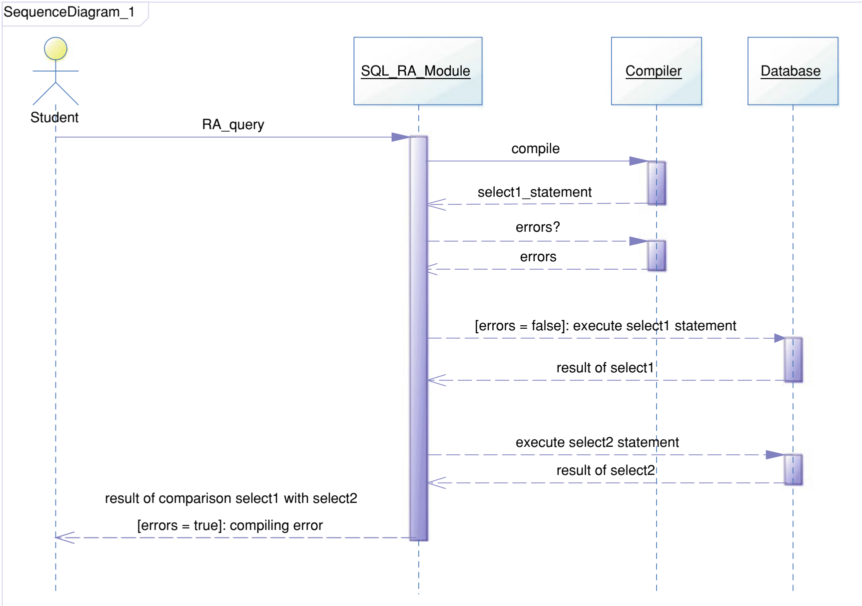


**Fig. 1** The relational algebra performance scenario

## 5 Conclusion

Described solution enables to achieve accurate results. It does not compare specified relation query as text but it compares two relations. On the present the basic operations of relational algebra (selection, projection, join, and aggregate function) are implemented. The next operations are developed. The dynamic evaluation of select statement and relational algebra query is the first step of understanding and correct writing of select statement in SQL.

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# On Synergy of Motivational Projects and Agile Software Development Practices

**Deniss Kumlander**

**Abstract** Nowadays the successful software vendor needs to pick up all modern software development techniques in order to face the globalization and rapidly evolving business world. Moreover we need to combine several techniques or derive more than one advantage from them. Agile software development practices are the one, which we discuss in this paper. These practices suit very well for the commercial software development although have certain common mistakes or problems, which we do propose to close during applying the software motivational projects. The main purpose of the last one is to motivate personnel as using only material techniques to motivate is clearly not enough. At the same time such motivational projects are a perfect opportunity to work and close agile software development problems like over or underestimating applying novel techniques, gold-plating in development and many others as we show in this paper.

## 1 Introduction

Invention of agile methodology of software development has sufficiently decreased the gap between software engineering process results and customers expectations, but wasn't able to eliminate software projects failures completely. Those failures costs and risks are still sufficiently increasing the overall cost of software development process and are ultimately carried by customers. It is important to examine reasons of failures and try to avoid them in order to make

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products' investments much more competitive considering modern software business society and involved risks.

Recent researches [1] have shown that nearly one third of all software projects fail directly since customers are not satisfied with the delivered packaging. A lot of others failures were also indirectly connected to this factor as software vendors were not able to meet time of budget expectations mostly trying to bridge gaps between vision of the project and/or customers and scopes that were defined either in the beginning or during the project. The more interesting fact is that a situation with so called "successful" projects is far from been ideal: just one fifth of the developed functionality was reported to be used "often" or "always" and extra 16 % was marked as been used "sometimes". Clearly, there is a lot of functionality, which is not correct, not working or not usable and all this took considerable time to develop and deliver [2].

Rapidly increasing competition between software vendors on the global market, much more demanding customers and quick change of business rules force software companies to stabilize their productivity and improve their development process in all possible ways [1] considering risks stated above very seriously. The key factor of this process is personnel strategy as personnel is recognized as a very important aspect of any company success [3]. Unfortunately the software industry is a highly technological sector [4] with a shortness of resources in many areas. Therefore the process of motivating employees become crucial to keep the current team stable and involved into projects. Unfortunately the motivation task is elementary and companies are still loosing skilled professionals despite all modern motivating approaches [5–7], like good salaries, friendly working environment etc. Therefore, it is important to address all kinds of needs and motivate personnel using innovating approaches recognizing their abilities and providing them with possibilities to use all their skills increasing this way their attachments to the organization.

Moreover it should be mentioned that the software development process quality also depends on the team performance and willingness to develop the product. The communication between all involved team that are not necessary bounded to the strict hierarchical way of pushing things is one of the key issues improving the quality [8]. Many modern software development methodologies do rely on the advanced team-work, which is stimulated by certain level of freedom in making decisions as long as those serve company targets.

At the same time those short motivational projects give as a perfect opportunity to evaluate certain techniques, quickly learn and phase problems. All this can be used either to avoid or to sufficiently decrease the occurrence probability for many common mistakes we do applying agile practices. Here we are going to revise what the motivational projects are and how those can be helpful to avoid such mistakes.

## 2 Material and Non Material Motivating Techniques: Why Do We Care?

Highly professional and motivated personnel are a key factor of the company success and unmotivated personnel can be seen as a major risk factor [5, 7] since workers either decrease their productivity or leaving the company. In the last case the company loses a professional and had to educate a new person losing a huge slice of experience with the gone person.

There are a lot of motivation techniques as we have already mentioned in the introduction, but the majority of those are materialistic and could not be always available for the organization. Moreover, reasons of losing one or another person could also be different and some could be just tired from doing the same, routine things using the same set of tools, others could like a rotation of environment and persons s/he communicates with or just fill that the knowledge in terms of using technologies become outdated and it is important to find a new place that will guarantee updating skills.

All stated previously clearly demonstrates that there are also non material reasons for losing experts and obviously there should be non material approaches to address stated risks. Besides, a consequence of been under motivated could be less dramatic than migrating to another work-place. It can be decrease of involvement into projects, drop of quality etc. All those risks need permanent attention primary using special personnel management techniques like for example recognizing the person inside the organization as an outstanding professional.

The technological needs can be addressed by recently proposed technique of organizing motivational software projects using novel technologies. This provides an opportunity for both involved parties. It is a perfect possibility for workers to upgrade their skills, learn something new and see novel technologies and approaches. At the same time the organization benefits from exploring new ways of building products that can ensure better quality, performance or usability than in current products. This clearly allows bridging the gap to highly technological products of competitors or coming up with a novel product to the market. Obviously such projects does require investments in term of resources and time, but those will be comparable to the re-education investments in case the company needs to find a new worker and having high chances to produce something novel and highly useful for the company future. Therefore, software engineering projects using novel approaches can be seen as an important motivation tool.

## 3 Personnel Motivating Factor and Software Engineering Strategies

There are two major strategies in the software engineering projects, which are general for all software engineering approaches. The first strategy asks to minimize time and resources spent on the development process. A project management in that case concentrates on the development efficiency of a certain software package. This strategy is usually applied in the following cases:

- A project cost should be minimum/less than usually to get a customer or certain sector of the market;
- There is no major shifts to be done in the development and the best development case is to be applied in this and future projects;
- A project is a standalone one and no future projects should be considered.

Another strategy concentrates on the overall development process optimization by considering future projects also. This strategy allows spending certain recourses on necessary experiments and adopting new technologies. The personnel factor is usually seen in that case as a restricting factor that should be overcame to ensure the project's success.

The project could be a motivating factor for the personnel and this should be considered while planning and implementing software engineering project. This element that looks to be quite small, could be crucial for the project's success. Contemporary software engineering methods ensure general success of projects, but high competition asks to maximize this success by applying additional restrictions for used resources, spent time and so forth [9] or providing much more professional services. The general success is not enough any more to win the race, outstrip competitors. That is why middle-size factors should also be considered to increase productivity and profitability of projects.

Another consideration is more internal for companies although is also indirectly caused by the business environment. There are a lot of countries where the shortness of skilled programmers affects a lot the development process. The personnel is an important part of a successful company and should be carefully used, grown and motivated to ensure the whole company success. All technical equipment is easy to buy and it will work for you 24 h, will not retire since would have other experience or because the work is started to be too boring.

## 4 Personnel Motivating Software Development: Benefits and Organization

There are a lot of developers that are working for a company during 4 or 5 years and then are changing the company since one of the following:

- They would like to obtain a new skill to ensure their future in the quickly changing technological world;
- They are tired to do the same things using the same tools;
- They would like to try other technologies and development principles.

Notice that major standard factors like friendly environment, salary and so forth are well-studied and are not considered in this paper because companies are already skilled in addressing those factors [4, 7]. At the same time developers are still changing workplaces, going sometimes to work-places with slightly smaller salaries because of the above listed factors. The new technologies question and a process of motivating personnel to stay in the company using the software engineering project are considered by us as an important method to ensure companies success and stability. Skilled developers leaving a company create certain troubles for the company in major cases. Often it takes several months or years to train a person replacing the left developer and it decreases the company productivity. The more stable is a workers group the more stable is the company. Therefore we see a challenge to motivate personnel by running certain type software projects and applying new technologies as an important tool to ensure company's profitability and ability to outstrip competitors.

## 5 Personnel Motivating Software Development: Benefits

In the following part of this section we will review benefits of the motivating software engineering. Major benefits are the following:

- Developers will have new experience, increase their number of skills. This provides workers with confidence in their future, since in case they will have to relocate, company will fire them etc. they will have up to date knowledge allowing finding a new position;
- New technologies can also be seen by developers as a challenge to improve they position in the company (versus learning new technologies to keep the level). It can provide them with possibilities to learn and try other areas like design languages, software applying sector rules etc.
- Developers see their work as more challenging and interesting. It results in a higher productivity of developers and leads to establishing much more creative team. Involving developers into the technical design could gain additional credits to that team and will support developers wish to be efficient. This topic will be discussed below under the supporting development approach;
- In the result developers remain in the company eliminating the need to learn new workers and keep companies productivity constantly on a high level, which is a clear benefit for employers;
- The proposed method addresses also workers fear to lose their workplace. In the described situation they will be able to see that management is willing to learn personnel instead of hiring new workers with other skills. It leads again to better "ecology" in the company affecting productivity etc.

There are also some indirect, but extremely important additional effects of applying the personal motivating software engineering, which are listed below:

- Employers can see in scope of those projects how workers can adopt to new technologies; are they willing and able to learn something new. Notice that inability to learn is not something bad. It just provides employer information about potentiality of their teams in future projects and allows segment the team by their ability to learn into innovating, slowly changing/slowly learning and finally static.

The segmentation process will allow keeping different people happy by addressing their requests and expectations in the best way. Static workers can be kept on fixed project that are not migrating to other technologies, while innovating should be used to start the technology migration process. Moreover this segmentation helps to plan the learning process as slowly learning developers need more time and this factor should be considered to avoid producing a stress situation for them;

- Software development motivating personnel in some cases can increase cooperation between team members, first of all between developers, as they need to discuss new techniques, may be learn something together in groups etc. [9]. Workers collaboration is a standard problem in many companies sometimes addressed by having external parties to establish contacts. The proposed method is one more instrument to make the collaboration between team members stronger;
- A person who is working always on the same things sometimes has too limited vision over those things. New techniques, principles and algorithms can be used make the vision broader and make a programming in old languages (since he still has to support old applications) more efficient. Participation in an innovating project extends the general understanding of programming principles, techniques and approaches a lot.

Another possible advantage of the same type that could appear: new projects and new technologies could show a new way to program old modules using new languages (not by applying new ways in the old languages as it was described above). There could be for example performance problems that are widely believed to be none-solvable in any other language, but the closer look at new programming languages can show hidden possibilities. Notice again that the close look is not possible without: (a) a practical knowledge of the new language (b) a deep knowledge of the problems that are believed to be unsolvable. Notice that if the a condition can be met using an external experience then the both conditions are quite hard to meet even using a round table with experienced experts and an applying developers in innovating projects can accidentally solve that. Establishing an innovating project to find if a new technology could solve problems could be not the best practice in certain cases, for example if there is no clear vision of what technology to use, but a possibility of the described advantage exists.

Another type of advantages is connected to workers who are not developers, i.e. is not connected to a group that is mainly concerned in this paper. Although those plusses cannot be a main output of this paper those are still worth to mention since can be used to increase new technology projects support from the organisation and management. Notice that individual plusses are usually not enough to run projects. A synergy of advantages from different categories is required to ensure management's support and success.

None software development personnel and organisational benefits can be the following:

- It is a common situation that many very well qualified specialists that are starting to work for an organisation feel to be locked in an old software system. They could have a lot of ideas that can be useful for the organisation, but which are hard to implement due workflow rules fixed in an information system. The new technology projects can be motivating for such specialists since provide a possibility to make changes that they were looking for; changes that will enable to release their potentials. A lot of specialists are leaving companies since they are not satisfied with what they are doing, because they see that can do much more and much better, because they cannot do it in the current company due certain restrictions;
- New technology projects can be very useful for an organisation if technologies are applied correctly and in the right place. Those provide new or better ways to achieve organisations goals. None-innovating companies face a risk to remain behind competitors that are moving forward;
- A better collaboration between departments can be again a reason to apply software engineering projects that are motivating personnel. The collaboration is normally improved if team members are interested in their work, motivated to do it and achieve results. A broad set of departments and teams can benefit from the collaborating work. It is a way for departments' chiefs, for example, to ensure that IT understands their needs, to improve personal relations to ensure fulfilling their requirements in the best way and so forth.

## 6 Common Mistakes of Rapid and Agile Development

The agile community collects not only the stories of success, but also failures trying to analyze reasons of that. During the analysis process some mistakes has been identified and certain mistakes are very often and so those are collected in the list of common mistakes of agile development. We will revise the part of this list here in order to see, which of them can be relaxed during our motivational projects.

The list is usually divided into the following groups: people-related, process-related, technology-related and product related. The people related mistakes are:

- Undetermined motivation
- Uncontrolled, weak or heroic personnel
- Personnel added on the late stage of software project

- Unrealistic expectations
- Wishful thinking

And some others

The technology-related mistakes are:

- Silver-bullet syndrome
- Overestimated saving from the new tool

The process-related mistakes are:

- Optimistic scheduling
- Insufficient planning
- Wasted time of fuzzy front-end
- Omitting necessary tasks from estimates
- “Cowboy” style programming producing a constant development debt in the code

The product-related mistakes are:

- The research oriented development
- Development gold plating

Clearly here we have collected only circa 60 % of the overall list concentrating mainly on those that can be processed by the software motivational projects. At the same time the overall percentage (60 %) is high enough to say that applying the propose technique will give a sufficient advantage applying and consuming rapid or agile software development practices.

## 7 Personnel-Related Mistakes and Software Motivational Projects

The motivation is the first target we are aiming executing the proposed type of projects, so we are directly eliminating the undetermined motivation problem from the top of the people-related mistakes list.

We do also learn to know our personnel during this project, cluster them into groups and find out how they do communicate and work been in the same group. The same people can be a trouble maker been in one team and be a leader in another. It can depend, for example, on the team members—if there is no one to compete with, no other leader, then the direction is constant and one and the team is working extremely well.

The motivational projects have also a clear and strong educational property. Teams’ members learn to estimate, apply their estimates and discovered the gap between their estimates and reality. The last one is the estimation error, which often comes from the overall wishful thinking, so their learn to add certain additional times on tasks their do normally fulfill, but do forget to estimate on a constant base.

## 8 Technology-Related Mistakes and Software Motivational Projects

One of the main ideas of motivational software development is to explore one or another technology, understand it either completely or as much as we need to have a full picture. Obtaining this kind of knowledge will give as a picture of where the explored technology is good and very it is bad or inefficient. This way we learn the technology application pattern, i.e. learn where we can and where we should not apply one or another technology.

The overestimating is the same kind problem as the described above from the motivational projects point of view. During the last we do learn to apply and so we learn to use the technology and consequently to estimate tasks which should be developed using it. The well-known uncertainty description in agile projects says that the largest difference between estimates and real spend time exists in the beginning of the projects and we do eliminate this uncertainty by doing steps and moving toward the desired result. The more we learned the better we can say when the project will be completed decreasing the release date variation. Of course in the main product we decrease uncertainty that comes from many sources like specification, users opinion and technology, but the last is not the least and many projects were over-budget due applying unknown technology or was rejected since the estimate was higher than is had to be purely due the risk time, which the team adds due technological uncertainties. Therefore it is very important to pilot and learn technologies motivating personnel.

## 9 Process-Related Mistakes and Software Motivational Projects

The well known principle of agile development says that we should not over-plan since during this process [9] we give more precise estimations that we actually could basing on our current knowledge of the future product, technology we are going to apply and so forth. Unfortunately it leads in many cases to under-planning since people believe that whatever number is the same good. The art of finding the right balance in the planning is very hard to acquire and motivational projects can actually give us certain practice serving as educational projects as well.

Another common problem of planning is planning very well for the first iterations and planning very weakly for the completion of the project. Many projects has been prolonged not due the fact that at the end some kind near fact and required tasks were discovered, but purely due the fact that last stage tasks were either underestimated or even forgotten. Therefore, if we would do them in motivational project then we would better see which tasks should be done and what is there relative weight (points) so we can better estimate and plan our main stream products development.

Finally we can learn in motivational projects how much we spend on UI and how do we develop. The shorter the cycle (the motivational projects are normally much shorter) the more intensive communication between developers is. This is an environment were "cowboys", that leaves too much either unsolved or in such a debt that other will be forced to redevelop, are discovered quickly and the pressure the team is directing to this development can help him to learn better ways of writing the code.

## 10 Product-Related Mistakes and Software Motivational Projects

Clearly the main goal of the motivational project is to conduct the research of new technologies exploring new ways of building products. All this is designed from the beginning to avoid research based development in main projects were the cost of applying unverified technologies is much higher than in motivational projects. Besides the main product line iterations are much longer so the fact that the wrong technology is applied can be discovered much later than in motivational projects, which serve as piloting also.

We can also say, that the gold-plating can also be partly covered in the proposed kind of projects since developers learn to deliver within a predefined, short time, so will have to prioritize one feature over another, learn to keep features on the right grain in order to have time for working on other techniques and features. This experience will be very useful for them later in main stream production environment were then apply it although they will deal there with different features or user stories rather than technologies.

## 11 Conclusion

In this paper we explored what the motivational projects are and how those can be used into additional to other material motivational techniques to avoid personnel migrating out from your organization. The last is very important since ensures the constant development flow, keeps the knowledge inside the company and eliminates the stress for the rest of the team having to close the unexpected schedule gaps produced by loosing personnel. The other part of the paper was dedicated to looking into what common agile software development practices mistakes can be eliminated by the personnel motivating projects. The agile practices are the key practices nowadays for the commercial software development and certain mistakes are known to be extremely common. Those mistakes are important to deal with since those can either lead to over-budgeting or even to not applying the agile development principles at all missing a lot of advantages (in case the very first agile project lead to a terrible failure). Therefore it is important to predict those mistakes and avoid them (or decrease a probability of occurrence) as early as possible and here we have examined a lot of them showing how the motivational projects can help us.

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# Expert System as the Tool for Information Asymmetry Reduction on RCBS Market in EU

**M. Hedvicakova and I. Soukal**

**Abstract** The paper is focused on retail core banking services in Central Europe where expert system named Retail core banking services calculator (Calculator) has been introduced at the beginning of the year. This online system is created to help the client to choose the best bank concerning his or hers usage pattern. The main part of the paper describes data analysis outcome from Calculator's respondents such as client clustering and average costs. The four main client clusters are identified and described by specific and detail month usage pattern gained using the non-hierarchic cluster analysis. There is also discussed charge structure in EU non-eurozone countries but the main focus of this paper is on the e-banking clients in the Czech Republic (non-eurozone member of EU).

## 1 Introduction

This paper is focused on the retail core banking services market (RCBS), which concern a great majority of consumers in European Union market (EU). These services include account administration, cash utilization, realizations of money transfers and additional services. Various studies assigned, or elaborated, by European Committee or European Union Directorate-General for Health and Consumers Protection [1–3] show the fundamental problem in this market from the point of view of the consumer. This problem is low transparency and very difficult product comparison of offers of individual banks with respect to client costs (generally included in the term bank charges), which restricts the principle of

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the invisible hand of the market. Opacity of offers of individual banks and impossibility to compare them, easily and clearly, is one of the key manifestations of asymmetry of information in the market. This problem was observed across the EU.

As the very response in the Czech Republic (CZ) to this situation the web-based RCBS expert system called The Bank charge calculator (Calculator) was created as an independent project of the RCBS market focused web bankovnipoplatky.com. This paper analyses Calculator respondent's data using cluster analysis based on k-means algorithm. Clusters were computed using statistical software IBM PASW 18 (formerly known as SPSS), for the rest of the computation was used MS Excel 2007.

The SEPA monitoring study focused only on imposition of charges on electronic banking confirmed how difficult it is to ascertain client costs of these services because of unclear and nontransparent tariff structures of bank products. One of the main findings was that with regard to 69 % of offers of bank institutions, even after studying these offers thoroughly, experts had to ask the banks subsequently about the exact amount of charges for the individual services [1]. The consequence of the non-transparency and lack of clarity was found out in the study of UK Office of Fair Trading and is the following. Customers basically do not know how much they pay for bank services, not even after they were already charged for the observed services [2]. On the basis of recommendation by the company elaborating the study, the EU commissioner for interior market Charles McCreevy, before the end of his term of office, took charge of several most crucial issues. The major issue for Central and Eastern European countries was to create an on-line accessible and easy to use comparison service, which enables customers to choose the bank most suitable for their needs from the perspective of costs.

## 2 Expert System the Calculator

As the very response in the Czech Republic there was created The Calculator. This service compares costs for clients in individual offered accounts on the basis of their RCBS use and recommends the lowest costs products. Knowledge base of the Calculator contains the tariff data of 12 banks (more that 98 % of the RCBS market in the CZ) and their 45 accounts. Client only fills the detailed form concerning the usage of specific services—52 questions in total (25 questions with attached sub questions and three additional questions). All fills are saved so the data for this study were acquired from 12,012 respondents who used the form of the Calculator in the time period from 12th October 2009 to 30th July 2010. The main tool for further help to choose the optimal cost account requires the identification of the most important RCBS client profiles. Because of specific respondent data gathering there has to be limited the population for which the client profiles will be identified. The client profiles in this paper are computed for and from e-banking client population (non-e-banking respondents were excluded from analysis). Analysis method of K-means was chosen by recommendation of [4–6] due to number of respondents and variable scale.

From the marketing research point of view there are gathered data:

A. Multivariate—there has been monitored 53 variable concerning RCBS usage, 2 system variables for respondent identification and 45 variables containing the calculated costs for each of monitored RCBS product,
B. Primary—data were gathered directly from the client,
C. Subjective—data came from respondent himself, respectively it is his or hers subjective judge.

Due to specific data gathering process the data analysis outcome cannot be applied on the whole CZ population. Although the ratio of client with active e-banking and clients without electronic access to the account is 4:1 [7] and it will rise year by year we cannot include non-e-banking clients in our research. So the analysis and results concern e-banking population only. Still it is major share of the RCBS population.

## 3 Client Index

The first analysis output is easily understandable for the general public but important for market analysis too. The Calculator saves the client's actual bank and account. Then there can be calculated how much average client of this account pays for RCBS per month. The average costs (AC) on each account are again determined by two main factors: level of RCBS charges and individual usage pattern of RCBS. In another word very passive can pay average fees at costly account and very active client can pay average fees when the RCBS provider is optimal. Usage pattern and optimal bank choice are crucial because some banks are low-cost when using just e-banking but very expensive when using at the desk services.

AC is not just actual information regarding charges of specific product but it can be also used as price level monitoring tool when client index (based on AC calculation) is calculated. The idea is very similar to consumer price index for inflation determination. From client index (CI) results can be constructed a time series that can monitor consumer/client nominal price level. When CI will be purged from inflation and season influence, then there can be CI monitored as a real price level index. Now there will be presented computation. The AC per month of hth account are:

$$AC_h = \sum_{h=1}^{k} \sum_{i=1}^{n_h} c_{hi} \tag{1}$$

Equation (1) is:
AC average costs,

$c_{hi}$ costs of the ith client using hth account per month,
h ordinal number of account,
i ordinal number of client,
k sum of the monitored accounts,
$n_h$ sum of the clients using hth account.

Client index is weighed sum of $AC_h$s where the weights are derived from shares of individual banks on the client population. There are two approaches. The first one uses shares from annual reports and bank's web pages. The second one is based on shares from the Calculator, respectively on shares of each account on the market. There has been chosen the second one because there isn't described whole population for which the first one should be used. The client index or it can be said the average costs of an average client are then:

$$\begin{gathered} w_h = \frac{n_h}{n} \\ CI = \sum_{h=1}^{k} w_h \cdot AC_h \end{gathered} \tag{2}$$

Equation (2) is:
AC average costs,
CI client index,
h ordinal number of account,
k sum of the monitored accounts,
n sum of clients (respondents),
$n_h$ sum of the clients using hth account,
$w_h$ weight (share) of hth account.

CI based on the data from almost 2,000 respondents gathered during 3rd quarter of 2010 is 6, 5 € per month so 78 € per year converted by actual exchange rate czech crowns—euro (thereinafter only as CZK and as EUR or €). The calculation is preceded by a verification validation part, so that the result is not distorted by for example respondents who should not, in fact, use retail products (the self-employed, small entrepreneurs with frequencies of use of bank services, which the client on a civil account can never achieve) or respondents, who just clicked through the form without filling out the key services. Total number of respondents before the validation and verification was almost 2,800. Concerning the methodology, a special case is Česká spořitelna member of Erste finacial group (CS). Here the client's costs depend not only on tariffs, but above all on the settings of the account configuration utility where the client will compile his account. The there is a lot of combinations and tariff changes. Means from the calculated costs expended by clients could not be used to discover these costs so there has to be used different approach. Profiles created by cluster analysis were used (Tables 1 and 2) and then using the prerequisite of rationality there has been found an optimal account configuration setting. Then there were calculated costs from actual tariff. The final costs for the client of CS were calculated by weighted

**Table 1** RCBS monitored by the Calculator

| | |
|---|---|
| **Account Management** | Opening and keeping current account |
| | Statements |
| | E-banking |
| | Tele-banking |
| Cash Utilization | Deposit and withdrawal at desk |
| | Deposit and withdrawal at bank's ATM |
| | Deposit and withdrawal at other banks' ATM |
| | Cash-back |
| Exceptions Handling | Card exceptions services |
| | Extra statements |
| Payments | Direct payment |
| | Standing order |
| | Encashment |
| | Credit card |
| | Debit card |
| | Internal wire transfer |
| | External wire transfer |
| | Domestic wire transfer |
| | Foreign wire transfer |

*Source* Own research

sum. Weights were derived from the number of elements in individual clusters and weighed average costs were optimal costs of each cluster.

CZ is a member of EU but not the member of the Eurozone (such as Great Britain, Poland etc.). It is interesting that year costs of an average non-eurozone client were calculated in study [8] as high as 71, 1 €. When our actual CI of 78 € is converted by exchange rate from the last year it is 72,4 €. Our result is very close to the one from [8] because there is only 1, 3 € difference per year.

## 4 Charge Structure in EU and Client Cluster Identification

Using data from the Calculator there can be identified client clusters or there can be said a market segments. This is valuable information not just for banks but mainly for clients themselves. The reason is that client can find cluster where he or she belongs—cluster with RCBS usage pattern closest to the actual client's one. Calculator team publishes on web 15 best banks by cost criterion for each cluster. So the client/respondent doesn't have to fill out the Calculator form. It is sufficient to choose the closest cluster and its best RCBS providers published on Calculator web. But before there will be presented computed clusters there will be discussed a charge structure in non-eurozone countries. Our cluster analysis is expansion of this charge structure study for CZ that gives detail inside look in the RCBS costs determination by client usage pattern and by bank tariffs settings.

**Table 2** Centroid values for each cluster

| Variable/cluster | 1 | 2 | 3 | 5 |
|---|---|---|---|---|
| Domestic ATM withdrawal, own bank | 3.1 | 2.5 | 2.8 | 2.1 |
| Domestic ATM withdrawal, foreign bank | 1.0 | 0.4 | 0.8 | 0.4 |
| Abroad ATM withdrawal, own bank | 0.4 | 0.1 | 0.1 | 0.1 |
| Abroad ATM withdrawal, foreign bank | 0.4 | 0.1 | 0.1 | 0.1 |
| Incoming payment from foreign bank | 3.1 | 1.7 | 2.2 | 1.4 |
| Incoming payment from own bank | 2.3 | 0.8 | 0.7 | 0.7 |
| Direct payments to own bank at desk | 0.1 | 1.1 | 0.0 | 0.1 |
| Direct payments to own bank Internet | 3.6 | 0.5 | 1.5 | 0.8 |
| Direct payments to foreign bank at desk | 0.1 | 1.7 | 0.0 | 0.1 |
| Direct payments to foreign bank Internet | 4.4 | 0.7 | 4.0 | 1.3 |
| Standing orders to own bank at desk | 0.0 | 1.6 | 0.0 | 0.1 |
| Standing orders to own bank Internet | 2.5 | 0.2 | 0.8 | 0.3 |
| Standing orders to foreign bank at desk | 0.0 | 2.7 | 0.0 | 0.2 |
| Standing orders to foreign bank Internet | 3.0 | 0.3 | 3.0 | 0.6 |
| Encashment to own bank at desk | 0.0 | 0.8 | 0.0 | 0.1 |
| Encashment to own bank Internet | 1.3 | 0.1 | 0.2 | 0.1 |
| Encashment to foreign bank at desk | 0.0 | 1.2 | 0.0 | 0.1 |
| Encashment to foreign bank Internet | 1.6 | 0.1 | 1.1 | 0.2 |
| Cash deposit at desk | 0.6 | 0.5 | 0.2 | 0.3 |
| Cash withdrawal at desk | 0.3 | 0.5 | 0.1 | 0.2 |
| Cash back | 0.3 | 0.1 | 0.1 | 0.1 |

*Source* Own research

Despite the fact that many banks in international markets are subsidiary companies of other banks or financial groups in Europe, which form certain groups together (e.g. Central Europe with Southeastern Europe and the group Erste or Central and Western Europe and the group KBC etc.), on the other hand in national markets, banks preserve the structure of charges typical of the market of the given country. Concerning the situation outside Eurozone, there can be identified 3 models of bank charges, as can be identified from Fig. 1:

The first model includes countries of Central Europe, Switzerland and Russia. In these countries, one-third of overall charges in average consist of costs of the account management costs. These costs are usually fixed costs and thus the client cannot influence their amount by his or her behavior. The second similar important group consists of charges for cash utilization. The main representative of this category includes ATM withdrawals and at desk cash utilization. These charges pertain to the group of variable costs and those fees proves, among others, the fact that clients from countries of Central and Eastern Europe still have a strong preference for cash. The rest of the charges consist of receiving and sending payments. These items also pertain to variable costs and therefore it can be stated that clients affect about 2 thirds of the total amount of their costs by frequency of RCBS usage. Charges for additional services account are negligible.

The second model includes Scandinavian countries Norway and Sweden, which impose charges almost exclusively on payment transactions, similarly to the banks

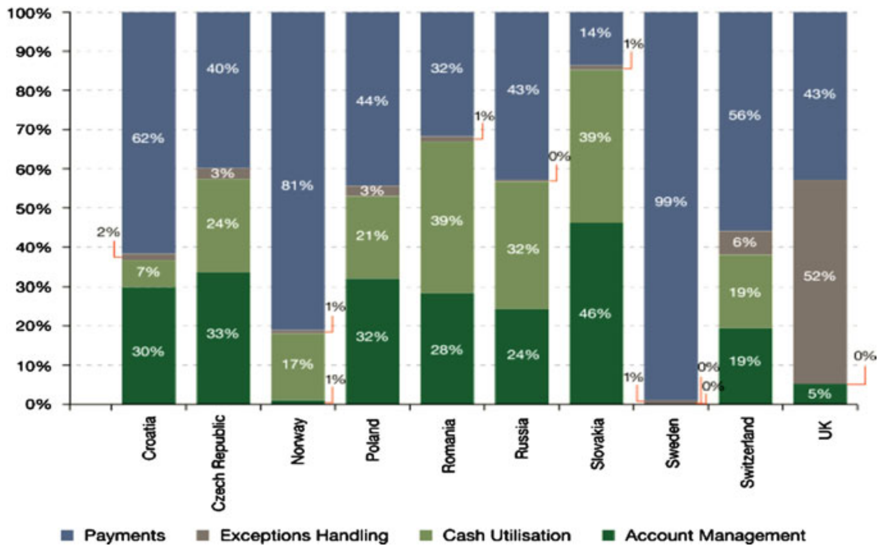


**Fig. 1** RCBS charge structure in non-eurozone european countries in 2009. *Source* [CAPGEMINI, 2009]

in the USA. It means that frequency of use of RCBS in these countries has almost total impact on the final costs. This makes it similar to the model 3 outside of Eurozone.

The third model is Great Britain, where charges for cash utilization and account administration have a minimum impact on the total costs of RCBS use. This means that the client has a great impact on his or her costs by means of frequency of using the account, as well as in the previous model. Another research [9] confirmed that British banking is one of the most fair with regard to the financial costs of RCBS, in the spirit of the thesis: “I pay for what I use.” It is caused by situation where fixed costs virtually do not exist and also individualized services play their role.

Now there will be described client clusters. Within framework of this clustering, 6,943 respondents passed the verification/validation phase and were analyzed on 21 variables using the listwise method. Data validation of this treatment used more strict data filtering to guarantee that source data won’t include extreme clients—self-employed, small business or well known half-legal internet auction businessmen without license, all those clients are not allowed to use retail products but it is public secret that sometimes they are doing so. After data validation and verification phase there have been studied the possibility of variable replacement by main components and multicolinearity risk. Because of variable and respondent count there has been used non-hierarchic cluster analysis algorithm K-means. Optimal number of clusters has been determined using the G5 rule recommended by [4], [6]. Optimal G5 value has been reached at number of clusters 5.

In the Table 2 there are shown values of cluster centroid for each of a typical client behavior pattern.

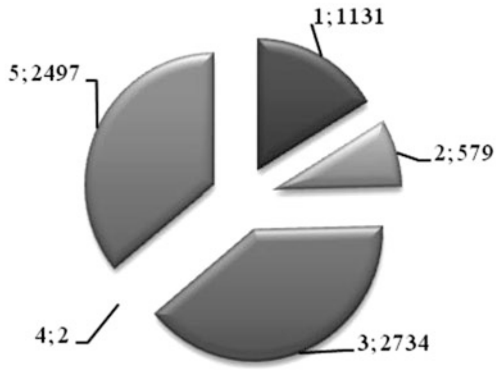


**Fig. 2** Shares of computed clusters. *Source* own research

The graph (see Fig. 2) then shows members count of the individual clusters. As it can be seen on the graph attached, there has been computed one extremely low-member cluster. Because of its insignificant influence there will be described in detail 4 clusters only:

The average client, 39, 3 %—cluster 3 is major group of the e-banking client population. It shares common frequency of ATM withdrawals with the others clusters (approximately 3 times from client's own bank and once from foreign bank). Typical for this client is preference of electronic banking usage both for direct payments, standing orders and encashment. Usage of at the desk services is sparse. Usage of these services is consisted of cash deposit, cash withdrawal only once or twice per year (this interpretation can be reversed as in the previous analysis, that is one from ten clients from this group uses an at desk cash withdrawal once per month).

The active client, 16, 3 %—cluster 1 is a group of the more active clients, where, compared to the average client, the frequency of incoming payments is 2 times higher. Usage of services direct payments to own bank, cash ATM withdrawal from foreign bank, cash deposit or withdrawal and standing orders to own bank is 3 times higher. Concerning other services, this profile is similar to the average client and this client also shares with the average client the preference of the communication channel of e-banking. This client also has the highest frequency of ATM use abroad, although it is only 3 withdrawals per year on average.

The average client with "at the desk services" preference 8, 3 %—cluster 2 is smaller than the cluster with desk preference clients from previous clustering. RCBS usage frequency of money transfers and incoming payments are very similar to the average client profile, the difference is that realization almost always occurs at the desk. This difference from the average client cluster can be noticed e.g. at almost 5 times higher frequency of cash deposits and withdrawals at the desk.

The passive client, 35, 9 %—cluster 5 includes clients with low frequencies of monthly usage of all the monitored services. It can be noticed e.g. on services of money transfers and incoming payments, where this client profile receives only 2 payments per month and carries out only 2 direct payments and one standing order. All transfer services are done via internet. Compared to the average client profile, this cluster also has three times lower month frequency of ATM withdrawals from own bank and frequency of ATM withdrawal from foreign bank is lower by half. This client could be called low-cost client.

Compared to the previous analysis (that included extreme clients), this treatment allowed cluster analysis to achieve better differentiation. It allowed the k-means algorithm to separate passive clients from the cluster of average clients. In the first clustering, passive clients had an effect up the profile of the average client. The major cluster (almost 70 %) then has been split up to two smaller clusters that can be described in greater detail. Cluster member count is almost equal (the difference passive-average client is only approximately 5 %). It is true that statistically this split did not have strong impact on average, but from the marketing point of view, it is a crucial to know the difference between the so-called low-cost client and average client with, however, 2–3 times higher use of services. Compared to the first treatment active client cluster's share is here lower by 4 %. The main reason is more strict data validation. The second treatment also raised the share of the client profile using mainly desk operations but an increase was less than 1 %. The main benefit of the second more detailed treatment lies in the separation of passive clients from those average ones.

## 5 Conclusion

The online RCBS Calculator expert system is fulfilling the EU Directorate-General for Health and Consumers Protection and EU Commission's main proposals—to help the clients to choose best RCBS provider concerning the bank charges by easy accessible RCBS product comparison service. Gathered data also provides very accurate market information due to very high number of respondents (10,000+).

Respondent data analysis showed that average year costs of the CZ client for RCBS are 78 €. Long term monitoring of quarter costs can be used to construct time series and then to monitor the RCBS price level. Year costs of an average non-eurozone client were calculated in study [8] as high as 71, 1 €. 78 € is converted by exchange rate CZK-EUR from the last year it is 72, 4 €. So the CZ is typical member of EU non-eurozone countries. In greater detail CZ is a typical member of the RCBS charge model for countries of Central Europe, Switzerland and Russia. Clients there can affect about 2 thirds of the total amount of their costs by frequency of RCBS usage. One-third of overall charges in average consist of costs of the account management costs—usually fixed costs. This model is less cost fair than the Scandinavian model or the British model where almost all costs are variable.

The e-banking population is consisted of the 4 main clusters. The major one (average client) makes per month 4 ATM withdraws (3 times from client's own bank and once from foreign bank), 5 direct payments, 4 standing orders and 1 encashment. Other services are used very sparse. Passive client is more than twice less active then the average one on the contrary active client is almost 3times active than the average one. All those clusters strongly prefer the e-banking. The last cluster has e-banking active but it prefers at the desk services (activity is close to the average one).

All analysis outcomes can be found on the Calculator's web so the client may just identify the most suitable cluster. For each cluster there are quarterly published the best 15 RCBS products so the clients even don't have to fill out the Calculator's form. This helps the client even more to choose the best product. Average costs and clustering are not the only outcomes to analyze. For year 2011 we are going to monitor the rationality index (relative frequency of client with costs optimal account chosen) and CI time series construction to monitor the RCBS price level.

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# Instructional Design for Building Entrepreneurial Competency in Romania: First Stage Research Framework and Results

**C. A. Hutu and S. Avasilcai**

**Abstract** Focusing on entrepreneurial competency, the paper presents the research framework and results concerning the current training needs in Romania as the first stage for specific instructional design. Key entrepreneurial competencies leading to business success—(1) personal, including dominant entrepreneurial values, (2) social, and (3) practical/professional—were analyzed against typical competencies described by the literature. The study was conducted in four Romanian NUTS Regions (North-East, North-West, West, and Center), as part of a larger research project, CE@ANPART—Partnership for developing entrepreneurial capability and competitive human capital in Romania, aiming at developing a flexible web-based education and training needs assessment complex tool to be used at national level.

## 1 Introduction

Since McClelland [1] has started the competency movement, competency modeling and measurement has become increasingly present in the performance-success equation. Focusing on entrepreneurial competency, the paper presents the research framework and results concerning the current training needs in Romania as the first stage for specific instructional design.

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Why investigating entrepreneurial competency in Romania? Because to develop and support the entrepreneurial potential in Romania as a critical part of the competitive potential of the country's economy is a vital factor for both overcoming the current economic and social crisis and performing the transition to the knowledge-based economy [2]. It is to be mentioned that the Global Entrepreneurship Monitor (GEM) Reports [3, 4] have not even included Romania in the sample of the analyzed countries until 2009, showing lack of preoccupation for this issue.

Within this context, the reported study, conducted during the period October 2008–December 2009, was part of the CE@ANPART national research grant aiming at "developing entrepreneurial capability and competitive human capital in Romania" through flexible web-based instruments for assessing entrepreneurial competency and the associated training needs, to be operationalized at national level by the CE@ANPART portal: Virtual Assessment Center for Entrepreneurial Competency.

Key entrepreneurial competencies leading to business success—(1) personal, including dominant entrepreneurial values, (2) social, and (3) practical/professional—were analyzed against typical competencies described by the literature in four Romanian NUTS Regions: RO21 North-East, the coordinating partner based at the Technical University "Gheorghe Asachi" of Iasi; RO11 North-West, The Technical University of Cluj-Napoca; RO12 Center, "Lucian Blaga" University of Sibiu; RO42 West, The Technical University of Timisoara.

The final result of the interactive evaluation of entrepreneurial competency will be a "Personal entrepreneurial competency development plan" which will indicate concrete training needs of each user, as well as a training needs data basis for designing specific entrepreneurial education and training programs.

## 2 First Stage Research Methodology and Results

Primarily designed as exploratory and descriptive [5], the CE@ANPART research methodology followed an integrated approach aimed at identifying key features of entrepreneurial competency significantly impacting the performance of Romanian companies, while the researchers didn't control behaviors and the attention was focused on the synchronic aspects of the studied phenomena, as following:

1. Analysis of the influence of entrepreneurship on organizational as well as business environment performance and development;
2. Identifying entrepreneurial competencies clusters having a major impact on an organization's performance and development in Romania;
3. Identifying key educational and training needs to enhance entrepreneurial capacity in Romania.

Although the research was limited to the investigation of the relationships between entrepreneurial competencies, including entrepreneurial values, the foundation of the "entrepreneurial spirit", and organizational performance, the complexity of the approach was very high. Consequently, in order to identify and clarify the relevant variables and to build a detailed description of entrepreneurial competency in Romania there was necessary to start with case studies followed by a quantitative approach.

The process of identifying the major themes of the "entrepreneurial spirit" was conducted based on literature [6–15] and in relation to qualitative research findings.

In respect of qualitative research, case studies were developed based on success stories with data collection techniques encompassing informal and semi-structured interviews, secondary data analysis (company documents, statistical reports etc.), and direct observations. There were conducted four case studies per participating Development Region and one case study on a successful Romanian entrepreneur currently based outside Romania (Bracknell, Greater London, UK) [16, 17].

Following literature and qualitative research, three categories resulted for use in an extended questionnaire ("The Entrepreneurial Competency Questionnaire") for data collection [18, 19]: (1) *Personal Competencies*—"Self-awareness", "Self-discipline", "Self-motivation", "Critical and creative thinking"; (2) *Social Competencies*—"Social awareness", "Social skills" ("Influence", "Communication", "Leadership", "Change catalyst", "Conflict management", "Building bonds", "Collaboration and cooperation", "Team capabilities"); (3) *Practical/Professional Competencies*—"The ability to recognize and analyze market opportunities", "Focus on performance", "Knowledge management", "Marketing", "Financial management", "Human resources management".

The Entrepreneurial Competency Questionnaire used pre-coded closed questions for reasons related to data collection and processing. The "entrepreneurial" variables were designed as ordinal while and the demographic data were defined as nominal. To measure the intensity of the ordinal type variables a six point Likert scale was used, as following: "1" = "to a very little extent" to "5" = "to a very large extent", and with "0" = "I do not understand the question/I cannot answer the question". For consistency, all questions begin with the formula: "To what extent…?"

Further, to assess entrepreneurial values, the Entrepreneurial Values Inventory was devised in a flexible manner, allowing the respondents to add other own entrepreneurial values if they were considered important and they were not included in the instrument. Among the key entrepreneurial values to be ranked by the respondents there were exhibited: "Autonomy"; "Challenge"; "Commitment"; "Creativity"; "Courage"; "Customer orientation"; "Ecology/sustainable development"; "Flexibility"; "Growth"; "Independence/Self-employment"; "Initiative"; "Innovation"; "Leadership/need for power/being in control"; "Quality"; "Perseverance"; "Risk taking"; "Teamwork"; "Winning" [20].

The questionnaires were administered as following:

- Each grant partner had distributed, clarified all aspects of how to fill in the forms and collected the questionnaires directly from the respondents in the respective Regions after a period that ranged between 1 day and 30 days;
- The grant coordinator had supervised the administration of questionnaires, centralized and performed data processing and analysis.

Non-probabilistic sampling was used because the target population—successful entrepreneurs, or equivalents, such as managers, or entrepreneurs to be—was not appropriate for probabilistic sampling, either dimensionally, or structurally. The sampling methodology was based on a mixture of Henry's types [21]: convenience, typical cases, critical cases, and "snowball".

150 respondents were targeted in each of the four EU-NUTS Regions participating in the study, with response rates as follows:

- The Entrepreneurial Competency Questionnaire: N–E Region—66 (44 %); N–W Region—100 (67 %), W Region—100 (67 %); Central Region—34 (22.67 %);
- The Entrepreneurial Values Inventory: N–E Region—67 (44.67 %); N–W Region—101 (67 %), W Region—97 (65 %); Central Region—34 (22.67 %).

The practical validation approach consisted in face/content validation. Still, considering the sampling method, "elitist bias", "acquiescence" and "save face" types of errors could have not been avoided.

Statistical data processing was performed using STATISTICA software. Complete statistical summaries were issued for individual variables as well as for the categories and sub-categories of the identified key entrepreneurial traits. Further, the MindJet MindManager software was used to create "entrepreneurial profiles" by Regions, grouping the scores related to the Likert scale as following: "1–3"—very low; "3–3.5"—low; 3.5–4—average; 4–4.5—moderately high; "4.5–5"—high; "5"—very high.

It should be noticed that, due to the above mentioned sampling errors, the reported results were considered as potentially *not* supportive for entrepreneurial behavior from 3.5 points below (the "alarm" threshold requiring entrepreneurial education and training interventions), with the average considered at 3.5–4 points on the 5 point Likert scale.

The data analysis for each of the four data sets—Entrepreneurial Values, Personal Competencies, Social Competencies, and Practical/Professional Competencies—is presented in Table 1 in terms of identified strengths and weaknesses in rapport to the traits indicated by the literature as indicators for success.

The data synopsis of the four Regions participating in the research showed the following:

- There were identified several common *entrepreneurial values* that could lay the foundation of stronger entrepreneurship in Romania: "Quality"; "Professionalism", "Honesty", "Customer orientation"; "Teamwork"; "Flexibility";
- It can be underlined though that core entrepreneurial values such as "Initiative", "Independence", "Challenge", "Courage", "Growth", "Risk taking", "Need

**Table 1** Sinthesys of research results in the four Romanian regions

| | The entrepreneurial values inventory | The entrepreneurial competency questionnaire | | |
|---|---|---|---|---|
| | | Personal competencies | Social competencies | Practical/Professional competencies |
| RO21 North–East | (1) Zero rated values: “Risk taking”; “Creativity”; “Growth”; “Need to inspire others”; “Need for power/ Control”; “Neatness”; “Patience”; | (1) Average scores: “Self-confidence”; “Self-control”; “Optimism”; “Innovation”; “Adaptability”; “Commitment”; “Achievement drive”; “Trustworthiness”; “Critical and creative thinking”; | (1) Average scores: “Political awareness”; “Influencing others and leadership”; “Change catalyst” through “Communication”, “Building bonds” and “Conflict management”; | (1) Average and below average scores: “The ability to recognize and analyze market opportunities”; “Business marketing”; “Focus on performance” (“Teamwork”, “Effective communication and negotiation”, “Learning and knowledge management”;“Human resources management”; “Financial management”); |
| | (2) Highest rated values: “Quality” (14.21 %); “Professionalism” (14.21 %); “Honesty” (8.95 %); “Winning” (8.42 %); “Customer orientation” (7.89 %). | (2) Moderately high scores: “Conscientiousness”; “Accurate self-assessment”; “Emotional awareness”. | (2) Moderately high scores: “Collaboration” and “Cooperation” reflected into “Social awareness” through “Empathy”, “Service to others” and “Leveraging diversity”. | (2) Moderately high scores: “Flexible strategic orientation”; “Effective organizational skills”. |
| RO11 North–West | (1) Zero & very low rated values: “Autonomy” (0.33 %); “Service to others” (0.33 %); “Personal development” (0 %); “Respect for each-other”; | (1) Below average scores: “Self-confidence”; “Self-control”; “Adaptability”; | (1) Below average scores: “Political awareness”; “Capacity to influence others”; “Leadership”; | (1) Below average scores: “Focus on performance”, including “Flexible strategic orientation”, “Demonstration of appropriate behaviors and attitudes in working with others”, “Effective communication and negotiation”, “Learning and knowledge management”, and “Financial management”; |
| | (2) Highest rated values: “Quality” (10.67 %); “Honesty” (9.33 %); “Professionalism” (8.67 %); “Teamwork” (5.67 %). | (2) Average scores: all other tested entrepreneurial competency components. | (2) Average scores: all other tested entrepreneurial competency components. | (2) Average scores: all other tested entrepreneurial competency components. |

(continued)

**Table 1** (continued)

| | The entrepreneurial values inventory | The entrepreneurial competency questionnaire | | |
|---|---|---|---|---|
| | | Personal competencies | Social competencies | Practical/Professional competencies |
| RO12 Center | (1) Zero rated values: "Need for power/Control"; "Autonomy"; "Own master"; "Orientation towards development"; "Initiative"; "Need to inspire others"; "Punctuality"; | (1) Average and below average scores: "Self-confidence"; "Self-control"; "Adaptability"; "Innovativeness"; "Initiative"; "Critical and creative thinking"; | (1) Below average scores: "Political awareness"; | (1) Average scores: all tested entrepreneurial competency components, excepting -> |
| | (2) Highest rated values: "Quality" (16.19 %), "Professionalism" (11.49 %), "Honesty" (9.52 %), "Customer orientation" (7.62 %), "Creativity" (6.67 %). | (2) Moderately high scores: - | (2) Moderately high scores: "Empathy"; "Ability to work in teams"; "Conflict management". | (2) Moderately high scores: "Effective organizational skills". |
| RO42 West | (1) Zero rated values: "Need to inspire others", "Challenge", "Service to others"; | (1) Average and below average scores: "Commitment"; "Initiative"; "Optimism"; Self-control"; "Adaptability"; Self-confidence"; "Accurate Self-assessment"; "Trustworthiness"; "Innovativeness; "Critical and creative thinking"; | (1) Below average scores: "Political awareness"; "The ability to influence others"; "Change catalyst"; | (1) Below average scores: "Focus on performance", including "Effective communication and negotiation", "Learning and knowledge management"; "Financial management"; "Human resources management"; |
| | (2) Highest rated values: "Quality" (16 %); "Professionalism" (10 %); "Honesty" (8.67 %); "Flexibility" (6.33 %); 'Teamwork" (6 %); "Creativity" (5.67 %). | (2) Moderately high scores: "Achievement drive"; "Conscientiousness"; "Emotional awareness". | (2) Moderately high scores: "Empathy"; "Service orientation". | (2) Average scores: all other tested entrepreneurial competency components. |

for power/Control", and "Autonomy" rated low against the more general ones mentioned above;
- The most critical elements of entrepreneurial competency scored average or below, as following:
  - *Personal Competency*—"Innovativeness"/"Critical and creative thinking", "Achievement drive/Initiative", "Adaptability", "Self-confidence", "Self-control";
  - *Social Competency*—"Political awareness"; "Capacity to influence others"; "Leadership"; "Change catalyst";
  - *Practical/Professional Competency*—"The ability to recognize and analyze market opportunities"; "Focus on performance" ("Flexible strategic orientation", "Appropriate behaviors and attitudes for working with others", "Effective communication and negotiation", "Effective learning"); "Financial management; "Human resources management".

Overall, it must be remarked that critical elements for entrepreneurial approaches, such as "Initiative", "Independence", "Challenge", "Courage", "Growth", "Risk taking", "Autonomy", "Adaptability", "Self-confidence", "Influence", "Leadership", "Change catalyst", "Financial management", or "Effective learning" scored at or under the "alarm" level while treats more representative for general managerial performance scored higher.

## 3 A Framework to Assessing Entrepreneurial Training Needs on the CE@ANPART Portal

The next authors' approach to constructing the pool of data concerning the current training needs related to entrepreneurial competency in Romania on the CE@ANPART portal was to devise the Entrepreneurial Competency Model (Fig. 1.) as a comprehensive synthesis of the specific literature [22–29] at the confluence with the findings of the above reported research.

The model was the basis for developing a flexible web-based education and training needs assessment complex tool for flexible interactive evaluation of entrepreneurial competency which will finally result in a "Personal entrepreneurial competency development plan" indicating individual concrete training needs as a building block for an evolving training needs data basis for specific instructional design.

Although the model addresses the three main components of entrepreneurial competency related to knowledge/skills, attitudes and capacities (inborn vs. learned), the entrepreneurial competency web-based complex assessment tool only targeted the elements which could be learned in order to provide the CE@ANPART portal the source categories for identifying the (continuing) education and training needs at the Abilities and Attitudes/Values levels.

The web-based complex assessment tool, to be tested now on the CE@ANPART portal, encompasses the following main categories:

- *Entrepreneurial Values*—“Initiative”, “Independence”, “Challenge”, “Courage”, “Growth”, “Risk taking”, “Need for power/Control”, “Autonomy”;
- *Personal Competency*—“Self-motivation”, “Critical and creative thinking/ Capacity to innovate”, “Self-management”;
- *Social Competency*—“Communication & Negotiation Skills”, “Interpersonal relationships”, “Political awareness”, “Leadership”, “Conflict management”;
- *Practical/Professional Competency*—“Identifying business opportunities”, “Product/service definition/development”, “Marketing”, “Strategic planning”, “Logistics”, “Business management”, “Financial Management”, “Human resources management”, “Business development/Focus on performance”, “Learning & Knowledge management”, “Change management”.

## 4 Conclusions

The study on entrepreneurial competency in Romania presented in this paper aimed at laying the foundations for developing a flexible web-based education and training needs assessment complex tool to be used at national level as a first stage for further specific instructional design.

The research results showed small differences among the four participating Romanian NUTS Regions, pointing out as a common denominator a limited inclination towards the dynamic aspects of core entrepreneurial values as well as personal, social and professional competencies as the driving forces of the “entrepreneurial spirit”, such as “Initiative”, “Independence”/“Autonomy”, “Challenge”, “Courage”, “Growth”, “Risk taking”, “Need for power/Control”; “Innovativeness”, “Self-confidence”; “Capacity to influence others”/“Leadership”, “Change catalyst”; “The ability to recognize and analyze market opportunities”, “Flexible strategic orientation”, “Teamwork”, “Effective communication and negotiation”, or “Effective learning”. This limitation could be a major failure factor for entrepreneurial organizations in times of crisis as well as a multiplying factor triggering the crisis.

To help improve the assessed situation, the Entrepreneurial Competency Model devised by the authors, based on the above findings and a synthesis of the specific literature, sought further clarifications concerning the elements of entrepreneurial competency that could be learned in order to provide the CE@ANPART portal the source categories for identifying the (continuing) education and training needs critical to building entrepreneurial capacity in Romania as a key factor for overcoming the present economic crisis and development.

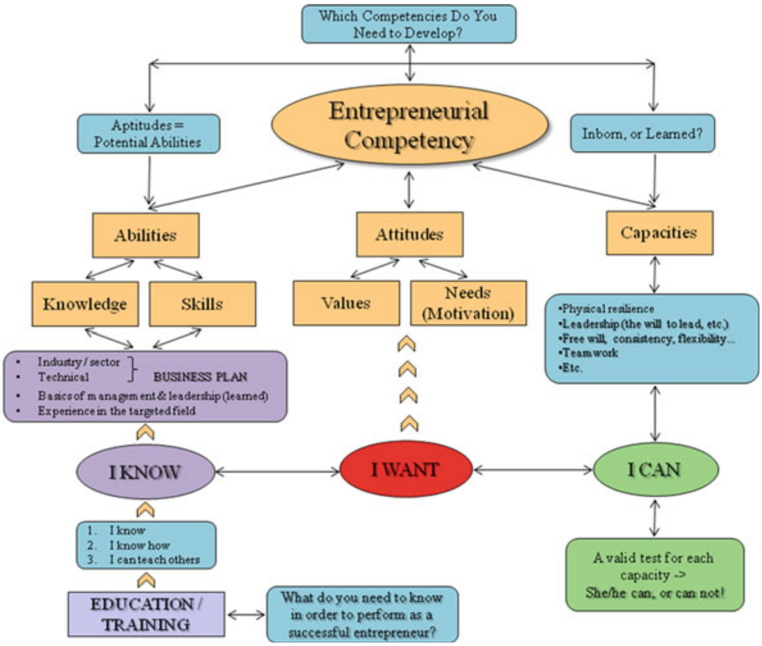


**Fig. 1** The entrepreneurial competency model

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# Security Requirements for Internet Voting Systems

**Md. Abdul Based and Stig Fr. Mjølsnes**

**Abstract** Voters cast their ballots to election officials over Internet in an Internet voting system. Eligibility of the voter, confidentiality and integrity of the ballot, privacy of the voter and the ballot, validity of the ballot, verifiability of the counting process, availability of the voting components, robustness of the voting system, receipt-freeness, and coercion-resistance are the main information security requirements for an Internet voting system. Besides these requirements, completeness of the counting process, soundness of the counting process, unre-useability of ballot in the counting process, and fairness of the counting process are also important for a practical Internet voting system. This paper gives an overview of these basic and expanded information security requirements for a secure and functional Internet voting system.

## 1 Introduction

Internet voting is also known as electronic voting or e-voting. Many countries, for example, the United Kingdom, the United States, Netherlands, and France have already implemented electronic voting in their areas. Estonia implemented Internet voting in 2007. Bangladesh ran electronic voting in a city corporation election in June 2010. Norway is planning to run Internet voting for the municipal and

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regional elections of 2011. For this reason, Internet voting has become a very interesting and challenging research topic in the modern research community.

We classify Internet voting as remote Internet voting and polling-booth based Internet voting. A remote Internet voting allows a voter to vote from anywhere, for example, from home or office. There is no cryptographic way to protect a voter from physical coercion when voting from home or office. A vote buyer or coercer can physically enforce a voter to vote for a particular candidate in this voting system. On the other hand, in the polling-booth based Internet voting, the voter first goes to a polling-booth controlled by the election officials or the Government for identification and authentication purpose. Then the voter casts the ballot without any physical coercion.

Like paper-based voting system, an Internet voting system should allow only the eligible voters to vote, hence voter identification and authentication is essentially needed. Also, the counting process should not count an invalid ballot or should not drop a valid ballot, and the counting process should not count a ballot cast by a voter more than once. So, verification of the ballot before the counting and verification of the counting process is also important. We will discuss these security issues of Internet voting in this paper.

The structure of the paper is as follows: Sect. 2 discusses some published papers related to electronic voting. The basic information security requirements for an Internet voting system are described in Sect. 3, and the expanded information security requirements are presented in Sect. 4. These two sections also briefly introduce the protocols and mechanisms required to fulfil the security requirements for Internet voting systems. Section 5 presents the summary and the future plan of the current research work.

## 2 Related Work

A publicly verifiable voting system is presented in [1]. In this paper the author describes a simple and efficient publicly verifiable secret sharing system and its application to e-voting based on homomorphic secret sharing. A non-interactive zero knowledge proof protocol for ballot verification is presented in [2]. The authors propose an Internet voting system that satisfies the basic properties of a secure and practical Internet voting system in [2]. An Internet voting system based on multiparty computations is published in [3]. Here, the authors propose multiple parties to cooperate to register the voter, to acquire the ballots, and to count the election results using the multiparty computations.

The security analysis of an electronic voting system is published in [4], and an efficient receipt-free voting system is presented in [5]. A secure and optimally efficient multiauthority voting system is presented in [6]. The theory and implementation of an e-voting system is published by Damgard et al. in [7].

In this paper, we are presenting an overview of the basic and expanded information security requirements that are important to make an Internet voting system secure and functional.

## 3 The Basic Requirements For Internet Voting Systems

We can classify the information security requirements of Internet voting systems as basic information security requirements and expanded information security requirements [8].

The basic information security requirements for Internet voting systems are:

- Eligibility of the Voter
- Confidentiality of the Ballot
- Integrity of the Ballot
- Privacy of the Voter and the Ballot
- Robustness of the Voting System
- Availability of the Voting Components
- Fairness of the Counting Process
- Soundness of the Counting Process
- Completeness of the Counting Process
- Unreuseability of Ballot in the Counting Process

### *3.1 Eligibility of the Voter*

Eligibility of the voter is the first requirement for an electronic voting system. The voting system should only allow the eligible voters to cast the ballots. Authentication of the voter is the way of verifying eligibility of voter. There are several existing techniques for this purpose.

In [9], the smartcard technology with biometric identification is proposed for authentication of the voter. The voter first identifies himself/herself by using smartcard enabled with fingerprint, and then smartcard authentication with server is done by using digital signature.

In [3], the authors propose multiple parties to cooperate to register the voter and to authenticate the voter. Their voting system is shown in Fig. 1. Their proposed voting system ensures that only the listed or registered voters can vote. In their scheme, unless a voter receives a signed key from the registrar, there is no way for the voter to send a ballot to the ballot acquirer that will be accepted. As shown in Fig. 1, the voter authenticates himself or herself to the registrar by generating a pair of private/public key ($K$, $K^{-1}$) and sending the public key $K$ and a *pid* (a pseudorandom value) to the registrar. The registrar checks against its census list whether the voter is eligible or not. Then the voter signs the ballot using his/her

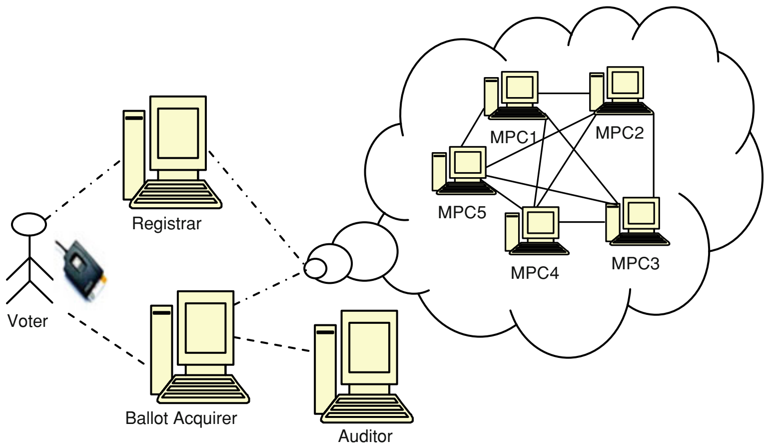


**Fig. 1** Internet voting using multiparty computations

private key value $K^{-1}$of the pair ($K$, $K^{-1}$), encrypts the ballot using the public key of the ballot acquirer, again signs it with the private key, and sends the signed and encrypted ballot to the ballot acquirer. The ballot acquirer can also verify the signature of the voter.

Blind signatures and Personal Identification Number (PIN) are also used in the authentication process of the voting system presented in [10].

## *3.2 Confidentiality of the Ballot*

The ballot cast by a voter must be confidential throughout the transmission from the voter to the servers. In some voting systems, the servers represent the election officials. In some systems, the servers represent the authentication servers or the counting servers. The Public Key Cryptography (PKC) is mainly used to provide the confidentiality of the ballot through the public key encryption techniques. The voter encrypts the ballot using the public key of the servers, so only the servers can decrypt and see the contents of the ballot.

The central server model of Internet voting shown in Fig. 2 [9] provides confidentiality with PKC. Since only the server has its own private key, when the voter encrypts the ballot using the public key of the server stored in the smartcard of the voter, no other can decrypt the encrypted ballot.

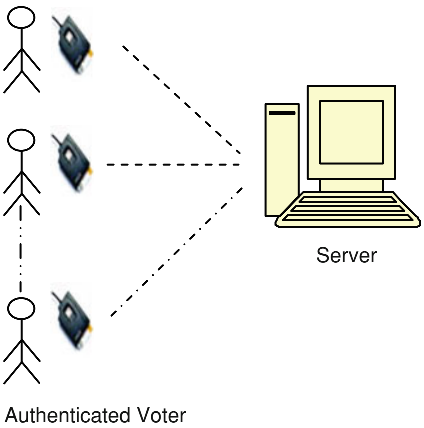


**Fig. 2** Confidentiality with PKC, since only the server has the private key; no other can decrypt the encrypted ballot

## *3.3 Integrity of the Ballot*

The ballot cast by an eligible voter should not be altered or modified by any unauthorized party. Digital signature or group signature is mostly used to provide the integrity of the ballot [2]. The voter signs the ballot using his/her private key and using the private key for the group signature. So, no one can sign the ballot except the voter. Group signatures [11–13] only verify the identity of a group rather than any individual.

With public key cryptography, the voting model shown in Fig. 3 [9] achieves integrity of the ballot through message authentication by means of digital signature (the voter signs the ballot using the private key of the voter and encrypts the ballot using the public key of the server).

## *3.4 Privacy of the Voter and the Ballot*

The privacy of the voter and the ballot should not be compromised. In [2, 14], the authors propose the group signature and public key encryption to provide the privacy of the voter and the ballot. In their voting systems (Shown in Figs. 4 and 5), the counting servers verify the group signature to see whether the ballot is from an eligible voter. But, the counting servers do not know who the actual voter is. The blind signature and public key encryption are also used to provide the privacy of the voter and the ballot [10].

In [3], the authors propose multiple parties (Registrar, Ballot Acquirer, Auditor, Voter, and Multiple Talliers) in their voting system to register the voter, to acquire the ballots, and to count the ballots. As shown in Fig. 1, their voting system proposes separation of roles to different parties to provide the privacy of the voter and the ballot.

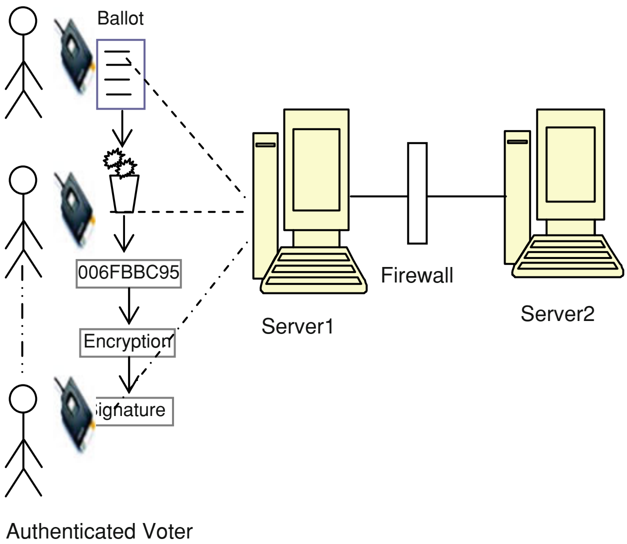


**Fig. 3** Anonymity of ballot by server separation

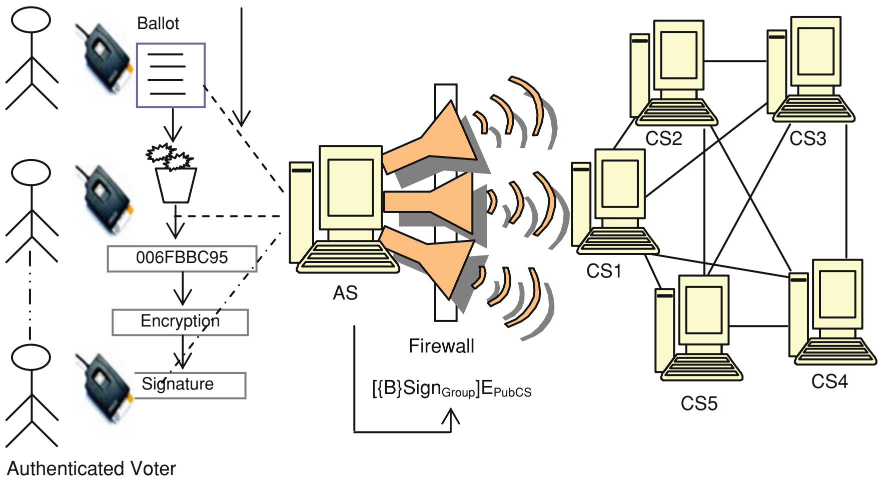


**Fig. 4** Internet voting with five Counting Servers (CS). First, the voter identifies himself/herself by the fingerprint scanner on the smartcard. Then the voter signs and encrypts the Ballot (B) using the smartcard. The voter first signs the ballot using the private key for the group signature, and then encrypts it with the CS public key. Then the voter signs the resulting value with the private key of the voter, and finally encrypts it with the public key of the Authentication Server (AS). The voter sends this encrypted and signed ballot to the AS. The AS decrypts and verifies the signature of the voter, and forwards the encrypted ballot (encrypted with the CS public key) to the CS

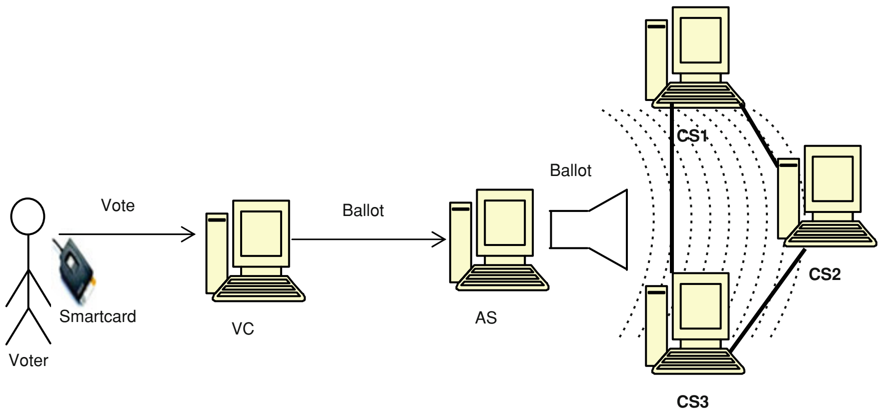


**Fig. 5** The Internet voting scheme exemplified with three counting servers. The voter chooses a vote for a particular candidate and delegates the remaining tasks to the Voter Computer (VC). The VC computes the ballot from this vote and sends the ballot to the Authentication Server (AS). The AS forwards the ballot to all the Counting Servers (CS)

## *3.5 Robustness of the Voting System*

The robustness of a voting system is related to the efficiency and performance of the hardware components of the voting system. The voting system should ensure that the components (both the servers and the voter computers) must be functional during the voting period such that if some components fail then the other components will still work without stopping the voting process.

In the voting schemes shown in Figs. 1, 4, and 5, the counting process works if a certain number of counting servers are functional and work together. In a $t$-threshold system, if $t$ counting servers cooperate then they can count and publish the tallies.

## *3.6 Availability of the Voting Components*

The availability of a voting system is related to the robustness of the system. This ensures that all the voting components must be available during the voting period. There are Denial-of-Service (DoS) attacks or other network attacks that can cause the unavailability problem in the voting systems. So, some protection mechanisms against these attacks are needed to provide the availability of the voting system.

### 3.7 Fairness of the Counting Process

In an Internet voting system, no participant should gain any knowledge about the partial results before the final tallying. Because, the knowledge of the partial results may affect the intentions of the voters who have not cast their ballots before knowing the partial results. So, a voting system should be fair.

To provide fairness, the counting process should not publish any partial results before the final tallying. That is, the counting process of the voting system should only publish the final tally. Multiple talliers or multiple counting servers, and the multiparty computations are used in this purpose.

The voting schemes (Shown in Figs. 1, 4, and 5) are fair since the counting servers only publish the final tally when a certain number of counting servers cooperate ($t$ counting servers cooperate in a $t$-threshold system). The counting servers can not publish any partial results, because, the ballots are sent as encrypted shares to the counting servers. To decrypt the shares and to count the ballots, the counting servers must cooperate.

### 3.8 Soundness of the Counting Process

A voting system should discard a ballot that is not valid. This is done by ballot verification as described in Section IV. The counting servers (Shown in Figs. 1, 4, and 5) first verify the ballots and then count only the valid ballots.

### 3.9 Completeness of the Counting Process

A voting system is complete if the counting process counts all the valid ballots. That is, the final tally is equal to the number of valid ballots cast by the voter if the voting system is complete. So, verifiability of the counting process (Described in Sect. 4) is important to provide completeness in a voting system.

### 3.10 Unreuseability of Ballot in the Counting Process

A voting system should count only one ballot for each eligible voter. In some voting systems, the authentication process does not allow a voter to vote twice or more. So, a voter can not cast more than one ballot. Some voting systems (Shown in Fig. 5) allow a voter to vote multiple times, but the counting process includes only the final ballot cast by the voter.

## 4 The Expanded Requirements For Internet Voting Systems

The expanded information security requirements for Internet voting systems are:

- Validity of the Ballot
- Verifiability of the Counting Process
- Receipt-freeness
- Coercion-resistance

### *4.1 Validity of the Ballot*

Validity of the ballot is very important in an Internet voting system to provide soundness, and completeness of the counting process, and unreuseability of ballot in the counting process. The ballots should be verified before the counting starts. A ballot is valid if it is cast by an eligible voter and the content of the ballot is also valid. The Zero Knowledge Proof (ZKP) Protocols [15, 16] are mainly used to verify the ballot. There are two types of ZKP protocols based on interaction between the prover and the verifier:

- Interactive Zero Knowledge Proof Protocol
- Non-interactive Zero Knowledge Proof Protocol

In an interactive zero knowledge protocol, the prover interacts with the verifier and proves the validity of the ballot. In voting systems, the voters play the role as the prover and the counting servers play the role as the verifier. The voter first commits to a value of the ballot, and then sends the ballot to the servers. The servers send a random challenge string to the voter, and the voter responds to the challenge string. Then the verifiers verify the ballot by verifying the responses. An interactive zero knowledge proof protocol is presented in [17].

In a Non-interactive Zero Knowledge Protocol (NIZK), there is no interaction between the prover and the verifier. The verifier verifies the ballot without interacting with the prover. A NIZK protocol is usually faster and more efficient, since it requires no online communication between the prover and the verifier. But, a NIZK protocol requires that both the prover and verifier share a common random string (as challenge string), usually provided by a trusted third party and a pre-arranged use of this random string is required. A non-interactive zero knowledge proof protocol is presented in [2].

### *4.2 Verifiability of the Counting Process*

There are two approaches of verifiability of the counting process:

- Universal Verifiability or Public Verifiability
- Voter Verifiability

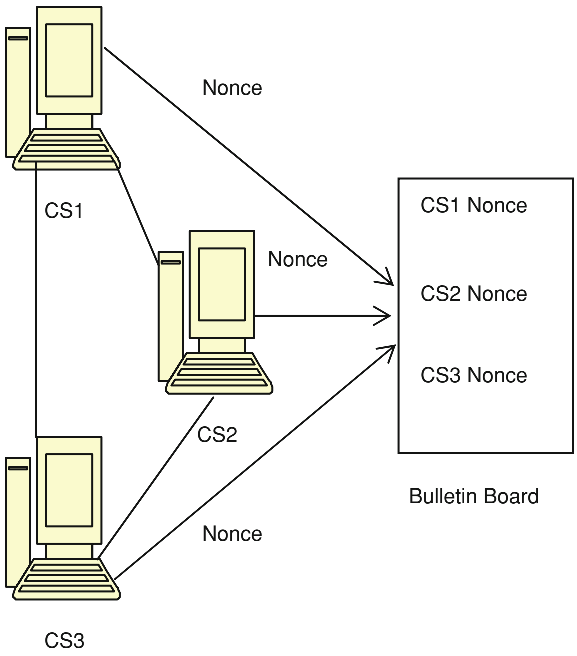


**Fig. 6** Voter verifiability. The counting servers (CS) publish the nonce values that were added with the ballots. Every voter can verify the nonce

If anyone can verify that the counting process contains all the valid ballots and the final tally is correct, then the voting system is called publicly verifiable or universally verifiable [1]. But, if only the voters can verify the counting process and the tally, then the voting system is called voter verifiable [14, 18]. In [14], the counting servers publish the final tally and the nonce values that were added to the ballot (Shown in Fig. 6). Every voter can verify the nonce values; hence the voting system is voter verifiable.

In the verifiable voting systems, generally a bulletin board is used. The content of the bulletin board is public, so anyone can observe the content. Some voting systems publish the identity of the voter on the bulletin board, and compromise the privacy of the voter. Some voting systems publish the sub-tallies on the bulletin board and lack fairness of the voting systems.

### *4.3 Receipt-Freeness*

Receipt-freeness is another challenging requirement of Internet voting system introduced by Benaloh and Tuinstra [19] to provide coercion-resistance in voting systems. In a voting system, the voters should not be allowed to produce a receipt to prove the ballot (for which candidate the ballot is cast). This is very important to protect vote-buying by the coercer or the vote buyer. Receipt-free voting system is presented in [5].

### 4.4 Coercion-Resistance

Coercion-resistance and receipt-freeness are related to each other. Voting systems should not provide with any scope to the vote-buyer or coercer to enforce a voter to vote for a particular candidate. Polling-booth based voting systems protect the voters from physical coercion since the polling-booth is controlled by the Government or election officials. But, there is no cryptographic way to make an Internet voting system free from physical coercion when voters cast the ballot remotely.

Receipt-free voting systems are free from coercion (in terms of logical coercion when voters can not logically prove for which candidate the ballot is cast). Some voting systems allow revoting or multiple voting [14] by a voter to make the voting systems coercion-resistant.

## 5 Conclusions

This paper provides an overview of the information security requirements for the Internet voting systems, and also introduces the protocols and mechanisms that are necessary to make Internet voting systems secure and functional. Our future plan is to present a voting system that satisfies all these security requirements.

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# A Multi-Algorithm, High Reliability Steganalyzer Based on Services Oriented Architecture

**Eman Abdelfattah and Ausif Mahmood**

**Abstract** Steganalysis deals with detecting the presence of hidden information in different types of media such as images and audio files. Such detection is very challenging because of the variety of algorithms that might be used in embedding secret information in a media type. This chapter presents a reliable Steganalyzer system with distributed services oriented architecture which allows easy incorporation of new algorithms to support different media types in the existing system. Moreover, the distributed architecture presented in this chapter allows concurrent processing which speeds up the system. High system reliability in distinguishing between the cover object and the stego object is achieved by employing multiple steganalysis algorithms, and further by employing efficient feature classifiers based on neural networks. The system developed is versatile with capabilities of detecting stego objects in JPEG images as well as WAV audio files.

## 1 Introduction

Steganalysis aims to identify if a carrier (image, text, audio or video) has been manipulated by embedding a secret message using some embedding technique. Since there are different possible carrier types, and many different embedding techniques, designing a reliable universal steganalyzer is extremely challenging.

The existing steganalysis techniques are classified under two categories; specific and universal steganalysis. The specific steganalysis techniques are designed for targeted embedding techniques. Thus, they yield very accurate decisions when they are used against the particular steganographic technique. In universal steganalyzers,

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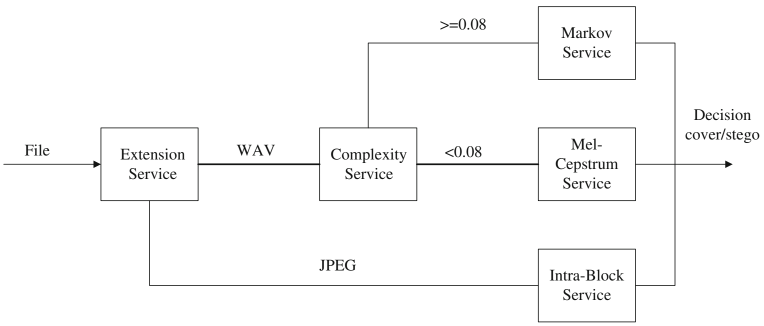



**Fig. 1** An overview of the service oriented architecture steganalyzer

dependency on the behavior of the individual embedding techniques is removed by determining and collecting a set of distinguishing statistics that are sensitive to a wide variety of embedding operations. As an example, universal steganalyzers dealing with images are composed of two important components; feature extraction and feature classification. In feature extraction, a set of distinguishing statistics are obtained from a data set of images by observing general image features that exhibit a strong variation under embedding. However, feature classification uses distinguishing statistics from both cover (original image) and stego (image with embedded message) images to train a classifier. Then, the trained classifier is used to classify an input image as either cover or a stego.

To be able to accommodate different media types and embedding algorithms in the steganalyzer, we use a Service Oriented Architecture (SOA) in our implementation. An SOA provides a service interface that is independent from the implementation, allowing easy addition of new services and upgrading of existing services. Each service can be thought of as an implementation of a particular steganalysis technique. An SOA also enables the reusability of existing services which means that a new application can be created on top of existing ones [1].

In this chapter, we present an SOA based steganalyzer that incorporates different media types and steganalysis algorithms. The steganalyzer architecture developed here is easily extendable to include other steganalysis techniques and media types. In Sect. 2, we discuss the different components of the steganalyzer framework. In Sect. 3, we cover the implementation details of our design. Then, in Sect. 4, we report the results obtained from different tests. Finally, we offer conclusions in Sect. 5.

## 2 Steganalyzer Framework Components

The proposed service oriented architecture based Steganalyzer contains the components shown in Fig. 1. In the following sub-sections we discuss each of the architectural components.

## 2.1 Extension Service

The extension service is the component responsible for identifying the type of files under steganalysis. The function of this component is designed to be a general service that can analyze any file type. Expected file types can include images, audios, videos, text, etc. Different image types such as BMP, GIF, TIFF, etc. can be supported by our architecture. Examples of audio files that might be handled by the framework are MP3, WMA, AU, etc. Also, video file types such as AVI and MOV can be integrated.

Our test bed implementation of the steganalyzer includes the following types:

(1) Audio files of type .WAV
(2) Image files of type .JPEG or .JPG

The choice of these two types is due to their popularity as cover images or audios from both users of steganograhy as well as steganalyzers. They are selected as a proof of concept. However, the developed SOA is generic enough to add any new file types as long as their features are well defined and it is possible to develop an efficient feature extraction module that can produce distinguishable features between the cover and the stego file.

## 2.2 Complexity Service

The complexity service is implemented for the .WAV files. The choice of two different service implementations of .WAV files is motivated by the fact that as the complexity of the .WAV audio files increases, a different technique can be used to obtain better results as reported in [2].

Several researches have evaluated the audio steganalysis performance based on using information hiding ratio or an embedding strength as a reference. According to Liu et al., information hiding ratio or embedding strength is not good enough to evaluate detection accuracy. Thus, we take the complexity into consideration as it is an important parameter for evaluating the performance of the steganalyzer. We have employed the following complexity equation based on Liu et al. [2].

$$C(f) = \frac{\frac{1}{N-2}\sum_{t=1}^{N-2}\left|D_f^2(t)\right|}{\frac{1}{N}\sum_{t=0}^{N-1}|f(t)|} \quad (1)$$

Where $C(f)$ measures the ratio of the mean absolute value of the second order derivative to the mean absolute value of the signal. The audio signal is denoted by $f(t)$ where $t = 0, 1, \ldots, N-1$. The definition of the second order derivative is as follows:

$$D_f^2(t) \equiv \frac{d^2 f}{dt^2} = f(t+1) - 2 * f(t) + f(t-1) \quad (2)$$

$t = 1, 2, \ldots, N-2.$

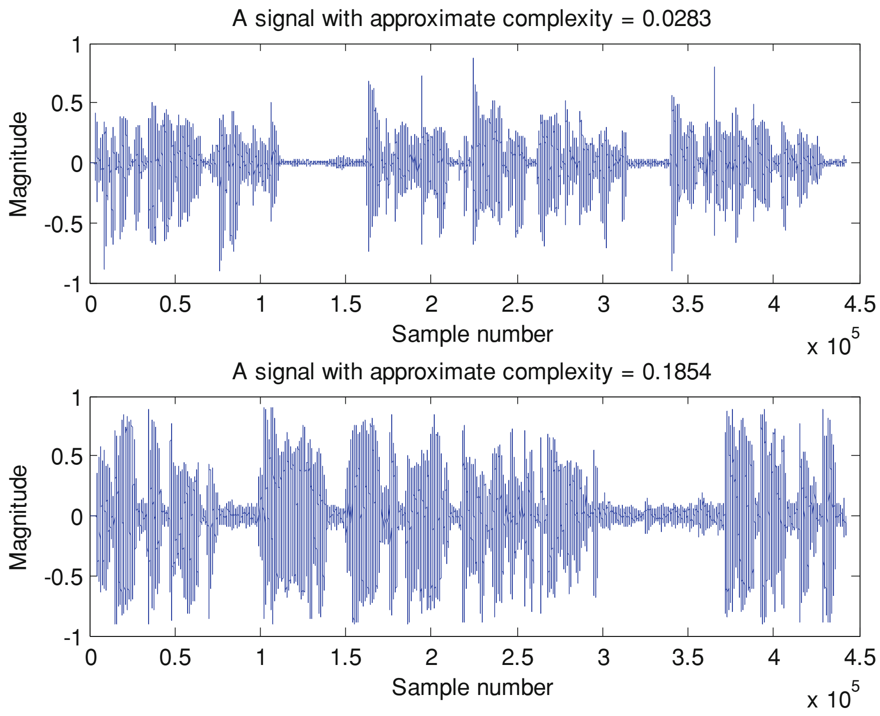



**Fig. 2** Magnitude distribution versus sample number for two distinct signals with different approximate complexities

Figure 2 shows the magnitude distribution of two signals that have different values for the approximate complexity calculated using Eq. (1).

The ratio of complexity is used to select one of the following services:

(1) Mel-Cepstrum Service is selected in case *C(f)* is less than 0.08
(2) Markov Service is selected in case *C(f)* is greater than 0.08

## 2.3 Mel-Cepstrum Service

The Mel-Cepstrum service provided by our steganalyzer is based on Mel-frequency cepstrum in conjunction with second order derivative which is widely used in image processing to detect isolated points, edges, etc. [3]. The Mel-frequency cepstrum coefficients (MFCCs) are coefficients that collectively make up the Mel-frequency cepstrum (MFC) which is a representation of the short-term power spectrum of a sound.

Initially, Kraetzer et al. [4] suggested a successful Mel-cepstrum based speech steganalysis by using both Mel-frequency cepstral coefficients (MFCCs) and Filtered Mel-frequency cepstral coefficients (FMFCCs) as follows:

1. Mel-frequency cepstral coefficients (MFCCs), $sf_{mel1}$, $sf_{mel2}$, …, $sf_{melc}$ are calculated by the following equation:

$$MelCepstrum = FT(MT(FT(f))) = \begin{pmatrix} sf_{mel1} \\ sf_{mel2} \\ \cdots \\ sf_{melC} \end{pmatrix} \tag{3}$$

Where FT is Fourier Transform and MT is Mel-Scale Transformation.

2. Filtered Mel-frequency cepstral coefficients (FMFCCs) are calculated by the following equation:

$$FilteredMelCepstrum = FT(SpeechBandFiltering(MT(FT(f)))) = \begin{pmatrix} sf_{mel1} \\ sf_{mel2} \\ \cdots \\ sf_{melC} \end{pmatrix} \tag{4}$$

To improve the work of Kraetzer and Dittmann [4], Liu et al. [2] suggested using a second order derivative MFCCs and FMFCCs as defined below:

$$MelCepstrum = FT\left(MT\left(FT\left(D_f^2\right)\right)\right) = \begin{pmatrix} sf_{mel1} \\ sf_{mel2} \\ \cdots \\ sf_{melC} \end{pmatrix} \tag{5}$$

$$\begin{aligned} FilteredMelCepstrum &= FT\left(SpeachBandFiltering\left(MT\left(FT\left(D_f^2\right)\right)\right)\right) \\ &= \begin{pmatrix} sf_{mel1} \\ sf_{mel2} \\ \cdots \\ sf_{melC} \end{pmatrix} \end{aligned} \tag{6}$$

The definition of the second order derivative is given in Eq. (2). In our steganalyzer we implement Liu et al. technique for extracting the features as it offers better accuracy than the suggested technique by Kraetzer. In the Eq. (6), a butterworth bandstop filter is used to remove the spectrum components between 200 and 6810.59 Hz. A total of 58 features are extracted, 29 MFCCs features and 29 FMFCCs features including the zeroth value that reflects the absolute log energy in the speech frame. The code used to calculate these features is based on the code available at [5].

## 2.4 Markov Service

Liu et al. [2] suggest design a Markov approach for audio steganalysis based on the second order derivative of audio signals as follows:

$$M_{D_f^2}(i,j) = \frac{\sum_{t=1}^{N-3} \delta(D_f^2(t) = i, D_f^2(t+1) = j)}{\sum_{t=1}^{N-3} \delta(D_f^2(t) = i)} \tag{7}$$

The second order derivative is defined as in Eq. (2). When the arguments of $\delta$ are satisfied, its value equals 1, otherwise $\delta$ equals 0. We have a $13 \times 13$ transition probability matrix for the range of $i$ and $j$ $[-6, 6]$. A total of 169 features are extracted. In our steganalyzer, we implement this technique for extracting the features in case the complexity of the audio signal is greater than 0.08 to obtain a better accuracy as reported by Liu et al.

## 2.5 Intra-Block Service

Our intra-Block service is used to handle JPEG steganalysis that is based on the work of *Liu* et al. [6]. The choice of implementing a service that handles JPEG steganalysis is based on the fact that JPEG is one of the most popular images in the Internet. In the approach used in [6], the neighboring joint density features on intra-block are extracted. These features are based on an observation of bi-variate generalized Gaussian distribution in Discrete Cosine Transform (DCT) domain. The intra-block neighboring joint density probabilities matrices on both horizontal direction $NJ_h$ and on vertical direction $NJ_v$ are constructed as follows:

$$NJ_h(x,y) = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{m=1}^{8} \sum_{n=1}^{7} \delta(C_{ijmn} = x, C_{ijm(n+1)} = y)}{56MN} \tag{8}$$

$$NJ_v(x,y) = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{m=1}^{7} \sum_{n=1}^{8} \delta(C_{ijmn} = x, C_{ijm(m+1)n} = y)}{56MN} \tag{9}$$

Where $C_{ijmn}$ denotes the compressed DCT coefficient positioned at the $m$th row and the $n$th column in the block $F_{ij.}$ The JPEG image contains $MxN$ blocks where the block's size is $8 \times 8$. The range of $i$ and $j$ in $F_{ij}$ is as follows $i = 1, 2, \ldots, M$ *and* $j = 1, 2, \ldots, N$. When the arguments of $\delta$ are satisfied, its value equals 1, otherwise $\delta$ equals 0.

The absolute of these neighboring joint density probabilities is forming the used features in training and testing processes as given in the following equation.

$$NJ(x,y) = \frac{\{NJ_h(x,y) + NJ_v(x,y)\}}{2} \tag{10}$$

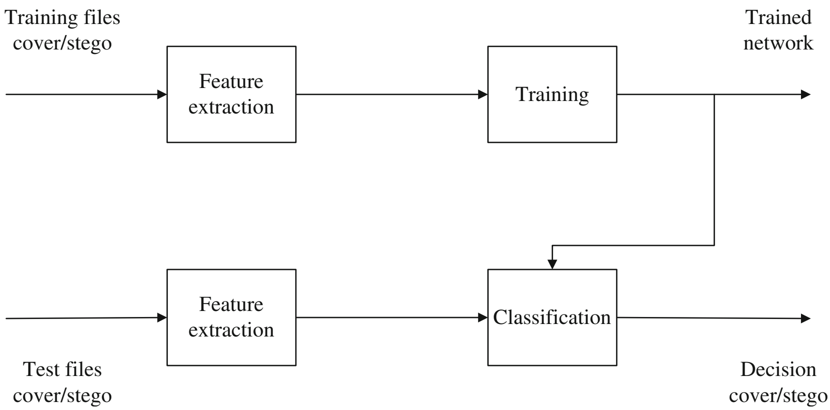



**Fig. 3** Overview of training and testing processes

## 3 Implementation

The service oriented architecture adopted in this work is implemented using Microsoft Windows 2008 Server platform and WCF services. We have used the following methodology in implementing the framework:

(A) The feature extraction algorithms for audio or image files using one of the methodologies explained above are implemented using Matlab.
(B) Classifiers using N-layer neural networks are developed using Matlab.
(C) Each of the neural networks is constructed and 50 % of the data set of the cover and the stego features are used to train the network.
(D) The remaining 50 % of the data set of the cover and the stego features are used to test the trained network to determine the neural network's accuracy.
(E) The feature extraction code for Mel-Cepstrum, Markov and intra-Block techniques and the corresponding trained classifier are converted to dynamic link libraries (DLLs) to be integrated in Mel-Cepstrum service, Markov service and intra-Block service respectively. Then, dynamic link libraries are integrated into the web services which increases portability.

Steps (A) to (D) are demonstrated in Fig. 3 and step (E) is shown in Fig. 4.

### *3.1 Neural Network Classifier*

A Neural Network (NN) is a predictive model that aims to map a set of input patterns onto a set of output patterns. A series of input/output data sets is used to train the network. Then, the trained network applies what it has learned to predict the corresponding output [7].

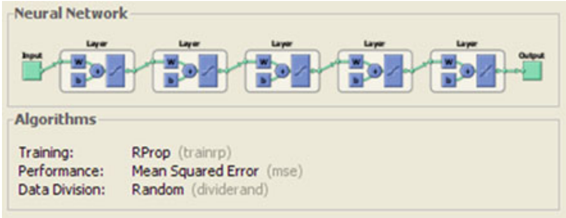



**Fig. 4** Overview of dynamic link library (dll) generation

Neural Networks have proven to be effective in accomplishing good results in classification problems. We used Neural Networks in our work. Using a neural network involves two processes; training and testing. In the training process, a feed-forward backpropagation network is created. In our implementation, the Matlab differentiable transfer function *tansig* is employed. The backpropagation training function *tainrp* is selected for its memory utilization. Three or four hidden layers are constructed in case the number of features is 58 or 169 respectively as explained in Sect. 4. Figure 5 shows the 4 hidden layers network used for the classification of 169 features.

Multiple stages of Neural Networks are constructed. In the first stage, only two cover objects and two stego objects are used in the training and the trained network is saved to be fed to the second stage when a satisfactory mean absolute error is obtained. In the case of WAV files, one hundred cover files and one hundred stego files are employed in the second stage. While in the case of JPEG files, 1900 cover files and 1900 stego files are employed in the second stage. The new network is constructed for training which is fed by the weights and bias from the previous stage until a satisfactory mean absolute error is achieved. This process is repeated until no more improvement is accomplished. Lastly, the final trained network is saved and applied in the testing process to obtain the testing accuracy.

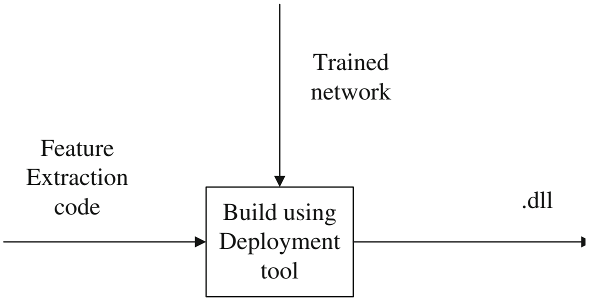
# 4 Results

We present in this section the results according to each type of steganalysis technique involved in our implementation.

## *4.1 Mel-Cepstrum Technique*

A sample of 200 mono cover wav audios and another 200 mono stego wav audios produced by Steghide available at [8] is used in the training and testing processes. These mono files are 44.1 kHz with 16 bit PCM quantization uncompressed but

**Fig. 5** Four hidden layers network used for the classification of 169 features




there is no guarantee that they are never compressed as they were collected by Liu from the Internet. Each audio has a duration of 10 s. In this experiment, 50 % of these audios are used as a training set and 50 % are left for testing. A feed-forward backpropagation neural network with three hidden layers is constructed and is used in the training process. The mean absolute error of zero is accomplished during the training process. An accuracy of 100 % is achieved during testing of 100 audio files. The calculated testing accuracy is based on the following formula.

$$Accuracy = (TP + TN)/(TP + FP + TN + FN) \tag{11}$$

where *TP, TN, FP and FN* are the number of true positive, true negative, false positive and false negative cases respectively.

## 4.2 Markov Technique

The same sample used in the Mel-Cepstrum technique is used here. In this experiment, 50 % of these audios are used as a training set and 50 % are left for testing. The matrix of the transition probability of the second order derivative is calculated for each audio file. Figures 6, 7 and 8 show the Markov transition probabilities of the second order derivative for the cover, its corresponding stego and the difference respectively. It is obvious from the figures how the calculated probabilities features are clearly distinguishable between the cover and the stego. A feed-forward backpropagation neural network with four hidden layers is constructed and is used in the training process. In the testing process, an accuracy of 85.5 % is obtained.

## 4.3 Intra-Block Technique

A total of 5,151 JPEG images are downloaded from [9]. The embedding technique Steghide [8] is used to produce the stego images. A text file with size 1 K is

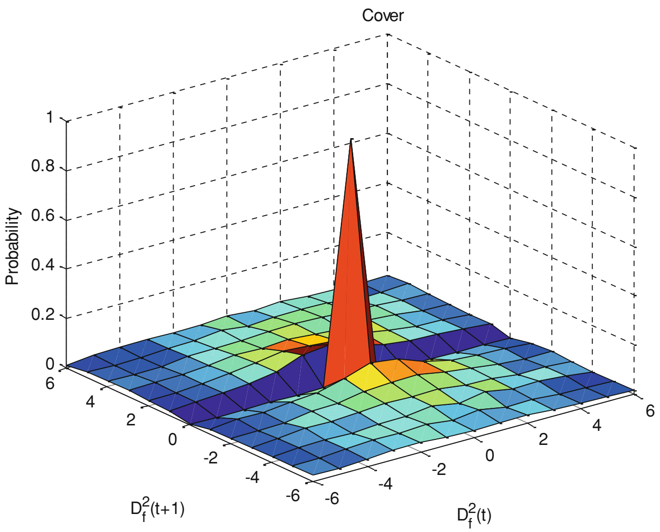



**Fig. 6** Markov transition probability of the second order derivative (Cover wave)

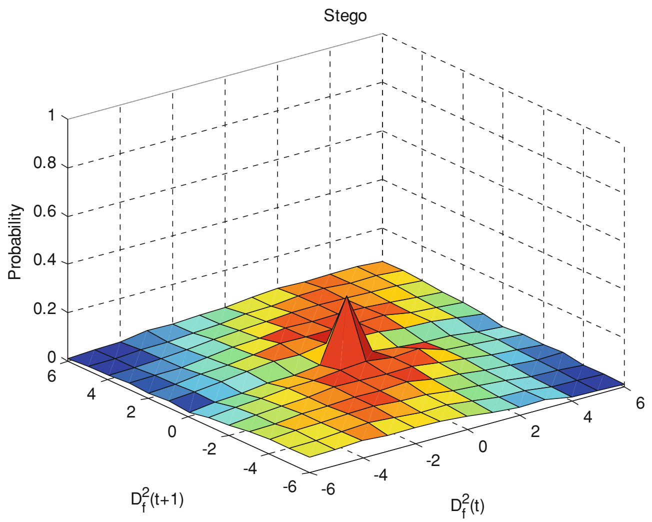



**Fig. 7** Markov transition probability of the second order derivative (Stego wave by Steghide)

embedded into JPEG images. Only 3796 stego images are produced and their corresponding cover images are used in training and testing processes. Steghide was unable to embed the other 1355 images because the images' size was not large enough to embed a 1 K file. 169 features are extracted for each image because the used range for x and y in the Eqs. (8) and (9) is from −6 to +6. 1900 images are selected for training and the remaining 1896 images are used in the testing process.

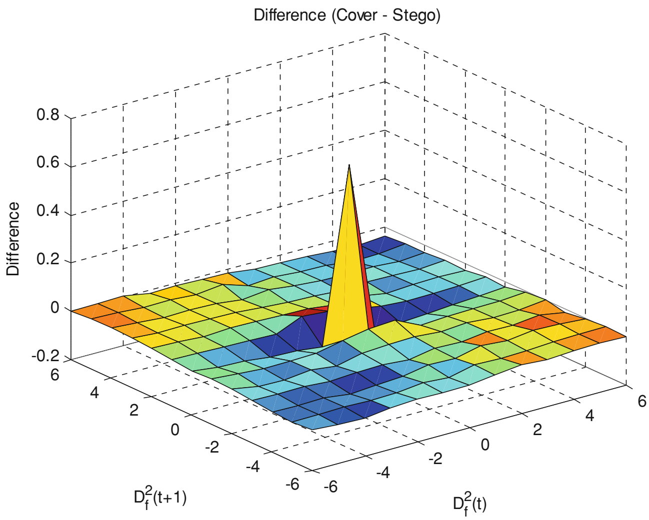



**Fig. 8** The difference between Markov transition probability between the cover and the stego

The mean absolute error for the trained network is 5.29 %. An accuracy of 97.36 % is achieved during testing process.

## 5 Conclusions

In this chapter we present a unified, reliable service oriented architecture Steganalyzer that supports two types of carrier media: WAV audios and JPEG images. In our implementation, reliability is achieved by integrating techniques that are accomplishing accurate results as reported in recent literature, and by the design of efficient multi-stage neural network classifiers which achieve very accurate results. The implemented architecture is scalable and allows easy addition of new services for different steganalysis algorithms as well as handles different data types which are not currently supported. The proposed architecture supports parallel processing which enhances the speed of the steganalyzer. The framework is capable of distinguishing between the cover and the stego objects with an absolute accuracy above 90 %.

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# A Quality Model of Metamodeling Systems

**Rünno Sgirka and Erki Eessaar**

**Abstract** A metamodeling system is a system for creating modeling systems. In this paper, we analyze the state of the art of metamodeling systems. We present a quality model of metamodeling systems that we have developed by instantiating a metamodel of the Computer Aided Method Engineering (CAME) quality model. In addition, we present a generalized process for creating new quality models based on existing quality models. We use the new model to analyze a set of metamodeling systems to find their problems.

## 1 Introduction

We have proposed a web-based and database-based metamodeling system that can be used to create web-based and database-based modeling systems [1]. We call it WebMeta in this paper. Metamodeling systems are important in the context of model driven development because they facilitate the creation of modeling systems that support the use of domain specific languages and generation of code based on these languages. The use of such languages and modeling systems improves communication between developers and users of the developed systems, increases productivity of developers, and helps developers to improve the quality of applications [2]. If we have a system, then we need a method for comparing it

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with other systems. In addition, the analysis of existing systems helps us to find their strengths and weaknesses. This information is important for designing a new system.

The *first goal* of the paper is to suggest a generalized process for creating quality models based on existing quality models. The *second goal* of the paper is to propose a quality model of metamodeling systems and use it for analyzing a set of metamodeling systems. The quality model is created based on the ISO/IEC 9126 quality model [3] and existing models that are used to evaluate Computer Aided System Engineering (CASE) [4] and Computer Aided Method Engineering (CAME) [5] systems. We use these models because CASE and CAME systems have similarities with metamodeling systems in their goals and expected functionality. Metamodeling systems are also known as meta-CASE systems.

The rest of the paper is organized as follows. In Sect. 2, we propose a quality model for analyzing metamodeling systems. We also describe a generalized process for creating new quality models based on existing quality models. In Sect. 3, we analyze several existing metamodeling systems using the quality model. In addition to our own web-based and database-based metamodeling system (WebMeta 0.5), we have chosen three advanced metamodeling systems: MetaEdit+ 4.5 SR1 [2, 6], a commercial tool produced by MetaCase; Generic Modeling Environment (GME) 10.2.9 [7], developed by the Institute for Software Integrated Systems at Vanderbilt University, in Nashville, USA; and Generic Eclipse Modeling System (GEMS) RC4 [8], which is also developed at Vanderbilt University, more specifically in the Distributed Object Computing (DOC) Group among other collaborators. We selected the latter three systems because Kelly and Tolvanen [2] consider them to belong to the top four metamodeling systems. MetaEdit+ is a commercial closed source system. GME and GEMS are open-source systems. In Sect. 4, we discuss the results of the analysis and point to general problems of existing metamodeling systems. Finally, we conclude and describe further work with the current topic.

## 2 A Quality Model of Metamodeling Systems

In this section, we propose a quality model for analyzing metamodeling systems. It is possible to analyze a metamodeling system from different perspectives—(1) by analyzing a metamodeling system as a system that facilitates the creation of modeling systems and (2) by analyzing modeling systems that are created by using the metamodeling system. In this paper, we analyze a set of metamodeling systems based only on the first perspective. We do not consider modeling systems that are created by using the metamodeling systems.

Niknafs and Ramsin [5] discuss assembly-based, extension-based, and paradigm-based method engineering. This kind of methods can be used to construct quality models of systems as well. In this case, we use the paradigm-based approach to create a quality model of metamodeling systems. According to this approach, “a new method is developed by instantiating, abstracting or adapting an existing metamodel" [5], p. 526.

To evaluate a particular type of systems, *one possible approach* can be the following.

- Find a quality model built for evaluating similar type of systems.
- Define a metamodel of this quality model (as an UML class diagram) or use an existing metamodel if it already exists.
- Validate the metamodel based on some known ontology (like the software measurement ontology [9]) and update the metamodel if necessary. Ideally, each concept/relationship that is specified in the ontology has a semantically equivalent concept/relationship that is specified in the metamodel.
- Create a new quality model based on the metamodel by using instantiation.
- Evaluate whether it is possible to use the concepts of the original quality model (e.g. measures) and if possible, use these measures either changed or unchanged.
- Research other quality models and frameworks to find additional measures that can be used (either changed or unchanged) in the new quality model.

In case of the propose approach, the metamodel is used by the creators of a quality model as a *guiding framework*. It ensures that all the necessary aspects, which are needed to make the quality model work, are taken into account during the creation process.

We created a metamodel of quality models of systems (see Fig. 1) based on the CAME quality model [5]. We evaluated the metamodel based on the software measurement ontology (SMO) [9]. In general, the proposed metamodel is consistent with SMO. The concepts *System*, *System type*, *Measure*, and *Quality characteristic* from our model correspond to the concepts *Entity*, *Entity Class*, *Base Measure*, and *Measurable Concept* from SMO [9], respectively. In addition, the metamodel has some classes like *Analysis* that do not have a corresponding class in SMO. There are also some differences in the multiplicities of relationships. For instance, in our model each *Quality model* can be associated with one or more *System type* because there are generic quality models like ISO/IEC 9126 that can be used to evaluate different types of systems.

We use the instantiation strategy to create a quality model of metamodeling systems based on the metamodel. It means that the quality model of metamodeling systems has the same metamodel but some instances are different (for example, different measures). In the following descriptions, we use *italics* to refer to the classes in the metamodel.

The CAME *quality model* is based on the ISO/IEC 9126 quality model [3]. ISO/IEC 9126 has been used as the basis of *analysis* of other software *systems* as well like B2B applications [10]. The proposed quality model of metamodeling systems is for another *system type*—metamodeling systems. Each *system type* has one or more possible quality models but each *analysis* is based on exactly one quality model. The current paper presents the results of one analysis (see Sects. 3 and 4).

The quality model of metamodeling systems is based on the metamodel of the CAME quality model.

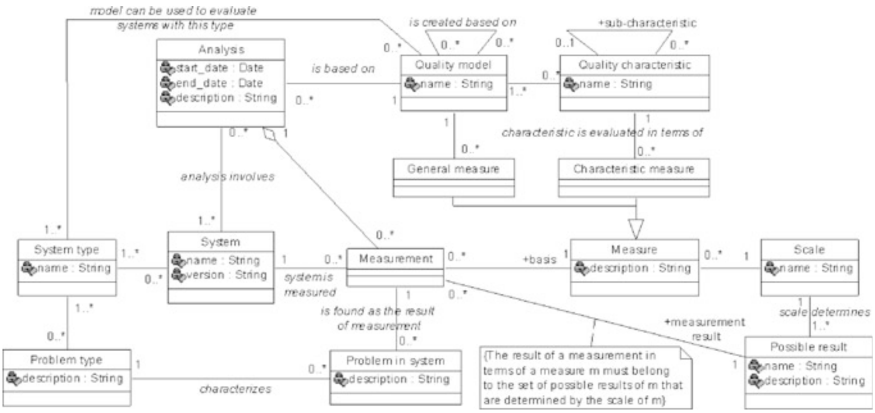


**Fig. 1** A metamodel of quality models of systems

Each quality model contains zero or more *general measures* that are not associated with a *quality characteristic*. Next, we list such measures in the quality model of metamodeling systems. We found them based on the CAME quality model [5]. Each *measure m* has exactly one associated *scale* that determines the set of *possible* measurement *results* in case of using *m*.

- What is the purpose of creating the system? Possible results: {Research, Commerce, Research and commerce}.
- What is the number of features? Possible results: {Low, Average, High}.
- How much literature is available? Possible results: {Low, Average, High}.

The CAME quality model, as well as the quality model of metamodeling systems, determine a set of *quality characteristics* that have sub-characteristics. These characteristics are a proper subset of the characteristics of the ISO/IEC 9126 quality model. We excluded the same ISO/IEC 9126 characteristics as the CAME quality model [5] from the quality model of metamodeling systems.

Each quality characteristic has a set of associated *characteristic measures*. Table 1 presents characteristic measures of the quality model of metamodeling systems. We will use the numbers of measures for referencing purposes.

We use the same scale as the CAME quality model [5] in case of measures in Table 1. The scale determines the following set of possible results of measurements {Supported to a good extent; Not supported; Inadequate information to assess}. We use the following annotations in Table 1.

1. ‡ measures that we found based on the requirements to domain specific modeling systems [2].
2. + measures from the CAME quality model [5] that we did not change at all.
3. * measures that we found based on the CAME quality model [5] and changed based on different semantics of metamodeling and CAME systems. For instance, Niknafs and Ramsin [5] found that "partial coverage of method

**Table 1** The quality model of metamodeling systems

| Characteristic | Sub-characteristic | Characteristic measure | Number |
|---|---|---|---|
| Functionality | Suitability | Whether the metamodeling system provides a suitable meta-metamodel ‡ | 1 |
| | | Whether the metamodeling system offers a suitable toolkit for the development of visual notation of modeling languages ‡ | 2 |
| | | Whether the metamodeling system offers a suitable toolkit for the development of systems for generating code based on models ‡ | 3 |
| | | Whether the metamodeling system allows development of modeling systems in the multi-user mode ** | 4 |
| | | Whether the metamodeling system provides adequate support to all the phases of modeling system development process * | 5 |
| | | Whether the metamodeling system provides means to check the correctness and consistency of the metamodels of modeling systems ** | 6 |
| | | Whether the metamodeling system provides means to generate documentation that specify modeling systems ** | 7 |
| | | Whether the metamodeling system offers facilities to define semantics of model elements of the underlying languages of modeling systems * | 8 |
| | Interoperability | Whether the metamodeling system is integrated with an integrated development environment (IDE) or compiler ‡ | 9 |
| | | Whether the metamodeling system provides an Application's Programmer Interface (API) ‡ | 10 |
| | | Whether the metamodeling system is able to interchange metamodels with other metamodeling or modeling systems ‡ | 11 |
| | Accurateness | Whether there exist third party evaluations that indicate the degree of effectiveness of the metamodeling systems + | 12 |
| | Functionality compliance | Whether the metamodeling system supports standards and techniques such as Meta-Object Facility (MOF) for creating metamodels, Object Constraint Language (OCL) for defining constraints, and XML Metadata Interchange (XMI) for exchanging models and metamodels between systems * | 13 |

(continued)

**Table 1** (continued)

| Characteristic | Sub-characteristic | Characteristic measure | Number |
|---|---|---|---|
| Usability | Understandability | Level of understandability and usability of the interfaces + | 14 |
| | | Level of understandability and usability of the language that is used to specify the underlying metamodels of modeling systems * | 15 |
| | Learnability | Whether the metamodeling system has adequate documentation + | 16 |
| | | Whether the metamodeling system provides guidelines to its users how to best construct a modeling system | 17 |
| | | Level of learnability of the language that is used to specify the underlying metamodels of modeling systems * | 18 |
| | Operability | Whether the metamodeling system has graphical tools that facilitate the development of modeling systems * | 19 |
| | | Whether the metamodeling system allows its users to use macros or templates ** | 20 |
| | | Whether the metamodeling system supports metamodel updates that cause automatic updates of artifacts that have been created based o n the metamodel ‡ | 21 |
| | Attractiveness | Whether the metamodeling system has attractive graphical design + | 22 |
| Portability | Adaptability | Whether the metamodeling system is a web-based system that simplifies the use of metamodeling client software because only a web browser is needed for that ** | 23 |
| | | Whether the metamodeling system uses a server database management system (DBMS) as its basis. It simplifies moving the software to other environments because server DBMSs are a kind of virtual operating systems that can be deployed to many different platforms and locations [11] | 24 |
| | Installability | Whether the provider of the metamodeling system provides technical support and online help for the installation of the metamodeling system + | 25 |
| | Co-existence | Whether the metamodeling system is capable to co-exist with other independent metamodeling systems in a common environment sharing common resources * | 26 |

engineering process" is a problem of existing CAME systems. Hence, we added measure "Whether the metamodeling system provides adequate support to all the phases of modeling system development process" to the quality model.

4. ** measures that we found based on the framework for comparison of system modeling tools [4].

The framework for comparison of system modeling tools [4] specifies 25 features that experts expect from modeling systems. 11 features (including three of the most important) have a corresponding measure in the quality model of metamodeling systems. The CAME quality model [5] specifies 14 measures and 12 of them have a corresponding measure (or measures) in the quality model of metamodeling systems. The following measures from the CAME quality model do not have a corresponding measure in the quality model of metamodeling systems because they are too CAME-specific: "Evaluates if the CAME environment supports various SME approaches" [5], "Evaluates if the CAME environment supports process enactment" [5].

Each measurement helps us to find zero or more *problems in system*. Each such problem is characterized by a *problem type* that is specific to one or more *system types*. A problem type could be specific to only one system type. For instance, problem type "Lack of support for situational method engineering approaches" [5] is specific to CAME systems. On the other hand, problem type "Does not provide graphical meta-modeling language" is relevant in case of metamodeling as well as CAME systems. A goal of performing analysis of metamodeling systems is to find problem types in case of metamodeling systems.

## 3 Analysis of Some Existing Metamodeling Systems

In this section, we apply the proposed quality model to analyze a set of metamodeling systems. This analysis includes metamodeling systems MetaEdit+ 4.5 SR1, GME 10.2.9, GEMS RC4, and WebMeta 0.5 (see Sect. 1). The results of the analysis characterize the state of the art of metamodeling systems and point to the shortcomings of existing systems. In addition, such analysis is necessary to empirically evaluate the proposed quality model.

We analyze the metamodeling systems by outlining the measures stated above and then present the corresponding measurement results for each of the systems in our analysis set.

Firstly, we consider the *general measures* (see Table 2).

Secondly, we focus on the *characteristic measures*. For each measure, we present the results of analysis by using the following scale and notation.

V—Supported to a good extent

X—Not supported

– —Inadequate information to assess

**Table 2** The analysis results in case of general measures

| Systems | Purpose | Number of features | Amount of literature |
|---|---|---|---|
| MetaEdit+ | Research and commerce[a] | High | High[d] |
| GME | Research and commerce[b] | High | High[d] |
| GEMS | Research and commerce[c] | High | High[d] |
| WebMeta | Research | Low | Low |

[a] MetaEdit+ is sold commercially; however, it has academic background
[b] GME is open-source and it is freely downloadable. Its end-user license permits the use of the system for developing commercial software. However, the license does not allow selling the system itself commercially
[c] The GEMS plug-in as well as the Eclipse platform are freely downloadable. In addition, the Eclipse Public License [12] allows including the plug-into commercially sold software
[d] Extensive help files, manuals and tutorials are available

**Table 3** The analysis results in case of suitability sub-characteristic

| Systems | Functionality—measures of suitability sub-characteristic: 1–4 | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| MetaEdit+ | V | V | V | V |
| GME | V | V | X[c] | V |
| GEMS | V | V | V | X[e] |
| WebMeta | –[a] | X[b] | X[d] | V |

[a] The suitability of the meta-metamodels of MetaEdit+, GME, and GEMS has been proved in general practice. The question, whether the meta-metamodel of WebMeta is suitable enough for different cases, requires an empirical and an ontological analysis
[b] The WebMeta system is form-based only
[c] GME metamodel can be turned into a binary file, which can then be used to configure another GME instance [2]. Code generation is not supported
[d] The current WebMeta prototype does not yet support code generation based on artifacts
[e] In our experience, the GEMS system is single-user only

In Tables 3 and 4, we present the analysis results in case of *Suitability*, a sub-characteristic of *Functionality* (measures with numbers 1–8 from Table 1).

In Table 5, we present the analysis results in case of the rest of the sub-characteristics of *Functionality*: *Interoperability*, *Accurateness*, and *Functionality compliance* (measures with numbers 9–13 from Table 1).

In Table 6, we present the analysis results in case of *Understandability* and *Learnability*, sub-characteristics of *Usability* (measures with numbers 14–18 from Table 1).

In Table 7, we present the analysis results in case of the rest of the sub-characteristics of *Usability*: *Operability* and *Attractiveness* (measures with numbers 19–22 from Table 1).

In Table 8, we present the analysis results in case of sub-characteristics of *Portability* (measures with numbers 23–26 from Table 1).

**Table 4** The analysis results in case of suitability sub-characteristic (continued)

| Systems | Functionality—measures of suitability sub-characteristic: 5–8 | | | |
|---|---|---|---|---|
| | 5 | 6 | 7 | 8 |
| MetaEdit+ | VX[a] | V[c] | V[e] | V |
| GME | VX[a] | X | X | V |
| GEMS | VX[a] | X | X | V |
| WebMeta | VX[b] | X[d] | X | V[f] |

[a] MetaEdit+, GME, and GEMS support the design and implementation of modeling systems to a good extent; however, in our experience, the requirement analysis, and in case of GME and GEMS, the validation of the modeling systems is not supported

[b] WebMeta supports the design of modeling systems to a good extent; implementation and validation of modeling systems should be further researched and improved. The requirement analysis is not supported

[c] MetaEdit+ includes MERL (MetaEdit+ Reporting Language), in which one can create a generator script to notify on illegal, incomplete or inconsistent model structures [Tolvanen (2010) Private conversation]

[d] WebMeta includes an integrated query subsystem [13] that allows checking the correctness and consistency of the artifacts defined in modeling systems. It is based on the use of database queries. Information about the metamodels is in the same database and hence it is possible to extend the system to use it for checking metamodels as well

[e] MetaEdit+ has pre-defined project and graph documentation generators, which are able to create HTML files and.doc or.rtf document files

[f] For example, WebMeta allows the user to describe the definition of model elements using human language (which itself is inaccurate). However, one can create queries to apply semantic rules

**Table 5** The analysis results in case of interoperability, accurateness, and functionality compliance sub-characteristics

| Systems | Functionality—measures of interoperability, accurateness, and functionality compliance sub-characteristics: 9–13 | | | | |
|---|---|---|---|---|---|
| | 9 | 10 | 11 | 12 | 13 |
| MetaEdit+ | X | V | V[b] | V[c] | X[e] |
| GME | X | V | V[b] | V[c] | V[f] |
| GEMS | V[a] | V | V[b] | V[c] | V[f] |
| WebMeta | X | X | X | X[d] | X |

[a] GEMS is a plug-in for the Eclipse platform and therefore is integrated with its IDE

[b] MetaEdit+ and GME support importing and exporting metamodeling data to XML files. Metamodels generated in GEMS system can be used as plug-ins in the Eclipse platform

[c] MetaEdit+, GME, and GEMS have all been used by large group of users. There is a substantial amount of publications available regarding the evaluation of these systems

[d] WebMeta has not yet been evaluated by a third party

[e] MetaEdit+ does not support MOF, OCL, or XMI, however, its own meta-metamodel for language definition supports, for instance, n-ary relationships among other features that MOF does not support [13]

[f] GME and GEMS use MOF-like language for creating metamodels and GME allows its users to define constraints by using a dialect of OCL [2]

**Table 6** The analysis results in case of understandability and learnability sub-characteristics

| Systems | Usability—measures of understandability and learnability sub-characteristics: 14–18 | | | | |
|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 |
| MetaEdit+ | V | V | V | X[b] | –[c] |
| GME | V | V | V | X[b] | –[c] |
| GEMS | V | V | V | X[b] | –[c] |
| WebMeta | –[a] | –[a] | X | X | –[c] |

[a] The understandability and usability of WebMeta should be further researched and possibly improved
[b] Apart from the tutorials and help files, in our experience, MetaEdit+, GME, and GEMS themselves do not provide any guidelines, how to best construct a modeling system
[c] An empirical analysis could determine the level of learnability of the language used to specify the underlying metamodels of modeling systems

**Table 7** The analysis results in case of the operability and attractiveness sub-characteristics

| Systems | Usability—measures of operability and attractiveness sub-characteristics: 19–22 | | | |
|---|---|---|---|---|
| | 19 | 20 | 21 | 22 |
| MetaEdit+ | V | V[b] | V | V |
| GME | V | –[c] | X[d] | V |
| GEMS | V | – | X[d] | V |
| WebMeta | X[a] | X | V | X[a] |

[a] The current prototype of WebMeta is form-based only
[b] MetaEdit+ supports the use of rule forms and templates for defining rules and constraints that guide the use of modeling languages [14]
[c] There are some references to macros in GME User Guide, but it is uncertain how extensive the support is
[d] When changing a metamodel in GEMS, the corresponding plug-in has to be regenerated for models to change. GME requires explicit operation to try to update the artifacts [2]

# 4 Discussion

We created a quality model of metamodeling systems and used it to analyze a set of systems. Based on the analysis, we found the following types of problems in case of the metamodeling systems.

1. Partial coverage of engineering process of modeling systems. Existing systems support design and implementation of modeling systems, but support to the requirements analysis and testing of modeling systems needs improvement. This type of problem was also detected in case of CAME systems, because there are shortcomings in support for method requirements analysis and testing of methods [5].
2. Weak support to the verification of modeling systems that have been created by using metamodeling systems. This kind of problem was also detected in case of CAME systems, because they do not provide enough support to the method verification [5].
3. Lacking support of graphical modeling languages in WebMeta.

**Table 8** The analysis results in case of adaptability, installability, and co-existence sub-characteristics

| Systems | Portability—measures of sub-characteristics: 23–26 | | | |
|---|---|---|---|---|
| | 23 | 24 | 25 | 26 |
| MetaEdit+ | X[a] | V[c] | V | X[g] |
| GME | X[a] | V[d] | V | X[g] |
| GEMS | X[a] | X | V | X[g] |
| WebMeta | V[b] | V[e] | X[f] | X[g] |

[a] MetaEdit+, GME, and GEMS have all desktop applications as client environments, which must be installed before use

[b] The current prototype of WebMeta is completely web-based and does not require any additional plug-ins or applications other than a web browser

[c] MetaEdit+ uses an object-oriented DBMS as its storage technology. It does not support SQL commands to access models directly. The user has to use a third-party program passing the SQL commands to the API of MetaEdit+ and back [Tolvanen (2010) Private conversation]

[d] GME supports MS SQL Server. Supporting an additional storage technology (e.g. Oracle database) requires the implementation of a single, well-defined, small interface component [7]

[e] WebMeta is built on PostgreSQL Object-Relational DBMS

[f] There is no online help at the moment for the current prototype of WebMeta. However, the use of the system requires only installation of a web browser to the client environment

[g] MetaEdit+, GME, GEMS, and WebMeta have all their own resources which are unique and cannot be used freely by other metamodeling systems

4. Inadequate learning and help support in WebMeta.
5. Inadequate interchangeability, particularly poor XMI standard support, in all of the analyzed metamodeling systems. Gray et al. [15] note that the use of XMI is a promising approach for resolving interoperability issues. However, ten years on it seems that XMI has not been able to resolve these problems.
6. Inadequate web-based environment support for MetaEdit+, GME, and GEMS.
7. No guidelines provided to the user in the metamodeling systems how to best construct a modeling system. There is a possible research topic regarding intelligent systems and integrating the intelligence technology with metamodeling systems. On the other hand, the guiding system should not be too restrictive, because it may cause resentment [15].
8. Weak support for automating and simplifying frequent tasks (by using macros and templates) in GME, GEMS, and WebMeta.

Kelly and Tolvanen [2] present functional requirements to metamodeling systems and analyze the following systems: MetaEdit+, GME, DSL Tools, and Eclipse Modeling Project. These systems are used to create domain-specific modeling environments. They do not use an explicitly defined quality model as the basis of the analysis. However, their experience in the field of metamodeling systems allows them to make many observations about the state of the art of these systems. Some of the observations are the same as made in our analysis. However, our analysis also points to some problems (for instance "Partial coverage of engineering process of modeling systems") that are not stressed in [2]. On the other hand, Kelly and Tolvanen [2] write, without mentioning concrete systems, that some metamodeling systems inadequately support the evolution of metamodels and their corresponding models and also have "difficulties in scaling to support multiple models, modeling languages and users" [2]. They are also critical about the use of UML as the basis of meta-metamodels and hence it is open question whether the support of standards like MOF (that is required in our quality model) is actually desired.

An advantage of the use of an explicitly defined quality model in an analysis of systems is that it provides a guiding framework for performing the analysis (what to investigate in case of the systems). In addition, one could analyze different versions of the same systems to find out how the systems have evolved over time. The use of the same quality model in these analyses improves the comparability of the results. A problem of the quality model is that some of the measures are too general and the results of the measurements are too subjective.

## 5 Conclusions

In this paper, we presented a quality model of metamodeling systems that we developed by instantiating a metamodel of the Computer Aided Method Engineering (CAME) quality model. In addition, we proposed a generalized process for creating new quality models based on existing quality models. We used the new model to analyze a set of metamodeling systems (MetaEdit+ 4.5 SR1, GME 10.2.9, GEMS RC4, and WebMeta 0.5) to find their problems. We found that existing metamodeling systems still have unresolved problems. We conclude that it is possible to use the proposed quality model to analyze metamodeling systems.

It is planned to apply the results of the analysis to improve the quality of our metamodeling system (WebMeta) [1]. One could repeat the analysis of the same systems based on their newer versions to find out how they have evolved over time. It is also possible to integrate the Analytic Hierarchy Process (AHP) [16] with the proposed quality model. For instance, AHP would allow us to find the relative importance of criteria and sub-criteria in the context of a particular analysis. It is also necessary to use the proposed process for creating quality models to create additional quality models to further empirically validate the process.

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# Selection of Appropriate Data Storage for Wavelet Transform Coefficients

**I. Žouželková, R. Vala and M. Juřík**

**Abstract** The study of transform coefficients brought a question of a useful tool for signal evaluation and comparison. The application should use a database storage system for fast inserting and selecting data and should be also capable of saving large amount of real numbers. This paper deals with performance tests of selected database management systems: relational MySQL, MS SQL and object-relational PostgreSQL. The tests were focused on different storage engines and used data types such as a numerical array, text and decimal. Besides the relational database models, a multidimensional approach was projected and analyzed. The results showed that the most effective solution is saving the transform coefficients into separated 16 atributes using the MySQL storage engine called MyISAM. The multidimensional model appeared to be less suitable for this kind of application.

## 1 Introduction

Transform coefficients, the outputs of the discrete wavelet transform, are widely employed in time-series processing and related fields to describe the frequencies contained in a sampled signal. The wavelet transform is further used for signal coding, representing a discrete signal in a less redundant form, and often as a preconditioning for data compression.

The study of transform coefficient has brought a question of a useful tool for signal evaluation. The application should use a database system for storage of a

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large volume of real numbers with very short response time. Moreover, each signal could be described by an array of coefficients which should be properly saved and should enable efficient search through signal records. These requirements have led to the selection of an appropriate database management system (DBMS).

Increasing demand for data storage has heightened the number of offered DBMS and database servers. Furthermore, different database models such as relational, object-oriented, object-relational and other schemes were projected. Developers have been confused by the wide choice and, consequently, the need for performance tests, which could bring an objective comparison, has become a favorite topic of different analyses [1].

Several researchers have designed time response tests of database systems, such as MySQL, MS SQL, PostgreSQL and other DBMS, in order to investigate their suitability for various applications. The testing methods and conditions differed and, consequently, the comparison of findings was inconclusive.

This study is designed to evaluate performance of the chosen database engines using the same hardware configuration and software tool. Moreover, in order to gain the best solution for the array storage, the paper compares the performance of two main approaches: a traditional relational database (MySQL, MS SQL and PostgreSQL) and a multidimensional model (MS SQL).

## 2 Relational Database Concept

### *2.1 Data Types and Testing Methods*

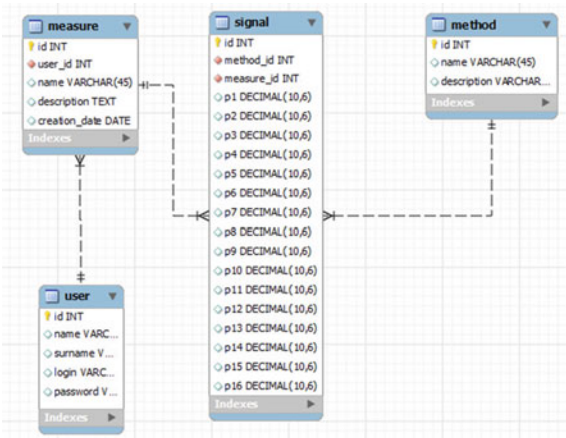
In order to investigate the suitability of the four storage engines (MySQL-MyISAM and InnoDB, MS SQL and PostgreSQL) a time response test using ADOdb tool was designed. ADOdb is a database abstraction library for PHP which allows developers to write applications in a consistent way and change the database without rewriting every call to it in the application [2]. In other words, the engines were tested by the similar script on the same hardware configuration under the equal conditions.

The structure of the tested databases was designed in the next step. The highest attention was paid to the choice of the proper data type for the coefficient records. As previously mentioned, each signal could be described by an array of 64 coefficients. The first concept, saving the coefficients into a data type *array,* seemed to be logical. However, the only DBMS offering this solution was PostgreSQL. Inserting the array into 64 created attributes (for test purposes 16 attributes were sufficient) with a numeric data type appeared to be the next possibility. This approach was feasible to work across different platforms. The last option offered by all systems was the usage of an attribute defined as *text*, saving the values into a string. This solution could bring problems with comparing the particular

**Table 1** Tested data types on chosen platforms

| Data type | Platform | | | |
|---|---|---|---|---|
| | MySQL | | MS SQL | PostgreSQL |
| | MyISAM | InnoDB | | |
| Decimal (16 attributes) | **X** | **X** | **X** | **X** |
| Text (1 attribute) | **X** | **X** | **X** | – |
| Array (1 attribute) | – | – | – | **X** |

**Fig. 1** MySQL, MS SQL and PostgreSQL database structure




coefficients and searching for data in the defined range of values. Table 1 shows a brief summary of the tested data types on the mentioned platforms.

According to Table 1, three concepts of table structure were created. The first model can be seen in Fig. 1. The database included four tables and the table signal contained 16 attributes for the coefficients. The attributes were replaced by only one column with the *text* data type in the second model and with the *array* in the last model (for PostgreSQL only).

Furthermore, the SQL *INSERT* and *SELECT* statements were chosen for the performance tests. The other queries were not included because they appeared to be unnecessary for the intention. In other words, the database should provide fast data reading and saving, other data operation were not expected. The *INSERT* query was used to enter 100, 1000 and 10,000 records. The *SELECT* statement with 16 restricted coefficients was applied on 100,000 rows. Each test was ten times repeated and the results were averaged out.

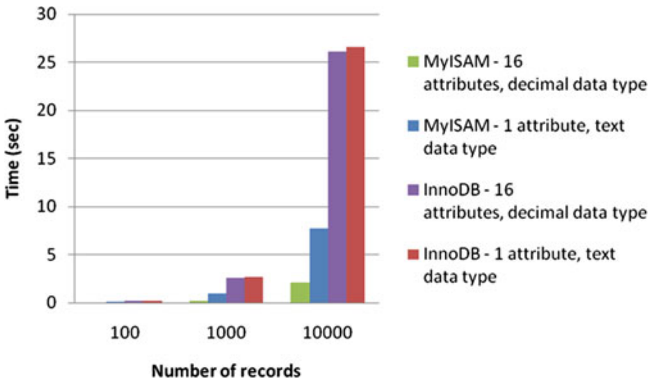



**Fig. 2** MyISAM vs InnoDB: Speed of the *INSERT* query

## 2.2 MySQL Tests

MySQL offers several data storage engines. This work deals with the two of them—MyISAM and InnoDB. Ref. [3] mentions the main differences between the engines. MyISAM was developed as a default MySQL storage system and contains many functions programmed during years of usage. The engine is very simple, suitable for many systems and widely known for very short response time. On the other hand, InnoDB was designed for transactions providing a data consistency check, which can be more demanding. Long response times of InnoDB can be caused by clustering primary keys, automatic check summing and other techniques preventing data corruptions [4]. Thanks to its properties, InnodDB is expected to be slower than MyISAM. However, InnoDB supports multi thread processing and can perform better in specific situations.

The test of each engine (MyISAM and InnoDB) was divided into two parts. The first part dealt with the *INSERT* query and the second part tested the *SELECT* query. Figure 2 shows the time response of the *INSERT* depending on the storage engine. According to this preliminary study, MyISAM tended to be more than three times faster than InnoDB. This expected difference in the engines may be due to the previously mentioned data storage process. The exact time values are not very important, because they depend on the used hardware configuration.

As can be seen, saving numeral values into 16 separate attributes was faster than inserting the coefficients as a string into one attribute.

Figure 3 compares the results of the *SELECT* query test. Searching the MyISAM *decimal* attributes seemed to be considerably faster than selecting the InnoDB *decimal* attributes. Also faster *text* search is offered by the MyISAM engine. These results could lead to a misinterpreted conclusion that InnoDB responds mostly worse than MyISAM. In real life workload results are likely to be very different, because the time response can be influenced by server stress. Ref.

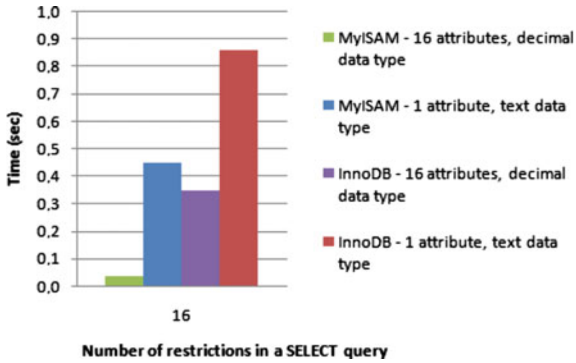



**Fig. 3** MyISAM vs InnoDB: Speed of the *SELECT* query (100,000 rows; 16 restrictions)

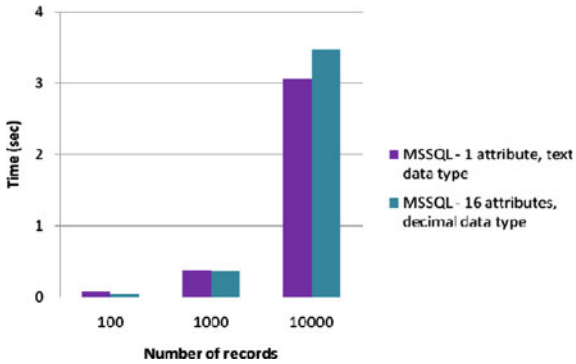



**Fig. 4** MS SQL: Speed of the *INSERT* query

[5] focused on InnoDB and MySQL benchmark running the *SELECT* queries on several co-current threads.

## *2.3 Microsoft SQL Server Tests*

Microsoft SQL Server supports different data types, including primary and also user-defined composite types. In order to compare the results with other DBMS, a decimal data type and a text data type were chosen for testing. Because the goal of this test case was not to compare the performance impact of different versions of the server, only the latest release (Microsoft SQL Server 2008 R2 Express edition) was used.

Figure 4 provides comparison of insert speed for the two chosen data types. In this case, entering a text attribute appears to be faster than inserting the numeric ones, but the results are on average comparable. As expected, the results of the SELECT query (Fig. 5) reflect more than two times worse response of a text search than a numeric coefficient search. Moreover the final select time has exceeded 1.6 s, which is the worse result of all DBMS.

**Fig. 5** MS SQL: Speed of the *SELECT* query

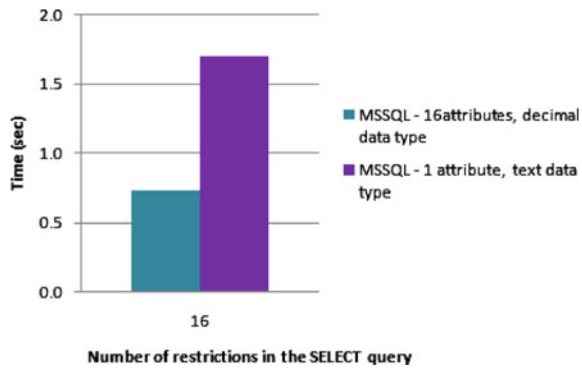
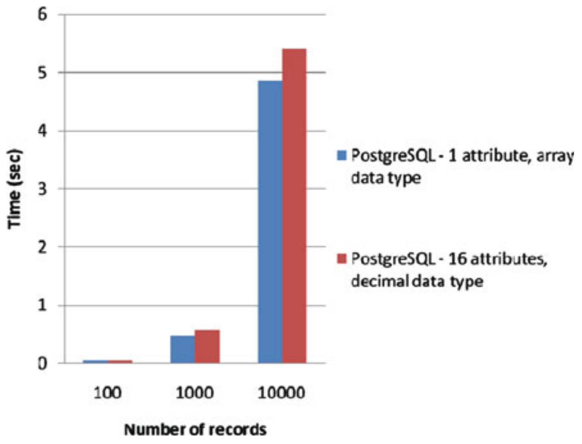



**Fig. 6** PostgreSQL: Speed of the *INSERT* query




## *2.4 PostgeSQL Tests*

PostgreSQL is an object-relational DBMS allowing columns of a table to be defined as variable-length multidimensional arrays of any built-in or user-defined base type [6]. In this case one *array* attribute of *integer* was created for the first part of the test. The second part dealt with 16 numeric attributes as it was done with MySQL DBMS.

As revealed from the comparison in the Fig. 6, inserting the array type attribute is almost 10 % faster than inserting 16 numeric coefficients. In contrast, selecting from 100,000 of rows is faster in case of the numeric coefficients (Fig. 7). This dissimilarity between the queries is logical. Entering 16 different attributes is more demanding than saving values into the only one column. On the other hand, searching for appropriate records, selecting according to the 16 restrictions, can be faster with more attributes than searching inside an array.


**Fig. 7** PostgreSQL: Speed of the *SELECT* query

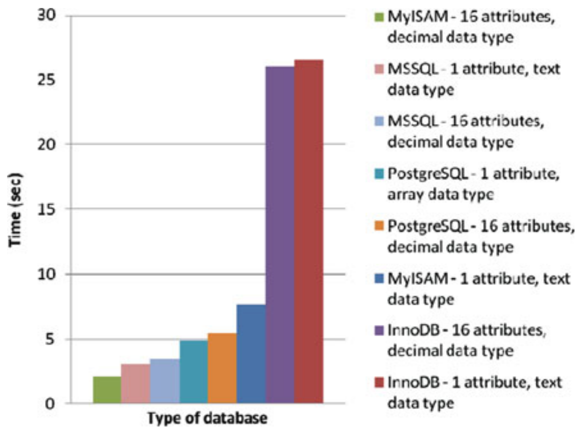



**Fig. 8** PostgreSQL vs. MySQL vs. MS SQL: Speed of the *INSERT* query (10,000 rows)

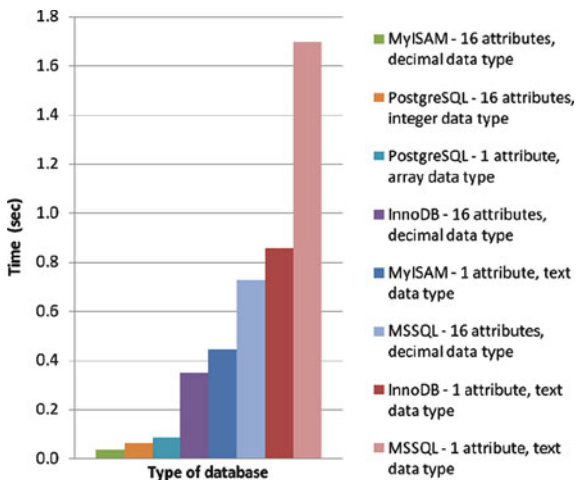



**Fig. 9** PostgreSQL vs. MySQL vs. MS SQL: Speed of the *SELECT* query (100,000 rows, 16 restrictions)

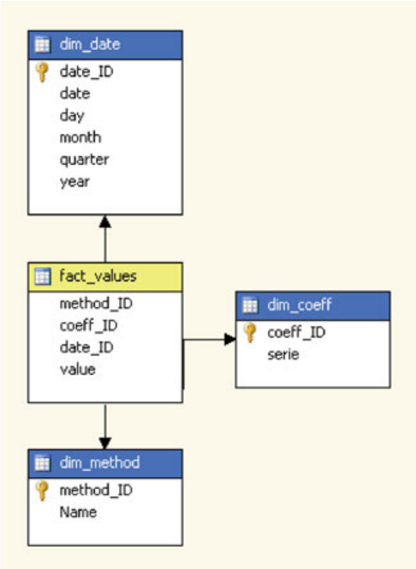



**Fig. 10** The multidimensional structure of the cube

### 2.5 *MySQL, MS SQL and PostgreSQL: Result Comparison*

The total comparison of the tested DBMS is given in Figs. 8, 9. The first graph provides complex results of the *INSERT* query. On the limited data available, MyISAM (MySQL engine) tended to perform better than other tested engines. It was almost three times faster in inserting 16 numeral attributes than PostgreSQL and even thirteen times faster than InnoDB. According to this simulation study, inserting the transform coefficients into 16 fields appears to be the best solution.

As can be seen in the second graph, the results of the SELECT statement are similar to the previous ones. MyISAM reaches the best results again. On the other hand, MS SQL is almost 4 times slower in a text search than the most effective MySQL.

## 2 Multidimensional Database Concept

A multidimensional database concept is closely connected with online analytical processing (OLAP). Traditionally, OLAP is a technique for aggregating data to solve business problems. On the other hand, it can be used in scientific analysis and research as well [7].

The multidimensional approach requires different view of the data. The fundamental parts of any OLAP solution are cubes, dimensions and measures. A cube collects numeric data organized by arrays of discrete identifiers. Essentially, a cube is defined by its measures and dimensions [7]. Dimensions can be interpreted as categories used to analyze the data. Each signal can be defined by three variables: a date, a method of transform and transform coefficients, which form the dimensions of the cube. The measures are the numeric data inside the cube. Details of the cube structure are provided in Fig. 10. Tables *dim_date, dim_coeff, dim_method* represent the dimensions, while table *fact_values* saves the measures.

The cube was created in MS SQL Server 2008 which offers Analytical Services for OLAP analysis. Because of the different structure, the comparison with standard relational databases would be quite complicated. The first outputs from this system were not satisfactory considering the defined requirements for the application. In fact, OLAP analysis deals with aggregated data and offers summarized facts depending on the depth of selected dimensions. The application for signal comparison would rather employ short response time of inserting and selecting data. According to these specified requirements, the multidimensional structure tends to be a less convenient method than the classical relational approach.

## 3 Conclusion

The main purpose of the survey was to analyse the performances of different database approaches. The multidimensional model appeared to be less acceptable for the real application. On the other hand, relational DBMS seemed to be more suitable. Especially the MySQL database engine -MyISAM acquired the best results in all tests. As can be seen from the data, the testing queries also revealed that implementation of 16 attributes of a numeral data type would perform effectively than using arrays or strings.

It should be noted that the findings of this study are restricted to the *INSERT* and *SELECT* query usage and, consequently, embedded procedures can perform differently.

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# Drug Delivery by Electroporation: Review

**Sadhana Talele**

**Abstract** Drug delivery is the method or process of administering a pharmaceutical compound to achieve a therapeutic effect in humans or animals. Most common routes of administration include the preferred non-invasive peroral (through the mouth), topical (skin), transmucosal (nasal, buccal/sublingual, vaginal, ocular and rectal) and inhalation routes. Current effort in the area of drug delivery include the development of targeted delivery in which the drug is only active in the target area of the body (for example, in cancerous tissues) and sustained release formulations in which the drug is released over a period of time in a controlled manner from a formulation. This is achieved by combining electroporation with the input of drugs at a location. This paper reviews the process of electroporation and then further discusses the electrochemotherapy, one of the most upcoming application of electroporation in biotechnology.

## 1 Introduction

Drug delivery is the method or process of administering a pharmaceutical compound to achieve a therapeutic effect in humans or animals. Most common routes of administration include the preferred non-invasive peroral (through the mouth), topical (skin), transmucosal (nasal, buccal/sublingual, vaginal, ocular and rectal) and inhalation routes. Many medications such as peptide, antibody, vaccine and gene based drugs, in general may not be delivered using these routes because they might be susceptible to enzymatic degradation or cannot be absorbed into the

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systemic circulation efficiently due to molecular size, to be therapeutically effective. For this reason such drugs have to be delivered by injection. For example, many immunizations are based on the delivery of protein drugs and are often done by injection. Current effort in the area of drug delivery include the development of targeted delivery in which the drug is only active in the target area of the body (for example, in cancerous tissues) and sustained release formulations in which the drug is released over a period of time in a controlled manner from a formulation [1–3]. This is achieved by combining phenomenon of electroporation with the application of drugs.

This makes the area of drug delivery a study in which experts from most scientific discipline can make a significant contribution. To understand the barriers to drug delivery, it is useful to consider anatomical structures at a length scale suitable for variety of structures: a cell, a tissue, a muscle, organ. Better medical treatments may not always require stronger medicinal drugs. A better effect could be achieved by an effective method of administration. Often differences in the mode of drug administration produce substantial changes in drug concentration requirement, and thus can affect the unnecessary side effects of some of the drugs in favor of the patient. A good example of this is electrochemotherapy (ECT). The major disadvantage of clinically established chemotherapeutic drugs is their lack of selectivity of tumor cells. Therefore for a noticeable antitumor effect, high doses of the chemotherapeutic drugs are needed, which often cause systemic toxicity leading to severe side effects [3]. In cancer chemotherapy, some drugs do not exhibit anti-tumour effects because of impeded transport through the cell membrane [4]. To overcome this difficulty, a number of new approaches for drug delivery systems have been attempted. One of the approaches to better drug delivery is by making it topical and more effective at the tumor site with the use of electric field. This is electrochemotherapy. In this article a brief overview of electroporation and its use in electrotherapy is discussed.

## 2 Electrochemotherapy

The ECT combined use of chemotherapeutic drugs along with electroporation caused due to application of electric pulses is known as electrochemotherapy and is useful for local tumour control. Bleomycin and cisplatin which are commonly used drugs for chemotherapy have proven to be much more effective in electrochemotherapy than in standard chemotherapy when applied to tumour cell lines in vitro, as well as in vivo on tumours in mice [5–7]. Clinical trials have been carried out with encouraging results [8–13]. Especially, bleomycin has been reported to have shown a 700-fold increased cytotoxicity when used in ECT [1, 2]. This helps to achieve a substantial anti-tumour effect with a small amount of drug, that limits its side effects [3].

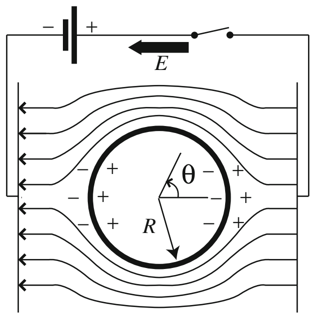


**Fig. 1** Spherical particle in electric field, $E$ is the electric field (adapted from [17, 18])

## 2.1 Electroporation

It is possible to induce the formation of hole in a cell membrane by applying a sufficiently strong electric field pulse. This is known as electroporation. The effect is reversible when the cell membrane is temporarily permeated. Irreversible electroporation occurs when the cell membrane poration is of such a nature as to induce cell death. Polarization is one of the basic mechanisms of interactions of membranes with electric fields, leading to electroporation and related phenomenons of dielectrophoresis [14, 15] and electrofusion [14, 16].

### 2.1.1 Polarization of Membranes

Polarization of membranes underlies their destabilization. Polarization is due to restricted motion of charges: electric fields exert forces on charges. These charges can either move if they are free (material is conductive) or accumulate if they are limited in their movement. This charge redistribution in a particular limited space leads to polarization. Figure 1 shows polarization of a single cell due to restriction by the cell membrane to the motion of ions.

## 2.2 Electric Field Interaction with Polarized Membranes and Pore formation

The interaction of external electric field with the polarized membranes results in forces which can induce motions inside particles. This motion can result in structural rearrangement or fracture in the material. This can subsequently lead to electroporation and related phenomenon in case of cell membranes [12, 15]. Membranes have low polarizability (relative dielectric constant about 5) and low conductivity $(3 \times 10^{-7}\,\mathrm{S/m})$ [19]. The cell membrane is generally bounded (externally and internally) by a medium of high dielectric constant (about 80) and a high conductivity (about 1.2 S/m). Application of external fields leads to accumulation of charge at the membrane surfaces; this creates an electric field inside the membrane that is much stronger than the surrounding field. The polarized membrane interacts with this field, resulting in structural rearrangements which can cause membrane poration.

It soon became apparent that a field-induced permeability increase is transient in nature although long-lived compared with the field duration. The term 'electropermeabilization' was used to explain the occurrence of permeability changes introduced by electrical impulses in vesicular membranes [20]. It was later shown that the electric field induced change was transient [21]. The resistance changes in the membrane were attributed to dielectric breakdown [22].

Subsequent studies showed that the cell membranes of pulse treated cells were permeable to molecules of a size smaller than a certain limit, suggesting the creation of a porous membrane structure [20, 22, 23]. It was also found that under appropriate conditions, the cells could recover, which implied that these electropores were resealable and could be induced without permanent damage to the cell [24], and the cytoplasmic macromolecular contents could be retained [23, 25]. Since then, a number of research groups have studied mechanisms of pore formation and detailed characteristics of the cell membranes modified by electric fields [26–29].

However, the pores themselves were not observed until the invention of rapid freezing electron microscopy in the 1990s. Chang and Reese [30] were the first to observe them. Other aspects of electroporation, for example, vizualization of transmembrane potential and its evolution in space and time, resealing of pores and asymmetry in permeability of porated cells (sea urchin egg and liposomes) with the help of an optical microscope, were also reported [31, 32]. These microscopes have a time resolution of sub-microseconds suitable for studying electroporation.

### 2.2.1 Types of Pores

The pores are assumed to be hydrophobic or hydrophilic. The hydrophobic pores, as shown in Fig. 2a [26, 28, 33], are simply gaps in the lipid bilayer of the membrane, formed as a result of thermal fluctuations.

The primary pores that participate in electrical behaviour and molecular transport are thought to be hydrophilic pores, with a minimum radius of about 1 nm, and a reasonable probability of various pore sizes much larger [34]. The 'hydrophilic' or 'inverted pores,' as shown in Fig. 2b, have their walls lined with the water-attracting heads of lipid molecules. Hence, the hydrophilic pores allow the passage of water-soluble substances, such as ions, while the hydrophobic pores do not.

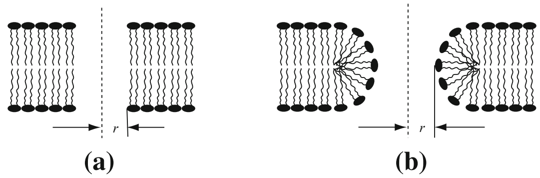


**Fig. 2** Types of electropores: **a** hydrophobic (nonconduting pore), **b** hydrophilic pore (conducting pore)

## 3 Facts About Electrochemotherapy

Due to the availability of these electropores, electroporation can and has been used to deliver a variety of molecules for the purpose of DNA transfer, anesthesia, cosmetics, vaccination and chemotherapy. We discuss the chemotherapy details and results in brief as below.

(1) Many studies reported that with belomycin doses far belowtoxicity, antitumour effectiveness of electrochemotherapy induced good responses of the tumours including tumour cures [2].
(2) It has also been found that some tumours are more sensitive to one drug than to another used in electrochemotherapy [2].
(3) Not all tumours have equal level of sensitivity to electrochemotherapy with bleomycin, but all tumor types (e.g., breast, colon, bladder, renal cell, malignant melanoma, basal cell carcinoma) have shown a response to electrochemotherapy [2, 35].
(4) Electrochemotherapy with bleomycin was performed on tumours in internal organs (brains and livers in rats) [2].
(5) Complete eradication of treated nodules occurs in approximately 75 % of the cases, and at least a partial remission occurs in 85–90 % of the treated patients [35, 36].
(6) Mostly square pulses of duration 100 us, with electric field intensity of 1,300 V/cm or 1,500 V/cm, repetition frequency of 1 Hz is used. With higher amplitudes more cells in the tumour are permeabilized [35].
(7) Permeabilization of tumour cells is also dependent on the number of electric pulses, with eight electric pulses found optimum [37].
(8) Antitumour effectiveness is dependent on drug concentration in the tumour during application of electric pulses, a 3-min interval between the treatments is optimal [37].
(9) The second most useful drug for electrotherapy has been found to be cisplatin. This is one of the drugs that induces resistance in cells, often early in the course of chemotherapy treatments. Electroporation has demonstrated itself to overcome this resistance of cells to cisplatin, at least to some degree [2].
(10) Other attempts to determine whether other drugs would be effective in electrochemotherapy protocol in vivo do not prove to be good candidates because of their lipophilicity (being soluble in fat solvents) [2].

(11) Achieving optimal electroporation during therapy without the need for repetitive treatment is an issue yet, however several ways of obtaining this are under research e.g. optimization of electric field by proper choice of value, number and duration of pulses and type of electric field, needle electrode design, rotating these needles between pulses [37, 38].
(12) Impact of electrochemotherapy on the formation of metastates is yet to be established with preclinical and clinical studies, however studies have shown decreased number of metastases in rats [39, 40].

## 4 Other Applications of Electroporation

There are many other applications of electroporation/electropermeabilization (EP) in biotechnology, biochemistry, molecular biology, medicine and other biological research. Some of them are as follows:

1. Electrogenetransfection (EGT): Application of electroporation for transfer of DNA into cells to effect some form of gene therapy, often referred to as electrogenetransfection, is currently being applied in some clinical trials. It is presently considered to have large potential as a non-viral method to deliver genetic material into cells, the process aimed at correcting genetic diseases [41].
2. Electrofusion (EF): Under appropriate physical conditions, delivery of electric pulses can lead to membrane fusion in close-contact adjacent cells. EF results in the encapsulation of both original cells' intracellular material within a single enclosed membrane and can be used to produce genetic hybrids or hybridomas [16]. Hybridomas are hybrid cells produced by the fusion of an antibody secreting stimulated B-lymphocytes, with a tumour cell that grows well in culture. The hybridoma is then able to continue to grow in culture, and a large amount of specific desired antibodies can be recovered after processing. Electrofusion has proved to be a successful approach in the production of vaccines [42, 43], antibodies [44], and reconstructed embryos in mammalian cloning [45].
3. Transdermal drug delivery (TDD): Application of high-voltage pulses to the skin allows a large increase in induced ionic and molecular transport across the skin barrier [46]. This has been applied for transdermal delivery of drugs, such as metoprolol [47], and also works for larger molecules, for example, DNA oligonucleotides [47].
4. Electroinsertion (EI): Another application of electroporation is insertion of molecules into the cell membrane. As the electric field induced membrane pores reseal, they entrap some of the transported molecules. Experiments on electroinsertion suggest the possibility of using the process to study certain physiological properties of these cells and understanding aspects of the lipid-protein interactions of the cell plasma membrane [48].

## 5 Conclusion

Electroporation may be widely used as a cancer treatment in near future with advantages of low toxicity and being topical and more effective at the tumor site. Newer drugs suitable for various types of cancers and an optimum methodology of application of the electric field is under extensive research.

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# Wine Maturation Using High Electric Field

**Sadhana Talele and Mark Benseman**

**Abstract** Wine maturation can take a long time and consumes storage space which can be a drawback while considering commercial aspect of wine making. In the past scientists have carried out experiments on maturing wine quickly using ultrasounds or gamma radiations. This study reports about maturing wine with high electric field at different frequencies applied for a short time duration. The electric field intensity and the frequency of the field along with the exposure time of wine to this field seem to be important parameters that could affect the the treated wine. Results obtained are encouraging and have a potential for commercial interest.

## 1 Introduction

While describing wine, two particularly important factors are colour and taste. Unlike many other variables, there is an insufficient understanding of the basic chemistry to allow full control or even to predict the final colour or taste of wine. This is because the chemical composition of wine has proven to be exceptionally complex, with pigmented molecules continually changing from the moment the grapes are picked, during the mash process, fermentation, storage in the barrel, and during bottle aging. The major components of wine are water and ethanol. Wine ethanol (alcohol) is produced by alcoholic fermentation in which yeasts and other micro-organisms convert glucose or other sugar to ethanol. Wine making, however, takes time for fermenting and for aging. Fermenting produces alcohol from

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the sugar, and produces flavour and taste from protein and other food components and/or their derivatives; however, it is aging which improves and perfects the wine properties that make wine pleasurable and increase its value [1]. In the first instance as wine ages, alcohols react with acids to produce esters. Simply, the wine becomes less acid as the alcohols reacts with the organic acids to produce a range of fragrant compounds. Red wines mellow as the bitter strong tannin molecules transform to some volatile molecules that contribute to wines aroma. These chemical reactions take time and can be a lengthy process as wine is stored in oak barrels in order to get a small and steady supply of oxygen [2].

In the past scientists have carried out experiments on maturing wine quickly using ultrasounds or gamma radiations [3, 4]. A study from China [5] reported that aging of wine can occur when an electric field was applied to it. Their study recommended an exposure time of 3 min at 600 V/cm, 3 kHz AC electric field. The equipment set reported in [5] is now being manufactured and deployed in China [6]. The objective of the first part of the work reported here was to construct a machine and verify the effects reported in [5]. The second part was to assess the impact of excitation frequency on the changes in the wine, and on the electronic complexity of the equipment. Neither the reason for the cited operating frequency, nor the sensitivity of the effect to it, have been reported in the literature to date.

## 2 Design

The principle behind this is simply to pass a high voltage AC electric field through the wine. Figure 1 shows a schematic diagram of the mechanics behind the machine. For electric fields to pass though the wine only a power and ground plate are required. Basically, the wine can be poured into a separation funnel at the top which then flows through glass tubes placed between two aluminum plates. It can then be collected in a beaker at the bottom. A frequency generator is used to create a small voltage, where the amplitude and frequency may be altered. This is then passed through a power amplifier with rail voltages of $\pm$ 55 $V$ thus resulting in a maximum peak to peak voltage of around 108 V (allowing for losses). To increase this voltage to the requred amount a step up transformer is utilised. The output from the transformer was connected to the Aluminum plates thus creating an electrical field.

### 2.1 Frame

The frame was constructed as shown in Fig. 2.

Firstly the pieces of 4 $\times$ 2 and MDF were cut to size. The 4 $\times$ 2s were then slotted to allow for the aluminum plates. This was done extremely accurately using the digital display on the mills. The glass tubing had an O.D. of 7 mm. The gap

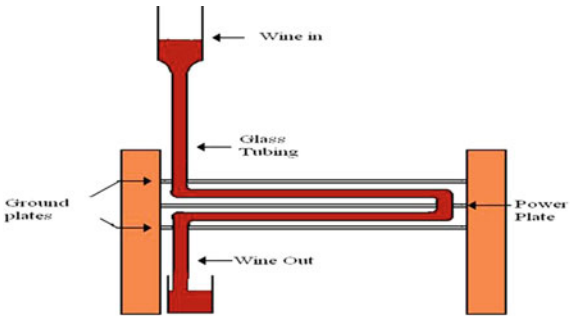


**Fig. 1** Mechanics of the wine aging machine

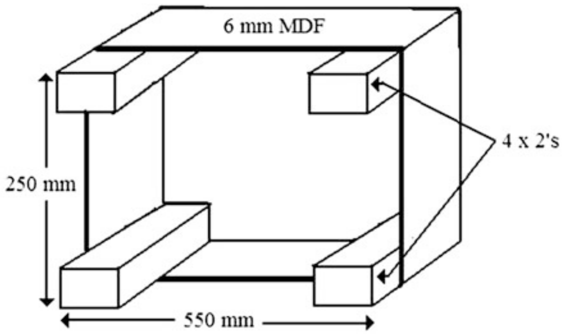


**Fig. 2** The frame

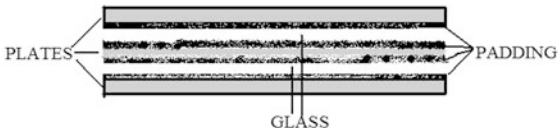


**Fig. 3** Cross section of the plate layout

between each aluminum plate was exactly 7.5 mm. This was done to allow a small gap so that padding could be used to protect the glass. A cross section of the plate layout is shown in Fig. 3.

## *2.2 Glass Work*

To do the glass work was a matter of deciding what would be a practical and efficient way of applying the field to the wine. From research done by Xin An Zeng et al in 2008 [5] it was seen that a time of approximately 3 min of exposure to the electric field was ideal. In order to replicate this; testing was done to time how long wine would take to flow through a glass tube. Three different diameters were tested and to use 4 mm inside diameter tubing. This meant that 18 metres of tubing would take approximately 47.6 s to pass through (not allowing for frictional losses). To work out the physical size that the plates, one side was set to a fixed length

**Fig. 4** The finished glass work

of 500 mm and the other was calculated using the equation below for Length=(((total ml)/(volume per metre))*length of glass)/(number of turns*2) = (((250 ml)/(50 ml))*1.5)/(19*2) = 0.197 m = 200 mm

The finished glass work is as shown in Fig. 4.

## *2.3 Electric Field Generator*

The electronics involved in powering the high voltage plates were a frequency generator, power amplifier and a high voltage transformer. The generator-amplifier combination supported a frequency range from about 10 Hz to 195 kHz. The amplifier was a MOSFET-based class AB amplifier capable of delivering around +/-50 V peak with peak current of about 10A and a nominal gain of about 30 dB. The amplifier was tested using a frequency generator and oscilloscope. It was found that an input voltage of 1.37 VRMS resulted in a Vp-p of 108 V. This voltage needed increasing approximately 30 times to achieve field strengths of up to 2000 V/cm across the plates. The transformer with turns ratio 1:34 was wound. When the secondary was wound, mila paper had to be inserted every 300 turns to prevent high voltage break down occurring. The capabilities of the transformer were an output from 50 to over 2000 Vp. The gap between the plates was 7.5 mm. This means that the field strength ranged from 66.7 to 2666 Vp/cm.

## *2.4 Flow Control*

To control the flow of the wine a peristaltic pump was used. The reason for using a peristaltic pump is that the only contact the wine has is with the tubing. Another


**Fig. 5** The fully functional wine maturing machine

reason for the peristaltic pump is that this gives very precisely controlled flow rates. This translates to good control of exposure time.

The fully functional wine maturing machine is shown in Fig. 5.

## 3 Testing and Results

Upon tasting the wine after it had gone through the process it was obvious that a change had occurred in the taste. For 'quantitative' test on the effects of the electric field a selection of students and lecturers were used to test a 2009 merlot. A small sample of 125 ml's was run through the machine at different field strengths for 2 min and 18 s. These were compared to the original wine which had an average score of 5 on a scale of 1–10 where 10 is the best. The results although very subjective did show an agreement about which wine tasted best and are showing in Fig. 6.

This subjective testing may seem a little arbitrary, but the impact of the processing is so enormous that it does not take a trained palate to get a crude assessment of the extent of changes in the wine.

We were alo invited by national televison for a coverage. To get a professional opinion grills magazine wine editor Keith Stewart was brought in. He definitely thought there was an improvement in the drinkability of the wine. His words were, "It tastes like a freshly opened bottle of wine but it has some really mature characters in there" [7].

A small amount of taste testing was done in regard to frequency with the results showing that 3 kHz tasted better than the 20 kHz in a double blind tasting. It is not important that the 3 kHz tasted better but more that this shows that frequency does have an effect. This is significant and has not previously been mentioned in the literature.

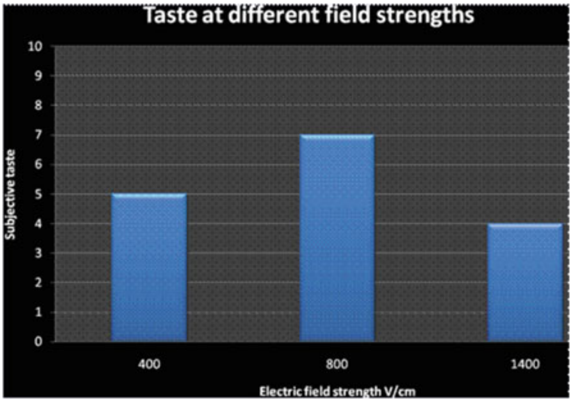


**Fig. 6** The results

Another point of interest was that the effect appeared to alter for different wines. The wines that seem to have been affected most were pinot noir and merlot. The cabernet was not so greatly affected. A possible cause behind this could be that in general pinot noir and merlot both have aging times of 2–8 years, whereas cabernet sauvignon takes between 4 and 20 years. The ability for a wine to be aged depends on both the acidity and the phenolics that are present in the wine [8]. Tannins are a type of Phenolic. Wines with high tannins will tend to age better than wines without. Wines with a low acidity such as pinot noir will also tend to age more readily [8].

## 4 Future Work

It still needs to be established as to how well is this aging effect retained as the treated wine is bottled and kept on shelf for several months. Analytical testing to figure out the several changes in the chemical constituents at the start and through the bottled period needs to be done.

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# A Computational Intelligence Approach for Forecasting Telecommunications Time Series

**Paris A. Mastorocostas and Constantinos S. Hilas**

**Abstract** In this work a computational intelligence-based approach is proposed for forecasting outgoing telephone calls in a University Campus. A modified Takagi–Sugeno-Kang fuzzy neural system is presented, where the consequent parts of the fuzzy rules are neural networks with internal recurrence, thus introducing dynamics to the overall system. The proposed model, entitled Locally Recurrent Neurofuzzy Forecasting System (LR-NFFS), is compared to well-established forecasting models, where its particular characteristics are highlighted.

## 1 Introduction

The primary motive for telecommunications service provision is profit. This is why charging and billing are vital in telecommunications business. However the aim of the telecommunications managers is not only the maximization of profit but also the reduction of unnecessary cost.

Making use of the historical data, the telecommunications managers may predict the future demand by creating a reasonably accurate forecast of the call volume. The planning ventures, the infrastructure investment and the call volume strategy are the topics for which managerial decisions depend on the forecast. Forecasting is an integral input into such network traffic management, infrastructure optimization and planning, and the scenario planning process. To successfully manage their business, carriers must rely on data to monitor, analyse and optimize their systems in order to map future trends and usage patterns.

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In the case of large organizations, who are actually the customers of the telecommunications carriers, the managerial policy has to be based on the allotment of telephony services to employees, primarily for use in normal business activities and secondary, on a limited basis, for personal use. With the primary mission of providing cost effective voice communication services, managers must find and capitalize on opportunities for controlling telecommunications costs.

A case of such an organization is a University Campus with more than 6,000 employees and 70,000 students, and an extended telecommunications infrastructure with more than 5,500 telephones. Due to the continuous increase of the faculty members and staff, new telephone numbers are added daily, and an increasing demand for outgoing trunks exists. It is obvious that the changes in call volume are vital to the planning of future installations.

The University holds an extended database, made by the call detail records (CDR) of the private branch exchange (PBX), which includes information such as the call origin, the area code and exchange, and the duration of each telephone call. The database is mainly used to determine the total number, as well as the number of the national, the international and the mobile calls per employee per month. A forecast of future call volume will help University managers to take financial decisions and negotiate the tariffs with national service providers. It is noticed that the call classification, into different categories, reveals certain and different patterns between destinations. Calls to national destinations comprise almost half the volume of the total outgoing calls from the campus.

In the past, the forecasting ability of several well established statistical methods on the University's call traffic have been studied [1]. Linear models are also suggested for forecasting trends in telecommunications data by the international telecommunication union (ITU) Recommendation E.507. A recent discussion on the issue may be found in [2]. We believe that it would be very interesting to apply non-linear computational intelligence approaches on same kind of data, in order to test their ability to forecast the outgoing call volume of a telecommunications network.

For this reason we propose a locally recurrent neurofuzzy forecasting system (LR-NFFS) and compare its performance with familiar forecasting approaches; namely a series of seasonally adjusted linear extrapolation methods, Exponential Smoothing Methods and the SARIMA method. All comparisons are performed on real world data.

The rest of the paper is organized as follows: in Sect. 2, a brief presentation of the classical forecasting methods that are compared with our proposed model is given. In Sect. 3, the Locally Recurrent NeuroFuzzy Forecasting System is presented. The training algorithm used to train the model is described in Sect. 4. In Sect. 5 the data used in the paper and the outcome of the comparison of the methods are presented. Last, in Sect. 6 conclusions are drawn.

## 2 Some Classical Forecasting Methods

In this section the time series analysis methods that were used to compare and evaluate our proposed LR-NFFS method are briefly presented.

First a simple method to forecast future values of the time series was used. This method, which is known as Na Forecast 1 (NF1) [3], takes the most recent observation as a forecast for the next time interval. After that, another simple method which takes into account the seasonal factors was applied. The method is somewhat different from the Na Forecast 2 Method (NF2), which is also described in [3].

The procedure, of NF2, is to remove seasonality from the original data in order to obtain seasonally adjusted series. Once the seasonality has been removed, one can use the most recent seasonally adjusted value of the series as a forecast for the next seasonally adjusted value. In contrast with the above procedure, we used the trend-cycle component to forecast the future values of the series by means of linear extrapolation. Then, the projected trend-cycle component was adjusted with the use of the identified seasonal factors [1]. Thus, when multiplicative seasonality is assumed we have the LESA-M while in the case of additive seasonality we have the LESA-ADD.

A familiar group of time series analysis methods are the exponential smoothing methods. In exponential smoothing a particular observation of the time series is expressed as a weighted sum of the previous observations. The weights for the previous data values are terms of a geometric series and get smaller as the observations move further into the past. Simple Exponential Smoothing (SES) applies to processes without trend. In order to accommodate linear trend, Holt modified the simple exponential smoothing model [4].

Winters extended Holt's method in order to cope with seasonal data [5]. Multiplicative seasonal models (Winters MS) as well as additive seasonal models (Winters AS) exist.

Although linear trend represents an improvement on simple exponential smoothing, it cannot cope with more complex types of trend. Other modifications of SES can be applied to time series that exhibit dampened trend. A dampened trend refers to a regression component for the trend in the updating equation which is expressed by means of a dampening factor. As before an exponential smoothing model with dampened trend and additive seasonality (DAMP AS) and its multiplicative seasonality counterpart (DAMP MS) exists. One may also try to fit a dampened trend model on time series with no seasonality (DAMP NoS).

For a comprehensive review on exponential smoothing methods, readers are referred to [6]. The above are popular in industry due to their simplicity and the accuracy that can be obtained with minimal effort in model identification.

Another familiar method to analyze stationary univariate time series data was developed by G. Box and G. Jenkins [7]. The method, which is called Auto Regressive Integrated Moving Average method (ARIMA), presumes weak stationarity, equally spaced intervals or observations, and at least 30–50 observations. The seasonal ARIMA (SARIMA) also exists.

After fitting a time series model, one can evaluate it with forecast fit measures. The data set is usually divided into a "training" set and a "validation" or "holdout" set. The training set is used to estimate any parameters and to initialize the method. Forecasts are made for the validation set which was not used in the model fitting. The observer may subtract the forecast value from the corresponding measured value of the validation set data and obtain a measure of error or bias. This is a genuine measure of the forecasting ability of the model.

To evaluate the amount of forecast error, one may employ the mean absolute error (MAE), the mean squared error (MSE), the sum of squared errors (SSE) for the whole forecast, and the root mean squared error (RMSE). The aforementioned statistics measure accuracy, but the sizes depend on the scale of data. So they do not facilitate comparisons between methods, especially across different time series and for different time intervals. A commonly used statistic that deals with this problem is the mean absolute percentage error (MAPE) [3].

Another statistic, which allows a relative comparison of formal methods with na approaches and also squares the errors involved so that large errors are given much more weight than small errors, is Theil's U-statistic:

$$U = \sqrt{\frac{\sum_{t=1}^{n-1} \left(\mathrm{FPE}_{t+1} - \mathrm{APE}_{t+1}\right)^2}{\sum_{t=1}^{n-1} \left(\mathrm{APE}_{t+1}\right)^2}}$$

where $\mathrm{FPE}_{t+1} = \frac{F_{t+1} - X_t}{X_t}$ is the forecast relative error, and $\mathrm{APE}_{t+1} = \frac{X_{t+1} - X_t}{X_t}$ is the actual relative error, [3].

## 3 Locally Recurrent Neurofuzzy Forecasting System (LR-NFFS)

The suggested LR-NFFS, for the case of an $m$-input–single-output system, comprises Takagi–Sugeno-Kang [8] rules in the form

$$\begin{aligned} &\text{IF } u_1(k) \text{ is } A_1 \text{ AND } u_2(k) \text{ is } A_2 \text{ AND } \ldots \\ &\text{AND } u_m(k) \text{ is } A_m \ \text{ THEN } g(k) = g(\mathbf{u}(k)) \end{aligned} \tag{1}$$

where $\mathbf{u}(k)$ is the input vector. The rule output $g(\mathbf{u}(k))$ is implemented by a recurrent neural network 1-$H$-1, having a linear input layer while the hidden and output layers consist of neurons with internal feedback [9]. It can be seen as a simplified version of the Dynamic Fuzzy Neural Network [10], having a considerably reduced complexity. The consequent part of the rules is depicted in Fig. 1.

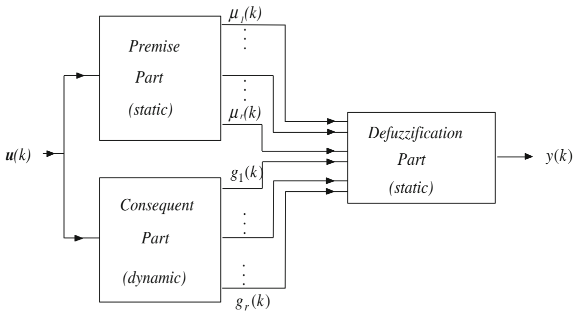


**Fig. 1** General representation of the LR-NFFS

In particular, the LR-NFFS has the following structural characteristics:The premise and defuzzification parts are static, described by

$$\mu_l(k) = f_\mu(z(k);\ \mathbf{m}_l(k), \sigma_l(k)) \tag{2}$$

$$y(k) = f_y(\mu_1(k), \ldots, \mu_r(k), g_1(k), \ldots, g_r(k)) \tag{3}$$

where $r$ is the number of rules, $\mu_l(k)$ is the degree of fulfilment of a rule and $\mathbf{m}_l(k),\ \sigma_l(k)$ its premise part parameters. The degree of fulfilment is the algebraic product of the corresponding membership functions and the weighted average defuzzification method is the one employed in this paper, as given below:

$$y(k) = \frac{\sum_{l=1}^{r} \mu_l(k) \cdot g_l(k)}{\sum_{l=1}^{r} \mu_l(k)} \tag{4}$$

The degree of fulfilment of the *l-th* rule is given by

$$\mu_l(k) = \prod_{i=1}^{m} \mu_{A_i^l}(u_i(k)) \tag{5}$$

where

$$\mu_{A_i^l}(u_i) = \exp\left\{ -\frac{1}{2} \cdot \frac{(u_i - m_i^l)^2}{(\sigma_i^l)^2} \right\} \tag{6}$$

The consequent parts of the fuzzy rules are dynamic. Their structural elements are neurons with local output feedback at the hidden layer and classic neurons at the output layer. Thus, dynamics is introduced to the consequent parts through the feedback connections at the hidden layer. No feedback connections of the rule's total output or connections among neurons of the same layer exist.

The operation of the consequent part of the $l$th fuzzy rule is described by the following set of equations:

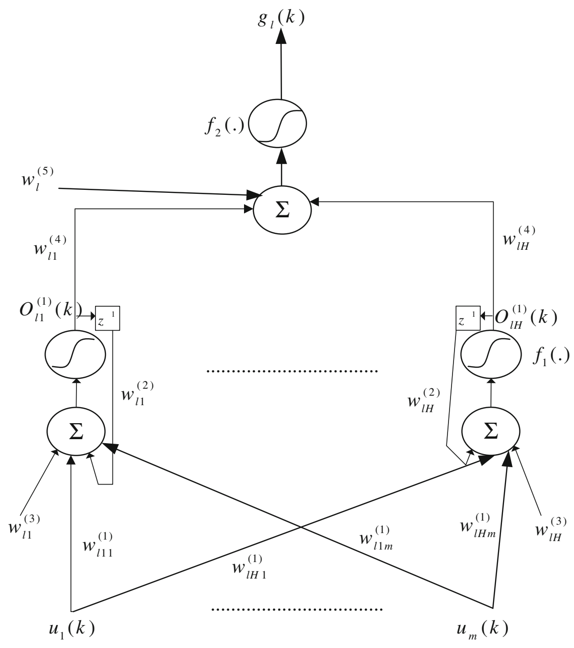

**Fig. 2** Consequent part of the fuzzy rules

$$O_{li}^{(1)}(k) = f_1\left(\sum_{j=1}^{m}\left[w_{lij}^{(1)} \cdot u_j(k)\right] + w_{li}^{(2)} \cdot O_{li}^{(1)}(k-1) + w_{li}^{(3)}\right) \qquad l = 1, \ldots, r,\ i = 1, \ldots, H_n \tag{7}$$

$$g_l(k) = f_2\left(\sum_{j=1}^{H}\left[w_{lj}^{(4)} \cdot O_{lj}^{(1)}(k)\right] + w_l^{(5)}\right) \qquad l = 1, \ldots, r \tag{8}$$

where the following notation is used:

- $f_1$, $f_2$ are the neuron activation functions of the hidden and the output layers, respectively. They are both chosen to be the hyperbolic tangenttanh(.)
- $O_{li}^{(1)}(k)$is the output of the hidden neuron at time $k$
- $g_l(k)$ is the output of the output layer neuron
- $w_{lij}^{(1)}$, $w_{li}^{(2)}$are the synaptic weights at the hidden layer
- $w_{lj}^{(4)}$are the synaptic weights at the output layer
- $w_{li}^{(3)}$, $w_l^{(5)}$are bias terms for hidden neurons and the output neuron, respectively

The general representation of the LR-NFFS is shown in Fig. 1 and the formation of the consequent part of the fuzzy rules is given in Fig. 2

The selection of the aforementioned features is dictated by the following:

- The LR-NFFS preserves the local learning characteristics of the classic TSK model, since it comprises fuzzily interconnected subsystems, which are locally-recurrent-globally-feedforward neural networks [9]. The rules are not linked with each other in time, neither through external nor internal feedback. They are connected merely via the defuzzification part. The premise part performs the input space partition and the consequent part performs the input–output mapping. Accordingly, each recurrent neural network is capable of tracking the dynamics of the internal states of the unknown system, in the input space's domain that is set by the respective premise part.
- The selection of the particular neuron as structural unit is based on [10], where a more complicated form, nevertheless sharing the same underlying philosophy, was employed. It exhibited improved identification characteristics compared to dynamic elements that have local synapse feedback. Additionally, the local output feedback contributes to the stability of the neuron's response.

## 4 The Training Algorithm

The LR-NFFS is trained by use of the dynamic resilient back-propagation algorithm (D-RPROP) [11], which constitutes a modification of the standard RPROP method [12], applicable to fuzzy models whose consequent parts are recurrent neural networks. Only minor modifications are made, such that the method takes into consideration the special features of the LR-NFFS, requiring calculation of the error gradients for the feedback weights. A brief description of the weight update scheme is given below, followed by the derivation of the error gradients, while a complete analysis of the learning method can be found in [11].

Let us consider a training data set of $k_f$ input–output pairs. The Mean Squared Error is selected as the error measure, where $y_d(k)$ is the desired output:

$$E = \frac{1}{k_f} \cdot \sum_{k=1}^{k_f} [y(k) - y_d(k)]^2 \tag{9}$$

Considering $\frac{\partial E(t)}{\partial w_i}$ and $\frac{\partial E(t-1)}{\partial w_i}$ to be the derivatives of $E$ with respect to a consequent weight $w_i$ at the present and the preceding epochs, respectively, D-RPROP is described in pseudo-code as follows:

(a) For all weights $w_i$ initialize the step sizes $\Delta_i^{(1)} = \Delta_0$

**Repeat**

(b) For all weights $w_i$ compute the error gradient: $\frac{\partial E(t)}{\partial w_i}$

(c) For all weights $w_i$, update step sizes:

C.1

$$\text{if } \frac{\partial E(t)}{\partial w_i} \times \frac{\partial E(t-1)}{\partial w_i} > 0$$
$$\text{then } \Delta_i^{(t)} = \min\left\{\eta^+ \cdot \Delta_i^{(t-1)}, \Delta_{\max}\right\} \tag{10}$$

C.2

$$\text{Else if } \frac{\partial E(t)}{\partial w_i} \times \frac{\partial E(t-1)}{\partial w_i} < 0$$
$$\text{then } \Delta_i^{(t)} = \max\left\{\eta^- \cdot \Delta_i^{(t-1)}, \Delta_{\min}\right\} \tag{11}$$

C.3

$$\textbf{Else } \Delta_i^{(t)} = \Delta_i^{(t-1)} \tag{12}$$

(d) Update weights

$$w_i : \Delta w_i(t) = -\text{sign}\left(\frac{\partial E(t)}{\partial w_i}\right) \cdot \Delta_i^{(t)} \tag{13}$$

**Until convergence**

where the step sizes are bounded by $\Delta_{\min},\ \Delta_{\max}$,. The increase and attenuation factors are set $n^+ \in [1.01, 1.2]$ and $n^- \in [0.75, 0.99]$, respectively.

- Since the output layer of the consequent parts of the fuzzy rules is static, the gradients of the error function with respect to $w_{lj}^{(4)}$ and $w_l^{(5)}$ are derived by use the classic chain rule (standard partial derivatives):

$$\frac{\partial E}{\partial w_{lj}^{(4)}} = \frac{2}{k_f} \cdot \sum_{k=1}^{k_f} \left\{ (y(k) - y_d(k)) \cdot \frac{\mu_l(k) \cdot f_2'(k,l) \cdot O_{lj}^{(1)}(k)}{\sum_{i=1}^{r} \mu_i(k)} \right\} \tag{14a}$$

$$\frac{\partial E}{\partial w_{l}^{(5)}} = \frac{2}{k_f} \cdot \sum_{k=1}^{k_f} \left\{ (y(k) - y_d(k)) \cdot \frac{\mu_l(k) \cdot f_2'(k,l)}{\sum_{i=1}^{r} \mu_i(k)} \right\} \tag{14b}$$

with $f_2'(k,\ l)$ being the derivative of $g_l(k)$, with respect to its arguments.

- The gradients of $E$ with respect to the weights of the hidden layer of the consequent part should be calculated using ordered derivatives [13]. The calculation of the error gradients is based on the use of Lagrange multipliers, as shown below:

$$\frac{\partial^+ E}{\partial w_{lij}^{(1)}} = \sum_{k=1}^{k_f} \lambda_{li}(k) \cdot f_1'(k,l,i) \cdot u_j(k) \tag{15a}$$

$$\frac{\partial^+ E}{\partial w_{li}^{(2)}} = \sum_{k=1}^{k_f} \lambda_{li}(k) \cdot f_1'(k,l,i) \cdot O_{li}^{(1)}(k-1) \tag{15b}$$

$$\frac{\partial^+ E}{\partial w_{li}^{(3)}} = \sum_{k=1}^{k_f} \lambda_{li}(k) \cdot f_1'(k,l,i) \tag{15c}$$

$$\begin{aligned} \lambda_{li}(k) &= \lambda_{li}(k+1) \cdot f_1'(k+1,l,i) \cdot w_{li}^{(2)} + \\ &+ \frac{2}{k_f} \cdot \sum_{k=1}^{k_f} \left\{ (y(k) - y_d(k)) \cdot \frac{\mu_l(k) \cdot f_2'(k,l) \cdot w_{li}^{(4)}}{\sum_{i=1}^{r} \mu_i(k)} \right\} \end{aligned} \tag{16}$$

$$\lambda_{li}(k_f) = \frac{2}{k_f} \cdot \sum_{k=1}^{k_f} \left\{ (y(k_f) - y_d(k_f)) \cdot \frac{\mu_l(k_f) \cdot f_2'(k_f,l) \cdot w_{li}^{(4)}}{\sum_{i=1}^{r} \mu_i(k_f)} \right\} \tag{17}$$

where $f_1'(k,l,i)$ is the derivative of $O_{li}^{(1)}(k)$ with respect to its arguments. Equations (16) are backward difference equations that can be solved for $k = k_f - 1, \ldots, 1$ using the boundary condition in (17).

## 5 Data Presentation and Method Comparison

The data in hand cover a period of 10 years, January 1998 to December 2007, and are the monthly outgoing calls to national destinations originating form the PABX of a large organization. National calls are analyzed because they comprise almost the half of the total outgoing calls of the organization.

Due to the variation of days belonging in different months, i.e. February has 28 while January has 31 days, all data have been normalized according to:

$$W_t = X_t \cdot \frac{365.25/12}{\text{no of days in month t}} \tag{18}$$

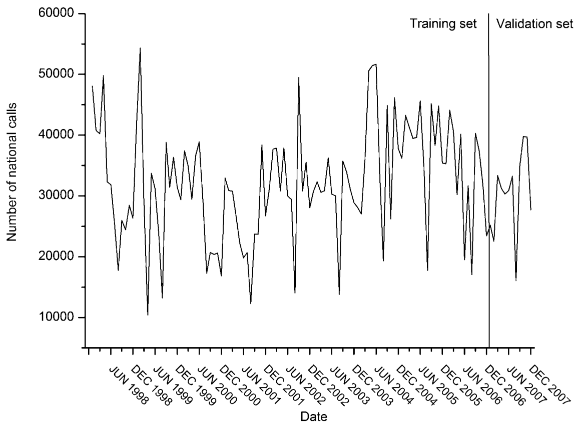


**Fig. 3** Monthly number of outgoing calls to national destinations

The data set was divided into two sets. The training set, which was used to estimate the parameters associated with each method, and the validation set, which was used for the evaluation of the forecasts. The training set was chosen to be 9 years (108 months) long and the validation set 1 year (12 months) long.

From the visual observation of the series (Fig. 3) a distinct seasonal pattern is noticeable which is made prevalent from the minimum that occurs in August.

The parameters, which were estimated during the fitting procedure, were used to forecast future values of each series. Since the validation set was not used in the model fitting, these forecasts are genuine forecasts, and can be used to evaluate the forecasting ability of each model. The forecasting accuracy can be evaluated by means of the accuracy measures mentioned in Sect. 2.

The fuzzy model has a single input, the number of the outgoing calls of the previous month, in order to investigate whether the model is able to discover the temporal dependencies of this time-series through its recurrent structure alone. After training, the resulting LR-NFFS consists of 3 fuzzy rules, with 6 neurons in the hidden layer of each rule. The membership functions of the fuzzy sets of the input are uniformly distributed along the input space, exhibiting 0.65° of overlapping. The training process is carried out in a parallel mode and the learning parameters of D-RPROP are hosted in Table 1.

For each method, three holdout accuracy measures were computed. These are the RMSE, the MAPE, and the Theil's U-statistic. The smaller value of each statistic indicates the better fit of the method to the observed data. The results for each of the twelve models are presented in Table 2; bold numbers indicate best fit.

To further exploit the forecasting ability of the methods, plots of the observed values for the validation set with the best fit model (LR-NFFS) and the second best fit model (SARIMA) are drawn (Fig. 4). Also 95 % confidence intervals for the forecasts are presented in the plots. These were estimated during the SARIMA fitting process and are denoted as Upper Confidence Level (UCL) and Lower Confidence Level (LCL).

**Table 1** D-RPROP Learning Parameters

| $n^+$ | $n^-$ | $\Delta_0$ | Δmin | Δmax | Epochs |
|---|---|---|---|---|---|
| 1.01 | 0.99 | 0.02 | 0.0001 | 0.5 | 1000 |

**Table 2** Comparative Analysis (testing data set)

| Model | RMSE | MAPE | Theil's U |
|---|---|---|---|
| LR-NFFS | **5124** | 15.072 | **0.381** |
| NF1 | 8914 | 23.846 | 1.000 |
| LESA-M | 8570 | 24.391 | 0.722 |
| LESA-ADD | 8418 | 24.798 | 0.713 |
| SES | 6748 | 20.943 | 0.515 |
| Holt's Linear | 6753 | 27.552 | 0.506 |
| Winter's MS | 7120 | 18.415 | 0.578 |
| Winter's AS | 6903 | 17.741 | 0.553 |
| Damped NoS | 6862 | 21.422 | 0.512 |
| Dumped MS | 7080 | 19.072 | 0.573 |
| Dumped AS | 7194 | 19.838 | 0.571 |
| SARIMA | 6064 | **9.535** | 0.513 |

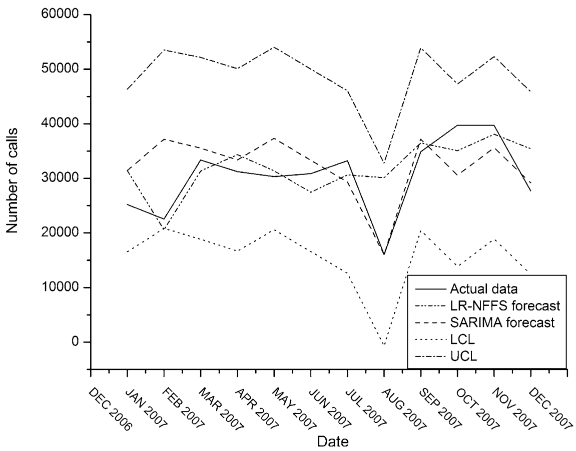


**Fig. 4** Forecast fit for National calls with 95 % CI. A comparison of LR-NFFS with the second best fit method (SARIMA) is also displayed

Visual observation of the plot (Fig. 4) reveals the differences between the two best-fit models. LR-NFFS gives better forecast, as it follows the evolution of the series more closely, identifies the first local minimum that appears in February, but misses the significance of the minimum in August. It should, also, be stressed that both forecasts fit well within the 95 % confidence intervals and would bear scrutiny with even tighter confidence.

## 6 Conclusion

A novel locally recurrent fuzzy forecasting system, with a relatively simple structure, has been proposed. The LR-NFFS is based on the classic TSK fuzzy model, with the consequent parts of the fuzzy rules consisting of small recurrent neural networks.

The ability of the proposed model to forecast telecommunications data has been evaluated by applying it on real world data. Additionally, a comparative analysis with a series of well-established forecasting models has been conducted, highlighting the efficiency of the proposed system.

We plan to extend our study on more real world telecom datasets as our first experiments have given promising results.

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# Designing a Networking Tool for Automatic Domain Zone Updating

**Charalambos Alatas and Constantinos S. Hilas**

**Abstract** The Domain Name System can be considered as one of the most important services in the core of the Internet. It translates names that are meaningful to humans into numerical IP addresses. The most commonly used DNS server on the Internet is BIND. In this paper we present the specifications and the design of a client—server application that aims to cope with the problem of exchanging BIND information between a primary DNS Server and its secondary servers in large and/or geographically dispersed networks.

## 1 Introduction

The domain name system (DNS) is a hierarchical naming system for computers, services, or any resource that is connected to the Internet. It associates various kind of information with domain names that are assigned to appliances and/or services. Its main contribution to the Internet semantics is that it translates humanly meaningful domain names to the numerical identifiers (IP addresses) that are associated with networking equipment addressing. The DNS, also, makes it possible to assign names to groups of Internet users, independent of their physical location. This is the feature that permits Internet contact information (like hyperlinks and e-mail addresses) to remain consistent and constant even if the current Internet routing arrangements change or the participant uses a mobile device [1].

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The DNS is maintained by a distributed database system, which uses the client–server model. The nodes of this database are the name servers. This is the largest and most distributed database currently on the planet, with the amazing feature of being updated and administered by millions of network administrators worldwide. DNS allows local administration of the segments on the overall database. Each domain or sub-domain has one or more authoritative DNS servers that publish information about that domain and any domains subordinate to it. The top of the hierarchy is served by the root nameservers, i.e. the servers that should be queried when looking up (resolving) a top-level domain name (TLD). Thus, data in each segment of the network (actually in each segment of the database) are available across the entire network through a client–server scheme consisting of name servers and resolvers.

The most commonly used DNS server on the Internet, especially on Unix-like systems, is BIND (*Berkeley Internet Name Domain* or "named"). The BIND server allows a standard way of naming the different types of objects and resources that exist in distributed network environments, and provides operations for storing and retrieving information about these objects. BIND servers collectively manage a hierarchical name space that is partitioned into domains reflecting administrative entities [2].

Despite its wide use, BIND has been the target of some criticism as regards three of its features: configuration procedure, zone support and security. When configuring BIND one should always include all higher level domain labels in each domain name. BIND does not offer a store and retrieve mechanism for zone data, especially when communicating with secondary name servers. Last, BIND like many other popular Internet services has got no embedded security, though current implementations take care of this problem.

In this paper we present the specifications and the design of a client–server application that cooperates with Bind and adds automatic zone synchronization. We have named this application DnsCluster because it was primarily designed to cope with the problem of exchanging BIND information between a primary DNS Server and its secondary servers in large networks. DnsCluster may actually be used as a plugin tool that cooperates with Bind and delivers a rock solid, load balancing, fault tolerant solution for serving the Domain Name System.

The application was conceived a few years ago when we were confronted with the problem of two or more Web Hosting Servers that were demanding an all-in-one solution for managing their domains. The main concept was the development of an application that would be able to synchronize zones between different installations of the nameserver daemon.

DnsCluster can be used from the smallest installation to the big enterprise DNS clustering system. It complies with the RCF-1591 and does not imply any new limitations. It is no exaggeration to state that the BIND nameserver is a great daemon for serving the Domain Name System, a statement supported by its widespread use. DnsCluster respects all of its features and simply adds an extra one.

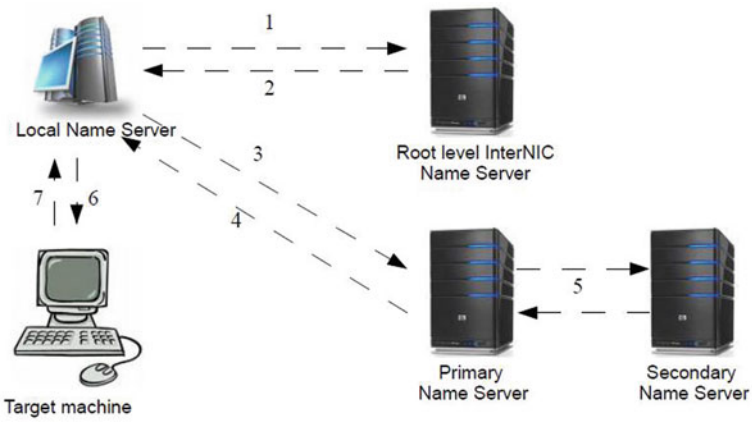



**Fig. 1** Basic DNS operation

The present paper proceeds as follows. In the next chapter the DNS operation is briefly discussed along with several applications that are designed for exchanging domain zone information between primary and secondary nameservers. In "Service and Information Security Improvement by Collaborative Business Process Management" the features and the development of the DnsCluster application are discussed. Three common DNS server cluster configurations are presented in "Software Design for Dynamic Stitching of Multi-Spectral Images of Field Crops" and the role of DnsCluster within them is presented. In the last chapter conclusions are drawn.

## 2 DNS Operation and Commercial Products

### *2.1 How DNS works*

The basic operation of DNS that allows a domain name to direct customers to a web site is depicted in Fig. 1. The figure describes basic steps that are followed when a web browser attempts to view pages on a web site.

The DNS system needs to determine which primary name server contains the requested domain name. So, the following procedure is followed.

1. The local name server contacts the root domain name server maintained by several Internet root server authorities. The local name server has already been contacted by the web browser, which is not shown in the figure. One may assume it is hosted in the same machine.
2. The root domain name server returns the IP address of the primary name server responsible for the requested domain name.

3. The local name server contacts the primary name server.
4. The primary name server holds the IP address information for the domain name in a database and satisfies the request from the local name server.
5. If the primary name server is unavailable, the local name server contacts the secondary name server that satisfies the request from the local name server. The local name server replies to the Web browser with the IP address for the requested domain name. It is common to contact directly the secondary name server and not the primary.
6. Using this IP address, the web browser contacts the web server.
7. Last, the web server (target machine) sends the web page to the web browser.

In cases of large domains, one may maintain several secondary name servers. And to make things more complex, the secondary name servers may be geographically dispersed. DnsCluster application is responsible to always keep the secondary name servers updated with information served by the primary name server.

## 2.2 Prior Work and Commercial Solutions

DnsCluster is not the only solution around. Several applications are available that try to cope with the challenge.

WHM/CPanel has developed a plugin, namely the cPanel DNS Only, that works quite similar to the way that the DnsCluster does. The major difference is that the WHM/CPanel's solution requires a dedicated and fresh installed server system to be installed on and may only cooperate with other WHM/CPanel installations [3]. On the contrary, we are proposing a solution than can cooperate in virtually any hosting control panel environment using BIND nameserver.

Microsoft Corporation provides a redundant system that relies on Active Directory Services. Using a Primary Domain controller and a Secondary/Slave Domain Controller one can easily build a fault tolerant system that replicates every zone from the Primary Domain Controller to the Slave Domain Controller. The drawback of Microsoft's approach is that it only works when these two systems are in the same subnet. Moreover, it can be used with only two nameservers and in simple network topologies [4].

As already mentioned the most popular DNS server is the BIND. Every bind nameserver can be setup to query another nameserver and cache the results given. This solution provides load balancing but no fault tolerance features are available because if the primary nameserver fails then the other nameservers are not able to reach and query each other. Also, cache is only stored in memory which renders it unusable in case of a secondary server reboot. Bind cannot handle zones synchronization between servers and there is no plug-in doing so. Bind can only transfer zone data and keep them up-to-date but every zone must be explicitly declared in the *named.conf* file. So there must be a mechanism for synchronizing the zone records in the *named.conf* file because bind is not doing this. DnsCluster handles exactly this situation with safety and reliability without adding any extra limitations to bind.

# 3 Description of the DnsCluster Application

## 3.1 Basic Operations

The DnsCluster implementation follows the classic client–server paradigm. Thus, it consists of two distinct programs. The DnsCluster is the server side application/daemon and the DnsNode which runs on the client side (and is also a daemon). The concept is to monitor for zone changes (added or deleted) and serve these changes to the DnsNode clients.

When DnsCluster starts running, it reads the zones file and uses the zones found to build a set of active zones. Then it starts building a log. This log contains and describes every change that DnsCluster will find in the *named.conf* file. DnsCluster will serve these changes to all DnsNode instances. This is done by means of appropriate commands executed at the DnsNode side.

On the client's site, DnsNode polls, in preset time intervals, a DnsCluster installation (or more) for changes. DnsNode accepts the commands an associated DnsCluster sends to it and executes them one by one to reproduce the zones file.

The server side of the program keeps track of every client connected to it. Thus, the next time a DnsNode daemon will communicate, DnsCluster will send only the new log commands (*update*).

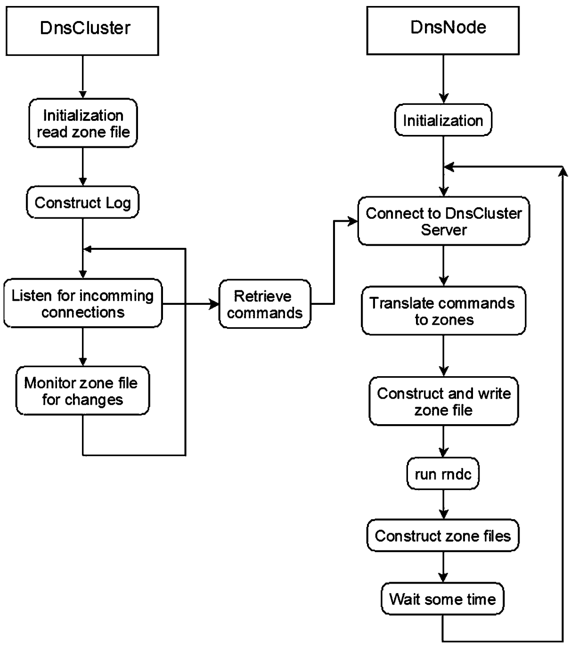
The application's operation is very simple. It complies with all the standards that a POSIX compliant system needs to work as a daemon [5]. DnsCluster has minimum memory footprint and requests less that a second of CPU time per day. It has also several security features embedded in its design.

## 3.2 A Closer Look to the Program

DnsCluster periodically monitors the BIND nameserver for changes and when a change occurs the program logs it. DnsNode, the client side daemon, communicates with the server, DnsCluster, and queries it for newly added or deleted zones records (Fig. 2).

The communication takes place via a secure SSL channel. DnsCluster must accept the Certification Authority (CA) that provided DnsNode's certificate. Otherwise communication stops. Adding to SSL channels, DnsNode validates all received data by means of SHA1 Hashes. Traffic burden is not an issue since DnsCluster can transfer up to 1,000 domain zones with as little as 100 kb of data.

**Fig. 2** Diagram of basic DnsCluster and DnsNode functions and communication




Also, thanks to its feature of keeping account of changes, DnsCluster generates even less traffic in the internet, by means of incremental updates.

DnsNode also notifies the Bind nameserver for changes. The *rndc* (remote name daemon control) provided with every installation of BIND nameserver is used to notify BIND that changes are present in the zones file. *Rndc* is a tool that controls Bind nameserver and it can do some very useful things like triggering *named.conf* to re-read the configuration file and reload all zones from scratch or refresh a particular zone from its master nameserver.

## *3.3 Important Features*

DnsCluster instances communicate with each other only through SSL channels. DnsCluster and DnsNode authenticate each other by means of the machine's IP address and appropriate digital certificates. If an invalid certificate is presented to the application then communication is canceled and terminated.

DnsCluster works seamlessly and transparently for very long periods, just listening for changes. When a change in the zones file happens then the distribution mechanism is triggered to update all the DnsNode clients with the new changes. Changes are propagated throughout the cluster in a few minutes.

Both may run for very long periods without crunching the resources of the host machine. They also provide great stability with a trustworthy memory management. DnsCluster consumes 6 MBytes of memory to operate and DnsNode consumes at most 3 MBytes to serve as much as 1,000 domain zones. These numbers confirm that DnsCluster can run in very small installations providing great performance and a rock solid stability.

DnsCluster incorporates an incremental zone logging system so every DnsNode gets only the new data. Every time a host authenticates itself in order to receive the new zone records or to delete old ones, the logging system records the last command sent to the client. So, the next time that the same client connects, DnsCluster will send only the changes from the previous state. The application also incorporates mechanisms to track client reboots in order to resubmit the entire zone list and thus avoid having consistency problems.

### *3.4 Security Issues*

There are no known security issues concerning DnsCluster and DnsNode. ACE Wrappers, [6], is used for the communication which provides great stability in the client–server communication.

Three authentication methods are used to authenticate each connected client. First, every client must have a security certificate issued by a CA known and accepted by the DnsCluster application. Because the communication is two way, SSL encrypted DnsCluster must also provide an SSL certificate from a known and accepted CA to the DnsNode. Second, DnsCluster must validate the IP address of the connected client against the list of known members of the cluster. If this is not the case then the connection is terminated. Third, DnsCluster authenticates the client via a digital signature. Every client must have its own. Every IP address in the cluster (i.e. every machine) is coupled with its distinct signature.

If any of these security checks fail then the communication is terminated immediately. One may consider this validation procedure extreme but it is not limiting the functionality of the application and it is offering a level of security that we consider more than adequate.

Running the service with root privileges is also not needed. DnsCluster may run with *named* or another user's *uid*. Also, DnsNode does not need root rights but it needs to be run with at least named *uid* so it can gain access to the *rndc* binary.

### *3.5 DnsCluster Development Process*

The DnsCluster application was totally developed with open source/free software tools. The Eclipse platform with CDT was used as the editor to develop the application. Eclipse has a powerful interface to develop applications using most

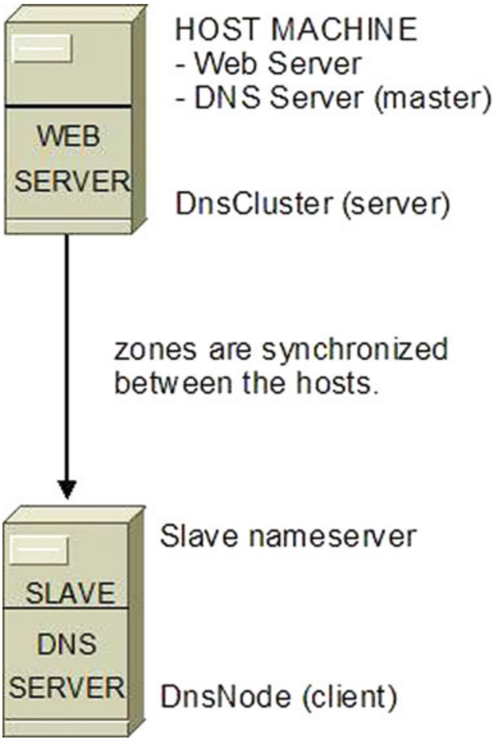



**Fig. 3** A simple primary—secondary DNS topology

programming languages [7]. The communication interface was developed with ACE Wrappers [6]. ACE makes socket programming a simple and straightforward procedure. Moreover, ACE supports SSL which is a very good reason to use the Wrappers. The application was compiled with the free GNU/Gcc compiler with static libraries to make deployment a simple procedure. *Valgrind* was used to troubleshoot all the issues concerning memory leakages and problems in the code [8].

## 4 Case Studies

DNS cluster topologies may differ from installation to installation. The simplest installation used in rather small web hosting environments is depicted in Fig. 3.

A host machine, usually the same that hosts the web server, is hosting the master nameserver. The DnsCluster application is installed on the same host. DnsNode is running on the machine that hosts the secondary (slave) nameserver. DnsCluster is responsible for synchronizing zone related information between the primary and the secondary nameserver.

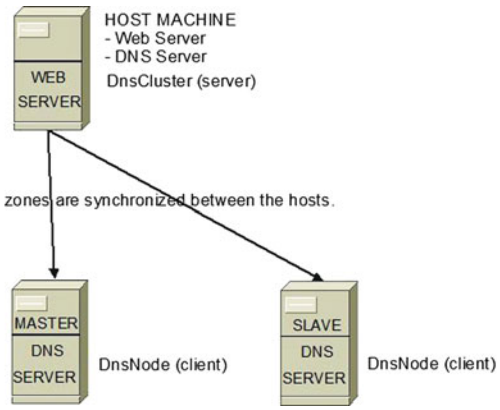



**Fig. 4** A more complex topology (*arrows* show the flow of information between DnsCluster and DnsNode)

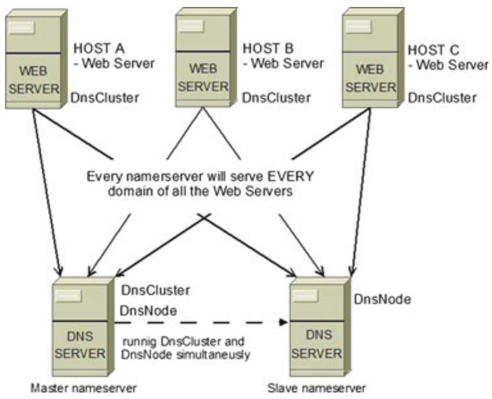



**Fig. 5** A topology with several WEB servers. Each one serves different zones (*arrows* show the flow of zone related information)

In Fig. 4 a more realistic, though more complex, configuration is depicted. Here, the host machine is the web server with a Bind instance that is only responsible to transfer the zones to the DNSnode servers. The DnsCluster and the DnsNode cooperate to transfer zone information to the slave nameserver who is the actual server of domain names to the rest of the network.

The most common web hosting environment is shown in Fig. 5. Here many web servers exist, each serving different domain zones. Usually only two (or three) nameservers are used to serve the zones of all the hosting servers. Web servers synchronize their zones with all the DnsNode servers in the cluster.

DnsNode servers are serving all the zones together. This configuration provides an extra benefit. If the network connection between a web server and a secondary nameserver is lost then this secondary nameserver may learn domain zone changes by querying its primary nameserver (dotted arrow in Fig. 5). Using multiple A records, Heartbeat and other familiar clustering techniques one can achieve maximum fault tolerance and load balancing.

## 5 Conclusions

In this paper a client–server application is proposed and presented that copes with the problem of exchanging BIND information between a primary DNS Server and its secondary servers in large domains. We have named this application DnsCluster. It may be used as a plug-in tool that cooperates with Bind nameserver and delivers a rock solid, load balancing, and fault tolerant solution for serving the Domain Name System.

DnsCluster has been designed and developed to be used in diverse Web Hosting environments and may serve different hosting control panels simultaneously. It was, also, developed with free and open source software tools. It has been tested in real networks and has proved to be a stable and lightweight application. Extra features are added daily and statistics are collected in order to help us enhance its features.

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# Open Source Software Development: Exploring Research Perspectives

**Preet Kanwal, Anu Gupta and Ravinder Kumar Singla**

**Abstract** Fundamentally speaking, Open Source Software (OSS) development has generated considerable interest following the success of projects like Internet, WWW and Linux. The principle steering this form of development is that the developers, through source code sharing, use a cooperative development model of rigorous peer review and parallel debugging leading to rapid innovative development and maintenance of projects. The phenomenon of Free/Libre Open Source Software (FLOSS) has grown within the past decade to revolutionize the ways of creation, distribution, acquisition and use of information systems and services. FLOSS is becoming an increasingly important topic of research for information systems researchers to understand the development process and the tools involved for its success. This paper adopts a general exploratory approach and focuses on the exploring research perspectives in the OSS development in present scenario. It aims to examine the concept behind OSS development, its origins and differences from traditional development approach. A brief literature review regarding various research approaches has been presented. Finally, research perspectives within the present scenario are described in three categories of research areas namely Developers', Metrics and Tools. This work highlights the OSS development research aspects with consideration towards areas which need exploration for consideration and comparison with traditional software engineering concepts.

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## 1 Introduction

The rise of the Internet and the excesses of intellectual property have led to the free and open-source software concept to become an inspirational and powerful force. Internet technology is a unique tool that has irreversibly changed personal and professional communication and information research and made massive, decentralized projects possible. Free-thinking programmers, scientists, designers, engineers and scholars are trying to come up with new ways of creating and sharing knowledge. The emergence of co-operative modes of knowledge production, distribution and utilization including its re-use in creating new products, among members of distributed communities who do not anticipate receiving direct remuneration for their efforts resulted in open source development revolution. The scale and speed of open source development work, the geographical dispersion of the participants and the voluntary nature of the contributors, is historically unprecedented. This approach forms a model that allows for creations of self learning and self-organizing geographically distributed teams which contribute for building applications based on Raymond's Bazaar model [1].

Architecturally, over the years computing has moved from centralized mainframes to distributed personal computers and hand held devices. With the concept of OSS projects, the development process itself and the developer force involved have become distributed.

## 2 OSS Development Phases

Although the concept of OSS rose to the level of being called as a phenomenon of the recent times, yet its basic behaviors have origins in old times. The tradition of code sharing and cooperation in software development is rooted in the origins of the software development process itself. Free sharing and exchange of programs developed by programmers associated either by way of hardware being used or by application requirements, was done even long before the term "Open Source" actually came into being. In fact, by viewing the history of software development, it can be observed that in the beginning of its history there was only "free (libre)" software. The proprietary software originated later on and quickly dominated the software landscape, to the point of being considered as the only possible model of development. Only recently has the software industry has started considering free software as an option again. In recent years, the widespread diffusion of internet has led to the expansion of both the scale and formalization of the activity. The discussion below highlights the distinct phases and significant events of software development approaches.

## 2.1 Phase 1 (1950s–late 1960s): Free and Shared Development Approach—Software as a Service

1950s—Organizations like SHARE[1] and DECUS[2] developed much of the software that computer hardware companies bundled with their hardware offerings. At that time the computer companies were in the hardware business; anything that reduced software cost and made more programs available resulted in the hardware companies being more competitive.

1960s—IBM and others, who sold the first large-scale commercial computers, bundled their hardware with some software which was free (libre) in the sense that its code could be freely shared among users and further improved and modified by them.

UNIX, introduced by AT&T Laboratories in 1969 for free use in the academic world, allowed sharing of code amongst developers for research environments.

## 2.2 Phase 2 (Late 1960s–Early 1980s): Closed Development Approach—Origin of Software as a Product

1968—Programmers at ADR[3] obtained a patent on automatic flowcharting program—a clear turning-point in the recognition of software as a product, not a service—which was licensed rather than sold to customers preventing them to share programs. IBM also made software an independent product separate and unbundled from its hardware.

1970s—In mid 1970s the proprietary software came into being, in the sense that neither the source code of such software was available to the users nor its modification nor redistribution was allowed. Microsoft Corporation was founded in 1975.

1980s—AT&T began enforcing its intellectual property rights to UNIX. The era of proprietary operating systems arrived with Microsoft taking the lead to emerge as dominant market leader in operating system and allied applications.

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[1] SHARE Inc. is an independent, volunteer run association providing enterprise technology professionals with continuous education and training, valuable professional networking and effective industry influence. It was established in 1955.

[2] DECUS was the Digital Equipment Computer Users' Society, a users' group for Digital Equipment Corporation (DEC) computers. After the acquisition of DEC by Compaq and Compaq by Hewlett Packard, DECUS has become HP User Society.

[3] Applied Data Research, a Princeton, New Jersey company founded in 1959 to sell computer programming services.

### 2.3 Phase 3 (1980s–1990s): Reinventing the Concept of Free Software

Mid 1980s—Richard Stallman started GNUGNU[4] project and created GPLGPL[5] license which guaranteed free availability of any software developed under GNU. In 1985 he founded Free Software Foundation (FSF) to support GNU project.

1990s—Bruce Perens and Eric S. Raymond founded Open Source Initiative (OSI) in 1998 which adopted the Open Source Definition from Debian Free Software Guidelines.

### 2.4 Phase 4 (Late 1990s–Present): Acceptance of a New Model of Software Development

The public acceptance of open source softwares like Linux, Apache, Perl, Mozilla etc. and internet has caused companies of all sizes to take serious view of this economic model of cooperative development. Companies and government institutions are moving towards open source for three primary reasons: to reduce IT costs, deliver systems faster, and make systems more secure.

## 3 FLOSS Versus Traditional Approach

Official definitions of free software and OSS cover the aspects of software use and distribution. The most significant points covered by both licenses i.e. Free Software by FSF[6] and Open Source Definition (OSD)[7] by The OSI are that software may be freely modified and subsequently redistributed, and it must be available to anyone to use for any purpose. One particularly imperative point about both definitions is that they are about terms and conditions for distributing software, and say nothing about the methods and processes used to develop it. Since source code is available and can be modified by anyone who has the skill and interest, FLOSS can evolve differently from commercial packages. One effect of the use of FLOSS licensing is the development of communities of developers and users around specific FLOSS projects.

The OSS development practices differ from the traditional commercial closed software development models in the following main aspects:

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[4] GNU—Gnu's Not UNIX project.

[5] GPL—General Public License.

[6] Available at http://www.fsf.org/about/licensing/essays/free-sw.html.

[7] Available at http://www.opensource.org/docs/osd.

- Traditional closed software approach prevents access of the source code to customers and outside developers whereas FLOSS allows its users with free access to the source code to study what the program does, modify it, distribute copies to other people and publish improved versions so that the whole FLOSS community can benefit without having to pay royalties to previous developers.
- Closed software is developed by centralized development teams whereas OSS is developed largely by team members who are volunteers and work in a distributed and decentralized manner and are not owned by any single organization.
- Open source follows an egalitarian approach where anyone can contribute and decisions are taken according to merit. In contrast closed traditional development follows a hierarchical approach of assigning projects and decisions are based on hierarchical status.
- In comparison to traditional organizations, in open source organization, more people can share power and be involved in group activities depending upon the skills.
- Open source development is self-organizing in nature where people find their own projects and processes to work upon; whereas in traditional environment, projects are assigned.

## 4 Research Perspectives

FLOSS is a complex phenomenon requiring interdisciplinary understanding of engineering, technical, economic, legal and socio-cultural dynamics. It includes groups with a wide diversity of participants and practices. In principle it resembles more than one phenomenon like those of virtual teams, distributed software engineering and user innovation, voluntary organizations, and social movements without being an exact replica of any. This leads to the problem of identifying and to relating corresponding relevant theories. The everyday actions of developers generate "trace" data which is publicly available. The data is available on (i) persons (ii) project files (iii) time span and (iv) communication amongst the developers and users. Since these data are limited to particular aspects of FLOSS work and are often difficult to connect to constructs of theoretical interest, there is a critical need of careful conceptualization and theorizing by categorizing project types.

### *4.1 Background*

The main concepts of OSS development have been described in the seminal work by Raymond [1]. In 'The Cathedral and the Bazaar', he explains the "Bazaar" or "open" model of software development as compared to the "Cathedral" or "closed" approach. Since then there have been various lines of research being followed in FLOSS.

FLOSS developers are generally skilled, experienced professionals. The first question raised by advocates and supporters of closed development, while trying to understand the relative success of FLOSS, is that what drives FLOSS developers to contribute their time and effort for the creation of free software products [2–5]. Learning forms the major motivational force [6, 7]. Reference [8], the results of a web based survey to learn the motivation factors behind the participation found the factors to be extrinsic—better job and career opportunities as well as intrinsic—creative intellectual stimulation and skill improvement. Many of the developers are paid to participate in the FLOSS development, still majority of them do it for intrinsic benefits.

The main characteristics of FLOSS development is the fast and reliable software development by a globally distributed developer force which have come out to be effective. It often entails shorter development times that can produce higher quality systems, and incur lower costs than may be realized through developing systems according to conventional Software Engineering techniques. A few researchers have investigated the FLOSS development process. Their studies have mainly focused on the participants and the processes involved in this form of development to understand the success of this model. The studies have been carried out to understand the evolution of the software [9], requirements and the processes [10, 11], the contributory roles of the participants, the team organization and the tools used by them. Very few researchers have made an attempt to address the issue of developing models for programmer participation and effort estimation. Reference [12–16], the researchers have used the data publicly available in software development repositories mainly sourceforge.net and build on a case study of GNOME project. Data on project size, persons involved, files and progression of the project over time was retrieved using Concurrent Version systems, discussion lists and bug reports. The findings were that the effort measurement based on output metrics like lines-of-code was less than that based on programmer participation metrics. The main point of concern which needs to be addressed is that since the requirements are not fixed and new functionality added on request over the lifetime of open source software, the estimates may not give the complete future effort forecast. The studies [17, 18] have provided a basis for studying the relationship between developers and corresponding effort. The researchers have studied the amount of effort required to create and maintain a large FLOSS system. Using tools to measure lines of codes and to study the version control log data, their preliminary results show that work in FLOSS communities happened at a regular predictable rate using linear, quadratic or exponential models. The studies [19, 20], provide a base for studying the coordination and knowledge sharing activities within a FLOSS project team. Reference [19], the findings from a content analysis of interaction within developer mailing list and web based forums and found that there is self assignment of tasks amongst developers who can also propose tasks to other volunteers explicitly or implicitly. In FLOSS projects, often there is no perceptible separation of the identification of a task and its assignment; and no explicit authoritative assignments to contributors.

From economic and policy point of view the research questions being raised mainly concern with (i) the economic relationship between OSS development communities and proprietary software firms, (ii) the effects on market innovation and corresponding incentives and (iii) legal mechanisms which allow for the sustainability of open source software. Apache, Perl and sendmail projects have been studied to understand the technological characteristics conducive for development, licensing and whether this approach can be transposed to other industries [21]. The case studies were developed through the review of published materials and interviews (available in print form as well as those posted on various web sites), face-to-face meetings with one or more key participants contributing in the development effort; and conversations with knowledgeable observers of the open source movement. In [22], the effects of component reuse on cost, productivity and quality have been studied. Literature review and exploratory study through interviews led to the findings which showed that systematic reuse could provide economic gains in terms of productivity and quality. In [23], the researchers use Linux kernel to look into the economic aspects like distribution of developer effort within the software projects, allocation of developer communities' efforts among projects, sponsorship support and relations between individual developers and commercial sponsors. They show the feasibility to study these aspects through data on technical features. The web based survey resulted in a preliminary analysis that FLOSS developers earn directly or indirectly through their work. Reference [24] critically looks at the assumptions about OSS to identify the actual original characteristics of OSS as compared to traditional approach. One of the observations in the work is that FLOSS can be commercially distributed and needs to be maintained and supported, thus allowing open source developers to sell services. Therefore, FLOSS *does cost*, as any other software. In the report on cost/effort estimation study (for libre software projects) by FLOSS Metrics Consortium [25], the researchers have used FLOSS Metrics database to provide an estimate by approximation of substitution cost i.e. the cost required to build the same software from scratch by a single firm using proprietary model for FLOSS project. Regression and Analogy based models have been applied. The estimation results depended upon data quality and characteristics. Being based on *Lines-of-code count* at a particular project time slot and various assumptions, only rough estimates could be found.

The studies carried out in the area of exploring the development process of OSS have been at project level as well as developers level using available data about particular project level measures to estimate the success. No comparative study is available amongst the studied projects and their results. Mostly the studies have been focused on singularly on successful projects like Linux, GNOME, Debian, FreeBSD, Mozilla etc.

One of the significant observations from available research about FLOSS is that despite this concept being sold as "free", it does involves human time and effort spent on the productive activity. There is very limited research literature available on cost and effort estimation for FLOSS projects.

## 4.2 Perspectives in Present Scenario

OSS has emerged as one of the most important phenomenon of present times with a growing trend of considering it as the future development strategy. It is important to understand the effectiveness of the process. As presented in Sect. 1 above, although research has been undertaken to understand this development model in relation to the traditional software development model yet many facets of the development process like evolution of the open source software, estimation of effort expended, is unexplored on a large scale. Empirical research in this area is still in the nascent stage. Limited work is available in the literature focusing on manpower distribution as well as effort spent in the actual development of the projects. The distinct feature of role transformation in FLOSS projects leads to a different social structure. Roles are not fixed: members can play larger roles if they aspire and make appropriate contributions [6]. Within the context of FLOSS, productivity and quality have garnered the interest of researchers. The metrics related to these areas measure the development output as a function of effort and time applied. For the purpose of estimation it is necessary to identify the various metrics to be used in such estimation. The communication and coordination tools used by the FLOSS developers form an integral part of the development process itself apart from the development technologies being used. Studying the coordination and communication mechanisms is a relatively new area of study where OSS is concerned. The original concept of OSS development does not depend upon deadlines or balance budgets. They are taken up by volunteers who contribute in their own time span. Thus for the purpose of estimating the effort, the documentation in the tools used for communication and coordination is the main source for information. It is important to understand the various roles and tasks involved in project development.

The research areas can be categorized according to three main perspectives viz. Developers' perspective, Metrics perspective and Tools perspective.

The following are the research questions which can be explored under each area:

### 4.2.1 Developers' Perspective

- Does any relation exist between the number of developers and the size or the type of the projects?
- What are the various possible roles a person can perform within the OSS framework and what percentage of developers change their roles within a project during its life span and what drives this change?
- What is the number of developers who contribute to more than one project within a common hosting repository? Can the results be generalized?
- What is the distribution of hired developers and volunteers within projects driven by community as well as those headed by companies?

### 4.2.2 Metrics Perspective

- What are the corresponding FLOSS metrics for: Work product delivered, Measures of errors uncovered before release of the software, Defects delivered to and reported by the end user, Human effort expended, Calendar time expended, Schedule conformance, Effort and time spent to perform umbrella activities?
- The literature does not provide any set of metrics which have been standardized for estimation of FLOSS projects. This can be one of the important areas for future research i.e. Can a set of metrics be found which serve as a standard for various estimations?

### 4.2.3 Tools Perspective

- What are the various possible tools used by FLOSS contributors for development as well as coordination?
- *What are the areas of* FLOSS *development and coordination which are* lacking in the availability of tools which could enhance the functionality?
- How does the use of various tools affect the FLOSS development process?

## 5 Conclusions

Open source development process provides an elaborative environment for empirical as well as evidence based exploration and development of software engineering models and techniques. FLOSS developers typically tend to be its end users also and the end users often participate and contribute towards development efforts. Understanding the nature in which the knowledge is generated, archived and shared by the developers is vital for the study of the development process of open source software. The efforts expended in this collaborative environment with unscheduled time spans need to be estimated so as to allow the stakeholders to make strategic decisions regarding management of the ongoing projects.

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# Informal Instructional Design to Engage and Retain Students in Engineering

**Cecilia K. Y. Chan and Tom Colloton**

**Abstract** Universities in US, Australia and Europe have been working explicitly and in focused ways to arrive at an understanding of issues relating to student underperformance, student retention and academic success in engineering and science disciplines. More importantly, they have been introducing interventions in the curriculum and instructional design that attempted to provide more support for students based on these issues. However, despite these efforts and extensive researches on the topic, student withdrawal rates are still on the rise and for some programme disciplines, the retention rate is at a point where the programmes are in danger of closure. In this paper, the author will present ideas for a retention strategy model to engage students in the curriculum by investigating students who withdrew in a five-year period. It will also present some informal instructional approaches. The model takes into account the root of the problem at any one time which is essential for designing successful approaches to student retention and engagement. Evidences will be cross-examined through literature reviews, data from students who have withdrew and interviews with academic tutors.

## 1 Introduction

Student retention has long been a problem in higher education and there is extensive research and literature [1–5] on the topic of student retention well before the turn of the century. Tinto's theoretical model [1] is probably one of the most

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well-known model to-date for predicting the factors that influence retention. It focuses on academic and social integration as a predictor of student success. Tinto et al. [6] also encourages the use of learning communities to promote collaborative learning and to help students integrate into the institution. Astin's Theory of Involvement [7, 8] emphasises the more involved a student is with the institution, the more likely the student remains. Summerskill [9] indicates individual personality attributes are the main reasons for persistence and leaving. Action plans such as rescue program [10], student monitoring and dropout alert system, peer mentoring [11], better induction program and engineering outreach [12] are all various retention strategies arise from these studies. However, despite these very extensive studies and strategies, student withdrawal is still on the rise and for some programme disciplines, the retention rate is at a point where the programmes are in danger of closure. Degree and diploma courses are in serious threat particularly for Higher Education (HE) institutes that are less renowned with low admission requirements [13, 14]. As the output of science and engineering graduates declines, external forces such as government and industrialists have been continuously putting pressure on 3$^{rd}$ level educational institutes on what is not only a national problem but also an international one. This decline [15] is likely to continue if we as educators do not bring about some kind of solution. In times of significant skills shortage in the employment market, as publicized by the report submitted by the Skills and Expert Group [16] to the Irish Minister of Enterprise, Trade and Employment, increases this pressure and emphases the breath of the issue.

This is peculiar as the decline in the popularity of engineering comes at a time when there is a general increase in the overall student numbers entering third level education [17, 18]. Data from the Science, Technology and Innovation Awareness Programme in Ireland [19] shown that many young school leavers find the engineering and science disciplines less attractive due to the overemphasis on theory and the lack of connection to everyday life. Some also realise it is easier to secure higher grades on non-mathematical subjects. For many, they feel uncertain on their future career paths if they do choose to become engineers or scientists. This is true even for students who are currently participating in these programmes in universities. In fact, many secondary students view engineering as some sort of mechanics, craft professions rather than a profession with various opportunities. As science subjects are becoming less popular for secondary level pupils, there is a need to increase our efforts to retain those students that we have managed to attract and naturally, creating strategies for student recruitment in order to attract future candidates into the Science Engineering Technology (SET) disciplines. After all, what is the point of recruiting students, if we cannot retain them?

HE institutions around the world particularly in North America, Europe and Australia have invested a vast amount of resources to try to improve student retention, adopting and researching multiple strategies in the curriculum. Some of these strategies are course, programme or faculty based initiatives; others are institutional based and some are even national based. Many of these strategies have been tried and faded away; some have been tried, improved and retried and then faded away; and some have simply been tried, succeeded, improved and succeeded more.

In this paper, the author will present ideas for a retention strategy model to engage students in the curriculum by investigating students who withdrew in a five-year period. It will also present some informal instructional approaches. The model takes into account the root of the problem at any one time which is essential for designing successful approaches to student retention and engagement. Evidences will be cross-examined through literature reviews, data from students who have withdrew and interviews with academic tutors.

## 2 Methodology and Study Approach

The third level education institution where the studies were conducted is a large public Institute of Technology (IoT) in Ireland. The IoT has an enrolment of nearly 21,000 undergraduate students, and only 1,000 postgraduate students. Like most institutes of Technology or Polytechnic colleges around the world, the history of the college is less research intensive and most of the degree programmes are more applied in nature. The programme in question is a three-year ordinary electrical engineering degree programme. The average class size was about 35 students. These students aged from 17 to 40 years old with diverse backgrounds. It has suffered critically in student retention from late 1990s to early 2000s, with an average retention rate of 45 % by the end of the first years and with less than 30 % student cohort of the original class actually graduated. With the introduction of several retention strategies including the employment of an academic tutor, there has been significant improvement in retaining the students to an average of 80 %. However, even with these successes, there were still student withdrawals which still fell short of the university strategic retention goals.

As an attempt to gain a deeper understanding of the retention problem, students who withdrew from the programme were interviewed. This was organised by the programme coordinator along with the academic tutor to gather data on the factors that affect their decisions to withdraw. The interview information requested includes some personal background information, their attendance level and their expectations on the programme, how difficult they found the programme, how they enjoyed their time in college and if they believe they have made the correct decision to withdraw, what they are currently doing and the actual reasons for dropping out. The students were also asked about their perceptions of the educational environment at the college, such as quality of relationships, support services provided by the institution, and contributions the institution adds to their educational experience. All 40 students who withdrew in their first year of the programme within a five year period from 2003 to 2008 were contacted by the academic. 27 students of them responded by telephone and face-to-face interview. This has given us detailed qualitative information on their decisions of their withdrawals. Out of the 40 respondents, two of them were international students from China and the rest were Irish citizens. About 81 % of the students withdrew came directly from secondary schools and most of them were first-time university entrants, 19 % were mature students who were over 23 years old. The majority of the respondents were male (this was likely due to the engineering discipline nature).

As a further addition to the study of student retention, 3 academic tutors and 5 academics who act as student advisors in the faculty of Engineering were interviewed to share their views on issues encountered in student retention. They commented on approaches used to tackle student retention and engagement problems and when and what actually worked. They also gave account of their own perspectives in relation to motivate the students.

## 3 Understanding the Root of the Problem at Any One Time

Many theoretical models and researches to tackle retention issues have already been extensively investigated. It is no surprise there are many underlying factors which influence the decisions of student withdrawal. Some of the most common reasons are transition from secondary to third level, socio-economic background, lack of motivation, uncertain or lack of student support, mismatched expectations and poor adjustment to the challenges of third level learning environments [14, 20]. But which one of these factors is most likely to affect a student's decision to withdraw at any given time? The problem with a lot of retention strategies for curriculum design is that sometimes HE institutions and faculties tackle retention without understanding the root of the problem at the time it occurs. Institutions and faculties often come across successful retention strategies from other institutions and determine to put the same strategies into practice. On one hand, it is commended for trying, but on the other hand, it is implemented without understanding the actual process, without identifying suitable practitioners, without training and without understanding if the same retention issue actually occurs in the institution or faculty and of course without serious commitment from the practitioners. This kind of misconstrued approach was adopted in the Faculty of Engineering at the Institute of Technology in 2003 in a peer mentoring programme. This programme involved senior students mentoring a small group of six first year students. The mentors were given only 2 h basic training on the expectations and responsibilities. During one day of the induction week, an academic introduced the mentor to their mentees. The mentors were responsible to introduce some college facilities to the mentees on the day, but no other organized meeting was arranged. In theory, the mentors are expected to organize further activities or gatherings with the mentees and report to the academic if matters arise. But in practice, this is difficult to arrange due to classes clashing and self-motivation from both the mentors and the mentees. After five years of implementing the peer-mentoring programme, the programme faded away without achieving anything significant. Peer mentoring has the potential to provide a lot of advantages (for example it can provide a sense of being connected to the larger community where they may otherwise feel lost in the changing environment of tertiary) for both mentors and mentees if it is implemented in a more structured manner focusing on factors driving its success.

In general, there are many underlying factors, which influence the decisions of student withdrawal in the Science Engineering and Technology areas. It is most valuable for us to understand which ones of these factors are priorities—at any one point in time for that programme and for the students enrolled. From practices and evidences, academic challenges are factors influencing student retention [21]. However, they are often not the primary factors for student departure during the first few months of enrollment. In fact, social contact and acceptance or excessive socializing is usually the primary factors for early departure as evidenced from the 5 years of data. Understanding the root of the problem in relation to time is therefore vital to successful retention strategies.

Figure 1 is a model indicating most of the possible and common factors of student retention for ordinary degree, diplomas and certificates from the data collected. This model is divided into different order of priorities.

## 4 Informal Instructional Design to Engage and Retain Students

A large percentage of withdrawal usually occurs in the first month due to the factors associated with the order above. These new students have to face a barrage of anxieties but yet have nowhere to turn. Research findings [22, 23] have founded that greater levels of personal attention from academic staff would significantly reduce wastage, or at least, help to pick up problems or concerns earlier. Below describe the 3 main steps of the very casual yet effective approach that we have adopted in order to gain trust from the students (Fig. 2).

## 5 Student Retention Model

Student retention factors can be viewed and analysed as a multi-dimensional model. One set of axis is the common factors which are usually student influenced such as social contact, certainty of career direction, academic ability and so on. Another set of axis is the potential retention strategies to tackle these issues. And finally there is time. Both sets of axis are interconnected and are dependent on time. Understanding the actual retention issue, and using appropriate retention approach at the appropriate time in the duration of the programme will ultimately maintain students. In addition, unexpected factors may also affect student withdrawal, they may occur at any time. They are often uncontrollable by student such

***High Order of Priority***
***Failure to adjust to Environmental Demands***

High Order of Priority indicates these factors would most influence the students to drop out of the programme and this is usually at a very early stage (likely in the first month). Note: a lot of these factors are personal factors, yet most retention strategies seem to have ignored these issues at our peril.

**Failure to adjust to the Environmental Demands**

- Gender related, ethnicity, sickness and disability
- Social contact and acceptance
- Homesick and lonely
- Financial and Family Problems
- Transition from secondary to third level
- Lack of informational resources, including contact with staffs

↓

***Medium Order of Priority***
***Uncertain on Future Prospects***

Factors with Medium Order of Priority usually initiate after the whole induction process when the realisation of college work starts to kick in, and college is becoming a new routine in life. This drop out stage usually occurs around the second to the end of $1^{st}$ term.

**Uncertain on Future Prospects**

- Uncertain of their career paths
- Doubtful or even disinterest of their course options
- Uncertain College choices, institutional services and facilities
- Unaware of the nature of the course and its academic requirements

↓

***Low Order of Priority***
***Lack of Motivation and Weak Academically***

Low Order of Priority do not suggest students are unlikely to drop out, it merely states the timing of these factors occur. Most of these factors are academic related and perhaps the ones we have most controlled and researches [21] on. Unfortunately, the withdrawal period of this degree is also the longest, usually occurs before the end of the $1^{st}$ term until the summer exams.

**Lack of Motivation and Weak Academically**

- Weak academically
- Weak in numerical and science subjects
- Short attention span
- Mismatch of Expectations – expecting engineering to be more projects and practically orientated
- Overwhelmed by the theoretical context in $1^{st}$ year
- Having difficulty with staff members

**Fig. 1** Factors influencing student retention showing its degree of priority

as financial difficulties, personal problems, economic downturn and unusual opportunities. It is these factors that must be considered independent of the model but reflected in how the model is viewed and measured for success and improvement.

It is clear that student retention in higher education is influenced by a complex and dynamic set of both internal and external factors. However, certain factors have a greater influence than others. Some are controllable by the educators and/or the students, some are uncontrollable by either. Through improved

**Step 1: Getting to know them**

Develop a relationship with the students – a leadership, a helping hand and more important, a friendship.

- Find out some personal information such as mobile number, hobbies, does he or she work.
- Develop a sense of trust and friendliness, so the students can approach you easily especially at the start of the term. Don't forget, the transition between secondary to third level can be very remote for some students, by being there for them, you can slow down this changing process, and let them ease into the environment slowly.
- Ensure they know where they can find you, don't assume they know how to use email, cause most of them don't!
- Talk to them like friends. Ask them about their interests, why did they pick the course etc. They will not drop out without coming to talk to you first.
- And try to remember their names.
- Students expect the tutor to know everything, from visa to grants support to accommodation and to where to get student travel cards. Be prepared, but don't bluff or send them away just because you don't know, try to find out for them.

*Don't just be their lecturers, be their friends!*

**Step 2: College is supposed to be fun**

Encourage and organize social events, allowing them to integrate between them. So they feel they are part of a team and have a sense of belonging!!!

- Allow and encourage more interactive tutorials or labs that allow the students to interact with each other such as designing a presentation for a Microsoft Powerpoint project.
- Organize social events – soccer competition against other classes, ice-skating, meeting etc. Their hobbies can be determined from the information sheet in step 1.
- Nominate a good class student representative could assist a lot of unnecessary running around.
- Invite past graduates to present informal talk about their careers to-date to the first year students, to help them be more aware of their career paths

*If you can them all integrated, they will enjoy college more, and that is 1/3 of the battle gone!*
*After all, going to college is like going to work, if you don't like what you do at work or people in your work, you don't feel like getting up in the morning and will eventually quit.*

**Step 3: Help them to motivate academically**

- Record all attendance for student tracking, maybe even introduce attendance award
- Give them a target, stress on the amount of marks they will get if they do a good job
- Most of these students have very short attention span and lack of imagination. It is important for us to relate our labs and lectures to real life applications, give good examples, how the theories are related in real life. Sometimes it is good to tell a story, it helps the students to remember and understand.
- Ask for inputs. 50 minutes can be a long time to sustain anybody's interest especially when they are 17 and 18 years old. Nobody wants to just sit there and listen whole day long, sometimes it is more effective to make it a 2-way conversation. Call on students for answer to shake students out of their passivity.
- Be tolerant and treat the students as adults. If you give them respect, they will give you respect also.
- Offer to help academically weak students
- Encouragement and reward with positive response. We humans tend to be motivated when our performance is followed by rewards.

*If they are given positive encouragement at the subjects, it doesn't matter if they are interest in it or not, they will like it.*

**Fig. 2** Informal retention strategy approach

understanding of the influences on student learning, better-informed and active learning and teaching strategies will enhance student experience and lead to lower retention rate.

## 6 Conclusions

HE institutions can try to understand, monitor, prevent and support students by providing the most suitable *environment for learning*—an environment which helps them to develop and adapt themselves in the society, to activate their prior knowledge and experience, to solve their lack of academic preparation, and to provide an integration socially and academically.

We have to remember science and engineering are actually difficult subjects, there is a large subject content and contact hours, much of the subject matter is non-intuitive, at least initially, and much of it has to be learned sequentially. Many students arrive ill-prepared for a challenge of this magnitude and duration and many are unaccustomed to the less-controlled, independent environment third level is infamous for. Without understanding the students and their problems at the time that they occur, any retention strategy implemented is just shooting in the dark.

Addressing retention is long-term work as it requires institutions and staff to make fundamental changes to their thinking, teaching and their policies. Any cycle of research, action and evaluation will take a minimum of three years and more likely four to five years. Although from research data, student withdrawal is predominantly a first year student cohort issue. It would be incorrect to believe that support for students' academic success should not extend beyond the first year. For the electrical programme, the academic tutor supports students at all years. The success in retention has led to success in the recruitment of engineering students for the programme through word of mouth.

It is also important to remember the world is evolving all the time, and in today's world, there are way more distractions such as TV, radio, music, computer games, internet, magazines and mobile phones. Students find it difficult to concentrate as they don't even have to go outside for entertainment and their friends are within easy reach, all of these distractions are now an integral part of our life, and it cannot be changed. But as educators, we must try to motivate them, rather than compare today's students with yesterday's students, we must accept the generation has changed and if one teaching method doesn't work; a new approach must be adopted. Students are the seeds of today and are the crops of the future. As John Dewey once said

> ..if we teach today as we taught yesterday, we rob our children of tomorrow.

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# TCP with Advanced Window Scaling Option

**Michal Olšovský and Margaréta Kotočová**

**Abstract** With the expanding amount of data transferred over transmission links it is necessary to improve the links and appropriate network devices to match the traffic requests. In general, the most common way of increasing network throughput and performance is the replacement of the network devices and links. This way is reliable but usually expensive. Different way of improving network performance is the change of network protocols and appropriate protocol stacks. This paper introduces an effective way of increasing network performance with some improvements in the most common transport protocol TCP. The improvement, called advanced window scaling option, enables a controlled usage of window scaling extension introduced in RFC1323. It means that this extension is used only under particular circumstances—when it is effective and necessary. In general, this improvement will reduce the end node's processing delay.

## 1 Introduction

The first version of the most common used transport protocol TCP was introduced in RFC793 in 1981 [1]. To match the increasing traffic requests (bandwidth, delay, etc.), it was necessary not only to improve hardware part of the communications,

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but software part as well. Improvements of the TCP, usually called TCP variants or extensions, are mainly focused on the most equitable use of available communication lines.

The first improvement of the TCP for higher performance was published in RFC1323 [2]. The most important part of this document is the one, where the window scaling extension is introduced. Since 1992 [2], there have been many new TCP variants like Reno, Vegas, BIC, CUBIC [3–5] and Compound TCP [6, 7]. These variants mainly focus on the intra/inter-protocol fairness and the way how the TCP deals with network congestion—the way how to increase or decrease TCP congestion window size [5].

The window scaling extension, introduced in RFC1323, solved the problem with small congestion window size. Based on the reserved field for window size in TCP header, the maximum size of congestion window can be 64 kB [1, 2]. It means that the amount of unacknowledged data in network cannot exceed the limit of 64 kB. This limit was sufficient in the early beginnings of the TCP but later, when the links with higher bandwidth were used, caused the inability to use the full potential of the link. Using this extension, it is possible to enlarge the unacknowledged amount of data in network up to 1 GB [2].

The usage of this extension is approved during the initial 3-way handshake when the scaling factors are set up. Once the usage of the window scaling extension is agreed, this extension is used during the whole communication. It means that is it already used in situations, when the process of scaling is not required due to actual size of the congestion window. In general it will increase the processing delay which is created at the end points of the communication.

Our new approach minimizes end node's processing delay by means of using the window scaling process only in situations, when it is really necessary. This extension can be used in combination with any existing TCP variant and extension.

## 2 The Principles of Main Features

While creating new TCP extension, it was necessary to keep in mind some important factors—features, which had to be observed. Some of the main features are:

- Backward compatibility with TCP protocol header and extension field format
- The usage of the highest version of window scaling type supported on both sides
- Automatic usage of the window scaling process.

### *2.1 Backward Compatibility*

To keep the backward compatibility with original TCP header, the only way how to create a new TCP extension was to use the field for extensions (Options). When

**Table 1** General extension format

| Type | Length | Value |
|---|---|---|

**Table 2** Window scaling extension format

| Type = 3 | Length = 3 | Value = <0;14> |
|---|---|---|

we want to keep backward compatibility with extension field format, we had to use format shown in Table 1. The minimum length of the extension is 3 B, while the field with changeable length is the Value field.

Basic window scaling uses 3 B length formats. The appropriate fields are filled as shown in Table 2.

To achieve the requested compatibility with basic window scaling, it was necessary to use the similar extension format as the window scaling do. It means that fields Type and Length have the same values. The only difference is in the Value field, which values can range from 29 up to 42. The new format of advanced window scaling option is shown in Table 3. Details why it was necessary to use these values are explained in the next chapter.

## *2.2 Appropriate Extension Selection*

Before the end node can use any extension, it has to have assurance, that the second end node will support the certain extension and choose it as well. As it was introduced in [2], when the end node wants to use the TCP with some extension, it has to announce this extension in appropriate TCP header part called Options during 3-way handshake at the beginning of the communication. This process was evident with the basic window scaling. The new approach with backward compatibility made it more complicated so it had to be improved and extended with some kind of coding and decoding processes of the window scaling extension's announced type.

Coding and decoding processes are performed only when announcing the advanced window scaling extension. It is necessary because advanced window scaling factor can range between 1 and 14 as well as the basic window scaling. In this situation end node has to know, what type of scaling is offered.

**Table 3** Advanced window scaling extension format

| Type = 3 | Length = 3 | Value = <29;42> |
| --- | --- | --- |

## 2.3 Message Coding

The main goal of the coding process is to calculate the number, which will be announced in the Value field. To calculate this number we use (1).

$$\text{Value} = \text{scaling\_factor} + 28 \quad (1)$$

The parameter scaling_factor stands for the scaling factor which uses the appropriate end node and belongs to the interval <0;14>. Another extension, which enables to cancel the scaling during communication, has been created and use +14 as an extension identifier, therefore this extension use +28. The number which is added has to be multiple of 14, because the basic scaling value ends at 14. This unique number includes the information about the type of the highest scaling extension the end node supports and about scaling factor which will be used.

## 2.4 Message Decoding

The aim of decoding is to find out, what the second end node supports. Firstly, the field Value needs to be checked. If the number belongs to the interval <0;14> it means that the number is not coded. The node supports only basic scaling and the Value number is the used scaling factor. On the other hand, if the number belongs to the interval <29;42> it means that the node support basic and advanced scaling as well. To get the scaling factor which will be used, the unique number has to be decoded with (2).

$$\text{Scaling\_factor} = \text{value} - 28 \quad (2)$$

To this point, we mentioned nodes that support advanced scaling. But in case that the node does not support it, it cannot decode the message. As we have mentioned in the begging, one of the main goals was to keep backward compatibility. It means that when the node does not support advanced scaling, it will not ignore this offer but will simply use the basic scaling and the second node will use the same option. This is possible because of these two things:

1. Default rule in RFC1323
2. Extension format.

Default rule in RFC1223 says, that if the node has received offer on window scaling (Type = 3) and the field Value is greater than 14, it will accept the offer (in case it supports it), set the local copy of the second end node's scaling factor to 14 and use the basic scaling instead of ignoring the offer. This brings us to the second thing—extension format. As we have written previously advanced window scaling uses nearly the same extension format—the same type and length. It means that the node which does not support the advanced scaling will look at the offer (Type = 3), check Value, set it to 14 and simply use the basic scaling.

The end nodes can use:

- advanced scaling if both of them support it.
- no scaling if at least one of them does not support scaling.
- basic scaling in other cases.

## 2.5 Automatic Usage

To enable the automatic stopping and resuming of the scaling process on both end nodes, it was necessary to create a notify system. This system consists of four information messages:

1. Cancel Request
2. Cancel Approval
3. Resume Request
4. Resume Approval

Notify system can be split into cancel phase and into resume phase. Each of these phases uses appropriate information messages.

In the cancel phase 2 types of messages are used—request and approval. Cancel Request is specified with Type = 254 and Cancel Approval with Type = 255.

It is allowed to send Cancel Request when some specific conditions are matched. Both of the nodes can send Cancel Request. Conditions which specify the situation, when can be Cancel Request created (congestion occurred) and sent (the link is free) are following:

1. It is allowed to create the Cancel Request if the congestion window was reduced x times, where x is defined as a threshold of the reductions, which were not interrupted with the increase.
2. Reductions are counted only if they appear while the size of the congestion window belongs to the interval $<1; 2^{f}>$, where f is defined as a local scaling factor.
3. It is allowed to send Cancel Request if the congestion window was increased $x^2$ times without being interrupted with the reduction.

The translation of the first point says that the congestion in the network is detected with the congestion window reduction. The second condition guarantees, that node will react only on congestion which is caused by another aggressive

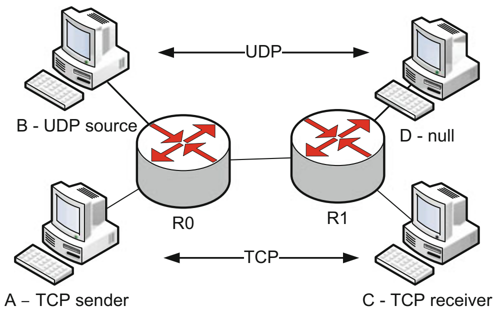



**Fig. 1** Simulation scheme

traffic burst. The third one guarantees that the sent request will not be dropped in the network because of congestion.

When the second node receives the Cancel Request, it will stop scaling and reply with Cancel Approval. Finally, when the first node receives the Cancel Approval, it will stop scaling as well.

At this point, the communication is recovering and under specific conditions, it can enter the resume phase. Resume phase uses two types of messages—Resume Request and Resume Approval. Resume Request is specified with Type = 252 and Request Approval with Type = 253.

Resume Request can be sent after matching some conditions and both of the nodes can do that. Conditions which specify the situation, when the Resume Request can be created and sent are these:

1. Scaling must be stopped.
2. It is allowed to create and send Resume Request if the congestion window was increased y times, where y is defined as an increase threshold.
3. Increases are counted only if they appear while the congestion window size belongs to interval $<2^{16} - 2^{f}; 2^{16}>$, where f is local scaling factor.

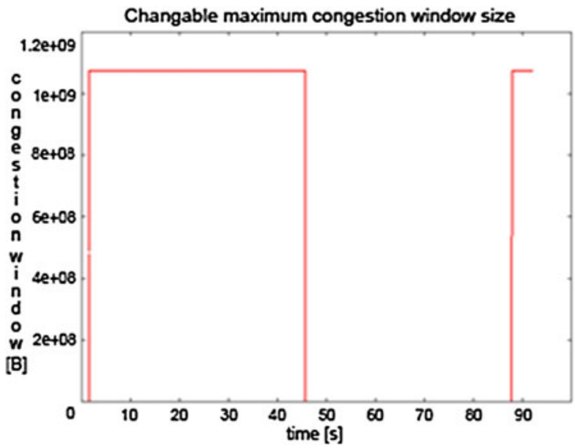
The second condition guarantees, that there is no congestion. The third one says that scaling is resumed only when the actual size of the window is nearly its actual maximum and there is no congestion. The node can keep on increasing the congestion window to increase the actual throughput.

With introduced notify system, advanced scaling option can dynamically adapt to the network situation. It can stop and resume scaling when it is necessary. This extension can be used in combination with any existing TCP variant and extension.

## 3 Testing Model

New approach, introduced in this paper was implemented and tested in ns-2 simulator [8]. We have done many tests, which were focused mainly on improving the TCP performance by means of decreasing the processing delay in the end

**Fig. 2** Changeable maximal congestion window size




nodes. First sets of tests were focused on extended 3-way handshake functionality. The rest of the tests were used to validate our assumptions about the processing delay's length in the end nodes.

Our testing scheme (Fig. 1) consists of two routers which were connected with bottleneck link. Two end nodes were connected to each router—nodes A and B to Router R0 and nodes C and D to Router R1. TCP communication was established between the nodes A and C, while the aggressive UDP traffic was flowing between the nodes B and D. UDP traffic was not generated all the time, only in specific intervals to achieve the state of congestion in the bottleneck link. Every link had 250 ms delay and 1000 Mbps bandwidth. Generated UDP traffic had 1000 Mbps rate. The queue size was 20,000 packets.

There have been many outputs and results, which confirmed the basic functionality of the advanced window scaling and its impact on end node's processing delay. Basic functionality was confirmed in tests, where we checked the 3-way handshake and notify system. As we can see in Fig. 2 end nodes at the beginning of the communication approved advanced window scaling—they increased the maximum size of the congestion window. Later, when the congestion occurred (45th second), they used notify system to stop the scaling process. This congestion lasted only few seconds but the nodes did not start scaling as soon as the congestion disappeared because it was not necessary. When then actual congestion window size nearly reached the maximum, notify system was used to resume scaling process (88th second).

To obtain confident results, it was necessary to repeat the simulations hundreds of times. To eliminate the influence of the operating system, simulations were performed alternately. It means, that simulations were not done in groups of the same simulations like group of simulations x followed by group of simulation y but they were performed in way like x–y–x–y. Because during each simulation could be transferred miscellaneous amounts of data which influenced the real simulation time, it was necessary to create new parameter which represents the amount of the real simulation time which is necessary for the 1 B transmission.

The time focused results confirmed that our new approach can save from 0.5 to 2 ns of the time that was required for transmission of the 1 B. Because the compared simulations differ only in the used type of scaling, we can declare that the saved transmission time equals to the saved end node's processing delay.

## 4 Conclusion

In this paper we have proposed the new approach of increasing of the TCP performance. Firstly, this approach reduces processing delay in the end nodes. Secondly, it shows how to improve TCP performance with keeping assumptions the full backward compatibility.

It seems from obtained results that we saved small amount of processing time. However, we must recognize that this time was measured for 1 transmitted B. If we recalculate the time for 1 GB it makes up to 2 s. The proposed approach can be taken as a sophisticated solution without the usage of replacement methods.

We believe that this paper can contribute to the important research field in the communication network performance.

**Acknowledgments** The support by Slovak Science Grant Agency (VEGA 1/0649/09 "Security and reliability in distributed computer systems and mobile computer networks") is gratefully acknowledged.

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# Implementation of the Handheld Decision Support System for Agriculture and Home Gardening

**Mária Pohronská and Tibor Krajčovič**

**Abstract** In this paper we describe the embedded handheld system for decision support that is aimed for the area of agriculture and home gardening. Based on the user preferences, environment measurements and knowledge base data, the system recommends the appropriate plant to be grown. The system consists of the wireless, battery powered sensor module and the handheld hardware platform based on the Windows Embedded CE 6.0 operating system platform. The paper describes the system's purpose, functionality and architecture in detail. We conclude that the proposed architecture is also applicable for implementing other expert systems into the embedded handheld computer platforms.

## 1 Introduction

The decision support systems have been in use for decades. Usually, they are implemented as complex expert systems that run on the dedicated high-performance computer. The task of such systems is to assist by the important decisions that require high amount of expert knowledge and input information. The reason for usage of such systems is mainly to "reduce the cognitive load on users or to enable them to increase their productivity without the cognitive load on them

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increasing” [1]. Such systems are used for example in the field of automation, biology, chemistry, computer science, ecology, education, genetics, hydrology, medicine, robotics and many others [2].

However, there are fields where we would appreciate the assistance of the decision support system but it is not affordable to build and maintain the expert system running on the dedicated stationary computer or it is not possible to feed the expert system with the needed data if the system is running on the dedicated stationary computer. There are also users that would appreciate the expert advice in their daily decisions—for example when preparing food for a special diet or making decision whether to take child to the doctor or not. There is currently no system aimed for such usage, especially when we want the system to be affordable for most of its potential users.

Hereby, we would like to thank Nadacia Tatra banky for financially sponsoring this project as part of its E-talent Grant program.

Nowadays the technical trend is to integrate as much functionality as possible to the personal handheld devices. The motivation for this trend can be various. It can be to increase user attractiveness, to satisfy the users’ needs, or because the application requires to be implemented in the mobile handheld system to offer the full functionality. Such need often arises in many problem areas, including the field of agriculture. In each case, there is always an ambition to keep the devices as universal and all-purpose as possible. Our proposed system corresponds with this ambition and brings the universal solution while maintaining its specific functionality needed in the problem area.

This paper presents the prototype of the handheld decision support system that is aimed for the field of agriculture and home gardening. The handheld system is easily usable by almost any operator and introduces an affordable solution for the wide spectrum of problem areas. The paper consists of six sections. The next section summarizes the related work in the problem area. The following section describes the principal architecture of the system and its functionality. Next, we describe the system’s architecture in detail. In the last two sections, the practical outcomes and lessons learned are summarized and the paper is concluded.

## 2 Related Work

In our work we focus on problem of fitting the right fruits and vegetables to the suitable time, place and environment. In agriculture, operational research methods are used in order to find optimal characteristics of the objects investigated, considering time, resources, technological and other restrictions. The methods of mathematical programming are successfully applied to improve agricultural system planning [3, 4].

These problems can be also solved by implementing a decision support system which considers input factors and expert knowledge to simulate the reasoning process of an expert in this area to come to a decision. A decision support system provides a farmer or consultant with a possibility to choose proper variants of farm management by evaluating dynamically changing weather conditions, new technologies, environmental changes and general agricultural policy. Various expert systems are widely used in agriculture; however, they are often developed for autonomous computers and aimed at solving highly specific agricultural problems. Our proposed decision support systems should also satisfy requirements of a non-expert user and should offer the possibility of easily updating its knowledge base. Convenient on-line systems serve the purpose [4, 5].

The concept of the handheld decision support system has already been published before [6]. However, our proposed system offers more functionality and is aimed for both professional and amateur users. The basic concept of the system has been proposed in [7].

## 3 The Handheld Decision Support System Overview

The overall purpose of the system is providing suggestions that infer from user input and externally gathered data. These input values are then processed by the knowledge base system. Subsequently, the acquired results are presented through the graphical user interface. The choice of problem area (agriculture in our case) is theoretically unrestrained and depends only on the knowledge base and modules used in the embedded system. The knowledge base contains information which, in combination with the input values, provide an expert advice. The basic principle is to gather environmental and user data and suggest the feasible vegetable or fruit to be grown at the given place and time. Example of externally gathered data is temperature, humidity, soil acidity, localization data, etc., while user input may consist of information about allergic reactions, preferred fruits, disliked vegetables, etc. With this information provided, the system is capable of making adequate decisions.

The handheld decision support system operates in two modes. In the first operation mode it gathers the data from the environment. In the few hours or days, it records and analyses the information on temperature, light intensity, soil humidity, geographical location and local time. It then stores the data and uses them in the inference process. The second operation mode consists of acquiring the user preferences and of the inference and decision support itself. To obtain the most accurate advice, it is recommended to run the system in mode one before each decision. The more time it stays in this mode gathering the data, the more accurate advice will be provided.

When developing the architecture of our system, we have focused on inexperienced users and designed the user interaction as simple as possible. The user interface is realized by a simple wizard that guides the user through the decision support process and gathers his or her preferences and other needed information and options. The examples of the screens are shown in the Figs. 1 and 2. The

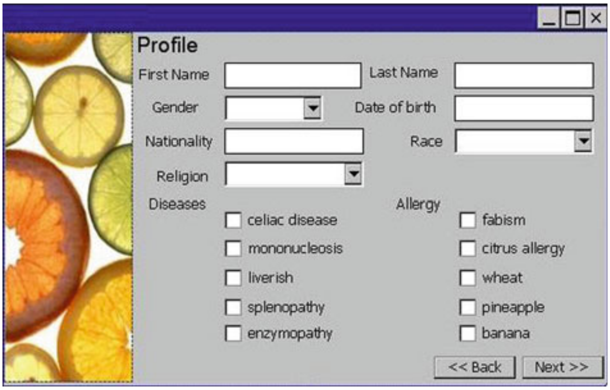


**Fig. 1** The decision support system wizard screen No 1. Filling in the basic user information

embedded device is equipped with a touch screen display, thus its usage is easy and intuitive. The user is able to start and stop data gathering, browse through the gathered data and obtain suggestions with explanation of the reasoning process. He or she can also easily synchronize the device with the additional web application. The main advantages of the implemented user interface are its intuitiveness, effectiveness and usability.

The decision support system consists of several elements. The main part of the system is the embedded handheld device that hosts the expert system and contains all data needed for the inference process. This device is connected to the sensor module which can provide it with various data according to the present sensors. The connection with this module is wireless, thus it can be placed apart from the device to obtain more accurate results. The handheld device can also be connected to the internet in several ways but the internet connection is not needed for the operation of the system. However, the internet connectivity and system's functionality enables us to manage the system in advanced way, especially to easily upload and store (backup) the application data, to access the system's data and to upgrade the knowledge base of the system. The conceptual architecture of the system is shown in Fig. 3.

The expert system is an inseparable part of the device's software equipment, however, it is entirely transparent for the user so he or she doesn't come in contact with the expert system at all. The outcome of the decision support process is the list of maximum ten commodities that system recommends, with the percent value indicating suitability of the commodity for the user. The list is created according to the user's preferences and the measured environmental data. For example, when the user suffers from mononucleosis, it is highly improbable that the system advices him or her to grow legume.

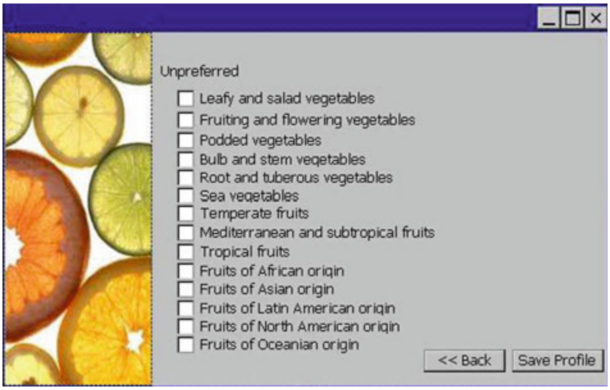


**Fig. 2** The decision support system wizard screen No 2. Checking the user's preferences

# 4 The Decision Support System Architecture

## *4.1 The Handheld System Prototype*

The handheld system prototype device is implemented on the DevKit8000 Evaluation Kit [8] development board equipped with the 600 MHz ARM Cortex-A8 processor [9]. Besides other useful features, it provides the SD/MMC interface, JTAG and camera interfaces, and supports up to 128 MB DDR RAM as well as USB, Wi-Fi and GPS through additional modules. The handheld system interfaces with external entities via various I/O ports, e.g. UART, GPIO, USB and SPI. Its purpose is to run the knowledge base system, as well as to gather data from the data acquisition system as displayed in the Fig. 4.

The handheld device is running the Windows Embedded CE 6.0 operating system. For the application, we have decided to utilize the .NET development platform, as it enables clear, fast and highly scalable implementation. The decision support application is composed of two subsystems—the expert system and the graphical and communication interface.

The expert system has been implemented using the tool CLIPS [10]. The tool is originally developed in the C language.

We planned to utilize the existing wrapper that provides interface for accessing the CLIPS methods directly from the .NET code. However, we have faced serious problems when trying to compile the system for the ARM platform and Windows Embedded CE environment. We were unsuccessful with compiling the CLIPS dynamic library but have succeeded with the compilation of the CLIPS standalone application. The communication with this standalone application is realized by file passing.

The second component of the decision support system is the graphical and communication interface system. This system provides the interface for the user interaction and manages the communication with peripheral devices and the sensor

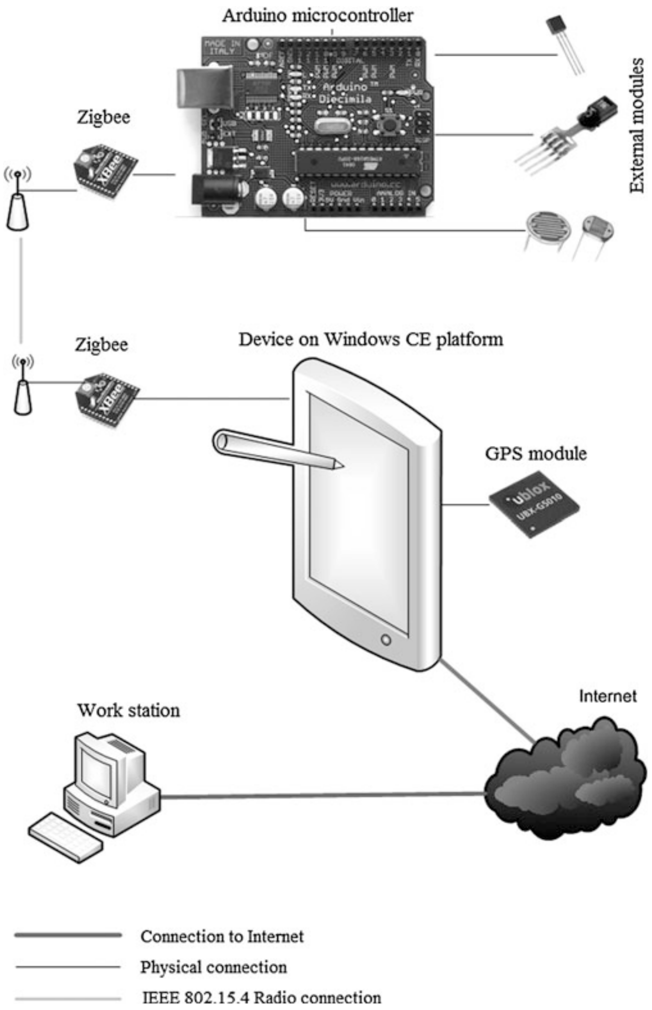


**Fig. 3** The basic architecture of the decision support system

module. It also controls and configures the expert system application. Its other task is to manage the communication and interaction with the web application and to provide the backend for the storage and presentation of the data. The handheld system gathers the sensor data and provides user interface to allow user to set preferences which influence the decision process. Afterwards, the acquired data and user preferences are transferred to the knowledge base system as additional input facts. The obtained data and inference results are then stored in the MS SQL database server running on the handheld system.

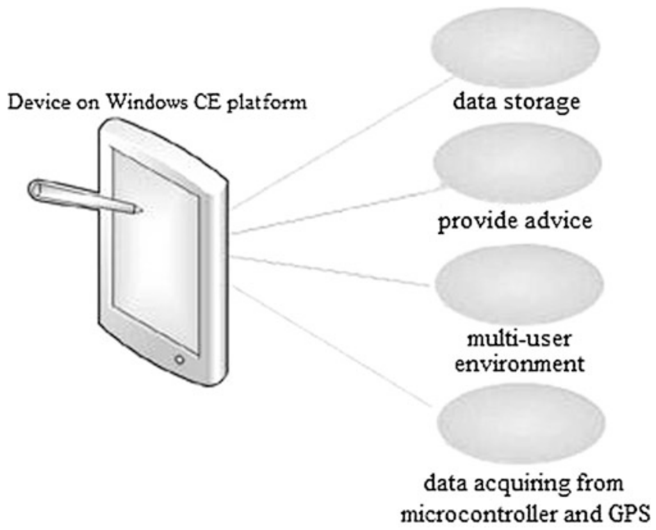


**Fig. 4** The decision support system functionality

## *4.2 The Sensor Module*

The sensor module is a standalone system equipped with various sensors and powered by battery. The system gathers data from sensors and sends them to the handheld computer when asked. The sensor module is based on the Arduino [11] development board equipped with the microcontroller of the ATMega family. The measured data are temperature, air humidity, soil humidity, light intensity and the GPS coordinates. All data from these sensors are collected and processed by the microcontroller to form the information message for the handheld system. The communication with the handheld system is realized by the Arduino XBee communication module that provides a convenient way to realize the communication according to the IEEE 802.15.4 (ZigBee) protocol.

## *4.3 The Web Application*

The additional control application is designed as the web page. Such solution well satisfies the requirements for the accessibility of the archived data, support of multiple computer platforms and for independence of the direct connectivity with the handheld device. After a successful user login, the web application provides the information on the user's settings, displays the history of measurements and visualizes the measured values in graphs. It also informs user about the outcomes of the reasoning system and displays the recommendations. Using the application, it is also possible to upgrade the knowledge base of the expert system.


**Fig. 5** The web application for the decision support system

The application is stored on the remote server that obtains the information from the system's database periodically or each time when the system is connected. The application has been implemented using the Javascript, PHP, HTML and SQL technologies. The application screen is shown in the Fig. 5.

## 5 Practical Outcomes and Lessons Learned

When designing and developing the system, we have faced several problems implied by the choice of the operating system. The chosen operating system is universal and capable of advanced functionality but its support by the embedded hardware is very poor. The process of porting the CLIPS tool to the system was also very complicated because of the missing support for some basic C functions. On the other way, the operating system provides very useful and sophisticated functions and technologies, so its usage also has remarkable advantages.

The practical outcome of our work is the handheld decision support system aimed for the field of agriculture and home gardening. The system has been tested in operation and denoted as fully functional, practical and usable. The architecture of the system is universal, so similar systems based on the expert system and sensors and actuators can be easily implemented. We could utilize and appreciate such systems for home, garden or industrial applications monitoring and intelligent control, advanced troubleshooting, early detection and prediction of the unwanted or potentially dangerous environment or system states, etc.

## 6 Conclusions

We have developed and tested the prototype of the handheld decision support system aimed for the field of agriculture and home gardening. The system consists of the sensor module, the handheld device and the web application. Even though the system is aimed for one particular problem area, its architectural concept and implementation can be utilized for developing similar systems for decision support or any handheld device based on the expert system. By porting the CLIPS tool to the Windows Embedded CE environment, we have enabled the usage of this free tool for the development of embedded expert systems based on the Windows CE operating system. In our further work, we plan to focus on extending and improving the knowledge base of the expert system and on optimizing the handheld system's design for the practical usage and manipulation.

**Acknowledgments** This work was supported by the Grant No. 1/0822/08 of the Slovak VEGA Grant Agency.

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# A Low-Overhead BIST Architecture for Digital Data Processing Circuits

**Roland Dobai, Marcel Baláž, Peter Trebatický, Peter Malik and Elena Gramatová**

**Abstract** A new built-in self test BIST method is proposed for digital data processing circuits. The advantage of the proposed method is lower area overhead than for conventional BIST. On-line and off-line testing capabilities are used simultaneously to ensure more reliable testing. Some existing circuit blocks are reconfigured for test pattern generation and test response compaction. The circuit after the partitioning is tested mutually by its subparts. The results show significant area reduction and negligible fault coverage loss in comparison with conventional BIST.

## 1 Introduction

The built-in self test (BIST) approach has become one of the most useful solutions for successfully handling otherwise unmanageable testing problems of complex circuits. The BIST architecture generates test patterns and compacts test responses directly on chip. The conventional BIST architecture is shown in Fig. 1. It contains a pseudo-random generator for test pattern generation (shown as TPG in the figure), a MISR to compact responses of the CUT, a comparator, a signature register and test control logic. The testing procedure is controlled and observed through functional ports of the circuit [1]. The effectiveness of BIST solutions is determined by the chip area overhead, the performance degradation that the BIST architecture

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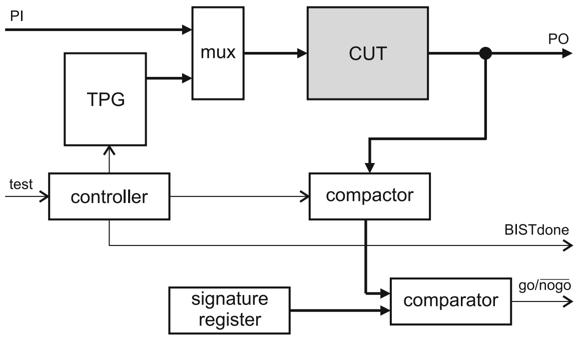



**Fig. 1** Conventional BIST architecture

causes and the achieved fault coverage. The amount of the area overhead depends on how much of the required hardware is already present in CUT for reuse.

Many general purpose computing structures based on datapath architectures or digital signal processing circuits contain lots of arithmetic and logic units. Available functional blocks can be utilized to generate test patterns and compact test responses. The advantage of this method in comparison with conventional BIST based on LFSR is thus in reuse of existing on-chip modules. An accumulator-based scheme with a procedure of finding maximum length sequences for bit-serial TPG is presented in [2]. A test response compaction in accumulators has been proposed by [3]. The hardware overhead required is only 1-bit register for the feedback between carry-out and carry-in modifying the circuit to operate as the rotate carry adder. A novel test technique achieving C-testable DfT design for arithmetic circuits based on the proposal of basic bijective cells for adder, subtracter, adder-subtracter and multiplier (one-to-one mapped I/O function) is presented in [4]. All the proposed arithmetic DfT designs can be cascaded and tested together for saving lots of test pins and area overhead. Evaluation of previously proposed test approaches and possible modification for higher test coverage are discussed in [5]. The method published in [6] improves techniques for concurrent BIST based on deterministic test. Test patterns are generated with a small number of specified bits, therefore the test length and fault detection latency is very low. The large number of unspecified bits results also in lower area overhead.

The mentioned digital data processing architectures usually comprise of several stages interconnected with sequential elements. Each stage includes variety of combinational blocks, e.g. adders, dividers, logic blocks. Another common feature of digital data processing circuits is the high number of peripheral ports. A digital data processing circuit can be characterized by $n$-bit computational precision which represents bit width of the processed data. An example of this kind of data processing architecture can be the MDCT computational block. MDCT is the basic processing block for high-quality audio compression in the international audio coding standards and commercial audio compression algorithms used in many modern audio compression systems for time-to-frequency transformation of digital signals [7]. Forward and backward MDCT computations are the most computationally intensive operations of the well-known audio coding standards [8].

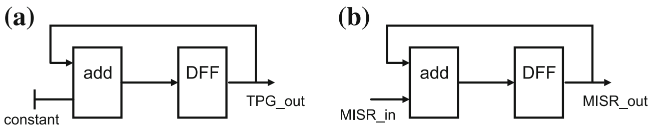



**Fig. 2** Example of **a** pseudo-random TPG and **b** MISR

A new BIST method is proposed in this paper for digital data processing circuits. The advantage of the proposed method is lower area overhead than for the conventional BIST. Our approach implements the most area consuming BIST blocks utilizing circuit functional blocks and appends on-line testing blocks for both TPG and MISR as well. Some existing circuit blocks are reconfigured for test pattern generation and test response compaction. The circuit after the partitioning is tested mutually by its subparts. The results show significant area reduction and negligible fault coverage loss in comparison with the conventional BIST. The proposed method was evaluated on a processing stage of universal MDCT IP core optimized for MP3 audio standards [9].

The rest of the paper is organized as follows. In Sect. 2 the new proposed BIST method is described. The achieved results are presented in Sect. 3. Section 4 concludes the paper.

## 2 Proposed Method

The design of the proposed BIST architecture method comprises of several steps: (1)TPG design, (2) MISR design, (3) Circuit testing partitioning, (4) On-line parity checking for sequential blocks, (5) Comparator with signature register(s) design.

The main idea is to reconfigure the circuit in the testing mode in order to create TPG and MISR using existing functional parts. Each of these BIST parts needs one sequential block and one combinational block (e.g. adder) both with identical bit width. General architectures are shown in Fig. 2. TPG generates test vectors from the previous vector and a constant value. The arithmetic function depends on the used functional block. MISR also uses the feedback as one operand, but the second operand is the circuit response. The MISR and TPG design determine whether the circuit needs to be tested by more test sequences or not. The last two steps of the proposed method are ensuring on-line testing by parity check for sequential blocks and test response evaluation.

### *2.1 Test Pattern Generation*

TPG of the proposed method is based on adders already present in CUT. Therefore, the area overhead is not significant. The adders are reconfigured in the testing mode and used for test generation based on incrementation of the initial value by a previously determined constant value.

Sequential blocks are required for storing the intermediate results but the bit allocation condition is not as strict as for the MISR design. The required TPG width is estimated by the following definition.

**Definition 1**. *The minimal bit width of TPG is* $n$ if $2^n \gg D$, *where* $n$ *is the processed data bit width and* $D$ *is the deterministic test length.*

The quality of pseudo-random test vectors generated by the proposed TPG depends on the functional block and the selected constant which is used as the second operand of the addition. This constant is circuit independent and determined as follows. Every $2^n$ possible constant values are examined as possible operand for the adder-based TPG, where $n$ is the TPG width. For every constant value a predetermined test of length $L$ is assembled and the proposed distribution estimate $k_{dist}$ is computed. The test length is selected based on the deterministic test length and represents an estimation of the final pseudo-random test length.

**Definition 2**. *The estimated test length* $L$ *for the adder-based TPG is greater or equal than* $3 \times D$, *where* $D$ *is the deterministic test length.*

Constant values with the lowest distribution estimates are considered as possible operands for the TPG because those constant values will generate test with the best value distribution.

The distribution estimate $k_{dist}$ for TPG of width $n$ and test length $t$ is computed as follows. Let

$$\mathbf{p} = \begin{pmatrix} p^{(0)} \\ p^{(1)} \\ \vdots \\ p^{(t-1)} \end{pmatrix} = \begin{pmatrix} p_0^{(0)} & p_1^{(0)} & p_2^{(0)} & & p_{n-1}^{(0)} \\ p_0^{(1)} & p_1^{(1)} & p_2^{(1)} & & p_{n-1}^{(1)} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ p_0^{(t-1)} & p_1^{(t-1)} & p_2^{(t-1)} & & p_{n-1}^{(t-1)} \end{pmatrix}$$

be the test of length $t$, where $p_m^u \in \{0,1\}$ is a bit of test pattern $p^u \, \forall u \in \{0,1,,t-1\}$ and $\forall m \in \{0,1,,n-1\}$. Let

$$\mathbf{fv} = \begin{pmatrix} fv_{(0,0)} & fv_{(0,1)} & & fv_{(0,n-1)} \\ fv_{(1,0)} & fv_{(1,1)} & & fv_{(1,n-1)} \\ \vdots & \vdots & \ddots & \vdots \\ fv_{(t-2,0)} & fv_{(t-2,1)} & & fv_{(t-2,n-1)} \end{pmatrix}$$

be the vertical flipping matrix of test $\mathbf{p}$, where $fv_{(i,j)} = l - i$ with $l > i : p_j^{(l)} \neq p_j^{(i)} \wedge p_j^{(k)} = p_j^{(i)} \, \forall k \in \{i+1, i+2,, l-1\}$, $\forall i \in \{0,1,,t-2\}$ and $\forall j \in \{0,1,,n-1\}$. Let

$$\mathbf{fh} = \begin{pmatrix} fh_{(0,0)} & fh_{(0,1)} & & fh_{(0,n-2)} \\ fh_{(1,0)} & fh_{(1,1)} & & fh_{(1,n-2)} \\ \vdots & \vdots & \ddots & \vdots \\ fh_{(t-1,0)} & fh_{(t-1,1)} & & fh_{(t-1,n-2)} \end{pmatrix}$$

be the horizontal flipping matrix of test $\mathbf{p}$, where $fh_{(i,j)} = o - j$ with $o > j : p_o^{(i)} \neq p_j^{(i)} \wedge p_q^{(i)} = p_j^{(i)} \, \forall q \in \{j+1, j+2, , o-1\}$, and $\forall i \in \{0, 1, , t-1\}$ and $\forall j \in \{0, 1, , n-2\}$. The distribution estimate $k_{dist}$ of test $\mathbf{p}$ with vertical flipping matrix $\mathbf{fv}$ and horizontal flipping matrix $\mathbf{fh}$ is computed as

$$k_{dist} = \sum_{b=0}^{n-1} \sum_{a=0}^{t-2} fv_{(a,b)} + \sum_{d=0}^{n-2} \sum_{c=0}^{t-1} fh_{(c,d)}.$$

The principles of the proposed test method for designing BIST are ilustrated with a representative data processing stage denoted as DPS (Fig. 3). The stage has sixteen 16-bit functional inputs and two 16-bit functional outputs. The combinational blocks included in the stage are 6 adders, 3 subtracters, 4 multipliers and one XOR block. Two 16-bit registers are placed at the end of the stage.

The deterministic test of length 313 for DPS in Fig. 3 was generated by ATALANTA [10]. The stage computational precision $n$ is 16. In this case $2^{16} = 65,536$ is very much greater than 313, so the TPG width can be 16. The only one 16-bit wide sequential block is used together with the TPG as shown in Fig. 2a. Every $2^{16}$ possible constant value was examined as possible operand in addition, and the predetermined test of length 1000 was used during distribution estimate computations. The three best constant values were determined as 43,691, 21,845 and 43,693.

*Example* Let assume $n = 4$ for TPG width, $t = 5$ for test length. If constant values 7 and 4 are given for comparison, then the tests are the following:

$$\mathbf{p(7)} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \end{pmatrix}, \quad \mathbf{p(4)} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}.$$

The flipping matrices for constant value 7 are

$$\mathbf{fv(7)} = \begin{pmatrix} 2 & 1 & 1 & 1 \\ 1 & 4 & 2 & 1 \\ 1 & 3 & 1 & 1 \\ 1 & 2 & 2 & 1 \end{pmatrix}, \quad \mathbf{fh(7)} = \begin{pmatrix} 4 & 3 & 2 \\ 1 & 3 & 2 \\ 3 & 2 & 1 \\ 1 & 1 & 1 \\ 2 & 1 & 2 \end{pmatrix}.$$

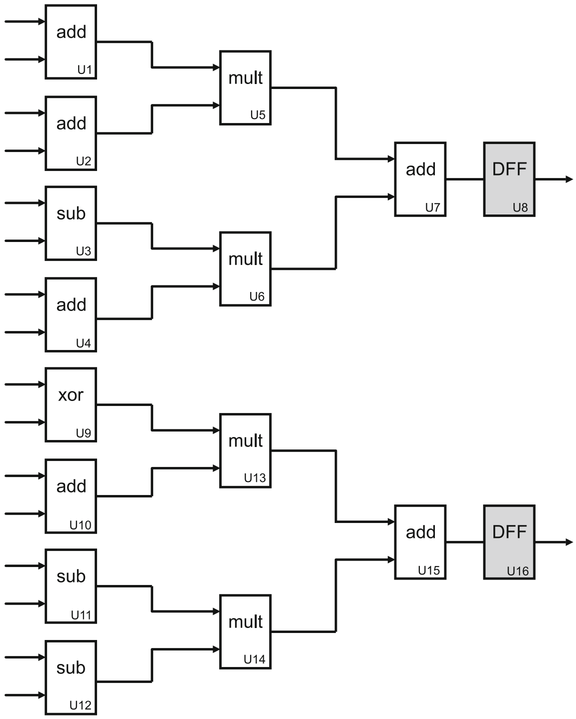



**Fig. 3** Representative data processing stage (DPS)

The flipping matrices for constant value 4 are

$$\mathbf{fv}(\mathbf{4}) = \begin{pmatrix} 2 & 1 & 5 & 5 \\ 1 & 1 & 4 & 4 \\ 2 & 1 & 3 & 3 \\ 1 & 1 & 2 & 2 \end{pmatrix}, \quad \mathbf{fh}(\mathbf{4}) = \begin{pmatrix} 4 & 3 & 2 \\ 1 & 3 & 2 \\ 1 & 3 & 2 \\ 2 & 1 & 2 \\ 4 & 3 & 2 \end{pmatrix}.$$

The distribution estimates are $k_{dist}(7) = 25 + 29 = 54$ and $k_{dist}(4) = 38 + 35 = 73$. The distribution of values for TPG with constant value 7 will be better because $k_{dist}(7) < k_{dist}(4)$, therefore it will probably generate the test with a higher fault coverage.

TPG designed according to Definition 1 is in most cases shorter than the total width of circuit inputs. In that case TPG outputs are distributed in the way that horizontal distribution provided with the determined constant remain unchanged. Table 1 shows four TPG outputs connections $c0, c1, c2, c3$ for DPS. TPG output is 16-bit wide and the circuit inputs are also 16-bit wide. *tpg_0* represents TPG outputs in standard order. *tpg_n* represents TPG output rotated right by *n* bits.

**Table 1** Examples of different TPG output connections

| Connection | c0 | c1 | c2 | c3 |
|---|---|---|---|---|
| *input*1 | *tpg*_0 | *tpg*_15 | *tpg*_10 | *tpg*_11 |
| *input*2 | *tpg*_1 | *tpg*_14 | *tpg*_12 | *tpg*_15 |
| *input*3 | *tpg*_2 | *tpg*_13 | *tpg*_14 | *tpg*_13 |
| *input*4 | *tpg*_3 | *tpg*_12 | *tpg*_15 | *tpg*_10 |
| *input*5 | *tpg*_0 | *tpg*_11 | *tpg*_13 | *tpg*_8 |
| *input*6 | *tpg*_1 | *tpg*_10 | *tpg*_11 | *tpg*_12 |
| *input*7 | *tpg*_2 | *tpg*_9 | *tpg*_9 | *tpg*_6 |
| *input*8 | *tpg*_3 | *tpg*_8 | *tpg*_0 | *tpg*_4 |
| *input*9 | *tpg*_0 | *tpg*_15 | *tpg*_10 | *tpg*_11 |
| *input*10 | *tpg*_1 | *tpg*_14 | *tpg*_12 | *tpg*_15 |
| *input*11 | *tpg*_2 | *tpg*_13 | *tpg*_14 | *tpg*_13 |
| *input*12 | *tpg*_3 | *tpg*_12 | *tpg*_15 | *tpg*_10 |
| *input*13 | *tpg*_0 | *tpg*_11 | *tpg*_13 | *tpg*_8 |
| *input*14 | *tpg*_1 | *tpg*_10 | *tpg*_11 | *tpg*_12 |
| *input*15 | *tpg*_2 | *tpg*_9 | *tpg*_9 | *tpg*_6 |
| *input*16 | *tpg*_3 | *tpg*_8 | *tpg*_0 | *tpg*_4 |

## 2.2 Signature Computation

MISR is connected to the outputs of CUT in the conventional BIST architecture. In a digital data processing circuit the sequential blocks are usually located at the end of the stages. Therefore, their use as MISR is obvious. However, the sequential block allocation has one condition. For every bit of the circuit (stage) outputs one bit in the sequential block has to be allocated. This condition guarantees that MISR aliasing would be at acceptable level [1].

## 2.3 Circuit Test Partitioning and On-Line Parity Checking

The test partitioning mainly depends on the quantity of sequential blocks presented in CUT. Not every CUT has enough functional sequential blocks for TPG and MISR simultaneously.

**Definition 3**. *If $a + b > N_{sq}$, where $N_{sq}$ is the number of all sequential bits presented in circuit, a is the number of sequential bits needed for TPG, and b is the number of sequential bits needed for MISR, then the circuit cannot be tested by one test sequence without additional sequential blocks.*

In this case the circuit has to be tested with additional sequential blocks and/or by several test sequences which is determined by the next definition.

**Definition 4**. *The number of test sequences needed for circuit testing is* $L = \lceil (a + b)/N_{sq} \rceil$.

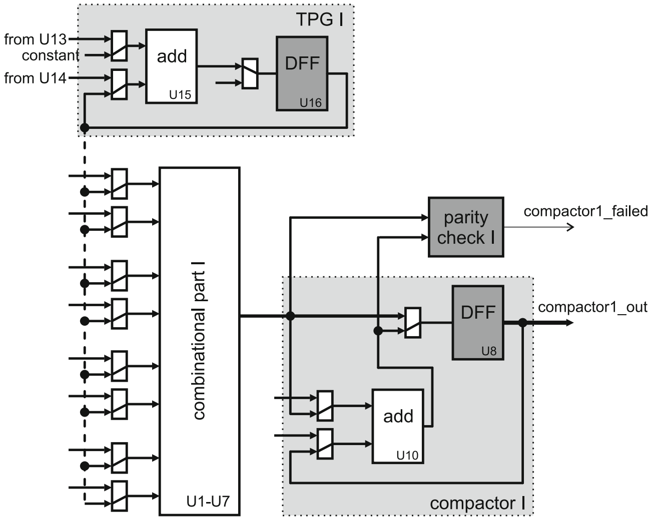



**Fig. 4** First testing sequence configuration for DPS

The goal of the proposed method is to design a minimal test architecture for a data processing circuit. Therefore, no additional sequential block is allowed to be inserted. Both testing blocks have to be constructed with additional conditions $a < N_{sg}$ and $b < N_{sq}$ added to the expression in Definition 4. The allowed number of test sequences without any additional area overhead is determined as $L \leq 2$.

If circuit testing is divided into several test sequences the sequential blocks are used in different testing modes. In the first test sequence the block can be used as part of TPG and in the next test sequence as part of MISR.

*Example* In the case of DPS $a = 16$, $b = 32$ and $N_{sq} = 32$. Then the number of test sequences $L = \lceil (16 + 32)/32 \rceil = 2$. The number of sequential bits needed for MISR is also 32. All available sequential bits in the circuit are 32.

Testing of DPS is divided into two test sequences. Combinational blocks $U1toU7$ are tested in the first test sequence and blocks $U9$ *to* U15 in the second. The test configuration for the first sequence is shown in Fig. 4. TPG is created from adder $U15$ and 16-bit sequential block $U16$. The TPG output is driven into all functional inputs. The dotted line symbolizes different bit connections in each functional input. MISR is created from the second 16-bit sequential block $U8$ and adder $U10$ from other part of the circuit. In the second test sequence the functions of sequential blocks are switched. The block $U8$ is used in TPG for the second eight 16-bit inputs and the block $U16$ is used in MISR for the second output.

Sequential blocks are used for testing of remaining combinational blocks. Even if the circuit testing is divided into several test sequences, sequential blocks are not properly tested. If a fault appears in a sequential block used in TPG or MISR there is a possibility that a test can not detect this fault. For that reason, each sequential

**Fig. 5** On-line test structure for **MISR**

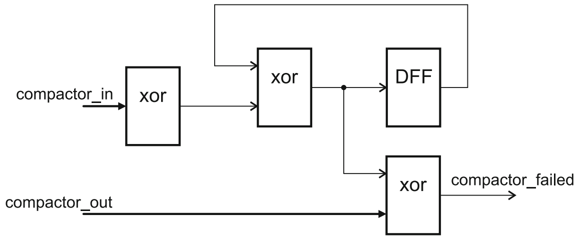
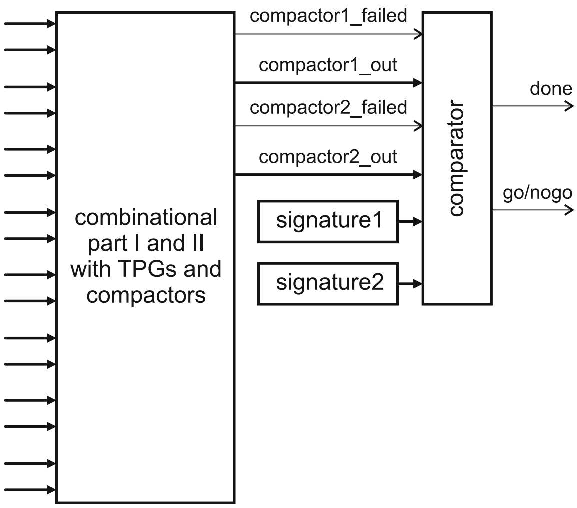



**Fig. 6** Proposed method applied on DPS




block used in MISR has to be enriched by an on-line test structure (Fig. 5). The on-line test structure computes parity bit from actual response of the circuit and from a parity of all previous responses. Parity checking blocks are also added into testing architecture for DPS. In each test sequence one parity checking block is used (parity check I block for the first test sequence is shown in Fig. 4).

The last step of the proposed method is design of the comparator and signature register(s). These blocks are similar with conventional BIST blocks. The number of signature registers is equal to the number of test sequences. In the case of more test sequences the signature is compared with the actual response at the end of each test sequence. Therefore, the comparator has to be slightly adapted for more than one comparison. The testing of DPS was divided into two test sequences, therefore the circuit has to incorporated two signature registers. The whole circuit designed with the proposed method is shown in Fig. 6.

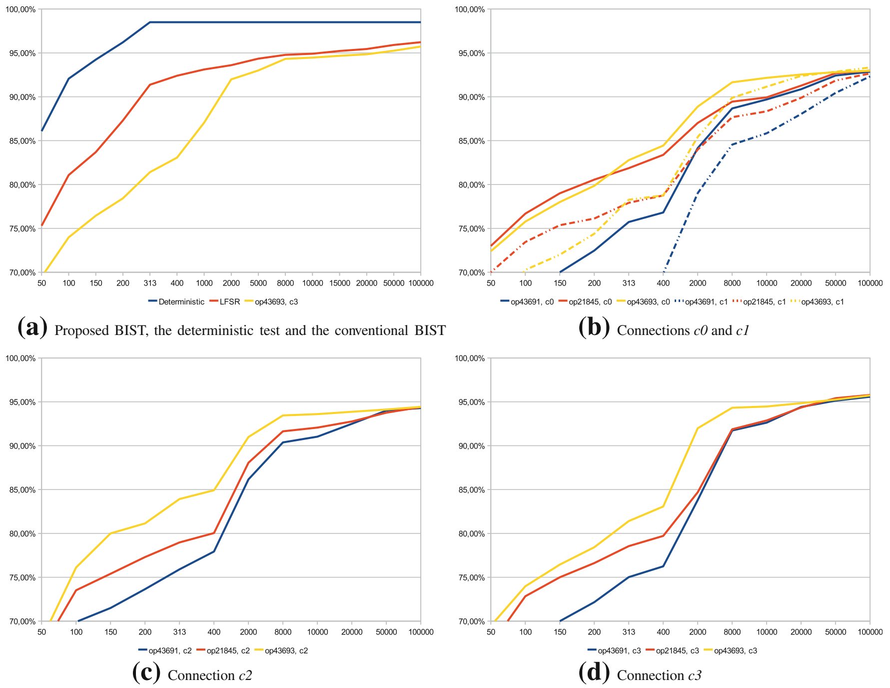
**Table 2** stuck-at fault coverage comparison

| Fault coverage as function of test length | 313 | 8,000 | 10,000 | 20,000 | 50,000 |
|---|---|---|---|---|---|
| ATALANTA (%) | 98.50 | | | | |
| LFSR (%) | 91.37 | 94.78 | 94.91 | 95.44 | 95.91 |
| $op43691, c0$ (%) | 75.73 | 88.67 | 89.70 | 90.86 | 92.42 |
| $op21845, c0$ (%) | 81.87 | 89.45 | 89.93 | 91.27 | 92.69 |
| $op43693, c0$ (%) | 82.78 | 91.65 | 92.16 | 92.54 | 92.81 |
| $op43691, c1$ (%) | 68.87 | 84.55 | 85.84 | 88.04 | 90.45 |
| $op21845, c1$ (%) | 77.92 | 87.68 | 88.34 | 89.88 | 91.85 |
| $op43693, c1$ (%) | 78.27 | 89.89 | 91.15 | 92.39 | 92.85 |
| $op43691, c2$ (%) | 75.90 | 90.37 | 91.03 | 92.49 | 94.00 |
| $op21845, c2$ (%) | 78.97 | 91.64 | 92.06 | 92.76 | 93.76 |
| $op43693, c2$ (%) | 83.92 | 93.45 | 93.60 | 93.86 | 94.12 |
| $op43691, c3$ (%) | 75.02 | 91.73 | 92.62 | 94.42 | 95.13 |
| $op21845, c3$ (%) | 78.55 | 91.87 | 92.87 | 94.35 | 95.41 |
| $op43693, c3$ (%) | 81.41 | 94.32 | 94.47 | 94.84 | 95.25 |

## 3 Results

Three main parameters were observed during the evaluation of the proposed method: (1) stuck-at fault coverage, (2) test length and (3) area overhead. Table 2 shows the test coverage results for DPS. The deterministic test generated by TPG ATALANTA [10] has 98.50 % stuck-at fault coverage achieved with 313 test patterns. The stuck-at fault coverage of the proposed method is also compared to a 256-bit pseudo-random LFSR. In the table there are 12 different TPG configurations created as the combination of three different operands $op43691, op21845, op43693$ and four types of TPG output connections $c0, c1, c2, c3$. The fault coverages are shown in Fig. 7. The proposed BIST achieves lower fault coverages than the conventional BIST with the deterministic test length (313) but after the increase of test length this difference becomes less significant. The results achieved with TPG configuration $op43693, c3$ are practically as good as the results of LFSR-based TPG achieved with the same test length (approximately by only 0.6 % less stuck-at fault coverage). These fault coverages are compared also in Fig. 7a where this difference is significantly reduced at test length 2,000 and becomes negligible at test length 8,000. The length 20,000 was selected based on a predetermined fault coverage acceptation level. Usually, the fault coverages of every operand converge to the same value. The maximum coverage can be influenced mainly by the used TPG connection. This can be seen in Fig. 7b, c, d also where the same connection type (independently on the operand) around test length 50,000 achieves the same fault coverage.

Table 3 shows the area overhead comparison of the proposed BIST and the conventional BIST for DPS. The comparison was done for implementations into three different technologies TSMC 0.35$\mu$, AMI 1.2$\mu$ and SCL 0.5$\mu$. BIST designed according to the proposed method has in all cases significantly smaller area overhead (at least 39.71 %) than the conventional BIST architecture.




**(a)** Proposed BIST, the deterministic test and the conventional BIST **(b)** Connections *c0* and *c1*

**(c)** Connection *c2* **(d)** Connection *c3*

**Fig. 7** Stuck-at fault coverages for DPS

The proposed method was evaluated also on a processing stage of universal MDCT IP core optimized for MP3 audio standards [8, 9]. The IP core computes 36-points forward and backward MDCT. It has 36×16-bit inputs, 36 × 20-bit outputs, 42 × 18-bit internal constants and hardware architecture with multi-stage computation. The operands $op43691$, $op21845$, $op43693$ used for DPS were also efficient for MDCT. The results are shown in Table 4. The proposed BIST with configuration $op43693, c1$ achieved almost the deterministic stuck-at fault coverage 86.73 % with reasonable test length 1,000. The area overhead was even less significant than for DPS because this circuit is bigger than DPS and the area overhead of BIST architectures depends not on the size but on the number of inputs and outputs.

## 4 Conclusion

A new BIST method was proposed in this paper for digital data processing circuits. On-line and off-line testing capabilities are connected to ensure more reliable testing. Some existing circuit blocks are reconfigured for test pattern generation and test response compaction. The experiments show practically the same stuck-at

**Table 3** Area comparison

| | BIST (gates) | Attached BIST (gates) | Difference (%) |
|---|---|---|---|
| TSMC 0.35$\mu$ | 2,336 | 855 | -63,40 |
| AMI 1.2$\mu$ | 2,731 | 1,609 | −41,08 |
| SCL 0.5$\mu$ | 5,193 | 3,131 | −39,71 |

**Table 4** Stuck-at fault coverage comparison for MDCT

| Fault coverage as function of test length | | | |
|---|---|---|---|
| | 200 | 500 | 1,000 |
| TPG (%) | 86.73 | | |
| $op21845, c0$ (%) | 58.65 | 61.73 | 63.92 |
| $op43691, c0$ (%) | 63.36 | 66.31 | 68.20 |
| $op43693, c0$ (%) | 66.96 | 74.22 | 78.58 |
| $op21845, c1$ (%) | 79.70 | 82.44 | 84.55 |
| $op43691, c1$ (%) | 78.97 | 83.59 | 85.07 |
| $op43693, c1$ (%) | 80.35 | 83.27 | 85.69 |

fault coverage (0.6 % less) than for conventional BIST independently of the test length and markedly smaller area overhead (39.71–64.30 %) according to the implementation technology. The proposed method was evaluated on a processing stage of universal MDCT IP core with similarly convincing results.

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# Dynamic Web Service Composition with MDE Approaches and Ontologies

**Eduardo D. C. Bezerra, Denivaldo Lopes and Zair Abdelouahab**

**Abstract** The use of the Internet as a way to publish new applications and deliver new functionalities has consolidated the Service Oriented Architecture (SOA) and web services technology for creating software systems. Once web services technology enables a high degree of autonomy and interoperability, it provides the atomic elements for development of large distributed software systems following a SOA philosophy. Thanks to SOA, web services can be composed and reused through a composition process for creating a new service with new functionalities. However, SOA is not enough to concept and design complex software systems. Recently, new paradigms are being developed to deal with the increasing complexity in the development, maintenance and evolution of software systems. Among the new paradigms, Model Driven Engineering (MDE) and the Ontology stands out as the most promising for handling complex software systems. In this paper, we present an approach based on MDE, Ontology and SOA philosophy to concept and design robust software systems and implement them as a composite web service. For this purpose, models powered by ontology and SOA capture the business logics, after these models are transformed in web services or composite web services. When a web service crashes or fails, a dynamic composition process assures reliability thanks to matching of models and web services. A case study is presented to illustrate our approach.

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# 1 Introduction

The web services technology brings considerable benefits to the management of business processes, providing the agility required by enterprises with necessities of quick changes in the business environments [1, 2]. One of the main advantages of using web services is its interoperability, achieved due to the adhesion to standard protocols [3], widely disseminated on the Internet, and the existence of a standard architecture, which defines the mechanisms required for their use. This interoperability allows the combination of services giving rise to other web services.

In fact, web services have become the basis for new initiatives in distributed computing and electronic business because they allow the building of networks of collaborative applications distributed within and between organizations. In this context, web services are self-contained modules, because they are described, published, located and dynamically invoked.

To make the dynamic composition of web services is necessary to have information or metadata about the involved services. This information can be achieved using ontologies and semantic web.

This paper is organized as follows. In Sect. 2 we describe an overview of the composition of web services and their main issues. In Sect. 3 we present ontologies to represent the semantic of web services. In Sect. 4 we introduce Model Driven Engineering, Domain Specific Language and Model-Driven Software Development. In Sect. 5 we present our MDE approach to the dynamic composition of web services. In Sect. 6 we present a case study and its implementation. In Sect. 7 we conclude the paper presenting the final considerations.

# 2 Overview

The combination of atomic web services to perform a certain task, characterizes a composition of web services (*Web Service Composition*). As Fig. 1 illustrates, the communication between the BPEL composition and partner services (WS1, WS2) is given by the invocation (invoke) of an operation directly to the *PortType* element that has the set of all operations of a web service. The *PartnerLink* represents a web service called "partner" and has the location of the servers where the services were published. In the possibility of recurrent absence of WS1 in the composition, there is a necessity to find a new service for replacing it. This new service must have similar characteristics of WS1 in order to be integrated in the composition on an automated and dynamic way.

The Dynamic Composition of Web Services has several unresolved issues. Initially, in an attempt to discover a new service considering its specific aspects (information), emerges the challenge of handling and differentiating many characteristics of services within a set (or repository) of services. These characteristics are often complex or poorly described (e.g. using WSDL) and even misunderstood.

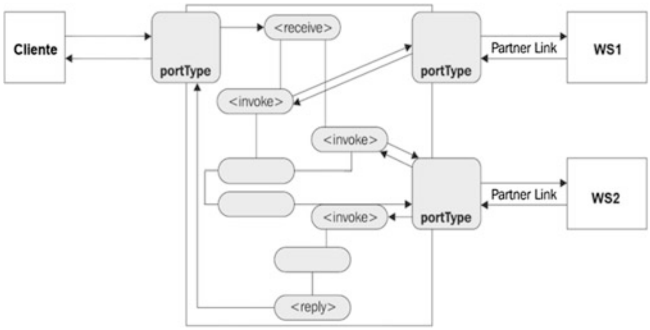



**Fig. 1** A composite web service: BPEL structure and web services

Later, once a service was discovered, it must be properly reused in a composition process defined in a language like *WS-BPEL*. For this purpose, it is necessary to infer the goals of services and identify the constraints on its applicability and its effects on a system.

## 3 Ontology to Represent the Semantic of Web Services

Ontology can be defined as a data model that represents a set of concepts and their relationships within a domain. For the web, ontology deals with an accurate description of a piece of information on the web and relationships between them. The use of ontologies in the form of more accurate "descriptors", conceptually richer for web services, must attend to the needs of discovery and adequacy, allowing better support for composition. The semantic web, jointly with web services, allows automating the process of discovery, invocation, composition and monitoring of services. Ontology Web Language for Services (OWL-S) is an ontology for services.

Before OWL-S, *Ontology Web Language* (OWL) was designed to provide a common way of processing the information content on the web instead of just displaying them. On the other hand, OWL-S is an ontology/language based on OWL to (formally) describe properties and capabilities of web services. The OWL-S structure is composed of three sub-ontologies with their respective capacities, as shown in Fig. 2.

*ServiceProfiles* has the ability of specification, i.e. general characteristics of services such as quality, category, limitations and description of what is done by the service.

*ServiceModel* defines how to interact with the service, flow control of services, inputs, outputs, conditions and results.

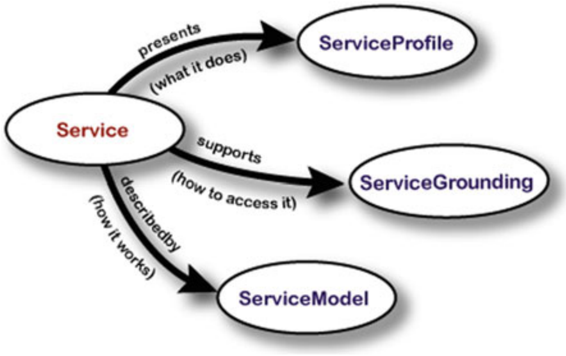



**Fig. 2** High level OWL-S ontology

*ServiceGrounding* defines the requirements to be met in order to execute services, does the mapping for WSDL, deals with communications protocols, defines message format, etc.

## 4 MDE

Recently, new paradigms are being developed to deal with the ever increasing complexity of the development, maintenance and evolution of software. Among these new paradigms, *Model Driven Engineering* (MDE) and Ontologies stand out as the most promising [4–8]. MDE is an additional proposal to the traditional software development process. The difference between MDE and other approaches resides in the artifacts created in the development process that are "formal models", i.e. models that can be understood and then manipulated by computers. MDE is a research domain that includes: transformation language and engine [9], tools for specification of correspondences between models [10, 11], transformation definitions [12, 13] metamodel matching algorithms [11], methodologies [14], processes [15, 16], and the application of MDE on final platforms as Web Services [12, 13, 17].

Some researches [10–13, 15] show that MDE is a promising paradigm for software development. Several organizations (e.g. OMG and the *Eclipse Project*), research institutions and companies encourage the adoption of MDE. Our approach is based on MDE and ontology in order to perform the dynamic composition of web services through model matching. The *Model-Driven Architecture* (MDA) by Object Management Group (OMG) [18–21], the Microsoft Software Factories [22], Eclipse Modeling Framework (EMF) of Eclipse Project [23] and the model management framework proposed by P. Bernstein [24] are examples of MDE. MDA, Software Factories and EMF have conceptual similarities, but differ in technology. For example, MDA uses MOF [25], and UML profiles, while the EMF uses Ecore [23] and favors the creation of the Domain Specific Language (DSL) [26].

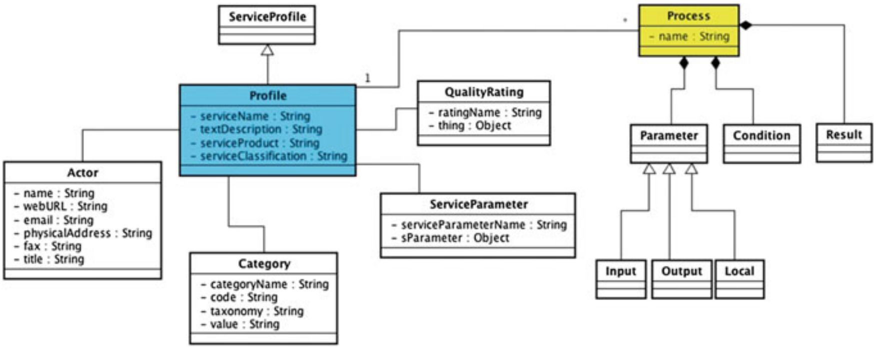



**Fig. 3** Semantic service metamodel

The focus of the *Model-Driven Software Development* (MDSD) is in the development and refinement of models of a particular domain (specific) to provide a standard vocabulary for use in development. DSL Toolkit is a set of tools of Eclipse Modeling Project that enables, besides the definition of a Domain Model (*DSL*), the Software Development with Model Driven mechanisms of creation and generation of tools and artifacts from a DSL (*Tooling*). A important aspect of the success of MDSD is the use of a common metamodel (*EMF Ecore Metamodel*).

## 5 MDE Approach for Dynamic Composition of Web Services

An initial metamodel was designed, as illustrated in Fig. 3, to describe the structural and semantic aspects of services. The service profile is described by the category, quality, additional parameters and service provider classes, i.e. what is performed by the service and non-functional properties. According to this figure, a profile describes one or more processes. A process is defined by its input, output and local parameters, conditions for performing the process and result of execution.

### *5.1 A Framework for Supporting Dynamic Composition*

A framework was designed to achieve the proposed solution for dynamic composition of web services. We organize this framework in three levels (meta-model, model and artifacts) such as presented in Fig. 4.

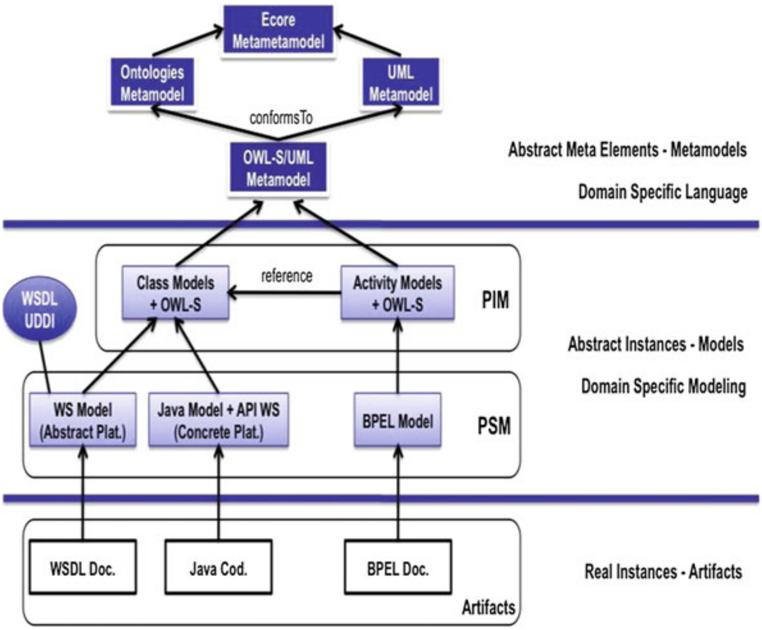



**Fig. 4** Abstraction levels of approach elements

### 5.1.1 First Level: Metamodels

The metamodel level contains our semantic metamodel of web services (OWL-S/UML Metamodel) that describes the semantic and structural aspects that a web service may have. This metamodel has at its essence characteristics of the ontologies and UML metamodels, and it conforms to the Ecore Metametamodel. We remark that at this level we define our domain-specific language (DSL), i.e. the domain of semantics for web service composition.

### 5.1.2 Second Level: Models

At the second, or intermediate level, we have abstract instances captured by our DSL. Specific Domain Models are constructed conform described in our OWL-S/ UML Metamodel. In this level, service models (represented by UML class diagrams) define the semantic aspects conform OWL-S. When services initiate the communication processes, workflow or structural aspects of services are revealed through activity diagrams (Activity Models) with reference to models of semantic services (Class Models). These two models are analogous to the *Platform Independent Model* (PIM) in MDA and from them are generated *Platform Specific Models* (PSM). *WS model* is specific to web service platform, but does not describe the platform as a whole, i.e. describes only semantic information not previously

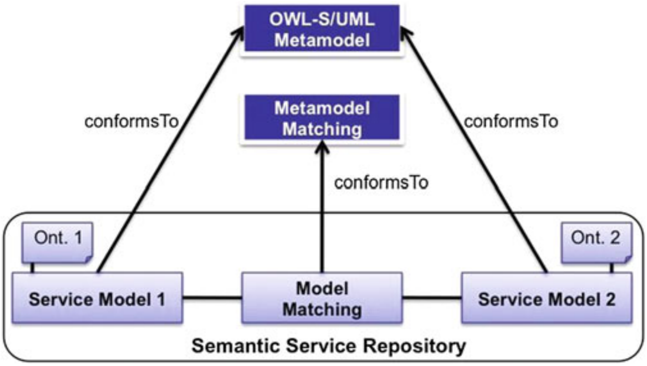



**Fig. 5** Generation tools and artifacts

considered by this platform. Therefore, *WS Models* cover the abstract part of web service platform, not discarding the WSDL that describes the concrete part of services such as *types, message, operation, port type, binding*. Such *WS Models* plus WSDL that will be published, located and compared on a repository (UDDI). On the other hand the Java plus Web Services API models describe the platform, i.e. a concrete platform. The last model, on this second level, is specific to Business Process Enterprise Language (BPEL) and is conform to the *Activity Model*.

#### 5.1.3 Third Level: Artifacts

The artifact level contains real instances based on the platform specific models and domain-specific models. These artifacts are WSDL documents from web services of a domain, BPEL documents with the interactions between the business process or web services and, finally, artifacts like Java code according to the web service API.

### *5.2 A Tool for Supporting Dynamic Composition*

Figure 5 presents an overview of the tool's role for supporting dynamic composition, based on our DSL and service models. This figure also illustrates how the service models are used to perform the matching of models.

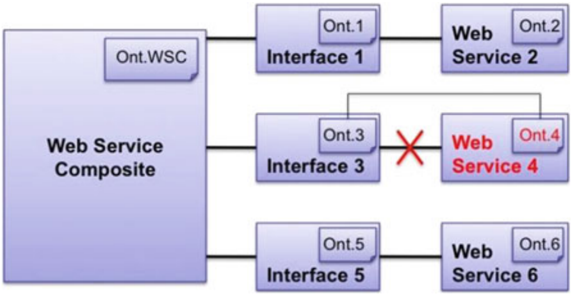



**Fig. 6** Web service, interface and ontology

### 5.2.1 Semantic Service Repository: Service Models

The semantic service repository will contain the service models created according to our semantic metamodel (*OWL/UML Metamodel*). Each service model has its corresponding ontology and its elements are related with elements of other service models through a *Model Matching*.

### 5.2.2 Model Matching: Structural and Semantic Aspects

In matching process, semantic and structural aspects of the services are compared using the models of services. Such comparison is achieved through the mapping or relationship between elements of two models according to their similarities. The result is a *Matching Model* containing all correspondences, and this model is generated according to its metamodel of mapping (or *Metamodel Matching*). After a service or list of services is found and according to the requirements specified by the service that failed, then is done a process similar to the mapping of elements. But now, as illustrated in Fig. 6, we will be mapping the signatures of operations (interface) of the problematic service with the service selected in the matching in order to generate a new BPEL fragment with the substitute service on the BPEL composition.

Up to this point, we remark that the models that represent the services must be linked on a way to reflect constantly the current state of the composition. If there are changes of services, their representations (or models) must be also changed. For this purpose, a runtime model can potentially support semantic integration of heterogeneous software elements at runtime—for example, dynamically adaptable metamodels—in the domain of systems of systems [27]. Runtime models can also assist in the automated generation of implementation artifacts that will be inserted into the system during execution and even by the system itself [28]. Finally, runtime models provide “abstractions of runtime phenomena” [29] and different stakeholders can use them in different ways [30].

**Fig. 7** Table of concepts and properties of DSL

| Concept | Property Name | Property Type | Examples |
|---|---|---|---|
| Profile | nameService | String | TravelAgency |
| | textDescription | String | Reserve Travel Packages |
| | serviceProduct | String | Travels |
| | serviceClassification | String | Reserve |
| Actor | name | String | CVC |
| | webURL | String | www.cvc.com.br |
| | email | String | cvc@gmail.com |
| ServiceCategory | categoryName | String | Tourism |
| | code | String | TUR |
| | value | String | Very Used |
| QualityRating | ratingName | String | Confiability |
| | valueRating | String | High |

# 6 Presentation of Case Study and Its Execution

In this section some initial models were proposed and an initial case study was modeled in order to perform testing and validation of the solution.

## *6.1 Designing the Domain Specific Language*

One way to organize the construction of a DSL is to specify its concepts, properties, property types and a real world property of a concept.

Figure 7 shows the designer of language, under the light of the semantic metamodel in Fig. 3, performs the task that aims to define the concepts that will compose the language and uses the DSL toolkit to build support for the specific language. Other roles within the universe of DSL's is the developer of applications, that uses the designed language together with the tools generated from the DSL (*Tooling*) to create applications belonging to the domain of the DSL in question. The latter role is the end user that consumes the programs developed by the developer.

## *6.2 Case Study*

A case study was proposed, according to Figs. 8 and 9, on the field of travel agency services. We have an airline service, travel agency and bank to make payments.

All actions taken in each class can be viewed as services or processes that compose a service. We can see in Fig. 9 that services can be modeled as processes and we can establish a workflow defining the execution order of processes performing a composition of processes.

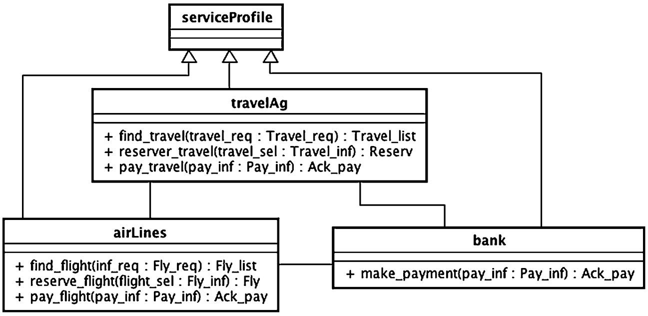



**Fig. 8** Class diagrams of service

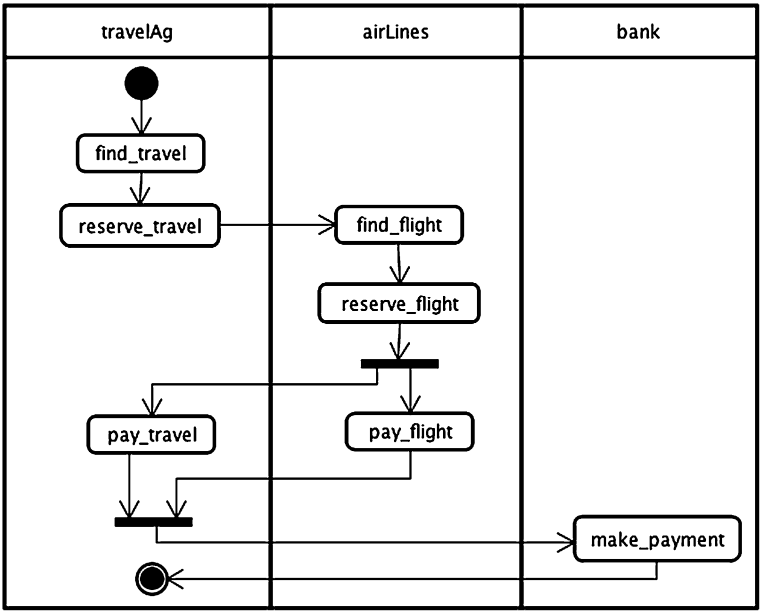



**Fig. 9** Activity diagram of services

## 6.3 Tests

From the proposed metamodel (Fig. 3) we can project the Ecore metamodel that is the base of our DSL of semantic service, as shown in Fig. 10. In addition to semantic features, this metamodel defines processes, their input, output and local parameters, also sets preconditions for performing the process and the results of its execution.

Analyzing in detail the Fig. 10, some classes and properties purposely converge for the domain of travel services, to which our case study is directed. But clearly

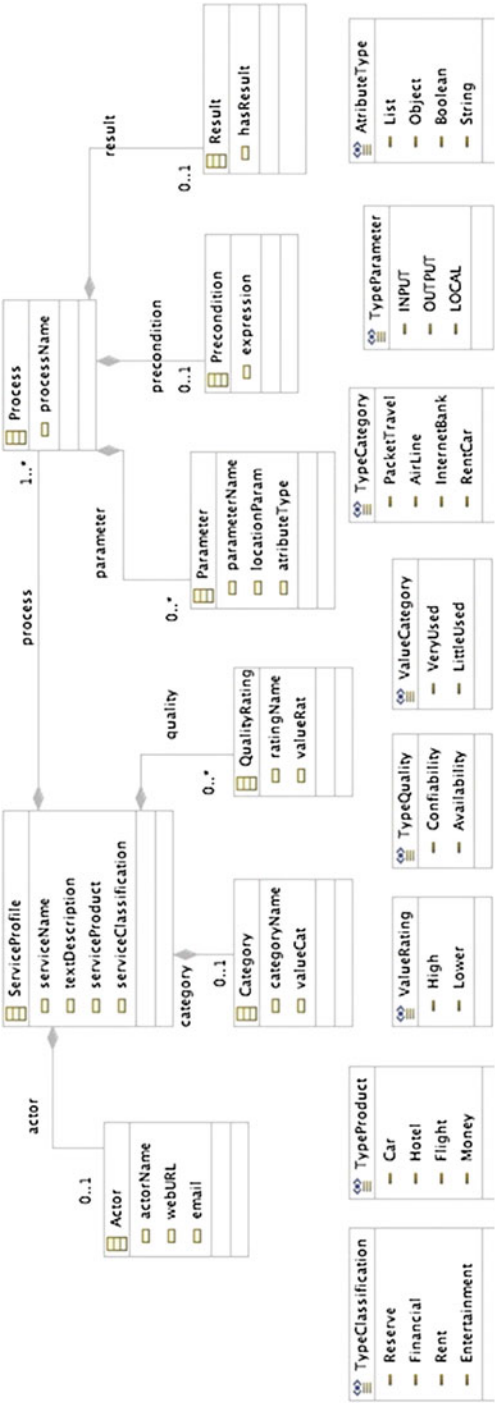



**Fig. 10** Semantic service metamodel on eclipse DSL toolkit

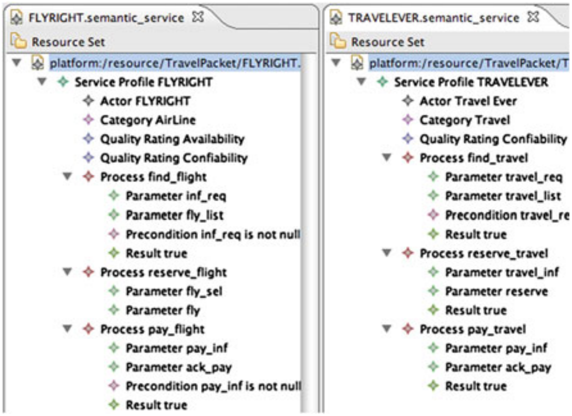



**Fig. 11** Plug-in for semantic services modeling

we can extend our metamodel for any domain of web services. For example, the *ServiceProfile* class has properties like service name, service description and two important parameters, the product to which the service is related and its classification. In the case of *serviceProduct* we created a enumeration type class (*TypeProduct*) that contains the list of products of this travel domain, where is not prohibited inserting products from various domains in the list.

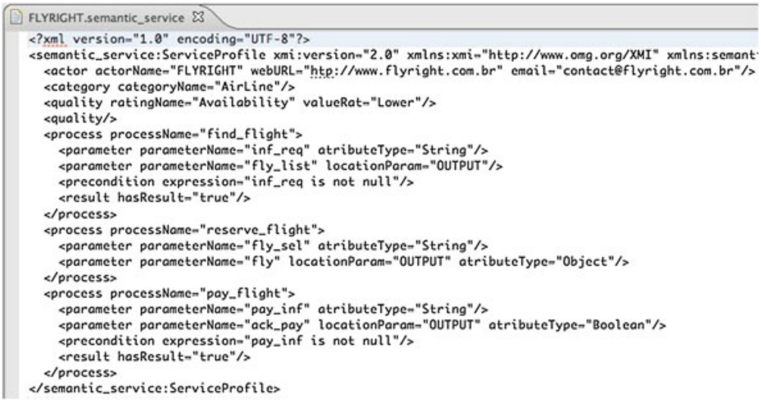
Similarly, we could extend to several domains the type of service classification, define new quality parameters and their values, create new categories and more. Once created the Ecore metamodel, the generator model (*. *genmodel*) is used to produce the corresponding plug-ins. As illustrated in Fig. 11, our generated plug-in allows building semantic models of services and getting their files, as illustrated in Fig. 12, in the format *XML Metadata Interchange* (*.XMI) that enables the exchange of metadata between different modeling tools.

The models created reflect the services of the diagrams on the Figs. 8 and 9. We have two models of web services related with airline services, called FLYRIGHT and FLYNOW, one model related with financial service, called SAFEBANK, and one model of service related with travel agency and reserve of travel packages, called TRAVELEVER. It's worth noticing, that all service models that were built with this plug-in conforms to our Ecore metamodel.

Once the models of web services published in the repository of semantic services, a tool for matching performs the task of creating semantic and structural correspondences between the elements of service models, as illustrated in Fig. 13.

The matching tool has a metamodel of mapping (*Metamodel Mapping*), which is the basis for establishing correspondences between the elements of the models. With the pre-established relations, according to the matching tool, a service is finally selected by analyzing the level of similarity between the semantic and structural features represented in the models.

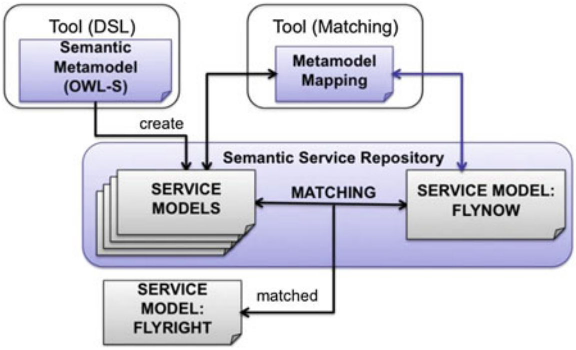
Once the model is selected, the web service it represents must be properly linked to service composition in order to replace the service that failed.



```
FLYRIGHT.semantic_service
<?xml version="1.0" encoding="UTF-8"?>
<semantic_service:ServiceProfile xmi:version="2.0" xmlns:xmi="http://www.omg.org/XMI" xmlns:semant
  <actor actorName="FLYRIGHT" webURL="http://www.flyright.com.br" email="contact@flyright.com.br"/>
  <category categoryName="AirLine"/>
  <quality ratingName="Availability" valueRat="Lower"/>
  <quality/>
  <process processName="find_flight">
    <parameter parameterName="inf_req" atributeType="String"/>
    <parameter parameterName="fly_list" locationParam="OUTPUT"/>
    <precondition expression="inf_req is not null"/>
    <result hasResult="true"/>
  </process>
  <process processName="reserve_flight">
    <parameter parameterName="fly_sel" atributeType="String"/>
    <parameter parameterName="fly" locationParam="OUTPUT" atributeType="Object"/>
  </process>
  <process processName="pay_flight">
    <parameter parameterName="pay_inf" atributeType="String"/>
    <parameter parameterName="ack_pay" locationParam="OUTPUT" atributeType="Boolean"/>
    <precondition expression="pay_inf is not null"/>
    <result hasResult="true"/>
  </process>
</semantic_service:ServiceProfile>
```

**Fig. 12** Service model in XML metadata interchange

**Fig. 13** Matching tool




## 7 Conclusions

This paper presents an MDE approach to dynamic composition of web services. Thus, services are represented by models that reveal semantic and structural aspects. This representation of service models is based and achieved through the ontologies.

A case study related to travel services is proposed in order to validate our approach and verify the use of the created modeling tools. The application of Model Driven Engineering (MDE) jointly with Ontologies have proved to be one of the most promising solutions for dynamic composition of web services, due to the high degree of representation achieved with ontologies (through OWL-S) and due to management of the complexity of development, maintenance and evolution of software achieved with MDE approach (through DSL and Metamodel Matching).

The tool for building models of semantic services based on ontologies has been built according to the Ecore metamodel proposed and is designed by our DSL. The artifacts generated by this tool are inputs, or service models based on ontologies, sometimes used in the model matching engine. Finally, the selected service, due to the best similarity of its model, will be linked with service composition, replacing the problematic service.

**Acknowledgments** The work described in this paper is sponsored by CAPES and FAPEMA through the grant BEPP-0413/10.

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# An Approach Based on Z Language for Formalization of Model Transformation Definition

**Carlos C. G. Mendes, Zair Abdelouahab and Denivaldo Lopes**

**Abstract** The creation of transformation definition is an important step in the process of model transformation in the context of Model Driven Engineering. However, the manual creation of transformation definition is vulnerable to ambiguity due to miss interpretation of the metamodels and their relationships or due to human factors like fatigue. In this paper, we propose an approach based on the Z formal language for specifying the transformation definition. Firstly, transformation rules are specified in Z language, and then validated by a testing tool called Z/EVES that supports statements in first-order predicate logic and set theory. Afterwards, the formalism in Z is translated in a transformation language such as ATL. An illustrative example is provided in order to demonstrate our approach.

## 1 Introduction

The development, maintenance and evolution of software systems have become a complex task. Several approaches have emerged as a viable alternative to manage complexities that appear during development. Among these approaches, Model Driven Engineering (MDE) has been accepted to manage the software system

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complexity. MDE uses models in the center of the development, maintenance and evolution of software systems [1].

Recently, many technological areas have adopted MDE like telecommunication, health and manufacture. The concepts of model, metamodel and transformation have been utilized to improve software development process. However, some elements of the MDE such as model, metamodel and transformation are inaccurate, because they contain ambiguity in their informal representation, especially when it comes to transformation.

For example, in "MDA Guide Version 1.0.1" [1] and "MDA Explained" [2] this concept is represented differently. The concept of a `transformationDefinition` in "MDA Explained", appears as `transformationSpecification` in "MDA Guide Version 1.0.1". This can result in confusion and wrong interpretations in the future by the reader, regarding the transformation between metamodels.

These models can be used to obtain simple answers to particular situations. However, it is not possible to obtain complex answers to complex questions that are not addressed by the models in question. Therefore, we are researching a formal approach to represent the transformation in MDE, through a methodology built supported by the formal specification of Z language [3]. The goal of the methodology is to describe formally the transformation between metamodels, thus avoiding ambiguity in interpretation, regardless of the context of the model.

This paper is organized in the following way. The first section gives the introduction. The second section describes some related works to substantiate our ideas. The third section describes the MDE and the formal specification of the Z language. The fourth section introduces the proposed solution to the problem of ambiguity for representing the transformation between metamodels and it also gives an illustrative case study. Finally the conclusions are given in the fifth section.

## 2 Related Work

In this section we discuss some works that use Z language to specify systems and increase the accuracy of applications.

Jean-Marie Favre [4] describes how language Z can help to understand the concepts of MDE and their relationships. And proposes a model of MDE concepts called megamodel.

Durga Kakollu et al. [5] proposes a specification in Z from the functional and non-functional and the relationship between them, as these requirements are not well described by the informal representation of stereotypes *Extend* and *Include*. In this work, the authors are still developing a tool to check the consistency of requirements and simulate the behavior of the system.

Maryam Shahreza et al. [6] describe how to create tables of appropriate databases, and SQL code that implement the Z specification based on UML diagrams made by the methods of Robert's [7]. This approach created some rules that translate Z specifications in SQL, making more accurate code for SQL. In this work, Z is treated as a specification language and SQL as the implementation language.

Miyazawa [8] develops a methodology that allows from Z to produce an implementation in Java code from Z specification, focusing on generating a skeleton of a Java application and instrumentation of that skeleton with mechanisms of verification and validation of the provided specifications. At the end of the work, it was considered a tool that partially implements this methodology.

These studies were used to support our approach and propose a methodology that will develop the transformation between models through the Z specification language.

# 3 Overview

## *3.1 Model Driven Engineering*

The MDE approach uses models at the center of software development providing benefits such as: reducing costs and time in software development; and improving the final quality of software products.

The relevance of models in MDE is not only to use them in a single phase of software development, but in all stages. Thus a model used in a step can be reused in another, bringing quick and efficient responses to meet the unexpected needs of new requirements both functional and non-functional, providing a better and faster adaptation of new technologies and integration of software developed on various platforms [9].

In MDE, the language used to create models is described by a metamodel, i.e. that comes before the model. A metamodel is a model that defines a language to express a model [10]. It is simply a model of the modeling language. It defines the semantics and constraints for a family of models [11].

The metamodel is expressed by a metametamodel. A metametamodel is a model that defines a language for expressing metamodels. The relationship between a metamodel and a metametamodel is similar to the relationship between a metamodel and a model [10]. There is also the platform that is a set of subsystems and technologies that provide a coherent set of functionalities through interfaces and specified usage patterns [9].

Among the standard technologies that were developed in MDE approach, we find MDT (Drive Model Testing) from IBM and MDA (Model Driven Architecture) from OMG.

MDA [1] is a standard created and specified by the OMG (Object Management Group) through an MDE approach, to provide a solution for managing the complexity of developing, maintaining and evolving software systems and thus to promote interoperability and portability of these systems.

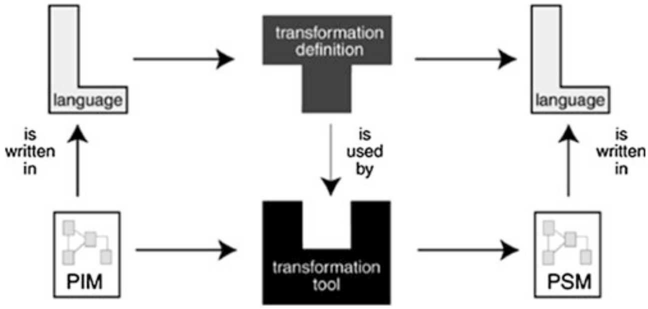



**Fig. 1** Basic MDA framework [2]

MDA is an initiative that spans the generation of code from a model, i.e. an approach in which a system specification is done independently of a platform, and for each of the specific platforms, such a specification can be automatically transformed to a corresponding implementation [1].

MDA allows the construction of computer systems from models that can be understood much more quickly than the "code" of a programming language [11]. Beyond this benefit, MDE also presents advantages such as productivity, portability, and interoperability. These benefits are due to adopt a policy that defines two specific types of models:

- PIM (Platform Independent Model)—this model is independent of any implementation technology. At this level, a system is described without any knowledge of the final implementation platform.
- PSM (Platform Specific Model)—It describes a system with full knowledge of the final platform. It is generated from a PIM via a model transformation.

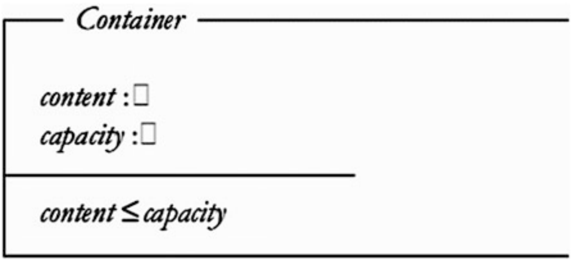
The basic MDA framework is described in Fig. 1.

The architecture of Fig. 1 shows a transformation tool and transformation definition. According to Klepper[10], a model transformation is "a process of converting one model to another model". The transformation process is based on the MDA approach, and after several transformations the goal of the process is achieved, which is the final system code. Thus, we need a well-defined solid language based on a methodology built using formal techniques that avoid ambiguity in its interpretation and representation.

### 3.2 The Z Formal Specification Language

Z was proposed in the late 1970s by Jean-Raymond Abrial [12], and developed during the 1980s by the Programming Research Group at Oxford University. This language is based on a first-order logic and a set theory of Zermelo-Fraenkel.

**Fig. 2** A scheme in Z




Z is a formal specification language used for describing and modeling computer systems. It has an alphabet, a syntax and semantics. The structure of Z specification is done through a *schema*, as shown in Fig. 2, which is decomposed into smaller parts of the specifications [13].

The *schema* is organized in a declarative part which is used to define the data types of the components of the *schema*, and a restrictive part which is used to impose restrictions on the values that the components of the *schema* can take over and establish properties that must be met (invariants). *Schemas* can be used to describe the state of a system and the operations that can change the state of the system [14].

Figure 2 represents an example of a *schema* in Z, where container is the *schema* name, and followed by the declarations of variables, of *Content* and *Capacity*. In the last block, a rule is placed in the form of a predicate logic. In this case, $content \leq capacity$.

In Z, the schema is composed of a formal and an informal part. The formal part is described mathematically whereas the informal part is just a textual description. Both are important. The formal specification provides a precise description of the specified software, while the informal texts provide a better understanding of the specification, thus bridging the real world of mathematical notation [15].

Z has an extension adapted for object-oriented programming, called Object-Z [16]. Where the state variables are considered as instance variables and operations are known as methods. It also introduces some kind of inheritance.

Z uses a mathematical notation, consequently a specification written in Z inherits the properties of mathematics. The formality that exists in mathematics is also incorporated in Z. For example, the schema of Fig. 3 shows the operations in Z and the mathematical relationships between the elements of a system Birthday Book [17].

Although a mathematical proof has a rigid mechanism with respect to ambiguity, there is no guarantee of compelling non-existence of errors in the specification. Errors can occur in various stages of development. However the use of Z in the specification of systems can clarify precisely the system requirements. Thus, we propose to represent the model transformation in the context of MDE through an approach based on the formal Z language to solve the problem of ambiguity in representing graphical and textual model transformations in MDE.

$$
\begin{array}{|l}
\multicolumn{1}{l}{\textit{AddBirthday}} \\
\hline
\Delta \textit{BirthdayBook} \\
\textit{name?} : \textit{NAME} \\
\textit{date?} : \textit{DATE} \\
\hline
\textit{name?} \notin \textit{known} \\
\textit{birthday}' = \textit{birthday} \cup \{\textit{name?} \mapsto \textit{date?}\} \\
\hline
\end{array}
$$

**Fig. 3** The Birthday Book specification

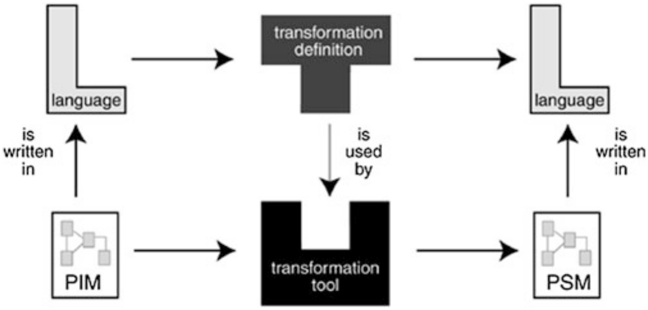



**Fig. 4** Transformation in MDA explained [2]

## 4 The Proposed Solution and a Case Study

Our approach is a formal proposal for a solution to solve the problem of ambiguity in an informal textual and graphical representation of transformation between models of MDE. As we can see, there is no consensus regarding the terminology in the literature of MDE related to transformation. As an example, in "MDA Explained" [2], a transformation is represented by *transformationDefinition* and it is shown in Fig. 4, and in "MDA Guide Version 1.0.1" [1] the transformation is represented by *transformationSpecification* and illustrated in Fig. 5.

Although these models can be used to obtain a simple answer for simple situations, they become inefficient to describe situations where informal reasoning is not enough, thus creating ambiguity in its interpretation.

For our tests we have used a model transformation between UML and Java RMI (*Remote Method Invocation*) [18]. The transformation comes from a source of UML 2.1 metamodel to a target of Java RMI metamodel, according to Fig. 6.

Figure 7 shows the PIM of our application, which consists of Client/Server model of distributed object technology Java RMI. In this model, they are defined basically two roles: the Client and Server. The Client makes a request to the Server, and Server in turn implements the methods that are defined in the interface and sends the reply to the Client.

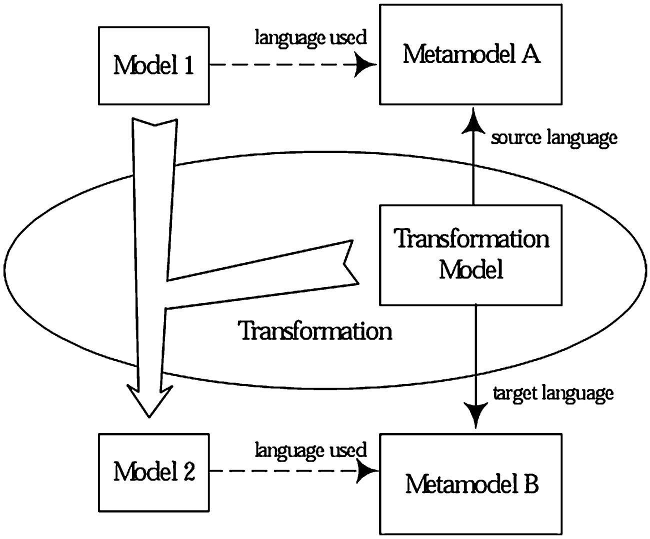



**Fig. 5** Metamodel mapping transformation [1]

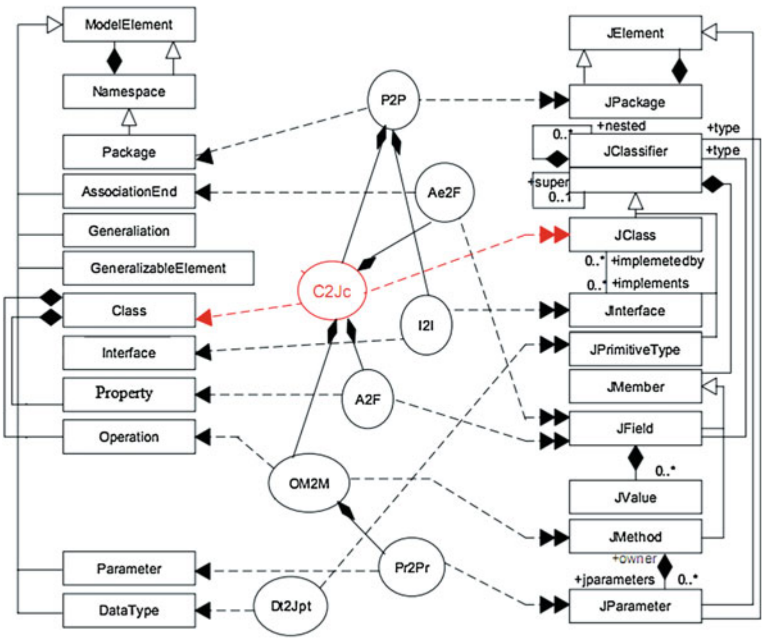



**Fig. 6** Mapping of the UML 2.1 metamodel to Java metamodel [19]

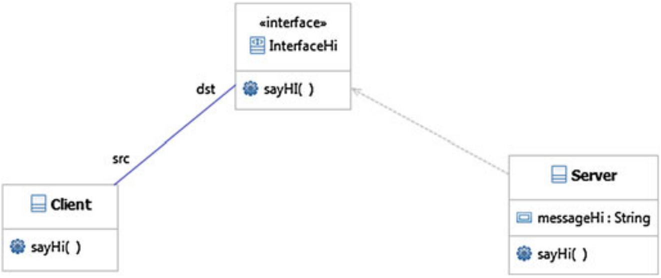



**Fig. 7** The client/server architecture

For this type of application, it is established transformation rules written in ATL language which makes the correlation between the elements of the UML 2.1 metamodel with elements of the Java metamodel, and which is used to develop the application of the case study of Fig. 7. To find out the requirements of this application, we have created the correspondences between the elements of metamodels presented in Fig. 8.

Once the correspondences have been established, the transformation rules have been specified by the application of Z language then the tests are carried out by the tool Z/EVES [20], i.e. the Z formal language tester. The formal specification of the model transformation is presented in Fig. 9.

Figure 9 shows the *schemas* containing the transformation rules specified by the Z language, where we first declare two data types of application in the following way:

*[ElementUML, ElementJAVA]*

The *ElementUML* is a generic representation of some element of the UML metamodel source that is mapped to an element of the target Java metamodel.

The *ElementJAVA* is a generic representation of some element of the Java metamodel which is related to some element of the UML metamodel.

This operation is similar to the Z mathematical representation of ordered pairs (x, y); this notation indicates that the element x is mapped to the element y, which can also be represented in Z by $x \mapsto y$; thus we can represent *[ElementUML, ElementJAVA]* by:

$$ElementUML \mapsto ElementJAVA$$

This notation indicates the mapping between the elements of the UML metamodel with elements of the Java metamodel.

Figure 10 shows the generic mapping between the elements of UML 2.1 metamodel with elements of the Java metamodel.

In the schema of Fig. 10, some important variables of the transformation are declared such as:

- *METAUML:* $\mathbb{F}$*ElementUML*—representing a finite set which consists of elements of the UML metamodel, which will be involved in mapping between metamodels. It indicates that the number of elements that are contained in the set *METAUML* is finite.

| UML | JAVA |
|---|---|
| Class | JClass |
| Interface | JInterface |
| Operation | JMethod |
| Parameter | JParameter |
| Property | JField |

**Fig. 8** Correspondence between elements of the metamodels

$[ElementUML, ElementJAVA]$

$$
\begin{array}{l}
\text{— } UML2JAVA \text{ ————————} \\
\quad METAUML : \mathbb{F}\, ElementUML \\
\quad Transformation : ElementUML \pfun ElementJAVA \\
\hline
\quad METAUML = \operatorname{dom} Transformation
\end{array}
$$

$$
\begin{array}{l}
\text{— } MAPEAMENTO\_Package2JPackage \text{ ————————} \\
\quad \Delta UML2JAVA \\
\quad Package? : ElementUML \\
\quad JPackage! : ElementJAVA \\
\hline
\quad Package? \in METAUML \\
\quad Transformation = \{Package? \mapsto JPackage!\}
\end{array}
$$

**Fig. 9** Transformation specified on language Z

$$
\begin{array}{l}
\text{— } UML2JAVA \text{ ————————} \\
\quad METAUML : \mathbb{F}\, ElementUML \\
\quad Transformation : ElementUML \pfun ElementJAVA \\
\hline
\quad METAUML = \operatorname{dom} Transformation
\end{array}
$$

**Fig. 10** Mapping between the elements of UML and JAVA metamodels

- *Transformation: ElementUML* → *ElementJAVA*—formally describes the transformation between the elements of the metamodels. The transformation between these elements is declared by a partial function in Z.Below the dividing line is declared the predicate $METAUML = \operatorname{dom} Transformation$ that establishes the relationship between the variables declared.

$$\begin{array}{|l}
\textit{MAPEAMENTO_Package2JPackage} \\
\Delta\, \textit{UML2JAVA} \\
\textit{Package?} : \textit{ElementUML} \\
\textit{JPackage!} : \textit{ElementJAVA} \\
\hline
\textit{Package?} \in \textit{METAUML} \\
\textit{Transformation} = \{\textit{Package?} \mapsto \textit{JPackage!}\} \\
\hline
\end{array}$$

**Fig. 11** Mapping UML package to JAVA JPackage

- According to the above, we observe that not all elements of the UML metamodel will have correspondents in the Java metamodel. These elements were selected according to the needs of the functional requirements of the case study of the application (in our case the Client/Server Java RMI model). These elements, which constitute the transformation, are contained in the set METAUML application.

We show the formal specification of a rule that transforms a UML *Package* in a JAVA *JPackage* such as Fig. 11.

This schema is specified according to the transformation rule written in ATL language, illustrated in Fig. 12. This scheme transforms an UML Package in a Java JPackage.The technique used here is proposed in the work of Miyazawa [8/16], where we compare Z with ATL, in order to obtain the rule of the schema in Fig. 11. Figure 12 presents the rule implemented in the syntax of ATL, the tool used to create this rule is the Eclipse Galileo.

In Fig. 11 the schema declares a state of a transformation represented by Δ *UML2Java*, the Greek letter delta indicates that the state of transformation is not fixed, i.e. the number of transformation rules can vary depending on the needs to meet the requirements established in the case study of the implementation of Java RMI. We still have the input variables and output of the transformation represented by:

- *Package?*—indicates the input variable of the transformation *ElementUML*.
- *JPackage!*—indicates the output variable of the transformation *ElementJAVA*.

The predicate ensures that the specification is declared by the following rule:

$$\begin{array}{l}
\textit{Package?} \in \textit{METAUML} \\
\textit{Transformation} = \{\textit{Package?} \mapsto \textit{JPackage!}\}
\end{array}$$

Where Package?ϵMETAUML, indicates that the input variable of the transformation must belong to the set *METAUML*.

The following statement indicates that the transformation must generate a mapping of the input element *Package?* for the output element *JPackage!*.

$$\textit{Transformation} = \{\textit{Package?} \mapsto \textit{JPackage!}\}$$

**Fig. 12** Transformation rule written in ATL

```
rule Package2JPackage{
        from upackage : UML!Package
        to jpackage : JAVA!JPackage(
                name <- upackage.name,
                jelements <- upackage.ownedElement,
                super <- upackage.clientDependency ->
collect(e|e.supplier)
        )
}
```

The schemas discussed here is the beginning of the formal specification between metamodels.

## 5 Conclusion

This paper has proposed an approach based on formal specification of Z language to specify the model transformation definition in the context of MDE.

We have described a case study within the context of MDE with an application based on distributed object technology Java RMI, where we propose how to specify formally the transformation rules that map the metamodel elements through Z language.

In this paper, the proposed case study contains a Z formalization that defines a transformation definition between UML Package and a Java JPackage.

After the step of specifying the rules in Z, the implementation is carried out in ATL language to perform execution of code that implements the mapping specified in Z.

We intend to end of the study, develop a framework that represents the implemented classes, the methodology discussed, the tool developed and formal representations of the transformation in the MDE.

We intend to the end of the study, develop a framework that represents the implemented classes, the methodology discussed, the tool developed and the formal representations of MDE transformations, and to make a comparison of this formal approach with other informal approaches to analyze the level of ambiguities prevention in the representations of MDE transformations.

**Acknowledgments** The work described in this paper is supported by CAPES and FAPEMA through the grant BEPP 0413/2010.

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# Intrusion Detection System for Botnet Attacks in Wireless Networks Using Hybrid Detection Method Based on DNS

**Raimundo Pereira da Cunha Neto, Zair Abdelouahab, Valéria Priscilla Monteiro Fernandes and Bruno Rodrigues Froz**

**Abstract** The expansion of defense mechanisms to combat attacks led to the evolution of malwares, which became more structured for the disruption of these new defense barriers. Among the numerous malwares, the Botnets became the bigger cyber threat because of its ability of control and capability of distributed attacks. In wireless networks, the signal propagation through unguided media, facilitates the actions of malware. This vulnerability makes wireless networks susceptible for Botnet attacks, which can establish control of their activities. This article presents a model of Intrusion Detection System for Wireless Networks (WIDS) which aims to expand Botnet detectors by using multi-agent technology, offering a collection of sensors, a preprocessing filter and detection based on signatures and anomaly.

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## 1 Introduction

The technology of wireless networks has become, over the years, much used in corporate, household and public networks, such as malls, airports and restaurants because of the ease of deployment and practicality of their use. The widespread implementation of wireless networks has also brought new challenges to security and privacy. Its organizational structure facilitates invasion by various types of attacks such as denial of service, sniffing, man in the middle, among others.

Among the increasing attacks, the Botnet have been highlighted by the organization to carry out distributed attacks and the impacts on major networks around the world [1], which would cause havoc on their mobile devices and services implemented.

Among the tools of today's defenses, we highlight the Intrusion Detection Systems (IDS) as mechanisms that focus on the detection of intrusive activities on networks [1]. Many of the proposed IDS technologies complement each other because different types of environments some approaches have better performance. The Intrusion Detection System for Wireless Networks (WIDS) proposed in this study aims data collection and analysis of packets transmitted within the network, supported by use of agents for increasing the detection of intruders in wireless networks, with emphasis to attack from a Botnet.

The structure of the paper is organized as follows. Section 2 introduces Botnets. Section 3 is about IDS, focus of this work. Section 4 shows related works. Section 5 explores the model suggested by this work under study. In Sect. 6 the implementation of the model is presented. Sections 7 and 8 describe the results and conclusions of our work.

## 2 Botnet

Botnet is a network of compromised computers, called Botnets, under the control of a remote human operator, the "Botmaster". The term "bot" is derived from the word "Robot." Bots are host devices designed to perform some pre-defined functions in an automated fashion, which enables the Botmaster to remotely control the actions of attack [1–5].

Unlike other malware such as viruses and worms, which are focused on attacking the infected host, Botnets have a structure of command and control, described in Fig. 1, where through servers Command and Control (C & C) are received commands from a Botmaster and these are passed on to the bots execute them, setting a platform for distributed attack [6, 7].

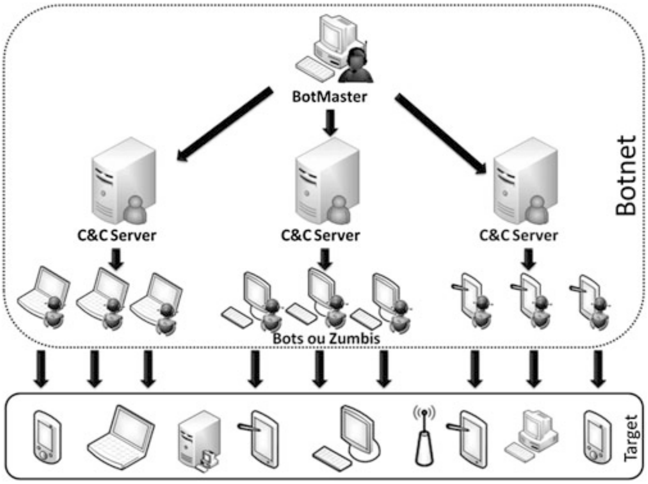


**Fig. 1** Botnet architecture

## 2.1 *The Architecture*

The architectural organization of the Botnet is composed of three basic elements:

i. Botmaster
   Botmaster is the human controller of a Botnet. It operates remotely controlling the bots through commands sent to server C & C, which make the communication with the Bots [1–4, 6]. Usually the Botnet is controlled by its creator, but many Botnets are created for marketing, leased for criminal actions.
ii. C & C server
   The C & C server is responsible for communication between the bots and Botmaster by routing commands to carry out attacks. According to its command and control structure the Botnets can be categorized as: IRC based, HTTP based, DNS based or based on Peer to Peer (P2P) [1, 2, 7]. P2P Botnets make use of P2P protocol to avoid single point of failure. Moreover, P2P Botnets are more difficult to locate and make the server shutdown C & C. The most prevalent Botnets are based on the protocol Internet Relay Chat (IRC) [1], with centralized command and control mechanisms.
iii. Bot or Zombie
   It is the compromised computer or device, remotely controlled by a Botmaster to perform some commands through the commands received. Once the code of the malware was installed on the infected computer, the computer becomes a zombie or robot [1, 2, 7]. The Bots are normally distributed on the Internet, looking for unprotected and vulnerable computers to infect. When they find an unprotected computer, they infect it and then send a report to Botmaster [6].

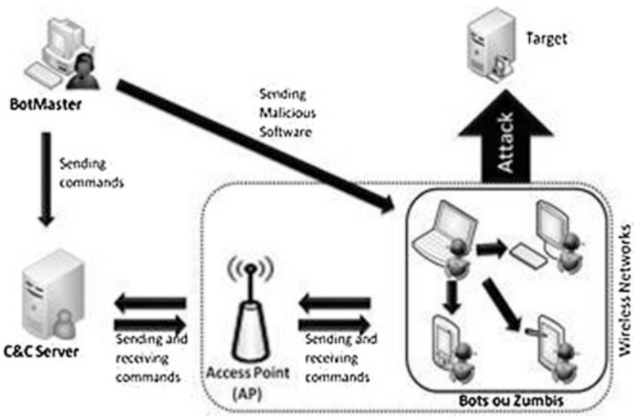


**Fig. 2** Botnet lifecycle in wireless networks

## *2.2 Life Cycle*

A typical Botnet can be created and held in four phases, including [2], this cycle is described in Fig. 2, applied in wireless networks:

i. Initial infection: the bots are infected in several ways, such as being actively exploited, vulnerabilities in the device, malware automatically downloaded when viewing web pages, or automatically downloaded and executed by opening an e-mail. In wireless networks this infection can be made easier by the structure of this network, the attack can be launched right into the device without the need to use the network structure.
ii. Secondary injection bond: after being infected with the bots running bot code and start the rally, which is the process of connecting to the server C & C, from that stage, the bots await the commands that are sent by Botmaster.
iii. Malicious activities: in this stage the bot communicates with the server C & C that sends instructions to perform actions such as sending spam attack and DDoS.
iv. Update and maintenance: because of the widespread availability of information to be exchanged on a Botnet, as the capture of information by bots, it's necessary to update the new commands and a change of server C & C caused by the fall of the previous Server service.

## *2.3 Activities*

Botnets, as presented earlier, have a control structure to perform various activities [8], these actions are listed below:

(i) The Distributed Denial of Service (DDoS) attack is achieved through the action of all the active bots, which aims at an attack on a computer system or network causing the loss of services.
(ii) The Key Logging with help of a key logger is very easy for a bot to obtain sensitive information, it receives the command and performs the action of gathering.
(iii) In the Traffic Sniffing the bots also use a sniffer to observe the text data, with purpose of obtain confidential information such as usernames, passwords, bank details, among others.
(iv) The manipulation of online polls, the bots, which have different IP Addresses, held a vote on the poll, validating it as being real people.
(v) Distribution of a new Malware is achieved by the bots using the mechanisms to download and execute a file using HTTP or FTP.

### *2.4 Using the DNS Botnet*

In Botnets execution are used, in some instances, the DNS protocol [9], these situations are:

i. The Infected devices seek for access, automatically, to the C & C server through your domain name. This procedure occurs in a group, since the bots perform tasks together.
ii. On the migration of C & C servers the Botnet when migrating to another C & C server must perform a DNS query.
iii. In changing the server's IP address C & C, if a server C & C uses dynamic IP, the corresponding IP address can be changed at any time and Botmaster can also change the IP address of the C & C intentionally, to make detection more difficult. With the change of IP address, the bots could not connect to the old IP address, so need to send DNS query to access the new server C & C.
iv. In malicious activities, the bots to start a DDoS or spam are accompanied by the transmission of DNS.

## 3 Intrusion Detection System

IDS are security tools that, like other measures, such as antivirus, firewalls and access control systems, are intended to enhance the security of information systems and communication [8], they are considered the second security force, since it aims to evaluate the data from one system and take measures of prevention and protection [10, 11]. In order to detect such behavior, intrusion detection systems typically contain two types of components [12]:

- Components of data collection;
- Components of data analysis.

## 3.1 Classification of IDS by Type of Data Collection

Components of data collection are composed by entities that are responsible for monitoring and collection of data about user activities and applications. The data collected are then used for a second type of components, called component analysis [10–12]. Two main approaches to data collection have been traditionally used, which are classified into two types of intrusion detection systems:

i. Host-based IDS (HIDS) which runs on a host and focuses on collecting their data, generally through audit logs of the operating system;
ii. Network-based IDS (NIDS) works on the networking and focuses on data collection by monitoring the traffic flowing through the network.

## 3.2 IDS Classification by Type of Data Analysis

Once data is collected it is necessary to analyze the data to detect malicious activity. IDS normally incorporate mechanisms of analysis that automatically analyze the data collected by several collectors to detect malicious activity. Data analysis involves the consolidation of data from IDS, possibly in a central location and identifies malicious activity [12]. We highlight three types of analysis techniques:

i. Signature-based IDS
   This type of IDS is aims to detect intruders through the use of attack signatures. These signatures are composed of a set of rules that characterizes the intruder. This process facilitates the detection. However, the detection techniques based on signatures can only be used for the detection of known Botnets. Thus, this solution is not useful for unknown bots [10, 12].
ii. Anomaly-based IDS
   Detection techniques based on anomalies [10, 12, 13]. This type of IDS designed to detect Botnets based on anomalies on the network traffic, such as high network latency, high traffic volumes, traffic through unusual doors and abnormal behavior of the system that could indicate the presence of malicious bots on network [1, 3].
iii. Hybrid IDS
   The IDS that uses the application of the techniques of signature and anomaly together are called Hybrid IDS. Aim to increase the power of intrusion detection, because they can detect both, known and unknown attacks. The present work uses this technique.

## 4 Related Work

Botnets have the dynamic characteristics, which make them difficult to detect by traditional IDS. The range of techniques used by bots, and the structure of control exercised by Botmaster, allows Botnet a high power attack and flexibility as a variation of its activities. Botnet detection techniques have been developed, we highlight the following relevant work in the context of this article.

Snort, one of the most used nowadays [10] is an open source tool for IDS that monitors network traffic for signs of intruders, configured through a set of rules and signatures traffic log, which is considered suspect [1, 12, 14]. New Botnets require human intervention to create signatures for their detection.

Miroslaw [4] suggests an approach for Botnet Detection in Computer Networks Using multi-agent technology. The proposed system is used to detect bots based on the assessment of the events in the operating system and network environment. Detection is performed using algorithms based on signatures derived from analysis of different types of malicious software bots. As happens with Snort, this model does not detect the bots that are not in your database subscription.

Choi et al. [9] developed a model Botnet Detection System following the Group of Activities of DNS traffic. This architecture for Botnet detection combines the detection of query from the bots and migration of C & C servers, which requires the use of DNS traffic data. This model is ideal for detecting incoming data coming from Botnets when there is large-scale DNS traffic data collected by sensors deployed, usually, scattered across different networks. The DNS- based detection of Botnet, is one of the most promising because detect Botnets regardless of its structure, centralized or distributed. However this model requires evaluation time, since bots spread rapidly.

## 5 Model System for Hybrid Intrusion Detection

The proposed solution was built using hybrid detection systems based on DNS on wireless networks with the use of agents to support the project architecture. Below, it is described the architecture and functionality.

### *5.1 IDS Architecture*

The architecture of the proposed model is shown in Fig. 3. We highlight in this paper the use of a WIDS to Botnet detection supported by a set of agents that interact directly or indirectly to collecting, filtering and analyzing packets in wireless networks. The model uses packet filtering through the WhiteList and

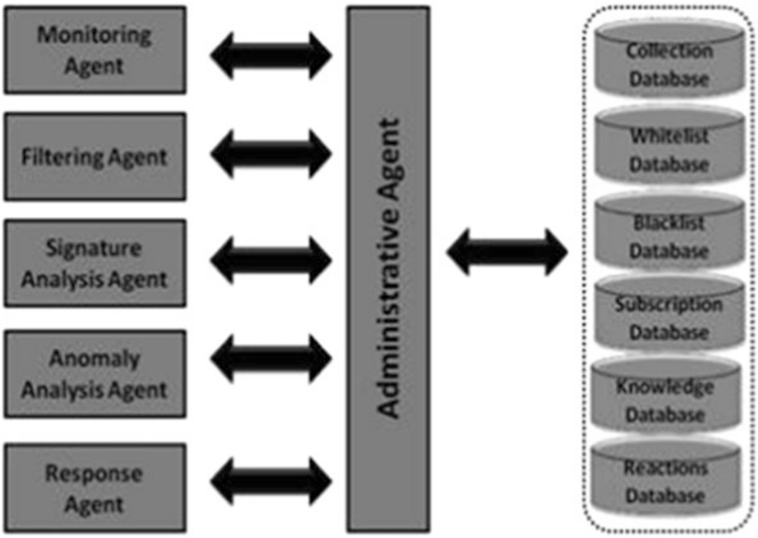


**Fig. 3** WIDS architecture model

BlackList, besides carrying the signature and anomaly analysis, to minimize the false positives.

i. Monitoring Agent
   The function of this type of agent is to capture packets on the wireless network. The monitoring agent stays in strategic points of the network and work as a passive network monitor, working in promiscuous mode, and does not interfere on the performance or the network traffic. In this work the packet capture is concentrated in regions close to the Access Point, because it is a concentration point of the wireless network. The collected data is stored in the Collection Database.
ii. Filtering Agent
   This agent receives the collected data to make a packet filtering. This procedure reduces the number of package to be analyzed by Analysis Agent, since it eliminates the classified packages on the filtering. The filter is composed by two databases: BlackList and WhiteList.

   1. WhiteList
      In this kind of filter, all allowed DNS are listed to the network traffic as authorized and without suspicious. In this model the WhiteList is provided by the system administrator, even if series of WhiteLists, organized by research groups. The non use of preexistent lists is made to reduce the list, and here it is applied only the necessary DNS applications by network users. The filter is applied to the captured packets and those detected on the filtering are discarded, in this case there is no warning by the reaction agent, because this filter aims only to eliminate the benefic packets.

2. BlackList
   There are a great number of lists available and being shared by several online communities containing suspicious IPs. These lists are generally known as "black" list [15]. Many of these lists are used to help block spam, malicious attacks, or nuisance users. Some blacklists are an excellent source of information when the data is used correctly, but some are so poor that any use of them would be detrimental to use the tool.
   This list of suspicious IP is collected daily by Shadowserver Foundation, as seen in List 1 and exported to the tool, where they are stored in the Blacklist Database. The files stored in the database, stay available for 60 days period in which they are automatically deleted due to rotation of IPs measured as a suspect. This feature makes the database not too large to perform the filtering. As made on the WhiteList, the captured packet is checked in the filter where the IPs are compared. In the case of detection, this packet is discarded and sent for further analysis to detect the intruder to the Response Agent.

iii. Signature Analysis Agent
   At this stage the signature analysis agent is responsible for examination of packages received at the filtering process. The collected packets are formatted so that attack patterns can be identified and subsequently confirm an attack. For this, we use the intrusion signatures database. These signatures are composed of rules to detect Botnet attacks.
   The most prevalent Botnets a based on IRC protocol [1] as a mechanism for command and control. IRC protocol was originally designed for large social chat rooms to allow multiple forms of communication and dissemination of data among large numbers of hosts. The high prevalence of Botnets based IRC is due the inherent flexibility and scalability of the protocol, this type of protocol usually uses ports 6667, 6668, 6669 and 7000. These features contribute to build a signature database, which are collected relevant information to each type of Botnet.
   The intruders are detected by this agent are informed to the reaction agent and the packets that not match with any signature are referred for further review by anomaly analysis agent.
iv. Anomaly Analysis Agent
   This agent receives the filtered packets and not detected by Signature Analysis, these packages will be analyzed to detect the activities of intruders according to the anomalous behavior.
   This agent uses anomaly detection algorithms applied on DNS traffic. As mentioned in Sect. 2, the bots begin the connection with the C & C server to receive commands. To access the C & C server, they perform DNS queries to locate their server. Thus, it is possible to detect the Botnet DNS traffic by monitoring and detection of anomalies in the DNS traffic [1]. The activities of intruders are forwarded to the agent response, so actions can be taken to prevent and protect the wireless network.

**List 1** List C & C server active

```
"IP Address", "Port", "Channel", "Country", "Region", "State", "Domain", "ASN", "AS Name", "AS Description"

"81.211.7.122 69.18.206.194",3267,"#B#t[r2]N#t","RU US","MOSCOW | COMMACK","MOSKVA | NEW YORK","GLDN.NET INVISION.COM","3216 12251","SOVAM INVISION","AS Golden Telecom, Moscow, Russia | Invision.com, Inc."

"81.211.7.122 69.18.206.194",3267,"#B.tN.t[r3]","RU US","MOSCOW | COMMACK","MOSKVA | NEW YORK","GLDN.NET INVISION.COM","3216 12251","SOVAM INVISION","AS Golden Telecom, Moscow, Russia | Invision.com, Inc."

"213.234.193.74 85.21.82.55",6667,"#secured","RU RU","MOSCOW | MOSCOW","MOSKVA | MOSKVA","NET.RU -","39442 8402","UNICO CORBINA","AS JSC UNICO | AS Corbina Telecom"
```

v. Response Agent
This agent aims to take countermeasures if a security incident is detected based on the evaluation of the BlackList, Signature Analysis, and Anomaly Analysis agents. These countermeasures are taken in accordance with the Reaction Database, notifying or even blocking the signal from an attacker.

vi. Administrative Agent
The administrative agent integrates all agents of WIDS. It is responsible for updating the information databases. Queries can be made directly to any layer, but insertions must be made only through this layer. It will also have the responsibility of maintaining the integrity and consistency of stored information.

vii. Database
The database is responsible for maintaining the persistent information from each agent. In this, we have the databases used by WIDS. Below is a description of them:

1. Collection Database stores the packets collected during the capture of traffic from the wireless network.
2. WhiteList Database stores the DNS allowed to travel across the network. This information is supplied by the administrator of WIDS.
3. BlackList Database stores the data containing suspicious IPs. These data are exported from existing blacklists.
4. Signature Database is the database responsible for storing all information concerning the signatures of Botnets.
5. Knowledge Database stores information about the existent hosts in the wireless network in order to identify devices that are suspected of attacks or were possible turned in bots.

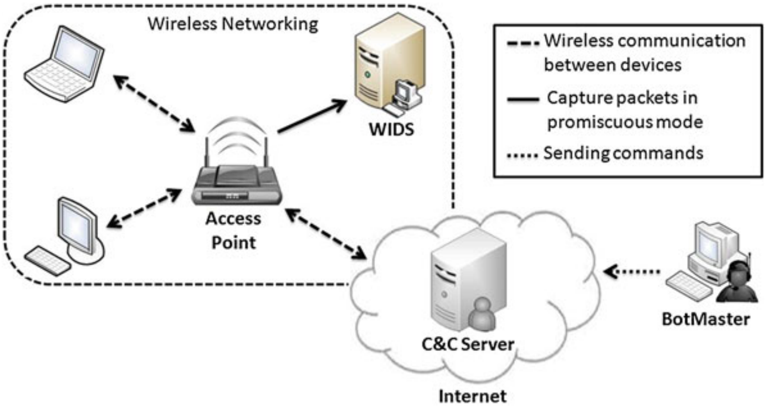


**Fig. 4** WIDS tests scenario

6. Reactions Database contains the information concerning the actions that could be taken according to the intrusions detection. It is adapted according to the policy of each organization.

## 6 The Implementation

According to the proposed model we made a WIDS prototype and tests to validate the tool were made, in the scenario showed in the Fig. 4.

The scenario was made in the Laboratório de Sistemas em Arquiteturas Computacionais, on the Universidade Federal do Maranhão. To the construction was necessary to implement an environment to Botnets actuation. We used RxBot, 7.6 version [16], and a IRC channel, as C & C server, working on the Internet. On the wireless network we infected some machines to simulate the bots. Commands were sent to the bots in order to execute the requested activities by the Botmaster.

The model components where implemented in Java using Java Server Pages to develop the Web interfaces [17, 18], the Wincap library component was used to the analysis an capture of network packets on Windows [19], and for the database was used MySQL5 [20].

During the infection process, maintenance and updating of the Botnet, the WIDS accomplished the capture of the wireless network traffic in a promiscuous mode, without interfering with network traffic. The localization of the WIDS Server, close to the Access Point, was due the centralized information exchanged with the external environment. The captured packets were filtered by the filtering agent and forwarded to the agent for signature analysis, the detected intruders were send to the reaction agent for taking the appropriate countermeasure for the type of the attack. The anomaly analysis agent is in development and was not initially tested.

**List 2** Identified data on the denial of service pingflood attack

```
1285340472:662462    /10.0.2.15->/192.168.88.130    protocol(1)
priority(0) hop(128) offset(0) ident(1818)type(8) code(0)
SRC: /10.0.2.15DST: /192.168.88.130tam: 596

1285340473:163094    /10.0.2.15->/192.168.88.130    protocol(1)
priority(0) hop(128) offset(0) ident(1819)type(8) code(0)
SRC: /10.0.2.15DST: /192.168.88.130tam: 596

1285340473:664911    /10.0.2.15->/192.168.88.130    protocol(1)
priority(0) hop(128) offset(0) ident(1820)type(8) code(0)
SRC: /10.0.2.15DST: /192.168.88.130tam: 596

1285340474:164664    /10.0.2.15->/192.168.88.130    protocol(1)
priority(0) hop(128) offset(0) ident(1821)type(8) code(0)
```

**List 3** Collected data

Traffic Bot 1

SRC: 10.0.2.15:1075 **DST: 158.38.8.251:6669** Size = 48 bytes
**SRC: 158.38.8.251:6669** DST: 10.0.2.15:1075 Size = 44 bytes
SRC: 10.0.2.15:1075 **DST: 158.38.8.251:6669** Size = 40 bytes
SRC: 10.0.2.15:1075 **DST: 158.38.8.251:6669** Size = 88 bytes
**SRC: 158.38.8.251:6669** DST: 10.0.2.15:1075 Size = 40 bytes

Traffic Bot 2

SRC: 192.168.88.130:1033 **DST: 194.109.129.222:6669**
Size = 48 bytes
**SRC: 194.109.129.222:6669** DST: 192.168.88.130:1033
Size = 44 bytes
SRC: 192.168.88.130:1033 **DST: 194.109.129.222:6669**
Size = 40 bytes
SRC: 192.168.88.130:1033 **DST: 194.109.129.222:6669**
Size = 87 bytes

## 7 Results

The prototype application, during the observation period, allowed getting important information about the Botnets behavior. The use of various commands of the bots were used; among them we can highlight the "pingflood" which consists of a flooding, a simple denial of service that overloads the victim's system [19]. The attack was observed as seen in the collected data in List 2.

In relation to the compromised machines, it was verified that even when is used one unique C & C server, the Botnet assigns different communication IPs, as shown on the traffic collected by the WIDS on List 3.

The attacks were identified with great efficiency and speed, due the possibility of eliminating packages not needed to evaluation, since the WhiteList removes common packages of internal traffic, according to the security policy of the organization. The traffic above, that was identified on the signature analysis agent, monitoring the 6669 port, used to IRC channel where the Botmaster established communication with the bots.

The study confirmed the effectiveness of the tool detecting Botnets, and that it is not necessary to collect a great amount of data internally on the organizations, since the Botnets action do not take very long internally on the network, specially the attack activities, what make necessary the real time identification of the intruder.

## 8 Conclusion

In the proposed architecture of this work, it is possible to detect Botnets on real time, based on data different packet filtering, since the amount of information is reduced to the analysis process.

The use of hybrid detection, signature an anomaly based, improves the tool potentially with a low level of false positives. The latest detection techniques based on DNS can detect bots on real world, regardless of its structure. It is very important mainly because the increase of new Botnets based on P2P protocols.

Thus, the use of signature-based techniques, anomaly and DNS used together to detect bots on wireless networks is a promising approach to combat new Botnets in online ecosystems and active computers.

**Acknowledgments** The work described in this paper is financed by Fundo Setorial de Tecnologia da Informação (CT-Info), MCT, CNPq (CT-Info/MCT/CNPq).

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# Parallelization of Closed-Form Stiffness Matrix Generation for Tetrahedral Finite Elements

**Sara E. McCaslin**

**Abstract** This paper expands on previous research into the use of parallelization tools for closed-form solutions with a focus on applications in finite element analysis (McCaslin SE (2010) "Parallelization of shape function generation for hierarchical tetrahedral elements." In: Sobh T, Elleithy K (eds.) Innovations in computer science and software engineering, pp 409–414). Recent advances in parallelization tools for computer algebra systems allow users to easily implement parallelization, using built-in tools. Previous work used the generation of higher-order shape functions for tetrahedral elements through *p*-level 20 as a simple test case to demonstrate the potential for increased computational efficiency (McCaslin SE (2010) "Parallelization of shape function generation for hierarchical tetrahedral elements." In: Sobh T, Elleithy K (eds.) Innovations in computer science and software engineering, pp 409–414). This research generates closed-form upper triangular stiffness matrices (not merely the shape functions) for straight-sided hierarchical tetrahedral elements (Shiakolas PS, Lawrence KL, Nambiar RV (1994) Closed-form expressions for the linear and quadratic strain tetrahedral finite elements. Comput Struct 50:743–747; McCaslin SE, Shiakolas PS, Dennis, BH, Lawrence KL (2009) "Closed-form matrices for higher order tetrahedral elements." In: Proceedings of the 12th international conference on civil, structural and environmental engineering computing, Madeira, Portugal, September 2009) through the 9th order on a dual-core desktop by exploiting available parallelization tools. A speed-up ratio of over 2,000 and reduction in required memory of up to 83 % was achieved.

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## 1 Introduction

Numerical methods, such as the finite element method and finite different method, have for many years successfully been used for analysis and simulation. Much of modern research into these areas focuses on how to improve the efficiency of these methods by exploiting available computing power, multithreaded architectures, and innovative algorithms.

While computer hardware and operating systems have continued to develop, so have software tools. Computer algebra systems (CAS) such as *Mathematica* [1, 2] and *Maple* [3] have made it possible to obtain closed-form, exact, symbolic solutions to problems that simply were not possible even 20 years ago.

Symbolic solutions have been a topic of interest in engineering, and are often more computationally efficient than the standard numerical approaches [4]. There are limitations, however, to the complexity of problems that can be solved using closed-form approaches. These include the memory needed to obtain the solution and the excessive amount of time that some solutions require. Limitations such as these hinder continuation of research into more closed-form solutions requiring more complex representation.

Using parallel processing to generate solutions can aid with time and memory issues, but not all researchers may have ready access to high performance computing systems. Parallelization tools available in modern CAS, however, make parallelization available to researchers working on multi-core workstations. However, most engineers and scientists do not have sufficient background in programming to effectively implement parallel computing paradigms into their current work [2].

Previous work developed a na methodology for quickly applying parallel processing to the symbolic generation of high order shape functions as used in finite element analysis as a simple test case that would demonstrate whether or not the potential exists for measurable increases in computational efficiency in generating closed-form solutions, not just shape-functions [5]. Having demonstrated that the potential exists, this paper takes the na methodology previously developed and applies it to the far more practical problem of generating closed-form stiffness matrices for straight-sided, hierarchical tetrahedral elements.

## 2 Software

This research continues to use *Mathematica*, which is often used to generate closed-form solutions [4]. By using a CAS as the means of developing the parallel scripts, the programmer can focus on generating symbolic solutions rather than the complicated details of machine-dependent, low-level parallel implementations. Furthermore, the user has access to all of *Mathematica's* built in mathematical

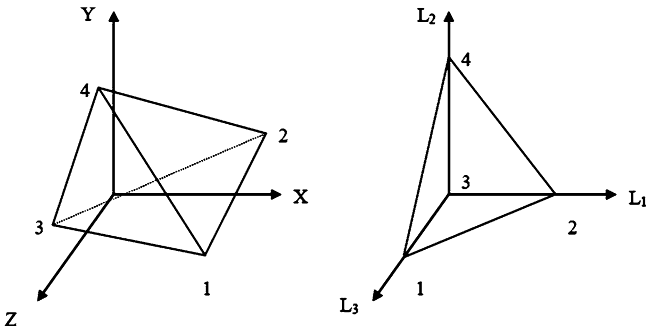


**Fig. 1** Global coordinates and local coordinates

capabilities, including matrix manipulation, simplification, factoring, algebraic manipulation, Legendre polynomials, and replacement rules.

## 3 Closed Form Stiffness Matrix

Closed-form solutions continue to be successfully used in finite element analysis to improve computational efficiency in comparison to commonly used numerical approximations [4, 6, 7]. In the area of tetrahedral elements, the most recent work has focused on obtaining the closed-form stiffness matrices for both hierarchical and isoparametric straight-sided tetrahedral elements through the fourth order [7]. Note that previous work in both isoparametric and hierarchical elements has limited to 4th order [4, 7].

To determine whether or not parallel processing will aid in the generation of closed-form solutions for higher order (and thus more complex) elements, stiffness matrices for straight-sided, hierarchical tetrahedral elements through the 9th order were generated.

The shape functions for tetrahedral elements are described in terms of local coordinates, called volume or natural coordinates and indicated by $L$, as shown in Fig. 1.

To map from the local coordinates to global coordinates, the transformation shown in (1) is used. Local coordinates $L_{\mathrm{i}}$ $(i = 1, 2, 3, 4)$ are mapped to global coordinates of any point within the element represented $\{x, y, z\}$ based on the global coordinates of the vertices of the tetrahedral element $\{x_i, y_i, z_i\}$ $(i = 1, 2, 3, 4)$

$$\begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ y_1 & y_2 & y_3 & y_4 \\ z_1 & z_2 & z_3 & z_4 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{Bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{Bmatrix} \tag{1}$$

Note $L_i = 1$ at vertex $i$ and 0 on the opposing face. Also, the sum of the volume coordinates is always equal to 1, which indicates that they are not independent. The relationship $L_4 = 1 - L_1 - L_2 - L_3$ is used to eliminate $L_4$ from (1), resulting in (2), where $x_{ij} = x_i - x_j, y_{ij} = y_i - y_j, z_{ij} = z_i - z_j$.

$$\begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix} = \begin{bmatrix} x_{14} & x_{24} & x_{34} & x_4 \\ y_{14} & y_{24} & y_{34} & y_4 \\ z_{14} & z_{24} & z_{34} & z_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} L_1 \\ L_2 \\ L_3 \\ 1 \end{Bmatrix} \tag{2}$$

The shape functions are expressed in terms of these local coordinates. The local coordinates for any point in a tetrahedral element can be obtained as a function of the vertices of the element, as shown in (3) and (4), where $C_{i1}, C_{i2}, C_{i3}$ and $C_{i4}$ (for $i = 1, 2, 3, 4$) are entries in the inverse of the coefficient matrix. The value of the determinant Jacobian matrix transforming Cartesian coordinates to volume or local coordinates |J| is equal to 6 times the volume of the element.

$$\begin{gathered} \begin{Bmatrix} L_1 \\ L_2 \\ L_3 \\ 1 \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix} \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}, \\ \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix} = \begin{bmatrix} x_{14} & x_{24} & x_{34} & x_4 \\ y_{14} & y_{24} & y_{34} & y_4 \\ z_{14} & z_{24} & z_{34} & z_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \end{gathered} \tag{3}$$

$$L_i = (C_{i1}x + C_{i2}y + C_{i3}z + C_{i4})/|J| \tag{4}$$

For this research, Szabo and Babuska hierarchical shape functions [8] as described by Adjerid et al. [9] are to obtain the required shape functions. Note that hierarchic elements are based on a complete set of polynomials, as illustrated in Fig. 2 by Pascal's pyramid through $p$-level 4 [8]. Polynomial level 4 was the lowest-order element generated for this research. Note that the family of hierarchic elements introduced by Babuska, Szabo and Katz (and used in this research) has the property that that polynomial $p$ is a subset of polynomial $p + 1$ [10].

There are four nodal shape functions and three types of modes (edge, face, and internal) for three-dimensional tetrahedral elements. Edge modes are associated with mid-side edge nodes (located at the mid-point of each edge); face modes are associated with the center of the face (area centroid of each face); internal modes are located at the element centroid.

The hierarchical shape functions are based on Legendre polynomials, and generated using (5) through (11).

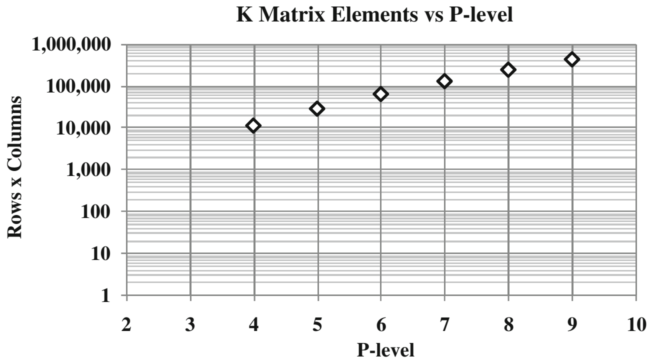


**Fig. 2** Elements in the K matrix plotted against *p*-level

$$\varepsilon_k(t_1, t_2) = \frac{-8\sqrt{4k+2}}{k(k+1)} P_i^{;}(t_2 - t_1) \tag{5}$$

$$F_{r_1,r_2}(t_1, t_2, t_3) = P_{r_1}(t_2 - t_1) P_{r_2}(2t_3 - 1) \tag{6}$$

$$\begin{aligned} &B_{r_1,r_2,r_3}(t_1, t_2, t_3) \\ &\quad = P_{r_1}(t_2 - t_1) P_{r_2}(2t_3 - 1) P_{r_4}(2t_4 - 1) \end{aligned} \tag{7}$$

Nodal shape functions (4 nodes)

$$\varphi_i^1 = L_i \text{ where } i = 1, 2, 3, 4 \tag{8}$$

Edge Modes (6 ($p-1$) nodes)

$$\begin{aligned} &\varphi_i^2 = L_{j_1} L_{j_2} \varepsilon_k \left(L_{j_1}, L_{j_2}\right) \quad \text{where } k = 1, 2, \ldots p - 1 \\ &j_1 = \begin{cases} 1 + j \bmod 3, 1 \le j \le 3 \\ 1 + j \bmod 4, 4 \le j \le 6 \end{cases} \text{and} \\ &j_2 = \begin{cases} 1 + (j+1) \bmod 3, 1 \le j \le 3 \\ 4, 4 \le j \le 6 \end{cases} \end{aligned} \tag{9}$$

Face Modes (2 ($p-1$) ($p-2$) nodes)

$$\begin{aligned} &\varphi_i^3 = L_{j_1} L_{j_2} L_{j_3} F_{r_1,r_2}\left(L_{j_1}, L_{j_2}, L_{j_3}\right) \\ &j_1 = 1 + j \bmod 4, j_2 = 1 + j_1 \bmod 4, j_3 = 1 + j_2 \text{mod} \\ &k = 3, 4 \ldots p \text{ and } r_1 + r_2 = k - 3 \end{aligned} \tag{10}$$

Internal Modes (($p-1$) ($p$–2) ($p-3$)/6 nodes)

$$\varphi_i^4 = L_1 L_2 L_3 L_4 B_{r_1,r_2,r_3}(L_1, L_2, L_3, L_4)$$
$$\text{where } k = 4, 5, \ldots \text{ p and } \mathrm{r}_1 + \mathrm{r}_2 + \mathrm{r}_3 = \mathrm{k} - 4 \tag{11}$$

The derivation of the closed-form stiffness matrix is based on the work of Shiakolas et al. [7], a summary of which follows. Element stiffness matrices for use in finite element analysis are typically represented using (12), where $[B]$ represents the strain–displacement matrix, $E$ is the elasticity matrix and $\Omega$ is the domain of integration.

$$[K]_e = \iiint_{\Omega} [B]^T [E][B] \mathrm{d}\Omega \tag{12}$$

The strain displacement matrix $[B]_i$ for node $i$ of an element is shown in (13), where $\varphi_i$ is the shape function for that node.

$$[B]_i = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial x} & 0 & \frac{\partial}{\partial x} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial z} \end{bmatrix}^T \varphi_i \tag{13}$$

The partial derivative of the shape function with respect to global coordinates $(x, y, z)$ are be obtained using the chain rule as shown in (14) and (15).

$$\frac{\partial \varphi_i}{\partial x} = \frac{\partial \varphi_i}{\partial L_1}\frac{\partial L_1}{\partial x} + \frac{\partial \varphi_i}{\partial L_2}\frac{\partial L_2}{\partial x} + \frac{\partial \varphi_i}{\partial L_3}\frac{\partial L_3}{\partial x} \tag{14}$$

$$\frac{\partial L_1}{\partial x} = \frac{C_{i1}}{|J|}, \frac{\partial L_1}{\partial y} = \frac{C_{i2}}{|J|}, \frac{\partial L_1}{\partial z} = \frac{C_{i3}}{|J|} \tag{15}$$

The partial derivatives found on the right-hand side of (14) are used to generate a new matrix, $[R]$. It is a function of polynomial order only and is the same for each element type.

The strain displacement matrix is then expressed as $[B] = [P]\ [R]$, where matrices $[P]$ and $[R]$ are generated symbolically using *Mathematica*. By substituting for $[B]$ into (12) a new expression, shown in (16), is obtained for the element stiffness matrix.

$$[K]_e = \int_{\text{volume}} [R]^T [P]^T [E][P][R]|J| dL_1 dL_2 dL_3 \tag{16}$$

Next, a new matrix $[G]$ is formed by grouping $[P]^T\ [E]\ [P]$. This $9 \times 9$ symmetric matrix is dependent only on the material and geometry. It has been used in the past to successfully reduce the rate of expression growth in closed-form implementations [6]. Substituting [G] into (16) gives the form of the stiffness matrix integral used for closed-form generation shown in (17).

$$[K]_e = \int_{\text{volume}} [R]^T [G][R]|J| dL_1 dL_2 dL_3 \tag{17}$$

For a straight-sided tetrahedral element, the integrand is comprised of the volume coordinates raised to various powers. The symbolic integration rule that applies is shown in (18) [11].

$$\iiint L_1^a L_2^b L_3^c L_4^d dL_1 dL_2 dL_3 dL_4 = \left( \frac{a!b!c!d!}{(a+b+c+f+3)!} \right) 6V \tag{18}$$

## 4 Closed Form Generation

The serial approach to generating the closed-form solution in *Mathematica 7* is given below. The first step is generation of the shape functions, which is detailed in previous work [5] and was not included in any timing or memory requirement results. The original algorithm below is based on the *Mathematica* scripts developed by Shiakolas et al. [7] for isoparametric tetrahedral elements.

Original Algorithm

1. Create *G* matrix using dummy variables to control expression growth
2. Create table of shape functions *NN*
3. Generate the *R* matrix
   a. Take derivatives of *NN* with respect to *L1*, and store in *RL1*
   b. Take derivatives of *NN* with respect to *L2*, and store in *RL2*
   c. Take derivatives of *NN* with respect to *L3*, and store in *RL3*
   d. Concatenate *RL1*, *RL2*, and *RL3* to form *R*
   e. Clear *RL1, RL2, RL3*
4. $K = \text{Transpose}[R] \cdot G \cdot R$ (matrix multiplication), results in $3 \times 3$ *nTot* symmetric matrix of symbolic expressions forming the integrand
5. Multiply *K* by $L1^t L2^t L3^t$ so that the integration rule can be applied even if a term does not have all three volume coordinates present
6. Expand *K* into individual terms (if the expressions are not expanded into individual terms, the substitution rule in the next step does not work properly)
7. Apply the symbolic integration rule of (18) to *K* through use of substitution
8. Set all remaining values of *t* found in *K* to 0

The most important issue encountered in using this version of the algorithm is memory limitations. Figure 2, a semi-log plot showing the number of elements in the stiffness matrix versus p-level, illustrates how quickly the problem size, in terms of rows and columns in the stiffness matrix, grows with *p*-level. Any attempt to generate the closed-form stiffness matrix for a *p*-level greater than 5 resulted in out of memory messages related to processing of the integrand matrix (see Steps. 6 and 7), even when virtual memory was increased. Attempts at direct parallelization of this algorithm (as discussed later) also faced the same limitation.

To reduce the impact of the memory requirements, it was noted that the stiffness matrix will be symmetric, as is the integrand matrix it is based upon. The original algorithm was refined so that only the upper triangular portion of the integrand matrix is actually manipulated. A similar approach was recently taken by Griffiths et al. [12]. This is accomplished by creating a vector based on the upper triangular portion of the matrix and releasing the original $K$ matrix from memory. All subsequent manipulation, including the steps of expansion and integration, are performed on the vector rather than on the full matrix. It is expected, although not tested, that this will result in decreased processing time, as found by Griffiths et al. [12].

This more efficient approach allows for the generation of higher-order elements than have previously attempted in closed-form. The approach is outlined below.

Memory efficient approach

1. Create $G$ matrix using dummy variables to control expression growth (Timing Begins)
2. Create table of shape functions *NN*
3. Generate the $R$ matrix
   a. Take derivatives of *NN* with respect to *L1*, and store in *RL1*
   b. Take derivatives of *NN* with respect to *L2*, and store in *RL2*
   c. Take derivatives of *NN* with respect to *L3*, and store in *RL3*
   d. Concatenate *RL1*, *RL2*, and *RL3* to form $R$
   e. Clear *RL1, RL2, RL3*,
4. $K = \text{Transpose}[R]\cdot G\cdot R$
5. Extract upper triangular portion of matrix $K$ and store in vector *kk*
6. Multiply *kk* by $L1^t\ L2^t\ L3^t$
7. Expand *kk* into individual terms
8. Apply the symbolic integration rule of (18) to *kk* through use of substitution
9. Set all remaining values of $t$ found in *kk* to 0 (Timing Ends)

Even with attempts at using memory more efficiently and using only the upper triangular portion of the integrand matrix, the complexity of the problem increases exponentially with $p$-level, as shown in Fig. 3. *Excel* 2007s trendline operation was used to generate an exponential fit relating $p$-level to the length of the vector used to store the upper triangular portion of the integrand, with an $R^2$ value indicative of a good fit.

The final approach used combines the memory efficient approach with the simply application of parallelization using *Mathematica 7* built-in tools.

Combined parallel and memory efficient approach

1. Create $G$ matrix using dummy variables to control expression growth (Timing Begins)
2. Create table of shape functions *NN using parallelization*

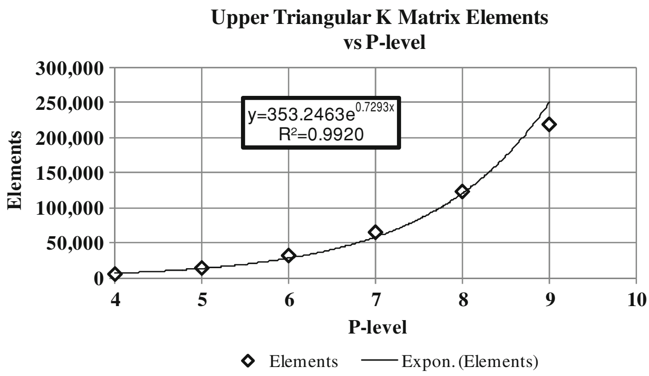


**Fig. 3** Size of upper triangular matrix versus p-level, showing exponential rise in number of elements

3. Generate the *R* matrix
   a. Take derivatives of *NN* with respect to *L1*, and store in *RL1*
   b. Take derivatives of *NN* with respect to *L2*, and store in *RL2*
   c. Take derivatives of *NN* with respect to *L3*, and store in *RL3*
   d. Concatenate *RL1*, *RL2*, and *RL3* to form *R*
   e. Clear *RL1, RL2, RL3*,
4. $K =$ Transpose[$R$]$\cdot G \cdot R$ *using parallelization*
5. Extract upper triangular portion of matrix *K* and store in vector *kk*
6. Multiply *kk* by $L1^t\ L2^t\ L3^t$ *using parallelization*
7. Expand *kk* into individual terms *using parallelization*
8. Apply the symbolic integration rule of (18) to *kk* through use of substitution
9. Set all remaining values of *t* found in *kk* to 0 (Timing Ends)

## 5 Testing Method

The maximum amount of memory and CPU seconds required by *Mathematica* to generate the closed-form straight sided hierarchical tetrahedral element stiffness matrices was recorded with the focus was on steps 3–9 of both the serial and parallel memory efficient approaches. The serial approach was used to generate *p*-levels 4–7 and the parallel approach generated *p*-levels 4–9.

The total seconds of CPU time needed to generate the stiffness matrix was determined using the command TimeUsed [13]. The system cache was cleared at the beginning of each stiffness matrix calculation so that results would not be based on reuse of any previously generated expressions, and all previous memory would be cleared. The maximum amount of memory required was determined using the MaxMemoryUsed command, which displays the maximum amount of bytes of memory required at any time during a *Mathematica* session [14].

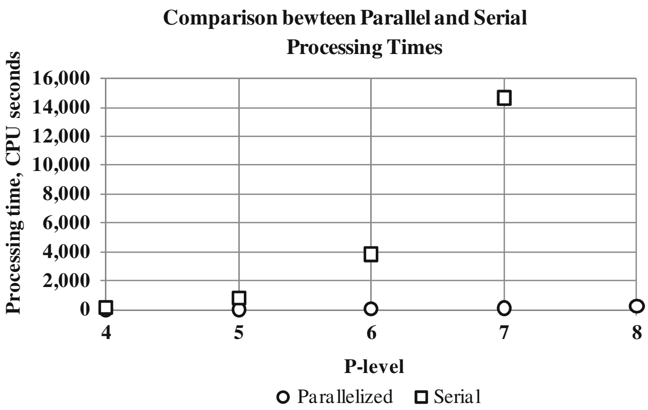


**Fig. 4** Serial and parallel processing time, in CPU seconds

The *Mathematica* scripts were implemented on an HP p630 w desktop computer with a dual core AMD Athlon II X2 215 Processor operating at 2.70 GHz with 4 GB RAM running Windows 7 Home Premium 64-bit operating system. The system has been set to 20 GB paging file size (virtual memory) to avoid the out of memory errors discussed in an earlier section. The results of the testing method described are summarized in the next section.

## 6 Results of Testing

Figure 4 compares the processing time for serial processing to that of parallel processing, and Figure 5 shows only the results for parallel processing. The decrease in processing time is very obvious, even for a merely dual core machine. The speed-up ratio achieved ranged from 150 for *p*-level 4 to 2, 093 for *p*-level 7. Note that *p*-level 7 was the highest order achievable using the serial processing method on the computer used for this study. Parallelization made it possible to extend the closed-form solutions up to *p*-level 9.

Observe that parallelization maintained the exponential relationship between *p*-level and processing time, as more clearly seen in Fig. 5.

The most interesting results, however, involved memory requirements. Figure 6 shows the maximum memory used to generate the closed-form stiffness matrices. Almost 12 GB of memory were needed to generate *p*-level 7 using a serial implementation, while less than 2 GB were required using the parallel implementation. Details regarding the percent reduction in required memory are shown between serial and parallel processing are provided in Table 1.

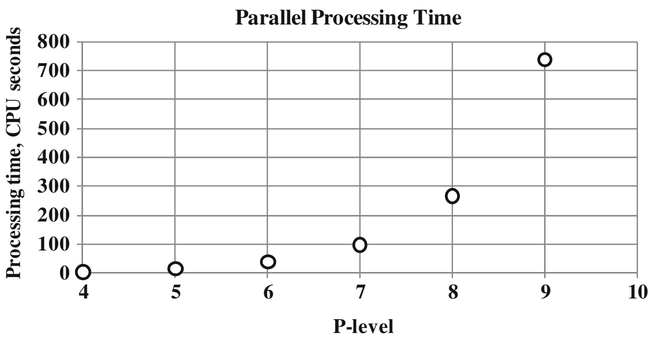


**Fig. 5** Parallel processing time, in CPU seconds

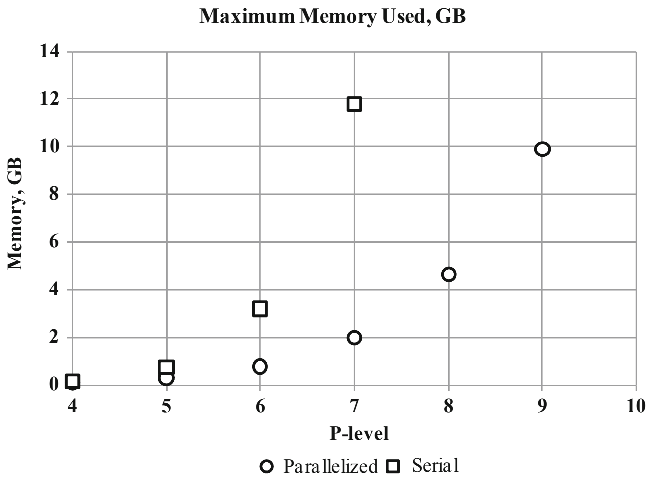


**Fig. 6** Maximum memory used to generate the closed-form stiffness matrices

**Table 1** Percent reduction in memory requirements achieved through use of parallel implementation

| P-level | % Reduction in memory |
|---|---|
| 4 | 29 |
| 5 | 60 |
| 6 | 76 |
| 7 | 83 |

Both methods show a similar exponential relationship between memory requirements and *p*-level, which is in agreement with the relationship between *p*-level and the number of elements in the upper triangular stiffness matrix.

## 7 Conclusions

This research has demonstrated that closed-form solutions currently hindered by memory and time issues may be facilitated through the application of parallel processing and simple attempts at using memory efficiently.

The generation of closed-form element stiffness matrices for straight-sided hierarchical tetrahedral elements has been extended past 4th order elements to 7th order elements through a more efficient approach to memory, and through 9th order by very na use of parallelization.

Most parallelization research in science and engineering has focused on numerical aspects of simulation and analysis, and very little on the symbolic aspects. However, the results presented in this paper and in prior research [5], show that even a simple approach to parallelization using built-in tools included with many common CAS can achieve two things: faster processing (up to 2000× times faster for *p*-level 9) and smaller memory requirements (12 GB compared to 2 GB for *p*-level 7).

The idea of parallelizing the generation and manipulation of symbolic solutions continues to have great promise for any area of science, engineering, or mathematics that makes use of symbolic, exact solutions but has been hindered to date by issues of time and available memory.

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# Metrics in Assessing the Quality and Evolution of jEdit

**Ilona Bluemke and Rafał Roguski**

**Abstract** Adequate metrics of object-oriented software enable to determine the complexity of a system, estimate the effort needed for testing and even locate some parts in the design that could be error prone or should be redesigned. The measurements and metrics are not widely used in the development of software. Contemporary systems are complex and adequate measuring tool is necessary in the design and evolution process. In this paper we present how software metrics can be used in assessing software. Next, a case study—an evaluation of three versions of a well known open source software—jEdit is presented. To measure this application Metrics 1.3.6, an Eclipse plug-in, was used. The correlation of metrics values and real quality attributes of software is described. On the basis of metrics values some conclusions concerning the quality of the design of each version and some general trends in the evolution of jEdit project evolution are derived.

## 1 Introduction

Measurement, metrics, and statistical analysis of data are the basic tools of science and engineering. When the software industry began in the early 1950s the first metric developed for quantifying the output of a software project was the metric named "lines of code" or LOC. Almost at once some ambiguity occurred, because a "line of code" could be defined either: a physical or logical one. Enough has

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been said about the inability of LOC to predict the complexity of software, even the traditional one. The function point metrics proposed by Albrecht's team and consisting of five key elements: inputs (screens, signals, etc.), outputs (screens, reports, checks, etc.), inquiries, logical files, interfaces are not of good use for object-oriented software as well. Other traditional metric the McCabe Cyclomatic Complexity [25] can be used to determine the cyclomatic complexity only of the methods of a class, not the whole software. This can be further used to determine a certain level of relative complexity of different classes in a system. The object-oriented literature abounds with descriptions of metrics for measuring multitude aspects of object-oriented designs and software

With the aid of metrics and heuristics the whole software project or part of it (e.g. classes) can be assessed [20, 26]. Design heuristics are rules of thumb that can guide designers as they choose between various alternatives, they capture the experience of skilled designers. A high degree of agreement between different authors in the literature might increase confidence in the validity of their heuristics. The utility of metrics will be questioned until sufficient number of empirical validations are performed. The experiments should enable to establish a relationship between metrics and real quality attributes of a system, such as reliability, testability, maintainability, etc.

Adequate metrics of object-oriented software enable one to determine the complexity of a system and estimate the effort needed for testing already in the early stage of system development. The metrics values enable to locate parts of the design that could be error prone. Changes in these parts could significantly improve the quality of the final product and decrease testing complexity.

Software metrics research is an important topic, but not yet a well-formed or mature topic. Each of the major software metrics candidates has splintered into a number of competing alternatives, often following national boundaries. There is no true international standard for any of the more widely used software metrics. Furthermore, the adherents of each metric variant claim remarkable virtues for their choice, and often criticise rival metrics. No conclusion has been reached yet about a good set of metrics for object-oriented systems.

Considerably research has been conducted on software metrics, some are described in monographs [13, 19, 30] others in separate papers e.g. [1, 4, 6, 8, 9, 19, 21, 22]. Several authors have shown the usability of object metrics in predicting test efforts or finding error prone parts in a program [4–6, 8, 10, 15, 18, 20].

There are also several works on assessing programs, especially Java programs, by object metrics. Some authors are assessing small students programs [2, 3], others are applying metrics to complex programs [12, 15, 18]. In [12] the results of measurements of several standard java libraries (J2SE, J2EE, J2ME, JWSDP) are presented. According to the author's knowledge, recently few works have been done on the assessment of software evolution [14].

The goal of this paper is to present how software metrics can be used in assessing software. Metrics for object programs are briefly described in section II. Next, in section III, a case study i.e. an evaluation of three versions of a well known open source software—jEdit [31] is presented. To measure this application

Metrics 1.3.6, an Eclipse plug-in, was used. The correlation of metrics values and real quality attributes of a system are described. On the basis of metrics values conclusions concerning the quality of the design of each version and some general trends in jEdit project evolution are derived. Some conclusions are given in Sect. 4
.

## 2 Software Metrice

In recent years many researchers and practitioners have proposed metrics for object oriented software [1, 4, 6, 8, 9, 19, 21, 22]. Almost all research has been dedicated towards associating a complexity number either to a class or to the whole system. In sub-section A some "class-level", and in sub-section B "system-level" metrics are described. Some of the proposed metrics are based on the general object-oriented features, so they can be applied to any object-oriented software, others are dedicated to only one programming language like C++ [21]. The language dependent metrics comprise class-level and system-level metrics.

### *2.1 Class Level Metrics*

Programmers can use class-level metrics to identify error prone classes. The class-level metrics can be also used to estimate testing effort, the possibility of code reuse, and to improve the quality of the class code as well. Some metrics were introduced for measuring different aspects of classes. Widely known set of such object-oriented metrics was introduced by Chidamber and Kemerer [9] in 1994 and is presented below—CK metrics. CK metrics contain:

1. WMC—weighted methods per class,
2. DIT—depth of inheritance tree,
3. NOC—number of children,
4. CBO—coupling between objects,
5. RFC—response for a class,
6. LCOM—lack of cohesion in methods.

In their papers [9, 10] Chidamber-Kemerer also provide an analytical confrontation of their proposed metrics with Weyuker's [29] list of measurement principles.

The NOC metric is defined as the count of immediate subclasses, with greater NOC values the probability of improper abstraction of parent class is greater. This metric gives also an idea of the potential influence a class has on the design.

DIT is the length of the maximal path to the root of the class hierarchy. It can be observed, that the deeper is a class in the hierarchy, the greater is the number of inherited methods, so more difficult is the prediction of its behaviour, and more time is needed for testing it.

WMC is the count of methods in a class. The number of methods and its complexity can be a predictor of how much time and effort is required to develop and maintain this class. Classes with large number of methods are likely to be more application specific, limiting the possibility of reuse. The more methods defined in a class, the greater is its possible impact on children classes.

The RFC is a measure of the potential communication between the class and another classes. If a large number of methods can be invoked in response to a message, the testing and debugging of this class becomes more complicated since it requires a greater level of understanding required on the part of the tester.

The CBO metric is approximately defined as the number of couples with other classes (where calling a method or using instance variable from another class constitutes coupling). The more independent a class is, the easier it is to reuse it in another application. To improve modularity and promote encapsulation inter class coupling should be small. The larger the number of couples, the higher is the sensitivity to changes in other parts of the design and therefore maintenance is more difficult. CBO metric is useful to determine how complex the testing of various parts of a design is likely to be. The higher the CBO is, the more rigorous the testing needs to be. CBO depends on the manner in which methods are designed and not on the functionality of the class.

The LCOM metric is defined as a count of the method pairs that do not have common instance variable minus the count of method pairs that do. The grater is the number of similar methods, the more cohesive is the class. If none of the methods of a class display any instance behaviour, i.e. do not use any instance variables, they have no similarity and the LCOM for the class will be zero. Cohesiveness of methods within a class is desirable, since it promotes encapsulation. Lack of cohesion implies classes should be probably split into two or more subclasses. Any measure of disparity of methods helps to identify flaws in the design of classes. Low cohesion increases complexity, thereby increasing the likelihood of errors during the development process

## 2.2 System Level Metric

The system-level metrics may be used by project managers to reduce the complexity of the design at early stages and to increase the quality of the design as well. Many metrics have been proposed to measure project characteristic. Below system-level metrics introduced by Brito et al. [8], called MOOD are presented. The metrics are evaluated in [16] and contain following metrics:

- MHF—Method Hiding Factor,
- AHF—Attribute Hiding Factor,
- MIF—Method Inheritance Factor,

- AIF—Attribute Inheritance Factor,
- CF—Coupling Factor,
- PF—Polymorphism Factor.

Other widely known set of system level metrics was proposed by Martin [23]. Martin proposed following metrics:

- Ca—Afferent couplings—the number of classes outside this category that depend upon classes within this category.
- Ce—Efferent couplings—the number of classes inside this category that depend upon classes outside this categories.
- I—Instability: (Ce/(Ce + Ca)), range [0,1], I = 0 indicates a maximally stable category while I = 1 maximally instable one.
- A—Abstractness: number of abstract classes in category/total number of classes in this category. A = 0 means concrete and 1 completely abstract class category.
- Main sequence:$D_n = |A + I - 1|$represents categories whose abstractness is balanced with stability.

Martin's metrics measure the quality of object design in terms of interdependence between subsystems. Designs which are highly interdependent tend to be hard to maintain and difficult to reuse. Interdependence is necessary if subsystems collaborate so some forms of dependency are desirable.

To estimate and compare software projects "size" metrics are also used e.g.:

- TLOC—total lines of not commented code,
- NOCL—number of classes,
- NOI—number of interfaces,
- NOP—number of packages,
- NOA—number of all attributes,
- NSA—number of static attributes,
- NOM—number of methods,
- NORM—number of overridden methods,
- NPAR—number of parameters in methods,
- NBD—nested block depth in a method.

## 2.3 Metrics Measuring Tools

There are many programs calculating object metrics, some of them are stand alone e.g.: jMetrics [17], Essential metrics [11], Understand 2.0 [28], others are Eclipse plug-in e.g.: XRay [32], Eclipse Metrics Plugin [23], Borland Together 2008 [7], Metrics 1.3.6 [24].

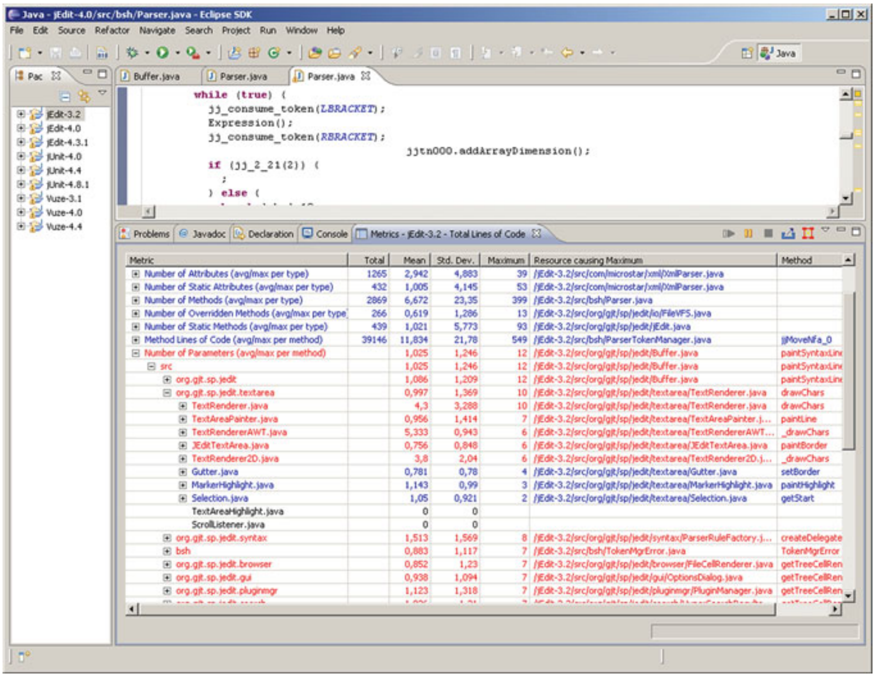


**Fig. 1** Screen of Metrics 1.3.6 calculating metrics for jEdit

We decided to use Metrics 1.3.6 [24] for the assessment of evolution of several complex, open source, applications. Metrics 1.3.6 is an Eclipse plug-in calculating many metrics. In Fig. 1 the screen with metrics for jEdit [31] is shown. The time to calculate metrics depends on the number of files in a project and is acceptable even for complex applications such as jEdit or Vuze [33]. We discovered some inconveniences in the calculation of CK metrics DIT and NOC. In the calculation of DIT metric, the inheritance of classes in standard Java libraries is also considered. Calculating NOC (number of children) Metrics 1.3.6 counts all instances.

Below, some results obtained for three versions of jEdit program are presented. Measurements of several versions of programs Junit and Vuze [33] can be found in [27].

## 3 jEdit Evaluation on the Basis of Metrics Values

Three versions of jEdit program i.e. 3.2, 4,0 and 4.3.1 were measured with Metrics 1.3.6 plug-in. At the beginning there were problems in compilation of the first two versions, more than 1,000 warnings and more than sixty errors were issued. Some warnings were probably caused by inappropriate Java environment. The

**Table 1** size metrics of three versions of jedit program

| jEdit | TLOC | NOCL | NOP | NOA | NSA | NOM | NORM | NSM |
|---|---|---|---|---|---|---|---|---|
| 3.2 | 53,735 | 430 | 17 | 1,265 | 432 | 2,869 | 266 | 439 |
| 4.0 | 61,918 | 504 | 19 | 1,506 | 525 | 3,348 | 321 | 510 |
| 4.3.1 | 103,237 | 853 | 33 | 2,558 | 787 | 5,523 | 435 | 986 |

compilation errors were caused by a variable named enum. The name enum is a keyword in Java used for enumeration type. In version 4.3.1 this variable was renamed as e. Second reason of compilation errors was caused by references to class SplashScreen. This class is present in standard Java package java.awt and in internal Jedit package org.gjt.sp.jedit.gui. Both packages were imported into jEdit application. When the references to class SplashScreen were preceded with package name, the compilation ended successfully and metrics values were calculated.

Some metrics values are given in Tables 1, 2 and 3. The values of metrics in Table 1 show, that the size of examined versions significantly increases. From version 4.0 to 4.3.1 the number of classes and code lines increased by 60 %, whereas from version 3.2 to 4.0 only about 15 %. Calculating metrics values with the Metrics plug-in does not take into account libraries. Similar regularity can also be seen in the number of packages (NOP). From version 3.2 to 4.0 the increase in NOP is more than 70 %, whereas from version 3.2 to 4.0 only about 11 %. The version numbers suggest, that the changes from version 3.2 to 4.0 should be greater.

In all three jEdit versions the same metrics: NPAR, NBD and Mc Cabe cyclomatic complexity (MCCC), Table 3, are beyond acceptable limits. If NBD (nested block depth) is high, it is difficult to understand the code and modify it. The accepted value for NBD is 5 and it was exceeded in 16 methods in the oldest jEdit version 3.2, in 21 methods in version 4.0 and in 39 methods in the newest version. The maximal value of NBD in jEdit is 15, 16. It is almost impossible to understand and modify code with so many nested blocks (if instructions).

The values of MCCC also exceeds acceptable limits (set to 10), for method jjMoveNfa_0 from class ParserTokenMana even 25 times. This method contains 540 lines of code and no comments at all. Many instructions contain bits operations in hexadecimal code. This method should be divided into several smaller methods with some comments included.

Another example of a method with high values of MCCC is method ForStatement in class Parser. In first two jEdit versions the value of MCCC was 80, in the newest version increased to 98. This is caused by case instructions in three switch constructs. However the value of MCCC is high, the code of this method can be easily understood. The percentage of methods having values of MCCC above the limits (shown in Fig. 2) is not high, and decreases in consecutive versions. This phenomenon shows, that some improvements in the methods code were introduced.

**Table 2** CK Metrics of jedit program

| jEdit | NOC av. | NOC max | LCOM av. | LCOM max. | WMC av. | WMC max | DIT av. | DIT max |
|---|---|---|---|---|---|---|---|---|
| 3.2 | 0.295 | 35 | 0.227 | 1.33 | 30.151 | 3,398 | 2.507 | 8 |
| 4.0 | 0.296 | 35 | 0.229 | 1.33 | 29.266 | 3,434 | 2.458 | 8 |
| 4.3.1 | 0.274 | 38 | 0.222 | 1.25 | 24.054 | 2,031 | 2.317 | 8 |

**Table 3** Other Metrics of jedit programs

| jEdit | Ca | Ce | A | I | NBD av. | NBD max | MCCC av. | MCCC max |
|---|---|---|---|---|---|---|---|---|
| 3.2 | 17.412 | 8.529 | 0.077 | 0.525 | 1.627 | 15 | 3.919 | 251 |
| 4.0 | 20 | 9.316 | 0.073 | 0.53 | 1.631 | 15 | 3.823 | 255 |
| 4.3.1 | 21.303 | 9.576 | 0.124 | 0.621 | 1.602 | 16 | 3.148 | 255 |

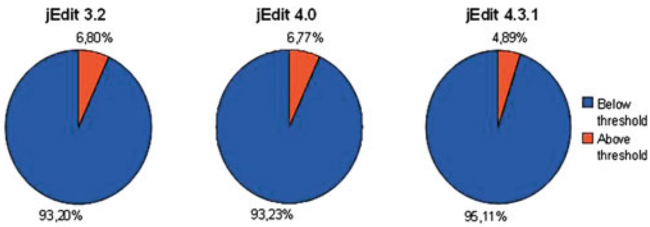



**Fig. 2** The percentage of methods exceeding limit of MCCC

The average value of DIT (Table 2) metrics is low. Calculating this metric Metrics 1.3.6 program counts also standard Java class inheritance. The maximal value 8 are in classes inheriting from class org.gjt.sp.jedt.gui.EnhancedMenu, which is the child of javax.swing.JMenu (standard java class).

The value of Martin metrics A (abstractness) is also low. Only in the latest versions of jEdit there are some packages with A >0.25 and only one with A equal to 0.5. It means that abstract classes, suitable for roots in the inheritance hierarchy, are not available. An example is class SimpleNode from package bsh. The value of NOC for this class is 35 and even 37 in version 4.3.1 while the value of DIT is only 1 meaning that this class inherits, as all Java classes, from standard Object class. In package containing this class there are more than 70 classes and there are even 90 in version 4.3.1. The value of LCOM equal to 0.879 for this class shows, that this class should be redesigned. This class provides 18 methods and only 6 of them are used in child classes so these classes inherit functionality which is useless for them.

Values of A metric is low, below 0.2, in all jEdit measured versions. Only in one package, in the latest version 4.3.1, A has value 0.75. Many packages are highly instable. In version 3.2 four packages have maximal instability (I) and one has I equal to 0.9. In the latest jEdit version maximal instability is in nine packages

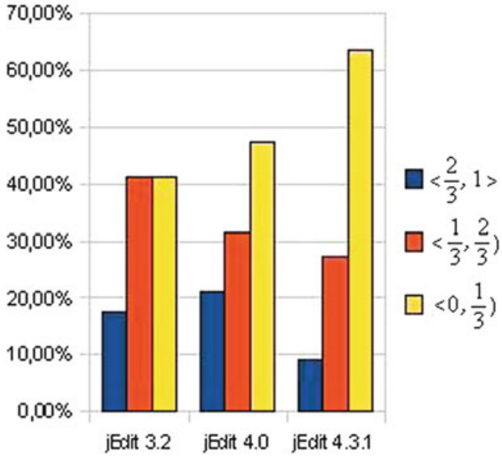



**Fig. 3** The percentage of packages with values of $D_n$ metrics in given range

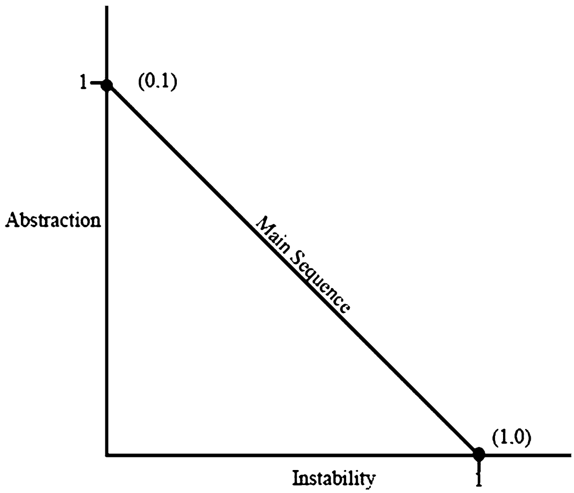
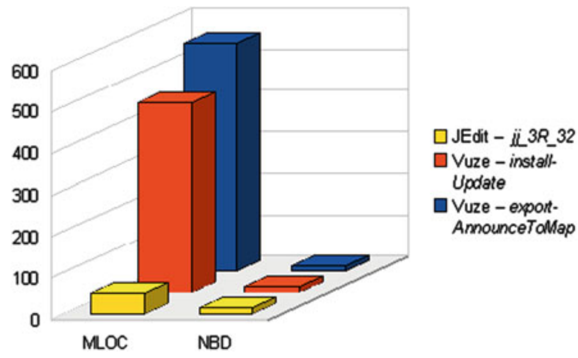



**Fig. 4** Main sequence ($D_n$) metric source [22]

and 63 % of packages have instability >0.5. These values are indicators of poor design with poor internal structure.

In Fig. 3 the percentage of packages with $D_n$ values in three ranges are presented. The value of $D_n$ improves in recent jEdit versions. In Fig. 4 the main sequence ($D_n$), balanced abstractness with stability, is presented in graphical form. Taking into consideration the values of A and I it can be noticed that packages that are close to main sequence are heading to point (1, 0) in Fig. 4. It means that the majority of packages is instable and there is small number of abstract packages. In Fig. 5 the comparison of the length of code in methods in jEdit and Vuze [33] with the same, and maximal values of NBD is presented. It can be noticed that in vuze the methods with high values of NBD are much longer.

**Fig. 5** Length of code of methods in jEdit and Vuze with the same and maximal values of NBD




## 4 Conclusion

In this paper we presented a metric based analysis of three versions of an open source software—program jEdit, an editor for programmers. Using different metrics were able to locate many flaws in the design. Many packages, classes and methods in jEdit should be redesigned. Analyzing the metrics values for three jEdit versions we did not observe significant improvement in the design.

Availability of a suitable and adequate measuring tool at the early stage of a program development enables early prediction of the system complexity, thus reducing the cost of making necessary changes. Metrics calculation should also accompany the evolution of a project, for the same reasons as in the design. Software architects may optimize their design for better quality and easier maintenance. Open source systems are widely used and often they are developed differently than industrial ones. The code of new version should be measured by object metrics to observe the changes in the design. The correlation of metrics and real quality attributes of a system, such as reliability, testability, maintainability was studied by several authors but still new experiments and research should be conducted.

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# Customising a BBVC for Asterisk VoIP Services

**Y. Oyedele, A. Terzoli and K. Mufeti**

**Abstract** Browser-based Voice over Internet Protocol Clients (BBVC) are used to access pre-determined VoIP services from VoIP service providers through Internet connections. For nomadic users within an organisation's Intranet, connections are made to the Internet to utilise these BBVC. An Intranet with an Asterisk Private Branch Exchange (PBX) as a VoIP provider however can be linked with any form of VoIP client to improve service accessibility for its users. This study aims to find a BBVC that can be customised to provide such accessibility within an Intranet. The study revealed that three BBVC are compatible. One of three BBVC was selected for customisation to provide nomadic accessibility to Asterisk. The functionality of the customised BBVC depended on the web technologies used and the available VoIP services.

## 1 Introduction

Asterisk is commonly set up to provide VoIP related services ranging from call services to traditional telecommunication connections within and outside organisational networks [1]. Asterisk VoIP services are utilised using VoIP clients

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such as hardware phones and software phones. Access to these VoIP clients is fixed in that they can only be accessed in the location where they have been set up. To provide nomadic access to VoIP services, BBVC were created. Although there are a few BBVC available for VoIP services, only few are compatible with Asterisk.

Several VoIP service providers such as Voice Commerce Group Limited [2], TringMe Company [3] and Gizmo5 Technologies Inc [4] developed their own BBVC as means to improve users' accessibility to their VoIP services. In this work, several BBVC were surveyed and a BBVC that is compatible with Asterisk was customised.

The remainder of this paper is organised as follows: Section 2 (BBVC) presents the common types of BBVC. Section 3 (Methodology) describes the setup of the BBVC survey and the customisation. Section 4 (Results) presents the survey results and customisation results. Section 5 (Conclusion) concludes the paper and presents recommendations.

## 2 BBVC

A BBVC is a Browser-Based Application (BBA) with a web phone used to provide nomadic users access to VoIP services. Like other forms of BBA, it uses some of the features available on Web browsers [5]. These features include support for web technologies which are used to implement the web phone.

Commonly used web technologies are ActiveX technology, Java Applets and Plug-ins such as Adobe Flash [6]. These web technologies, with compliant web browsers, have to be already installed on the PC that will be used to access the BBVC. Unlike ActiveX, which is supported only on Microsoft Windows Operating System (OS) and Microsoft Internet Explorer (IE) web browsers, both Adobe Flash and Java are supported by most web browsers that work on Microsoft Windows, Linux and Macintosh OSs. Adobe Flash and Java come installed with Microsoft Windows OS but often need to be updated before they can be used in web browsers. On Linux OS, both Flash and Java are installed during or after the installation of the OS. Java on Microsoft Windows OS has to be installed after the OS installation [7] & [8].

BBVC are used to access VoIP services like other types of VoIP clients. Unlike the other VoIP clients, they are accessible from web browsers on PCs connected to an IP network anytime, anywhere, thus providing nomadic accessibility as indicated in Fig. 1 [5]. Most of the available BBVC are created specifically for individual VoIP service providers thus making them proprietary.

Designed to work with the individual developer's VoIP services through Internet connections, BBVC are proprietary in that they cannot be used for another VoIP service different from the one it was developed for. VoIP service providers with their own BBVC include Voice Commerce Group (Busta—an ActiveX based BBVC) [2], TringMe company (TringPhone—a Flash based BBVC) [3] and Gizmo5 (GizmoCall—a Flash based BBVC) [4]. Among the mentioned BBVC,

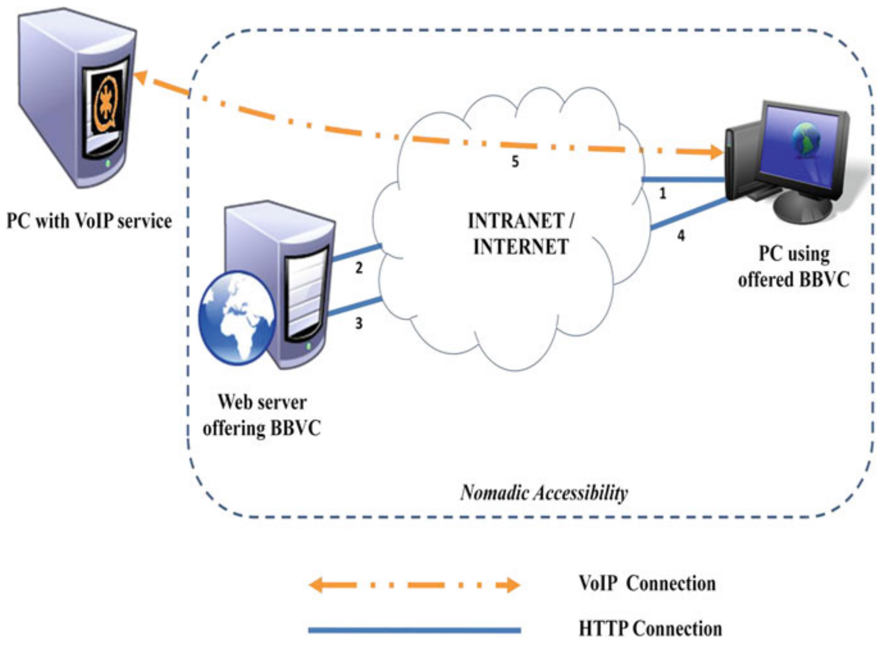


**Fig. 1** A simple VoIP Setup for nomadic accessibility

GizmoCall is the only proprietary BBVC that can be used with Asterisk through the use of a prepaid Opensky service [4]. Non-proprietary BBVC, such as JSAP (Java based BBVC) [9], JIAXC (Java based BBVC) [10] and iaxClientOcx (ActiveX based BBVC) [11], can be used directly with Asterisk.

## 3 Methodology

For this study, a survey of available BBVC with free trials and demo applications was conducted, to find Asterisk-compatible BBVC. These applications were set up and examined, focusing on the web pages containing the voice transfer functionalities, the BBVC features, support for Asterisk VoIP services and provision for nomadic accessibility within an Intranet. The BBVC evaluated were Voice Commerce Group's Busta, Conaito's VoIP EVO Enterprise SDK (web demo application), Mexuar Communications' Corraleta Connect (web demo) [12], Gizmo5 Technologies Inc's GizmoCall, Hello2Web, Silicon Technix's iaxClientOcx, Java IAXClient (JIAXC) library demo application (which is a group of applet jars), JAIN SIP Applet Phone (JSAP), British Communications plc's Ribbit (formerly owned by Ribbit Corporation), TringMe's TringPhone, Vax VoIP SDK (Web demo application) and VIMAS Technologies' Web Voice Chat.

The results of the survey were used to identify the common features to be included in a customised BBVC for Asterisk and to design a state diagram for the customable BBVC (BBVC4A Website). For the setup, a replica of the Asterisk setup in the Department of Computer Science of the University of Namibia (DCS-UNAM) was used as the VoIP service provider—Ubuntu PC running on a Pentium IV 2.8 GHz processor and a 512 MB memory along with a LAMPP server (XAMPP for Linux) application chosen as a web server to host the BBVC4A website. This setup was done to save time and cost of re-configuring or re-installing the actual Asterisk VoIP server used in DCS-UNAM, should something go wrong with the system. Both Asterisk and LAMPP were installed on the same Ubuntu PC because both are designed to work with minimal PC resources available. The setup was also configured to for accessibility from any network.

The BBVC4A website was implemented using PHP scripting for the server-side and HTML for the client-side of the website. Asynchronous JavaScript and XML (AJAX) scripting was used to get and display available users from the database without having to reload the web page. Interfaces were designed for existing users who are logged into the website, with the exception that these interfaces cannot be accessed by other types of users such as website visitors.

A dummy website manager—an administrative user of the LAMPP server —and a "User" database table was created using MySQL, for the BBVC4A website. The contents of the database table included the website login details and Asterisk VoIP values for existing users. These details were utilised by the BBVC4A website through PHP scripting with Cookies containing PHP sessions about logged-in users. The main benefit of using cookies is that they can be used to store some of the users' details which otherwise will load the web server.

The BBVC4A website was tested with main focus on the web page containing the web phone. The network traffic generated when the web phone was registering with the Asterisk server were captured and analysed using Wireshark [13].

## 4 Results

The survey results indicated that the available Asterisk-compatible BBVC have limited features to support nomadic accessibility. The most common BBVC features are Dial pad to type in numbers, Dial pad to send DTMF signals, Dial user, Receive (Answer) calls from other users, Call Ignore (or Reject), Hang up (End) call, Message waiting indicator, User's presence, Automatic selection of best audio codec, Clear entry field (button, keyboard or mouse), VoIP audio codec support, VoIP protocol support, Web technology support, Login (Logout). The least common features are the authentication support for the BBVC, support for many users and support for Asterisk VoIP call services. Based on the results of survey, a state diagram was designed for the BBVC4A Website as shown in Fig. 2.

The Asterisk-compatible BBVC are Mexuar Communications' Corraleta Connect [12], JAIN SIP Applet Phone (JSAP), Silicon Technix's iaxClientOcx and

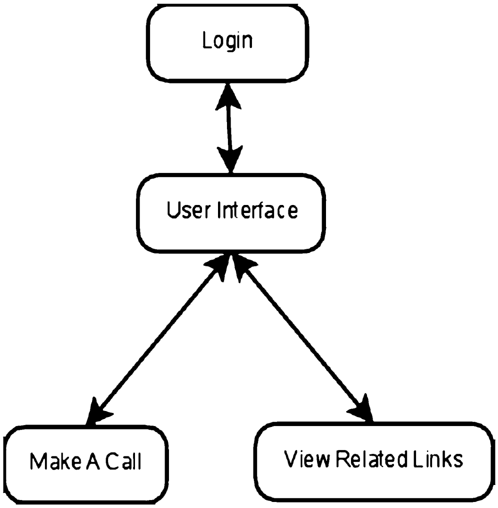


**Fig. 2** The BBVC4A website state diagram

Java IAXClient (JIAXC) library demo application. The advantage with these BBVC is that their features can be enhanced to support Asterisk VoIP services. Out of these BBVC, the JIAXC library application was found most appropriate to be customised for nomadic accessibility to Asterisk, with its demo application used as the web phone for the BBVC4A website.

JIAXC uses Inter Asterisk eXchange (IAX) VoIP protocol to communicate with Asterisk, with support for VoIP audio codex such as GSM and Speex. The JIAXC application supports all Java-enabled web browsers on Microsoft Windows and Linux PCs, but with few features. In addition, the JIAXC application, as a BBVC, provides support for one user, but can be customised to provide support for many users. Two major features of a typical BBVC were missing from the JIAXC demo applications. They are the dial pad to type in numbers and send DTMF signals, and 'clear entry' button. The addition of these features to the JIAXC demo application involved partial re-designing of the application.

Also, the status display of the applet phone did not reflect commonly known status of commonly used IAX based VoIP clients. So, the *statusLine* label was modified to display the status of the phone with respect to the activities of the BBVC4A user.

Adding these features proved more challenging than initially expected as thorough knowledge and understanding of the JIAXC library and its dependencies (IAXClient library written in the C programming language, and the GNU build system) were required. A more recent version of the IAXClient library was required because the IAXClient library on which the JIAXC library was based on, and other versions of the IAXClient library, were not installable on the Ubuntu PC, except for version 2.1 beta3. There was limited information available on how to use the JIAXC library and the IAXClient library.

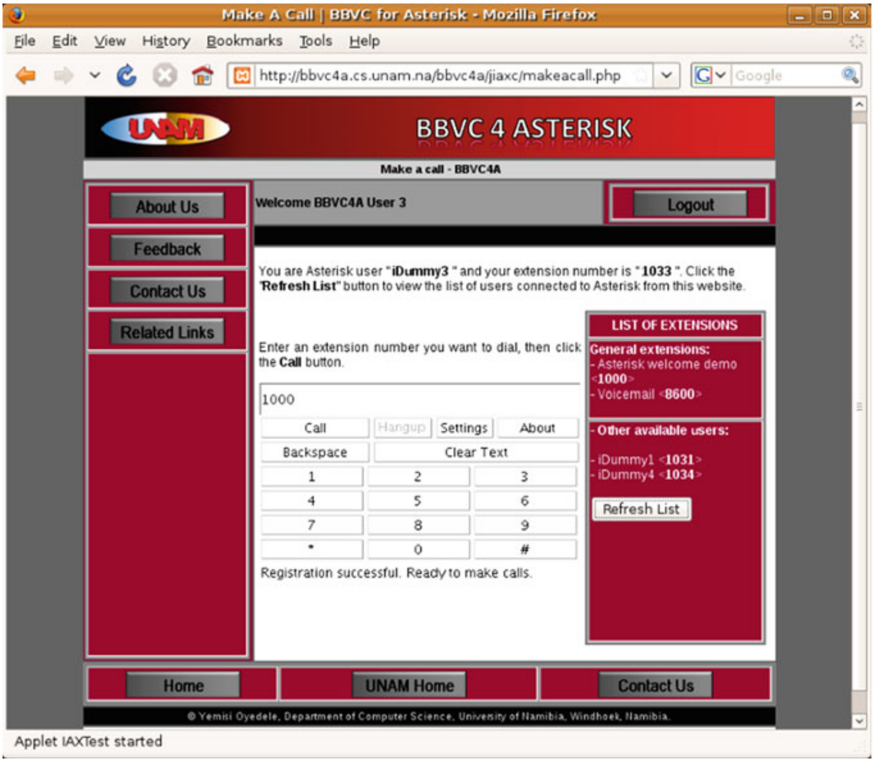


**Fig. 3** BBVC4A web phone page

A custom BBVC (BBVC4A website) was developed for the Asterisk setup at DCS-UNAM. It contained the JIAXC application (applet jars) serving as its web phone. The website utilises a combination of HTML, AJAX, PHP and Java Applet for its functionalities but the enhanced JIAXC application ran only on Linux PCs. After the web phone had been loaded through BBVC4A's Make-A-Call web page on a Java-enabled Firefox web browser, it could not be initiated in the web browser. The errors retrieved from Firefox's error console indicated that the user of the web browser needed administrative/root privileges to access the system's Java Runtime Environment (JRE). Figure 3 shows BBVC4A's Make-A-Call web page, with the enhanced JIAXC application as the web phone, when accessed by a super user.

The VoIP data from the network traffic data generated were analysed to see the flow pattern of the communication (IAX2 protocol) between user "iDummy3" (192.168.122.7) on the web phone and the Asterisk VoIP server (192.168.122.33). Figure 4 shows the graph analysis for the captured VoIP packets. The arrows indicate the direction of each packet sent as the web phone successfully connects to the Asterisk VoIP server.

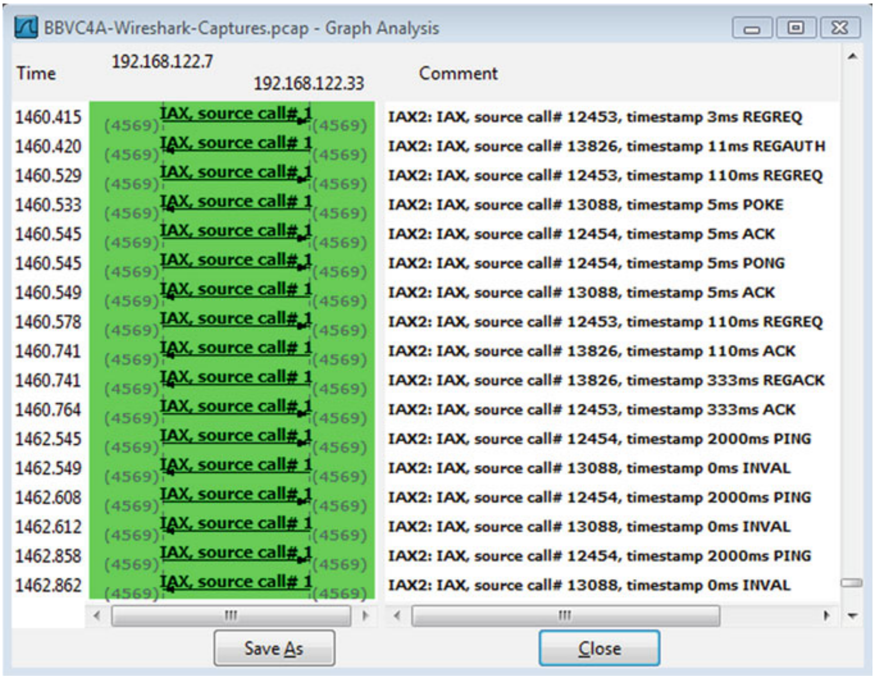


**Fig. 4** Wireshark flow graph analysis of an initial connection between user “iDummy3” (192.168.122.7) and asterisk server (192.168.122.33)

## 5 Conclusions

In this study, several BBVC were surveyed to find compatible BBVC for Asterisk server. JIAXC application was found most appropriate and was customised as a BBVC for Asterisk. The registration process between BBVC4A’s web phone and Asterisk server was captured and analysed.

It is recommended that a customised BBVC be integrated with Asterisk server through the use of a database management system so that the number of available features of the BBVC can be enhanced based on avaliable VoIP services.

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# An Exploratory Empirical Study of Internal Quality Attributes of Open Source Software Systems

**Denis Kozlov, Jussi Koskinen, Markku Sakkinen and Jouni Markkula**

**Abstract** This exploratory empirical study has focused on open source software (OSS). Seven medium-sized OSS systems from the SourceForge repository were analysed. Over 100 internal quality attributes and programming practices were scrutinized by using two semi-automated source code analysis tools (FindBugs and SoftCalc). Many statistically significant relations were revealed by the conducted regression analyses. Seven so-called bad programming practices; as manifested by the measured source code inconsistencies were identified as having significant relations to internal software quality. Additionally we set and tested two hypotheses. That investigation provided mixed results partly supporting some of the earlier findings between software size and potential maintenance problems; especially related to some of the programming practices.

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## 1 Introduction

We will investigate *software quality* related to *open source software* (OSS). The importance of software quality as such has been generally increasingly recognized, especially due to various well-known quality problems in some of the widely used commercial software systems. Also the importance of OSS systems has been increasing during the last 10 years and even some of the well-known commercial software companies initiate and lead OSS projects nowadays [1]. OSS engineering has also become an increasingly organized phenomenon.

One of the remaining problems is that it may be more difficult to ensure proper software quality in case of developing OSS than in case of the more traditional forms of software engineering. Potentially complicating factors include issues such as the extreme numbers of involved developers and maintainers, their potentially differing programming conventions and non-standardized or irregularly followed quality assurance procedures. The relations between the so-called *bad programming practices* and other internal quality attributes are currently yet not well understood. Knowing such relations could help in reducing the quality problems related to the development and maintenance of OSS systems.

The goal of this study is to bridge this important gap between the current practice and scientific knowledge to some extent. We aim at investigating empirically the relations between bad programming practices, source code inconsistencies and similar flaws and other important internal quality attributes. The source code inconsistencies will be revealed by semi-automated static analysis of the source code. Chess and West [2] point out that static analysis is well suited to identifying issues such as security problems. Static analysis tools apply checks thoroughly and consistently, without any bias that a programmer might have about which pieces of code are interesting from a selected perspective or which pieces of code are easy to exercise through dynamic testing. Static analysis also enables an early catch of the problems.

Our research method will be systematic; we apply an enhanced version of the static measuring approach of OSSs as used in our earlier studies [3, 4]. Here the preliminary relations between the studied metrics will first be identified based on correlation analysis. Strong relations between the metrics will be identified and then regression analysis applied.

The following main concepts will be used in this paper. An *attribute* is as measurable physical or abstract property of an entity [5]. A *quality attribute* is a management-oriented attribute of software that contributes to its quality [5]. *Internal quality attributes* are attributes which can be measured purely in terms of the software product itself; i.e. solely by examining it on its own, separately from its behaviour [6].

The rest of the paper is organized as follows. Firstly, a short overview of the most related research background is given (Sect. 2). An in-depth description of our empirical research approach follows (Sect. 3) and the main results of the conducted statistical analyses are presented (Sect. 4). Finally, the results are discussed (Sect. 5) and the most important conclusions shortly summarized (Sect. 6).

**Table 1** Research background

| Study | Static analysis tools used | Software products analysed | Identified main relations between the metrics |
|---|---|---|---|
| Rutar et al. [7] | PMD, FindBugs, JLint | 5 middle-sized OSSs | The total number of warnings is in general not correlated with the number of lines of code. |
| Spacco et al. [8] | FindBugs | 116 releases of one OSS | There is a relation between the number of correctness warnings and the number of non-commenting source statements. |
| Allen et al. [9] | No tools | None | There is a relation between software complexity and reliability. |

## 2 Research Background

There are a number of studies using static analysis to investigate source code and to find out some of the conditions and evolutionary patterns related to bad programming practices. We have chosen only those studies that revealed specific relations between code inconsistencies and internal quality attributes. The summary of those studies is provided in Table 1. The studies of Rutar et al. [7] and Spacco et al. [8] are experimental case studies, whereas Allen et al. [9] is more theoretical; although it is probably based on experimental studies, those are not mentioned explicitly in that paper.

## 3 Case Study

This section presents our research objectives and methods, as well as the hypotheses raised based on the literature review, and our research setting.

### *3.1 Research Objectives*

Our main research objectives are: (1) to find out bad programming practices indicated in the source code of seven selected medium-sized Java-based OSS and (2) to find out how those bad practices can be explained statistically by internal quality attributes. The palette of the analysed metrics consists of 63 internal quality attributes and 40 bad programming practices.

## 3.2 Hypotheses

Our hypotheses are raised based on the results of the papers mentioned in Sect. 2. However, our metrics differ from those used in the previous studies, and thus we define our hypotheses in a general form. The metrics used in the previous studies and in this study can be regarded as operationalizations of the more general concepts used in the hypotheses. The set hypotheses are:

**H1**: *There is a negative relation between software complexity and reliability*. The hypothesis is based on the results of Allen et al. [9] showing that complexity due to technical difficulty, size, and conflicting objectives often makes software systems more prone to failures and more vulnerable.

**H2**: *There is a positive relation between number of warnings and software size*. The hypothesis is based on the results of Spacco et al. [8] showing that there is a positive relation between *Number of Non-Commenting Source Statements* (*NCSS*) and *Number of Correctness Warnings (NCW)*. The correctness warnings cover coding errors, poor programming practices and style violations. Security vulnerabilities and other non-correctness issues are not included into this category. On the other hand, the study of Rutar et al. [7] showed that there is no strong correlation between *Number of Non-Commenting Source Statements* (*NCSS*) and *Total Number of Generated Warnings (TNGW)*.

## 3.3 Analysed Software

We analysed seven Java-based medium-sized OSSs. The main criteria for having selected those OSSs were their popularity, software size and coverage of various software application domains.

1. Data Crow (v. 2.1.0.–3.1.3.), a cataloger or database for movies, videos, books, images, software and music [10];
2. Eclipse CheckStyle Plug-in (v. 3.3.1.–4.4.0.), a plug-in integrated into the Eclipse IDE, which provides real-time feedback to the user about violations of rules that check for coding style and possible error-prone code constructs [11];
3. FreeMind (v. 0.0.2.–0.8.1.), a mind mapper and at the same time an easy-to-operate hierarchical editor with strong emphasis on folding [12];
4. JFreeChart (v. 0.5.6.–1.0.9.), a free chart library for the Java platform [13];
5. Jin (v. 2.1.0.–2.14.1.), a Java client for various chess servers [14];
6. Jmol (v. 9.0.0.–11.4.rc10.), a molecular viewer for three-dimensional chemical structures [15];
7. Phex (v. 0.6.–3.2.0.102.), a P2P file sharing client, which connects to the Gnutella network [16].

All these OSSs are available in the online OSS repository Source Forge [17]. Table 2 gives the main information about them.

**Table 2** Analysed OSSs—basic metrics

| OSS # | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Number of releases | 19 | 15 | 15 | 47 | 20 | 30 | 21 |
| Max. *NSL* (KLOC) | 158.0 | 36.9 | 39.8 | 223.9 | 87.9 | 134.3 | 148.7 |
| Avg. *NSL* (KLOC) | 64.7 | 26.8 | 16.9 | 134.3 | 67.1 | 114.0 | 118.4 |
| Avg. *NM* | 106.0 | 24.0 | 24.2 | 45.6 | 115.4 | 40.3 | 82.0 |
| Maintenance time (years) | 2.0 | 4.0 | 8.0 | 7.5 | 6.0 | 4.0 | 7.5 |
| Number of developers | 1 | 4 | 6 | 9 | 1 | 29 | 9 |
| Average number of downloads per week | 1,037 | 23,719 | 37,244 | 8,941 | 902 | 1,466 | 2,275 |

Software size was given in terms of maximum and average *Number of Source Lines in All* (*NSL*, in thousands of lines) and average *Number of Modules* (*NM*). The maintenance time is considered to be the time between the release dates of the first and last versions available.

## 3.4 Internal Quality Attributes

The internal quality attributes were measured by means of the static analysis tool SoftCalc [18]. This tool is listed among the efficient Computer Assisted Software Measurement and Evaluation (CAME) Tools [19]. In total we measured 63 internal quality attributes, which can be divided into the following categories: (1) basic internal quality attributes, e.g. *Number of Source Lines in All* (*NSL*), *Number of Modules* (*NM*), *Number of Comment Lines* (*NCL*), etc. and (2) complexity metrics, e.g. *Data Complexity Chapin Metric* (*DCCM*), *Interface Complexity Henry Metric* (*ICHM*), etc.

## 3.5 Bad Programming Practices

We measured a number of inconsistencies in the source code that indicate bad programming practices. These metrics were measured by means of the static analysis tool FindBugs v.1.3.4 [20]. The inconsistencies are divided into the following groups [20]: (1) Bad practice, (2) Correctness, (3) Internationalization, (4) Malicious code vulnerability, (5) Multithreaded correctness, (6) Performance, (7) Security, and (8) Dodgy. Detailed information about all errors measurable by FindBugs can be found on the web site [21].

In total we measured 40 kinds of bad programming practices, although FindBugs can detect more than 250 different source code inconsistencies. From those 40 metrics we excluded: (1) metrics with ambiguous names and definitions, (2) metrics belonging to several groups (see above) at the same time, (3) metrics accounting for other aspects, e.g. security and vulnerability rather than bad programming practices, and (4) metrics that had no statistically significant correlations with the studied internal quality attributes. After this pruning, the following listed seven metrics remained. All these metrics are determined as counts of the occurrences of the identified bad programming practices.

1. Dropped or ignored exception, i.e. a piece of code creates an exception (or error) object, but doesn't do anything with it.
2. Method ignores results of InputStream.read(), i.e. a method ignores the return value of one of the variants of java.io.InputStream.read() which can return multiple bytes. If the return value is not checked, the caller will not be able to correctly handle the case where fewer bytes were read than the caller requested.
3. Stream not closed on all paths, i.e. a method creates an IO stream object, does not assign it to any fields, pass it to other methods that might close it or return it, and does not appear to close the stream on all paths out of the method. This may result in a file descriptor leak.
4. Method returning an array may expose internal representation, e.g. a public static method returns a reference to an array that is part of the static state of the class. Any code that calls this method can maliciously modify the underlying array.
5. Storing reference to a mutable object, i.e. returning a reference to a mutable object value stored in one of the object's fields exposes the internal representation of the object. An array is considered to be an object in Java. Therefore bad programming practices 4 and 5 are related to the same type of source code inconsistencies.
6. Questionable integer math, i.e. a piece of code converts an integer value to a floating point number and then passes the result to the Math.round() function, which returns the integer/long closest to the argument.
7. RunTime exception capture, i.e. a method uses a try-catch block that catches Exception objects, but Exception is not thrown within the try block, and RuntimeException is not explicitly caught.

## 3.6 Statistical Methods Used

We used a combination of Pearson product-moment correlation analysis and multiple regression analysis to find out the relations between bad programming practices and internal quality attributes. Both analyses were applied to the whole sample of all the studied metrics from all seven OSSs. This is in contrast to our previous studies [3, 4], in which we analysed each OSS project separately.

Firstly, correlation analysis was used to identify potential explaining variables (among the internal quality attributes) for each of the studied bad programming practices. Linear correlation analysis is applicable in this study because all the internal quality attributes and programming inconsistencies are measured on interval scales. Furthermore, quadratic and cubic models did not show significantly better fitting to the observations than the linear model.

Secondly, we chose as the explaining variables for each inconsistency, those quality attributes that achieved a correlation of magnitude 0.8 or higher, and with statistical significance $p < 0.05$.

Thirdly, we applied multiple regression analysis with the explaining variables for each of the analysed inconsistencies, and computed their regression coefficients.

### 3.7 Research Procedure

The study was carried out as follows:

- The internal quality attributes for all the releases of the analysed OSSs were measured via SoftCalc.
- The inconsistencies in the source code caused by bad programming practices were measured via FindBugs.
- All the measured metrics (i.e. internal quality attributes and inconsistencies) from individual OSSs were merged together to build one solid sample.
- The potential relations between the metrics under study were identified by means of correlation analysis, using the statistical software product Statistica 8.
- Multiple-regression models were built to quantify the relations found. The multiple regression analysis was carried out using Statistica 8.

## 4 Results

In this section, because of the space limitation, we present only our final results. The obtained regression models binding the internal quality attributes with bad programming practices are provided in Appendix A. We provide there information about standardized coefficients (betas), standard errors of the estimates, t-tests that a coefficient takes the value zero and confidence intervals.

The bad programming practice 'Dropped or ignored exception' is explained by four internal quality attributes (Appendix A, Table 3). Our results are statistically significant with respect to the internal quality attribute *NAV*.

The bad programming practice 'Method ignores results of InputStream.read()' is explained by five internal quality attributes (Appendix A, Table 4). Our results are statistically significant with respect to the internal quality attributes *NAV*, *NPCD* and *NLS*.

The bad programming practice 'Stream not closed on all paths' is explained by four internal quality attributes (Appendix A, Table 5). Our results are statistically significant with respect to the internal quality attributes *NAV* and *NLS*.

The bad programming practice 'Method returning array may expose internal representation' is explained by 17 internal quality attributes (Appendix A, Tables 6, 7, 8). Because of the computational problems associated with the great number of explaining variables we built three regression models for this metric. The internal quality attributes appearing in those models have been selected randomly. Our results are statistically significant with respect to the following internal quality attributes: *NAV*, *NDR*, *NAIV*, *NROV*, *NPCD*, *NSS* and *NLiS*.

The bad programming practice 'Storing reference to mutable object' is explained by 16 internal quality attributes (Appendix A, Tables 9, 10, 11). Because of the computational problems associated with the great number of explaining variables we built three regression models for this metric. The internal quality attributes appearing in those models have been selected randomly. Our results are statistically significant with respect to the following internal quality attributes: *NGCL*, *NAV*, *NAIV*, *NS*, *NLS* and *NRS*.

The bad programming practice 'Questionable integer math' is explained by six internal quality attributes (Appendix A, Tables 12, 13). Because of the computational problems associated with ill-conditioned matrix calculated for all those metrics we built two regression models for this metric. The internal quality attributes appearing in those models have been selected randomly. Our results are statistically significant with respect to the following internal quality attributes: *NAIV*, *NROV*, *NPCD* and *NPFA*.

The bad programming practice 'RuntimeException capture' is explained by five internal quality attributes (Appendix A, Table 14). Our results are statistically significant with respect to the internal quality attributes *NAV*, *NPCD* and *NLS*.

## 4.1 Hypotheses

H1: *There is a relation between software complexity and reliability*. In our study we used five metrics accounting for software complexity. None of those metrics showed statistically significant strong correlations with bad programming practices. Therefore, this study does not support the hypothesis.

H2: *There is a relation between number of warnings and software size*. In our study we have used several metrics accounting for software size. One of those metrics, viz. *NGCL* showed strong positive correlation ($r = 0.875$, $p = 0.00$) with the bad programming practice 'Storing reference to mutable object'. Our results indicated also a strong statistically significant correlation between the total number of programming inconsistencies and *NGCL* ($r = 0.682$, $p = 0.00$). Those results support the hypothesis.

# 5 Discussion

This has been an exploratory empirical study. We have analyzed seven medium-sized open source software systems regarding large numbers of internal quality attributes. The studied issues have included bad programming practices as revealed via source code inconsistencies. There were many interesting and statistically significant results revealed related to seven of the studied programming practices as shown by the conducted regression analyses (Appendix A). Additionally, two hypotheses were raised based on earlier studies as presented in scientific literature.

Firstly, our study did not corroborate the hypothesis regarding the relation between software complexity and reliability (H1). One reason to this counter-intuitive result may be that instead of having used data on actual identified system failures and corresponding corrected bugs as measures of external reliability, we had to here rely on surrogates in this sense (i.e. bad programming practices which can be determined statically according to our measuring approach). Bad programming practices essentially indicate only a *potential* of formally acknowledged and thereby measurable bugs manifesting themselves and being identified at some point. Nevertheless, this negative result is meaningful as a basis for further hypotheses. For example, it would be important to know whether software complexity indeed affects programmers in such a way that bad programming practices are avoided, as could be expected, since complexity makes maintenance harder. Another explaining factor reducing the negative final effects which complexity has to the reliability would be the increased effort targeted to preventive maintenance in those cases where bad programming practices have been applied.

Secondly (related to H2), there is a positive correlation between number of warnings and software size. This result is in line with intuition—it is harder to program high-quality code for larger systems due to program comprehension overheads. As a further research direction, in principle, it could be interesting to determine which kinds of correctness warnings have the most significant correlations with actual amounts of corrected errors.

Thereby, the results related to the set hypotheses can be summarized as follows. H1: assumed negative relation and was not supported by this study. H2: assumed positive relation and was supported by this study. As noted, this study has purposively focused on OSSs. Since we studied many quite different kinds of non-trivial OSSs the results can be considered as rather generalizable within the context of OSSs.

Some of the results are easy to interpret based on their detailed analysis. For example, exceptions can result from unspecified conditions in conditional statements. Therefore, the metrics accounting for bad programming practices associated with exceptions are likely to depend on the number of such statements. At the same time, some of the correlations are not so easy to interpret. For example, the relation between 'Dropped or ignored exception' and some of the internal quality attributes; such as *NAV*. It is likely that *NAV* does not have a direct effect in this case. Most probably it affects a number of other internal quality attributes which contribute to the change of *NAV* indirectly. Further research would be needed to know more about these and similar kinds of details.

# 6 Conclusion

This exploratory empirical study has focused on open source software (OSS). Seven medium-sized OSS systems from the SourceForge repository were analyzed. Over 100 internal quality attributes and programming practices were scrutinized by using two semi-automated source code analysis tools (FindBugs and SoftCalc). Many statistically significant relations were revealed by the conducted regression analyses. Seven so-called bad programming practices; as manifested by the measured source code inconsistencies were identified as having significant relations to internal software quality. Additionally we set and tested two hypotheses. That investigation provided mixed results partly supporting some of the earlier findings between software size and potential maintenance problems; especially related to some of the programming practices.

## Appendix A. Regression models for the studied bad programming practices

**Table 3** Regression model for the bad programming practice dropped or ignored exception

| | Beta | Std.Err. of Beta | t(162) | p-level |
|---|---|---|---|---|
| *NAV* | 0.839 | 0.130 | 6.476 | 0.000 |
| *NSS* | 0.239 | 0.247 | 0.968 | 0.335 |
| *NCS* | −0.370 | 0.248 | −1.489 | 0.138 |
| *NLS* | 0.198 | 0.140 | 1.415 | 0.159 |

**Table 4** Regression model for the bad programming practice method ignores results of inputstream.read()

| | Beta | Std.Err. of Beta | t(161) | p-level |
|---|---|---|---|---|
| *NAV* | 0.855 | 0.073 | 11.739 | 0.000 |
| *NPCD* | −0.673 | 0.059 | −11.489 | 0.000 |
| *NSS* | 0.053 | 0.139 | 0.379 | 0.705 |
| *NCS* | −0.204 | 0.141 | −1.450 | 0.149 |
| *NLS* | 0.877 | 0.105 | 8.393 | 0.000 |

**Table 5** Regression model for the bad programming practice stream not closed on all paths

| | Beta | Std.Err. of Beta | t(162) | p-level |
|---|---|---|---|---|
| *NAV* | 0.271 | 0.124 | 2.182 | 0.031 |
| *NSS* | −0.356 | 0.236 | −1.504 | 0.134 |
| *NCS* | 0.419 | 0.238 | 1.762 | 0.080 |
| *NLS* | 0.599 | 0.134 | 4.462 | 0.000 |

**Table 6** Regression model for the bad programming practice method returning array may expose internal representation (part 1)

| | Beta | Std.Err. of Beta | t(160) | p-level |
|---|---|---|---|---|
| *NGCL* | −0.034 | 0.243 | −0.140 | 0.889 |
| *NAV* | 0.487 | 0.065 | 7.496 | 0.000 |
| *NDDTU* | 0.300 | 0.244 | 1.230 | 0.221 |
| *NDR* | 1.158 | 0.558 | 2.075 | 0.040 |
| *NAIV* | −2.614 | 0.750 | −3.485 | 0.001 |
| *NROV* | 1.721 | 0.710 | 2.423 | 0.017 |

**Table 7** Regression model for the bad programming practice method returning array may expose internal representation (part 2)

| | Beta | Std.Err. of Beta | t(160) | p-level |
|---|---|---|---|---|
| *NPCD* | 0.831 | 0.166 | 5.017 | 0.000 |
| *NPFA* | −0.012 | 0.091 | −0.136 | 0.892 |
| *NS* | 0.123 | 0.075 | 1.633 | 0.104 |
| *NIS* | −0.150 | 0.196 | −0.768 | 0.444 |
| *NSS* | 0.344 | 0.169 | 2.038 | 0.043 |
| *NCS* | −0.139 | 0.164 | −0.851 | 0.396 |

**Table 8** Regression model for the bad programming practice method returning array may expose internal representation (part 3)

| | Beta | Std.Err. of Beta | t(161) | p-level |
|---|---|---|---|---|
| *NLS* | 0.311 | 0.203 | 1.529 | 0.128 |
| *NRS* | 0.206 | 0.314 | 0.658 | 0.512 |
| *NCFB* | 0.388 | 0.456 | 0.850 | 0.396 |
| *NLiS* | 0.222 | 0.078 | 2.823 | 0.005 |
| *NDST* | −0.128 | 0.139 | −0.921 | 0.358 |

**Table 9** Regression model for the bad programming practice Storing reference to mutable object (part 1)

| | Beta | Std.Err. of Beta | t(160) | p-level |
|---|---|---|---|---|
| *NGCL* | 0.978 | 0.272 | 3.593 | 0.000 |
| *NAV* | 0.810 | 0.073 | 11.126 | 0.000 |
| *NDDTU* | −0.164 | 0.273 | −0.599 | 0.550 |
| *NDR* | −0.138 | 0.625 | −0.220 | 0.826 |
| *NAIV* | −1.853 | 0.840 | −2.207 | 0.029 |
| *NROV* | 1.441 | 0.795 | 1.812 | 0.072 |

**Table 10** Regression model for the bad programming practice Storing reference to mutable object (part 2)

| | Beta | Std.Err. of Beta | t(161) | p-level |
|---|---|---|---|---|
| *NPCD* | 0.316 | 0.197 | 1.599 | 0.112 |
| *NS* | 0.385 | 0.080 | 4.822 | 0.000 |
| *NIS* | −0.047 | 0.210 | −0.222 | 0.825 |
| *NSS* | 0.175 | 0.197 | 0.892 | 0.374 |
| *NCS* | 0.181 | 0.195 | 0.927 | 0.355 |

**Table 11** Regression model for the bad programming practice Storing reference to mutable object (part 3)

| | Beta | Std.Err. of Beta | t(161) | p-level |
|---|---|---|---|---|
| *NLS* | 0.944 | 0.243 | 3.886 | 0.000 |
| *NRS* | 0.854 | 0.375 | 2.277 | 0.024 |
| *NCFB* | −0.998 | 0.545 | −1.831 | 0.069 |
| *NLiS* | −0.034 | 0.094 | −0.362 | 0.718 |
| *NDST* | 0.277 | 0.166 | 1.667 | 0.098 |

**Table 12** Regression model for the bad programming practice questionable integer math (part 1)

| | Beta | Std.Err. of Beta | t(163) | p-level |
|---|---|---|---|---|
| *NDR* | −0.655 | 1.016 | −0.645 | 0.520 |
| *NAIV* | 6.204 | 1.345 | 4.613 | 0.000 |
| *NROV* | −4.722 | 1.156 | −4.084 | 0.000 |

**Table 13** Regression model for the bad programming practice questionable integer math (part 2)

| | Beta | Std.Err. of Beta | t(163) | p-level |
|---|---|---|---|---|
| *NPCD* | 0.767 | 0.328 | 2.339 | 0.021 |
| *NPFA* | 0.544 | 0.116 | 4.685 | 0.000 |
| *NIF* | −0.453 | 0.377 | −1.201 | 0.231 |

**Table 14** Regression model for the bad programming practice runtime exception capture

| | Beta | Std.Err. of Beta | t(161) | p-level |
|---|---|---|---|---|
| *NAV* | 0.830 | 0.082 | 10.162 | 0.000 |
| *NPCD* | −0.413 | 0.066 | −6.300 | 0.000 |
| *NSS* | 0.151 | 0.156 | 0.971 | 0.333 |
| *NCS* | −0.189 | 0.158 | −1.200 | 0.232 |
| *NLS* | 0.559 | 0.117 | 4.773 | 0.000 |

## Appendix B. Abbreviations

| | |
|---|---|
| *DCCM* | *Data complexity chapin metric* |
| *ICHM* | *Interface complexity henry metric* |
| *KLOC* | *Thousands of lines of code* |
| *NAIV* | *Number of arguments or input variables* |
| *NAV* | *Number of arrays or vectors* |
| *NCFB* | *Number of control flow branches* |
| *NCL* | *Number of comment lines* |
| *NCS* | *Number of case statements* |
| *NCSS* | *Number of non-commenting source statements* |
| *NCW* | *Number of correctness warnings* |
| *NDDTU* | *Number of different data types used* |
| *NDR* | *Number of data references* |
| *NDST* | *Number of different statement types* |
| *NGCL* | *Number of genuine code lines* |
| *NIF* | *Number of If statements* |
| *NLiS* | *Number of literals in statements* |
| *NLS* | *Number of Loop statements* |
| *NM* | *Number of modules* |
| *NPCD* | *Number of predicates or conditional data* |
| *NPFA* | *Number of parameters or function arguments* |
| *NROV* | *Number of results or output variables* |
| *NRS* | *Number of return statements* |
| *NS* | *Number of statements* |
| *NSL* | *Number of source lines in all* |
| *NSS* | *Number of Switch statements* |
| *TNGW* | *Total number of generated warnings* |

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# An Approach to Information Technologies for Solving Mathematical Physics Problems

**A. Jansone and L. Zacs. K. Jakimov**

**Abstract** In this paper the authors describe solution of mathematical physics problems by use of information technologies in the Institute of Mathematical Sciences and Information Technologies of Liepaja University.

## 1 Introduction

All environmental processes are important for the ecological and economical aspects. Nowadays, the information technologies (IT) are increasingly used to tackle mathematical problems.

The aim of the research is to study and choose appropriate software for modelling of the mathematical models of environmental processes.

One of the methods for modelling environmental processes is advection, diffusion and reaction, in literature called advection–diffusion reaction (ADR) equation [1]. ADR models the processes that occur in nature, for example, distribution of chemical substances in soil, taking into account pollution sources, mutual chemical reactions of various elements, distribution of chemical substances in the porous environment. Another way of applying ADR equation is a model of heat or temperature distribution [2]. ADR equations play an important role in the modelling of electromagnetic processes.

Solution of ADR equation is quite a time-consuming process. The acquisition of the results is encumbered with limitations proposed by the stability conditions, which can crucially increase the computation time. Therefore, it is crucial to

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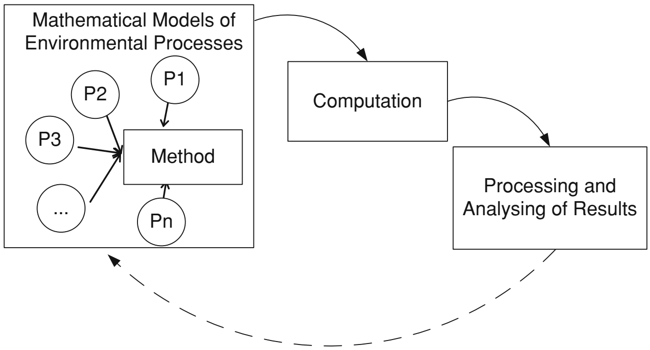


**Fig. 1** Concepts of modelling environmental processes

elaborate effective and fast methods in order to weaken the limitations created by the stability conditions. One of the new methods elaborated by the Institute of Mathematical Sciences and Information Technologies (IMSIT) [3] is the propagator method. This method was tested with test examples for on-dimensional and multidimensional cases and applied for modelling of the mathematical models of environmental processes [4, 5].

The solution of ADR equation is usually a time-consuming process and a significant role for effective equation solution is attributed to the choice and development of the software; also, powerful computer networks are necessary for parallel computations and successful task execution.

## 2 Concepts of Environmental Processes Modelling

The progress of environmental processes depends on many factors that influence the process—parameters that play a significant role in the mathematical modelling. Although a lot of software exists for direct mathematical challenge solving, such as MatLab [6], Mathematica [7], special programmes are elaborated for construction of complicated models. For elaboration of such programmes, firstly (Fig. 1) the model of input data has to be defined, that is, which parameters (Pn) (for example, velocity, hydraulic coefficient, concentration of elements, spatial coordinates, index of the spatial mesh, time step index, iteration, index etc.) are necessary for the modelling of the studied problem to make the problem solution process more precise. The next step is to choose the appropriate solution method, for example, the propagator method or some other method. After that, computations are performed and the acquired results are processed and analysed. For testing the mathematical model for the real environment and when changing the values of parameters in the process of modelling, this procedure can be repeated several times. Therefore, when elaborating the software, one of the requirements is easy input of parameters. The next requirement is the computation speed, in order

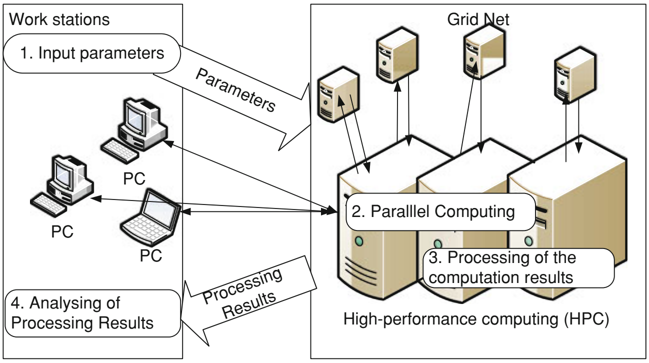


**Fig. 2** IT concepts for modelling environmental processes

to obtain the results and perform the analysis of the results within a short time. Therefore, to obtain the results quickly and precisely, it is necessary to choose an appropriate programme for each step.

## 3 Information Technologies for Modelling Environmental Processes

One of the research aims of the IMSIT is to elaborate a solution for complex inter-branch problems within the framework of the ESF project "Effective Analytical and Numeral Method for Direct and Inverse Solution of Mathematical Physics Problems in Material Science, Environmental Science and Economics". The project will explore six independent mathematical problems. This article describes one of the project research directions: definitions of the quality of the process, described by partial differential equation (PDE) and/or system of PDE.

The conception for modelling environmental processes (Fig. 2) by using information technologies consists of 4 steps. The first one is parameter input and sending of parameters to the software, which will perform the calculations according to the chosen method. In the second step fast computations have to be provided. To provide high-speed performance, grid technologies of parallel computations are used. These technologies give a possibility to access large computation resources, which are established in many organisations and stationed worldwide. With the help of special software super computers and grid network, these resources are joined into one infrastructure and submitted to the user as one whole powerful computation machine. The next step is the processing of the computation results and the last one—the analysis of the computation results.

In IMSIT, within the framework of the research, the software for the propagator method was elaborated in Fortran environment. Fortran is the most appropriate programming language for solution of various problems of physics and

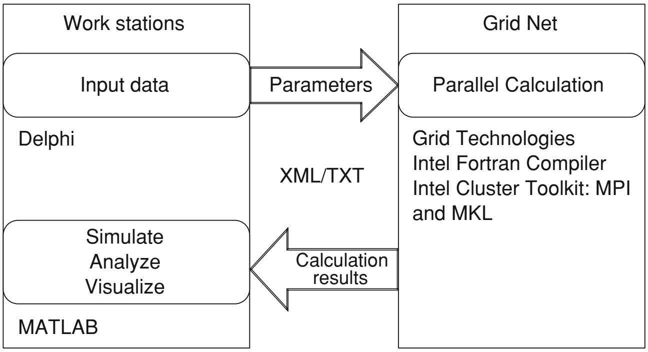


**Fig. 3** IT solution for modelling environmental processes

mathematics. Fortran is suitable for parallel computations and compatible with MPI (Message Passing Interface) standards [8]. Therefore it was decided to use the existing software. The main disadvantage of this software is that there is no possibility to change parameter values without changing the software code. In order to provide a requirement for “easy parameter input”, the software we elaborated the software input of parameter values. Delphi was chosen as the programming language. To join both programmes, a special data input/output mechanism was elaborated. Two options are possible: text format file (TXT) and Extensible Markup Language (XML) format file. Presently, the compilation of the Fortran programme is being performed on the server in test mode and execution thereof is sent from server to the super computers for parallel computations within the grid network. After the computations are performed, the computers send the results back to the server. The results are collected from all engaged resources and then sent for the analysis. For analysis of the results, IMSIT uses MatLab opportunities in order to visualise the results of the modelling (Fig. 3). In future, it is planned to use MatLab also on the server and then send already processed visualised data to the user for analysis.

Currently, some research has been performed to introduce the grid network technology. We have two experimental clusters.

## 3.1 The First Experimental Cluster

When building experimental data-grid cluster there are many reasons to build a small cluster for testing. There are always some possibilities that the new cluster will not work as it is supposed to. In some cases it is not working at all due bad topology, incompatible software or hardware (even in the cases when it obviously must work). There are several main goals you can achieve when building such small (pocket) cluster. First of all it is due to compatibility and if the cluster is not fully compatible, it can be modified for low cost.

The More equipment you have the more different combinations you get. The next good reason is to make experiments with the software part, it is always interconnection (network) drivers + operating system + a layer between network and user software or framework + and of course the target software. After these experiments it is possible to make decisions like what operation system (OS) to use, or how to configure networks and other devices.

When the main cluster is started and operates, the pocket cluster can be used for optimisation, configuration and benchmarking etc.

After some time there is new software or OS updates that need to be installed, but in some cases it is possible to lose some functionality, and in this case the pocket cluster useful again.

And the last but important thing is that there are always spare parts for the main cluster. There are also some less important reasons (for building a pocket cluster), i.e. in case of queues and large number of developers there appears a problem of running “raw” programs on the main cluster, therefore a pocket cluster can be used as a playground for programmers and it is safer because mistakes (in the program code) are possible when developing, which lead to the full shutdown of the cluster (and it is not permitted).

Configuration of the first cluster:

- Clovertown Node (Dual Core Clovertown E5345 2.33G 8 M 1333FSB CPU, 2 GB FB-DIMM LP FMHS PB-FREE ECC DUAL RAM, SCSI—147 GB SCSI 10 K HDD); Myrinet-2000 M3F-SW16 M/2U switchboard,
- Myricom M3F-PCIXF-2, 64-bit, 133/66 MHz network cards, M3F-CB-1 M 50/125 multimode optical cables 1 m with LC connectors, HP Procurve 1800-24G switchboard and UTP 5 CAT cables.

The whole experimental cluster uses such technologies:

(1) 64 bit Debian
(2) GCC (64 bit)
(3) Myrinet drivers (MX + Tcp/IP)
(4) MPICH2 (compiled GCC)
(5) ScaLapack (compiled GCC)
(6) Our own developments (Mpich2 + Scalapack + compiled GCC)

As the main computation process requires large amount of data and also prior computations performed directly on client machines, it was offered to elaborate a visualisation mode of input data system and a possibility to browse the results in graphical mode. Information is transferred via the Internet, because operators usually use remote access to the cluster. Data management is provided by the use of XML files archived by gzip, because there are plenty of tools for working with XML suitable for any system and the archived files save free space on the hard disk without losing the flexibility of the approach. When building cluster systems based on free OS, interaction of such systems are the main problems to be solved. So, the main goal is to join various technologies. As we had only problems to solve and did not have any special software for it we decided to cut the expenses for elaboration of the necessary algorithms by using the already existing solutions. Cluster nodes are connected with each other with Myrinet and Gigabit Ethernet. After successful installation of Myrinet drivers a new IP sub network with other numbers appeared. This created additional expenses for IP configuration just at the same time, when SLAE (system of linear algebraic equations) problems appeared. Therefore ScaLapack was chosen as the most appropriate tool. Lapack itself is not a “parallel” tool, therefore ScaLapack was created, which had several possibilities for supporting MPI based cluster calculations. Thereafter it was necessary to choose an MPI compatible technology, which is also compatible with Myricom (it was already known that a standard TCP/IP does not suit due to its overhead) and ScaLapack. It is a special middleware between network infrastructure (Myricom drivers) and computation programs. It was not desirable to elaborate the software on the basis of Myricom drivers, because it will definitely lead to binding all our elaborations to certain hardware and we would like to avoid it. Finally, MPICH-2 was chosen, which is MPI compatible. It was also found that this tool supports MX driver and this allows MPI cluster establishing connection within its nodes without using TCP/IP. It is also more attractive for elaboration of computation programs due simplicity and full and detailed documentation.

### *3.2 The Second Experimental Cluster*

Experimental cluster consists of a masternode and slavenodes—with Intel® Pentium® 4 architecture and the following configuration: Scientific Linux 5.3 + Samba and SSH.

The necessary cluster network solutions for parallel computing:

- Intel® Cluster Toolkit 3.2.1—Intel® MPI Library 3.2 Update 1, Intel® Trace Analyzer and Trace Collector 7.2, Intel® MPI Benchmarks 3.2,
- Intel® Fortran Compiler Professional Edition—Intel® Math Kernel Library (Intel® MKL), Intel® Debugger, Intel® Fortran Compiler building applications that run on IA-32, Intel® 64 and IA-64 architecture systems running the Linux operating system.

Scientific Linux is a Fermi National Accelerator Laboratory and the European Organization for Nuclear Research (CERN) Linux distributive SL, which is based on Red Hat Enterprise Linux version. In addition SL OS has a configured service Samba for sharing network resources between the server and slave nodes, SSH network protocol, which allows secure sending of commands from the server and sending of parallel computing commands to all nodes. In addition SSH has a configured sudo option to execute commands in a security mode, which requires user root permissions by additionally generating SSH keys in order to provide automatic connection without confirmation of root password each time.

Configuration of the second cluster:

- Intel® Pentium® 4—slavenodes (1x Intel® Pentium® 4 3,0Ghz, 1 GB RAM)
- Intel® Pentium® 4 server—masternode (1x Intel® Pentium® 4 3,2Ghz, 1 GB ECC RAM)
- Specifications of cluster network: 1x HP Procurve 1800-24G switchboard and UTP 5 CAT cables

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# Multiple Software Watchdog Timers in the Linux OS

**J. Abaffy and T. Krajčovič**

**Abstract** In this paper we present a software interface for multiple watchdog timers, which can be also used as a software watchdog. Watchdogs are generally used to improve reliability of a computer system. In our proposed approach we use watchdogs to secure not only the whole system, but also the processes self. In embedded systems it is common to check processes by using software watchdogs and to check the system by using one or few hardware watchdogs. Multiple HW watchdogs are not supported by widely used operating systems, and we present a communication interface for the Linux operating system to support multiple watchdog timers per process.

## 1 Introduction

A watchdog timer is a piece of hardware that can be used to automatically detect software anomalies and reset the processor if any occur. Generally speaking, a watchdog timer is based on a counter that counts down from some initial value to zero. The embedded software selects the counter's initial value and periodically restarts it. If the counter ever reaches zero before the software restarts it, the software is presumed to be malfunctioning and the processor's reset signal is asserted. The processor (and the embedded software it's running) will be restarted as if a human operator had cycled the power [1].

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A properly designed watchdog mechanism should, at the very least, catch events that hang the system. In electrically noisy environments, a power glitch may corrupt the program counter, stack pointer, or data in RAM. The software would crash almost immediately, even if the code is completely bug-free. This is exactly the sort of transient failure that watchdogs will catch [2].

External hardware watchdog timers are used to detect errors where the OS is not performing any useful work and is in an infinite loop. A watchdog timer has to be periodically reset (kicked) by the OS and will signal the processor (bite) if the timer expires. Watchdog timers are normally wired to the reset pin on the processor and cause a full reboot of the system for recovery. Unfortunately, a reboot of the system results in a loss of user data and applications currently in memory [3].

Typically, only one of the processes fails, and in this case it is not needed to reset the whole operating system. In our approach we will target on how to secure processes in the Linux operating system using hardware watchdog timers per process.

Linux was developed as general purpose operating systems without any consideration for real-time applications and is widely used as a server operating system. In recent years, it has become attractive also as desktop operating system, and nowadays it finds its way to the real time community due to its low cost and open standards. In the last years, Linux is also popular as an operating system for mobile devices.

Embedded systems generally require high reliability, stability, performance, and low latencies. Watchdog timers are widely used in embedded systems because of their simplicity and effectiveness, and most operating systems, especially real-time operating systems, used in embedded systems support watchdog timers from different vendors.

Linux thanks to its open standards, big community, and increasing deployment in the area of embedded systems has a long term and stable support of watchdog timers.

The main disadvantage of this long acting support for watchdog timers is that the watchdog device is always expected as/dev/watchdog in the operating system. This is historically caused and traditional UNIX systems have static device nodes in the/dev/directory [4].

The trend is that device nodes are managed dynamically and can be created using user defined rules. Some of the files are still statically created to support backwards compatibility [5].

In Linux, there is allowed only one watchdog timer and all the applications expect it on the same place—/dev/watchdog, which when opened must be written to within a timeout or the machine will reboot. Linux provides software watchdog as a kernel module to simulate watchdog functionality, when no hardware watchdog is presented and there is a need of higher reliability. In the case of the software watchdog the ability to reboot will depend on the state of the machines and interrupts. The hardware boards physically pull the machine down off their own onboard timers and will reboot from almost anything [6].

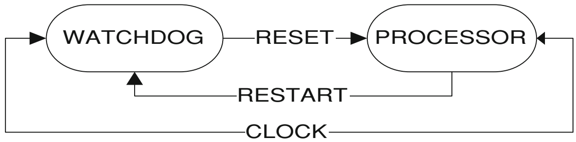


**Fig. 1** Hardware watchdog timer

## 2 Related Work

Watchdog timers are widely used in embedded systems as they are easy to implement. Typical use of watchdog timer is a hardware circuit connected to reset pin of the processor which is periodically restarted by the main processor. The watchdog timer and a processor are synchronized by external clock (Fig. 1).

In this approach only one part of the system is checked—the main processor. Modern embedded systems are more complex, and there is a need to check the processes running in an embedded system.

In Linux, usually a user-space software watchdog will notify the kernel watchdog driver via the/dev/watchdog special device file that user-space is still alive, at regular intervals. When such a notification occurs, the driver will usually tell the hardware watchdog that everything is in order, and that the watchdog should wait for yet another little while to reset the system. If user space fails, the notifications cease to occur, and the hardware watchdog will reset the system (causing a reboot) after the timeout occurs [7] (Fig. 2).

Using this approach, we are able to monitor running tasks in the user-space, and the software watchdog can perform defined action per process. If one of the processes fails, it can be restarted by the software watchdog or it can restart the whole system. Software watchdog is secured by hardware watchdog, so if it fails, hardware watchdog timer expires and the whole system is restarted.

Our work is based on the work presented by Pohronská 0. In this work, multiple watchdog device is proposed for the implementation in programmable hardware. The programmable hardware provides the possibility of implementing a hardware watchdog timer for each of the concurrent processes in the system. The creation and assignment of the own hardware watchdog timer for each of the system's processes eliminates the possibility of disabling the watchdog timer for another process.

Other advantages of such implementation are summarized below. Firstly, we can theoretically implement as many timers as we need for the system. The only limitation lies in the size of the programmable device. For larger architectures and systems, we can use multiple FPGA devices. Second advantage lies in the enhanced security of the system—when a fault occurs in the process, it can only modify its own timer or, in the worst case, the timer of another process.

At any rate, it is far better than the alternative of disabling the common timer of many processes. Furthermore, the service routine for the single dedicated hardware timer is much more simple that the service routine for the timer which is shared by multiple processes. Thus, the system gains on speed and software simplicity.

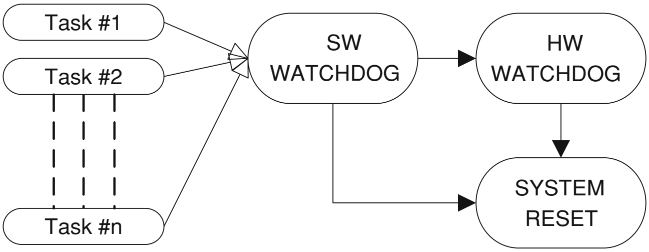


**Fig. 2** SW watchdog per process

## 3 Software Watchdog Interface

In this approach only one part of the system is checked—the main processor. Modern embedded systems are more complex, and there is a need to check the processes running in an embedded system.

We have created a simple communication interface for the Linux operating system. It is planned to be the frontend for the multiple watchdog device presented by Pohronská [8].

Multiple watchdog device is now simulated in a process with a watchdog thread for each secured process and will be replaced by multiple hardware watchdog device (Fig. 3).

To manage the watchdog device from the user-space a special device/dev/multiwdt is registered in the operating system. When a process needs to be secured, it sends its PID and watchdog interval to this file, and a named pipe/dev/watchdogs/PID is created. Each process in the operating system has its own and unique PID number, so it is transparent for the process and also for the operating system which watchdog belongs to which process. In the watchdog interface in the operating system a PID of the process is associated with a next free watchdog in the multiple watchdog device [9].

For communication with the multiple watchdog device any bus or port with the support in the Linux operating system can be used. It is planned to communicate using USB, but as we show in this paper, almost any bus can be used. To change the bus, it is only necessary to change the communication module, but the interface stays the same for the userspace.

When a process writes to its named pipe/dev/watchdogs/PID, its watchdog in the multiple watchdog device is reset. The conversion is performed in the watchdog interface. When the timer expires, it sends a message to the interface in operating system, and the interface finds a PID of the process associated with this timer. The corresponding process is then killed and restarted.

The watchdog interface is periodically resetting the system watchdog. This is the default watchdog for the operating system. When it expires, the whole system is restarted.

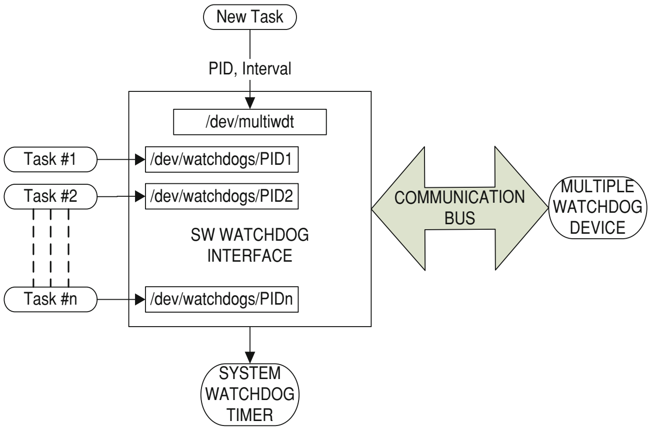


**Fig. 3** Software watchdog interface

## 4 Support for User-Space

The main advantage of this approach is that it is transparent for the user-space. Each process can be secured by its own watchdog, and every user who was given the permissions by the administrator of the system is able to secure his processes.

For the developers we provide a C/C++ library multiwdt.h and a developer can secure his processes by including this library. The library defines three functions for securing the processes:

```
int watchdog_init (struct timeval tv);
int watchdog_kick ();
int watchdog_close ();
```

The first function initializes the hardware watchdog for this concrete process and sets its timeout to the specific value. From now on the process has to periodically kick the watchdog timer in intervals shorter than the initialization interval. The last function has to be called when exiting the process, because the watchdog interface will assume that the process is still running stuck in a loop or it crashed unexpectedly. In this case the software watchdog will restart the process, and the process will never end.

The applications written in different programming languages and also shell scripts can be secured by writing its PID and watchdog interval to the watchdog management interface. On success a named pipe/dev/watchdogs/PID is created, and the checked process should periodically write to this pipe. On exit the process sends its PID to the control file, and its watchdog is then closed. This is the main advantage of using POSIX standard inter-process communication mechanisms.

**Fig. 4** Latencies when using different inter-process communication

| | Pipe | Socket | Wi-Fi |
|---|---|---|---|
| **Average [microseconds]** | 14.219 | 246.001 | 3530.461 |
| **Standard deviation [microseconds]** | 1.650 | 6.099 | 139.642 |
| **Relative standard deviation [%]** | 11.606 | 2.479 | 3.955 |

## 5 Proof of concept

In our approach we just simulate the watchdog device with multiple watchdog timers. To prove the concept, that the communication bus can be replaced by any bus, we simulated the bus via standard POSIX pipes, via Internet stream sockets and via 802.11 g Wi-Fi network. In the first and second case, the software watchdog device and also the checked processes were running on the same host. In the last case, the software watchdog device was moved to another host and we choose Wi-Fi for the experiment, because it has higher latencies than Ethernet.

We wanted to prove, if the latencies also via slow communication bus are sufficient for deployment. We measured the latencies in communication between processes and their watchdog timers. We performed 1,000 measurements and repeated each ten times. In each experiment, ten processes and to them assigned ten watchdog timers were running and communicating via specified communication interface.

Times were measured in microseconds using the system function gettimeofday() before resetting watchdog timer and after receiving a signal about successful reset.

As you can see in the Fig. 4, for communication on the same host are the standard POSIX pipes the best solution. But Internet sockets have the ability to communicate also on different hosts. Latencies in Wi-Fi network are around 3.5 ms, what is still acceptable, because timeouts for watchdog timers are usually set to several seconds.

When communicating via TCP/IP sockets, the checked processes can run on any host, which have access to the host, where the watchdog software is running. But there is the need to secure the network and to be sure, that the latencies in the network are acceptable.

## 6 Conclusions and Further Work

The presented approach was implemented and tested in Linux operating system, and because it was created using the POSIX standards and as platform independent as possible, it should be portable also to other POSIX operating systems. To demonstrate it, we plan to port and test it in a different operating system—FreeBSD.

Multiple hardware watchdog device is still under heavy development, and now we are working on the implementation of the communication interface between the operating system and the watchdog device. The communication will be secured by using Hamming (7, 4) linear error-correcting code to perform well also when used in electrically noisy environments.

Presented approach can be now used for securing user-space processes, but the disadvantage is that it is based on software watchdogs which simulate hardware watchdogs. The watchdogs are running on the main processor and they are increasing its utilization.

In the current implementation, when the watchdog timer for the process expires, the process is restarted by the watchdog interface. The planned improvement is implementation of the checkpoint/restart system, so that the process does not need to be restarted from the beginning, but its state can be periodically saved and then restarted from the checkpoint using BLCR [10].

The presented approach can be used to secure processes on the same host, but it can be also run as a special software watchdog on one host securing processes on different hosts and communicating via TCP/IP network.

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# An Ontology-Based Fuzzy Approach for Alert Verification and Correlation in RFID Systems

**M. Esposito**

**Abstract** The proliferation of radio frequency identification (RFID) tags has implied that the pervasive RFID technology has become object of a broad range of malicious attacks, such as RFID malwares. This research is aimed at integrating the principles of both ontology and fuzzy logic modelling techniques in the intrusion detection paradigm to perform alert verification and correlation and determine this kind of attack. The proposed approach relies on three key points: (i) heterogeneous sensors diffused throughout the RFID infrastructure; (ii) fuzzy rules to handle imprecision and fuzziness in calculation of a confidence for each detected symptom in the verification procedure; (iii) a formal alert model, represented by means of an ontology and combined with fuzzy rules to represent knowledge for reasoning about complementary alert evidence and provide a comprehensive view of relevant symptoms indicating really potential attacks. Experimental tests are reported to give a proof of the feasibility of the methodology in the detection of malwares in RFID systems.

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## 1 Introduction

The RFID technology plays a pivotal role among non-intrusive sensing technologies that can be suitably applied in a variety of application scenarios. In the recent years, several pilot research projects have been conducted, with the aim of investigating the feasibility of RFID technology [1–3].

Nevertheless, there are still a vast number of problems that need to be solved before their massive deployment. As a matter of fact, an intense public concern with security issues has gone largely unaddressed and poses critical challenges to several RFID applications.

RFID malwares represent one of the recently emerging security attacks against RFID systems since, as demonstrated in [4]; they are realistically feasible also with the limited resources of RFID tags. Generally speaking, a typical RFID system is composed of a combination of tags, readers, and middleware. Basically, a reader broadcasts a radio frequency signal to get the data stored on the nearby tags. The data can be a static identification number, a user written data or a data computed by the tag. After obtaining tag data, the reader informs via a wire or wireless network the middleware that stores both tag and reader data in a back-end database. In the typical infrastructure of an RFID system just described, malwares can directly exploit security holes of the back-end middleware.

As a practical solution to defend an RFID system against malwares, we propose the appliance of an intrusion detection system (IDS) to be transparently and seamlessly integrated into the RFID infrastructure by means of being positioned at the middleware level. Nevertheless, we think that using a single intrusion detection sensor is not feasible for a large environment like the RFID infrastructure; indeed, a single sensor reaches its limit as soon as more than one component of the infrastructure needs to be protected. However, simply deploying more sensors is not a scalable solution, since it generates an over-abundance of alerts [5]. Moreover, the intrusion detection problem involves many numeric thresholds and building a procedure directly on numeric thresholds can cause high detection errors. For example, an intrusion deviating only slightly from a threshold may not be detected or a small change in normal behaviour may cause a false alarm. Finally, the security itself includes fuzziness, because the boundary between the normal and anomaly is not well defined.

As a result, this research has been focused on the definition of an alert correlation approach aimed at (i) applying heterogeneous sensors diffused throughout the RFID infrastructure; (ii) making them cooperate so as to face the complexity of the RFID infrastructure; (iii) enhancing the monitoring coverage and providing security operators with a comprehensive view of relevant and reliable symptoms indicating really potential attacks.

The strength of such an approach relies on fuzzy rules to handle imprecision and fuzziness in calculation of a confidence for each detected symptom in the verification procedure, on a consistent and formal alert model, represented by means of an ontology [6] in the language web ontology language (OWL) [7] combined with fuzzy rules [8] to represent knowledge for reasoning about complementary alert evidence in the correlation procedure.

The rest of the paper is organized as follows. Section 2 discusses related work. Section 3 describes the proposed alert correlation approach. Section 4 presents a proof-of-concept implementation and discusses results. Finally, Sect. 5 concludes the paper.

## 2 Related Work

The research community addresses RFID security primarily by applying variety of countermeasures, such as tag cryptography, authentication and access control. To the best of our knowledge, the RFID security literature has not yet addressed applications combining ontology and fuzzy logic modelling techniques to perform both alert verification and correlation with the final aim of detecting intrusions in RFID systems, neither system-oriented researches appear to have been developed in that direction.

With reference to the application of the intrusion detection paradigm to RFID systems, two very interesting approaches have been proposed [9, 10]. Mirowski et al. describe in [9] an IDS for RFID systems, named Deckard, based on a statistical classifier and focused on the detection of change of tag ownership. This is one of the preliminary researches to address the need for IDSs in RFID. G. Thamilarasu et al. present in [10] another remarkable approach, similar to Deckard in its intrusion detection architecture. Such an approach focuses beyond change in tag ownership and provides a more generic security framework to detect various RFID attacks.

Concerning the alert correlation paradigm, no experience has been reported until now in the RFID security literature. More generally, in the past few years a number of alert correlation techniques have been proposed for other application scenarios [11, 12].

The existing alert correlation approaches rely on knowledge about the characteristics of potential symptoms, actual attacks and the context in which they occur, but they are not focused on how to represent and use this knowledge. Indeed, they adopt ad-hoc solutions embedded in specific environments and developed in proprietary formats. We claim that having a knowledge model appropriately formalized in a rich-semantic language and a set of rules to handle fuzziness can improve any alert correlation technique to be applied. This is why we focus on the integration of ontology and fuzzy logic modelling techniques in this work.

Until now, there is only limited literature about the utilization of ontology models to describe attacks or about their use in existing IDSs. In particular, Raskin et al. in [13] advocate the use of ontology modelling in the field of information security in order to provide a common ontology that lets IDS sensors agree on what they observe. Undercoffer et al. propose in [14] a target centric ontology for intrusion detection that models properties that are observable and measurable by the target of an attack.

Differently, fuzzy logic techniques have been employed in the computer security field since the early 90's [15, 16]. Its ability to model complex systems made it a valid alternative, in the computer security field, to analyze continuous sources of data and even unknown or imprecise processes [15]. Fuzzy logic has also demonstrated potential in the intrusion detection field when compared to systems using strict signature matching or classic pattern deviation detection.

Nevertheless, there is no literature at all addressing the issue of engaging ontology or fuzzy rules in RFID environments. Summarizing, the proposed approach closely resembles the idea of applying the intrusion detection in RFID systems already proposed in [9, 10], but its novelty with respect to the other existing approaches relies on the synergic integration of the principles of ontology and fuzzy logic modelling techniques in the intrusion detection paradigm applied to RFID systems with the final aim of performing alert verification and correlation and reasoning about complementary alert evidence.

# 3 The Alert Correlation Approach

## *3.1 The Alert Correlation Architecture*

The architecture of the proposed IDS consists of the set of components presented in this section.

In detail, events from different parts of the RFID infrastructure being monitored are observed by different event sensors. These low-level sensors, such as RFID Reader Monitors, DataBase Monitors, etc., process these events looking for possible symptoms of RFID malwares, for example searching for certain attack signatures (in the case of misuse-based IDS) or anomalous behaviour (in the case of anomaly-based IDS). If symptoms are detected, they are generated and passed to the normalization component. The normalization component accepts different symptom formats from the heterogeneous sensors and outputs symptoms in a normalized format, for example, the Intrusion Detection Message Exchange Format, IDMEF [17], which is an XML-based format to represent intrusion detection events and messages. These normalized symptoms are passed to a verification engine. This component tries to verify the symptoms with the aim of improving the quality of the received information [18], by calculating a confidence value for each symptom by means of fuzzy rules.

The verified symptoms are then sent to the alert correlation engine. Alert correlation groups and conceptually reinterprets symptoms. The alert correlation engine accepts low level symptoms and generates the indication of a really potential attack out of these symptoms by means of the knowledge formalized in an ontology combined with fuzzy rules. The ontology contains the knowledge about the alerts, the monitored components of the RFID infrastructure, the attacks with the related possible symptoms, and the sensors deployed throughout the infrastructure. Fuzzy rules model the knowledge required to correlate different symptoms in the context of a potential detected attack. The output is a lower number of alerts on a higher semantic level. These high-level alerts from the correlation component are then presented to the security operator. In the next sections sound descriptions of the alert verification procedure, the ontology and the alert correlation procedure have been reported.

## 3.2 Alert Verification Procedure

The proposed alert verification procedure is based on a first calculation of partial confidence values associated to the symptoms produced after the normalization by means of a set of verification steps and, successively, on the final combination of these calculated values by means of rules formalized in fuzzy logic. The overall result is a numeric value, ranging from 0 to 1, expressing the level of trustworthiness in the detection of a symptom from a sensor in the context of a specific attack. In more detail, each step of the verification procedure attempts to check a single aspect of a symptom so as to measure the likelihood that it corresponds to a real attack.

The first step tries to verify the reliability of a sensor that has generated the symptom. A sensor may be badly configured or compromised. For instance, by applying anomaly detection methodologies on the behaviour of a sensor and correlating these results with the behaviour of other sensors, configuration problems or misbehaving sensors can be detected. The partial confidence generated at the end of this step is approaching to 0 for an unreliable sensor and to 1 for a reliable one.

The second step takes into account the confidence an administrator has in a sensor to detect an attack. For example, an administrator is able to express more trust in a hardened and carefully tuned RFID Reader Monitor to detect tag cloning. On the other hand, an experimental RFID Reader Monitor will be less trusted to detect the same kind of attack. The partial confidence is calculated in this step by combining the static measure of trust the administrator has in each sensor to detect an attack with the output of a real-time observation of the sensor at work that evaluates the number of detected symptoms corresponding or non-corresponding to actual attacks.

The third step of verification is able to check if the same symptom has been already detected by a sensor in the past. We take into consideration only the confidence of previous symptoms detected by the sensor monitoring the same component of the RFID infrastructure.

After these single steps and the calculation of the partial confidence values, a fuzzy engine has been used in order to combine the different contributions and calculate the overall confidence for a detected symptom.

Generally speaking, fuzzy logic incorporates an alternative way of thinking, which allows for complex modelling of systems using a high-level of abstraction of gained knowledge and experience. Fuzzy logic allows the expression of qualitative knowledge, including phrases such as “medium” and “high”, which are mapped to exact numeric ranges. The fuzzy inference process consists of five parts: (1) fuzzification of the input variables (2) application of the fuzzy operator (AND or OR) to the antecedent (3) implication from the antecedent to the consequent (4) aggregation of the consequents across the rules, and (5) defuzzification.

Results coming from the single verification are used as input to the fuzzy engine. Membership functions for the input and output variables modelling the partial confidences calculated in the different verification steps have been defined. Membership Functions are curves that define how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. We used trapezoidal distribution as the type of the membership functions with *Low, Medium* and *High* as possible fuzzy subsets.

In addition, fuzzy rules have been defined in order to formulate the conditional statements that make the fuzzy inference. An example of rule is reported as follows:

| |
|---|
| if SensorReliability is Low and AdministratorConfidence is Medium and *OldSymptomConfidence* is *High* then *SymptomConfidence* is *High* |

where *SensorReliability*, *AdministratorConfidence* and *OldSymptomConfidence* are input variables, *SymptomConfidence* is an output variable.

The fuzzy engine first takes the input values from the calculated partial confidences and then fuzzifies them using the membership functions defined for the corresponding input variables. Then, the rules will be evaluated to generate the output set for each active rule. All the outputs will be aggregated and a single fuzzy set will be provided. Finally, this fuzzy set will be defuzzified in order to give a numeric value that represents the overall confidence associated to the detected symptom.

## *3.3 Alert Ontology*

The proposed ontology is designed to formalize a conceptual model for the alert correlation procedure. It is structured into two separate but interrelated component ontologies, that are domain ontology and application ontology. The domain ontology captures concepts of unique relevance to the domain of interest that is the alert correlation. The application ontology meets the specific information requirements for the RFID infrastructure and tunes the domain ontology in an actual implementation. Both the ontology components are discussed in detail below. A high level view of the domain ontology, named Alert Ontology, is depicted in Fig. 1.

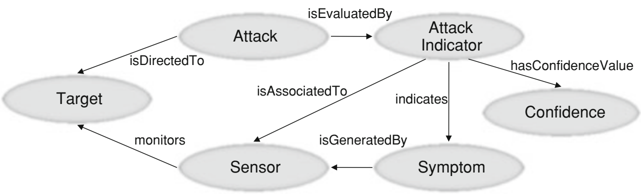


**Fig. 1** A simplified graph-representation of the Alert Ontology

All properties of each concept are not shown because it would make the representation unwieldy. An event generated by a sensor represents a potential symptom of an attack. Each kind of attack, directed to a target, is related to the set of its potential symptoms. Moreover, each attack is described with attack indicators that estimate, depending on a specific symptom, the confidence of a sensor to detect it.

As a result, at the top most level the concepts *Attack* and *Symptom* have been defined. *Attack* has two properties, namely *isDirectedTo* and *isEvaluatedBy*: the range of the property *isDirectedTo* is defined by the concept *Target*, whereas the range of *isEvaluatedBy* is specified by the concept *AttackIndicator*.

*AttackIndicator* has three properties, namely *hasConfidenceValue*, *isAssociatedTo* and *indicates*: the range of the property *hasConfidenceValue* is defined by the concept *Confidence*, the range of the property *isAssociatedTo* is specified by the concept *Sensor*, and the range of the property indicates is represented by the concept *Symptom*. Finally, *Symptom* has the property *isGeneratedBy*, whose range is defined by the concept *Sensor*.

The application ontology, named *RFID Alert Ontology*, models knowledge that is specific to the function of the alert correlation for the RFID infrastructure. In other words, it specializes, refines or adapts the fundamental concepts of the domain ontology shown in Fig. 1.

In particular, it contains a simplified view of the possible attacks that can target an RFID infrastructure. These are all the possible attacks that can be detected by the alert correlation procedure, ranging from passive attacks, such as eavesdropping, to active attacks, such as malwares, brute force attacks, spoofing and denial of service. They have been modelled as sub-concepts of the domain ontology concept *Attack*. Moreover, it contains the list of possible sensors that can be deployed in an RFID infrastructure is reported. These possible sensors have been modelled as sub-concepts of the domain ontology concept *Sensor*. Finally, it models the possible components of the RFID infrastructure that can be target of attacks is shown. These are all the possible targets used by the alert correlation procedure, ranging from credentials, such as passwords, to technological assets, such as network, software and hardware components, data. They have been modelled as sub-concepts of the domain ontology concept *Target*.

### 3.4 Alert Correlation Procedure

The alert correlation procedure, mainly based on the presented ontology, has been devised with the aim of recognizing when symptoms gathered from multiple sensors refer to the same attack so as to reduce the number of alerts that a security officer must address. Moreover, symptoms generated from several sensors employing diverse detection techniques may reinforce each other, enhance the confidence of the detection and minimize the number of false positives (FPs) and false negatives (FNs). Finally, this procedure is intended to enhance the detection capability and give a more complete and semantically-described picture of attacks that an individual sensor may observe only partially.

In detail, the alert correlation procedure can be described as follows. Each symptom, first gathered by the sensor, then processed by the verification engine and finally labelled with a confidence value, is sent to the alert correlation engine.

This engine exploits the knowledge formalized in the ontology to detect all the potential attacks that can bring to such a symptom. In the context of such potential attacks, the engine correlates the detected symptom with the other incoming ones, by combining, for each of them, the confidence, as calculated by the verification engine with the level of intensity detected by the specific sensor, so as to produce more accurate alerts.

More specifically, such operations have been realized by using fuzzy rules and a fuzzy engine, as just described for the verification procedure. In particular, a first set of fuzzy rules has been defined to combine, for each symptom, the confidence coming from the verification engine with the level of intensity detected by the specific sensor. Again, we used trapezoidal distribution as the type of the membership functions with *Low, Medium* and *High* as possible fuzzy subsets. A rule example is reported as follows:

| |
|---|
| if SymptomConfidence is Medium and SensorIntensity is High then *AlertConfidence* is *High* |

where *SymptomConfidence* and *SensorIntensity* are input variables, *AlertConfidence* is an output variable.

Moreover, another set of fuzzy rules has been formulated in order to correlate to correlate, in terms of alert confidence, a detected symptom with other incoming ones in the context of the potential attack identified by exploiting the ontology.

Also in this case, we used trapezoidal distribution as the type of the membership functions with *Low*, *Medium* and *High* as possible fuzzy subsets. A rule example to correlate symptoms is reported as follows:

| |
|---|
| if AlertConfidence1 is Medium and AlertConfidence2 is High then *OverallAlertConfidence* is *High* |

where *AlertConfidence1* and *AlertConfidence2* are input variables, *OverallAlert-Confidence* is an output variable. For sake of clarity, in the reported example alert confidence values of only two symptoms have been correlated, but a similar solution can be also applied for a greater number of detected symptoms.

The fuzzy set assigned to the output variable after the fuzzy inference will be defuzzified in order to give a numeric value that represents the overall alert confidence associated to the detected attack. In such a way, alerts are not generated as results of all the detected symptoms, but only when the calculated overall alert confidence is greater than an alert threshold, preventively set up by the security operator. In such a way, security operators are provided with a comprehensive view of relevant and reliable symptoms being monitored in the RFID infrastructure and representing really potential attacks.

## 4 Proof-of-Concept Implementation

The case study implemented to prove the feasibility of the proposed IDS is essentially represented by an attack of SQL Injection against the back-end database of an RFID infrastructure. RFID tags are a perfect way to hide a SQL exploit since they can contain any query or statement on any table in the back-end databases. The SQL attack is based on this consideration: some databases return query-portion containing syntax errors, which are provided to the front-end in error messages. In detail, we have inserted a SQL malicious code into an RFID tag in order to generate syntax errors when the database, after storing data contained in the RFID tag, tries to read them. By watching the error messages carefully, it is possible to learn iteratively the database layout and, hence, develop proper injection methods.

An experimental implementation of this case study has been set up by using UHF tags conforming to the EPC standard. A prototype has been developed and tests have been performed for assessing its behaviour in a simulated RFID network. All the described components of the IDS have been implemented as fully portable Java entities. Moreover, two different sensors have been developed and deployed, namely an RFID Reader Monitor and a DataBase Monitor. The RFID Reader Monitor is a fully Java entity responsible for detecting the number of read/write operations performed on a tag. On the other hand, the DataBase Monitor is a fully Java entity in charge of detecting the number of error messages generated by the database in response to failed queries.

The experimental RFID infrastructure consisted of a MySQL database management system used to build the backend database, a small "home-grown" RFID middleware system and the simulated RFID network. This RFID network consisted of 10000 tags and 4 readers, each of them observed by an RFID Reader Monitor; the backend database was observed by a DataBase Monitor. When a tag was read, its data were sent by means of the middleware to the database for their storage; after that, the middleware launched an inventory query to visualize the current number of tags present in the environment.

**Table 1** Confidence values of the sensors used in the simulated scenario

| Attack: SQL injection | RFID Reader monitor 1 | RFID Reader monitor 2 | RFID Reader monitor 3 | RFID Reader monitor 4 | Database monitor |
|---|---|---|---|---|---|
| Symptom: Abnormal number of read/write operations | | | | | |
| Reliability | 0.5 | 0.7 | 0.6 | 0.8 | – |
| Administrator confidence | 0.4 | 0.8 | 0.5 | 0.7 | – |
| Symptom: Abnormal number of failed queries | | | | | |
| Reliability | – | – | – | – | 0.8 |
| Administrator confidence | – | – | – | – | 0.9 |

During the normal execution of this scenario, an increasing number of malicious tags, i.e. tags with the same SQL code, were randomly introduced in the simulated RFID network. The sensors deployed in the environment were able to recognize symptoms that could indicate the occurrence of the SQL Injection attack. In particular, an abnormal number of read/write operations determined by the RFID Reader Monitors were considered as a symptom since it could be generated when malicious tags contained the same SQL code. On the other hand, an abnormal number of failed queries determined by the Database Monitor were interpreted as a possible symptom for the previous considerations about SQL injections.

The confidence values for all the sensors were set up with reference to this attack and the associated symptoms, as reported in Table 1. It is worth noting that in the initial phase of this simulation the sensors had not detected any symptom yet. As a result, the third partial value of confidence described in Sect. 3.2 was initially set up to 0.

The final confidence value was calculated applying the fuzzy rules defined for the verification procedure to the values reported in Table 1. Each intensity was combined with the calculated symptom confidence by using the first set of rules defined for the correlation procedure. The alert threshold was set up to 0.8 to be compared with the overall alert confidence obtained after the application of the second set of rules defined for the correlation procedure and the relative defuzzification process.

A correctly identified SQL Injection attack generated an alert, called a true positive (TP). Conversely, the absence of an alert in situations where no SQL Injection attack was executed is a true negative (TN). An alert generated when no attack actually took place is a FP. The absence of an alert when an attack has happened is a FN. Table 2 shows the detection performance in terms of accuracy, true positive rate (TPR) and false positive rate (FPR), computed for the number of malicious tags running from 0 to 10,000 in two different situations, i.e. with and without the proposed alert correlation approach.

From the results, it is possible to observe that the proposed solution minimizes FPR and achieves both a higher TPR and a higher accuracy than the simple

**Table 2** Experimental results for the simulated scenario

| Number of malic. tags | Number of tags | Accuracy without corr. (%) | TPR without corr. (%) | FPR without corr. (%) | Accuracy with corr. (%) | TPR with corr. (%) | FPR with corr. (%) |
|---|---|---|---|---|---|---|---|
| 1,000 | 11,000 | 98.45 | 98.00 | 1.50 | 99.45 | 99.00 | 0.50 |
| 2,000 | 12,000 | 98.19 | 97.65 | 1.70 | 99.32 | 98.90 | 0.60 |
| 3,000 | 13,000 | 97.94 | 97.13 | 1.82 | 99.17 | 98.80 | 0.72 |
| 4,000 | 14,000 | 97.71 | 96.75 | 1.91 | 99.06 | 98.73 | 0.81 |
| 5,000 | 15,000 | 97.53 | 96.62 | 2.02 | 98.91 | 98.58 | 0.93 |
| 6,000 | 16,000 | 97.28 | 96.35 | 2.16 | 98.81 | 98.52 | 1.01 |
| 7,000 | 17,000 | 96.95 | 95.89 | 2.31 | 98.72 | 98.44 | 1.08 |
| 8,000 | 18,000 | 96.56 | 95,56 | 2.65 | 98.61 | 98.39 | 1.21 |
| 9,000 | 19,000 | 96.30 | 95.46 | 2.94 | 98.50 | 98.32 | 1.34 |
| 10,000 | 20,000 | 95.85 | 94.82 | 3.12 | 98.44 | 98.30 | 1.43 |

execution without the correlation. Even as both TPR and the accuracy lower with the increase in large number of attacks, they still remain high enough, respectively with values of 98.30 and 98.44 % for the worst attack scenario considered in the simulation (Table 2).

Moreover, it is worth noting that FPR is remarkably low, since its value still remains lower than 1.5 % even in the worst attack scenario.

These results are also due to the third partial value of confidence that has become greater than zero in the course of simulation, contributing to increase the overall symptom confidence and, thus, to better tune the detection capabilities. The results are motivated by the value chosen for the alert threshold. The application of a strict threshold might result in lowering FPR but missing many actual attacks, whereas relaxing the threshold may increase TPR but also lead to too many non-actual attacks. The threshold value applied to the test were chosen in order to strike a right balance between TPR and FPR, with the relief that, in this application context, it is better to detect non-actual attacks rather than missing actual ones.

## 5 Conclusion

The present research was intended to investigate whether it was feasible to integrate the principles of both ontology and fuzzy logic modelling techniques in the intrusion detection paradigm to perform alert verification and correlation with the final aim of identifying RFID malware attacks.

The approach proposed in this work has been focused on three key points: (i) the application of heterogeneous sensors diffused throughout the RFID infrastructure; (ii) the definition of fuzzy rules to handle imprecision and fuzziness in calculation of a confidence for each detected symptom in the verification procedure; (iii) the definition of a formal alert model, represented by means of an ontology and combined with fuzzy rules to represent knowledge for reasoning about complementary alert evidence and provide a comprehensive view of relevant symptoms indicating really potential attacks. Experimental tests performed on a proof-of-concept implementation gave a proof of the feasibility of the approach, also suggesting that an actual deployment of the proposed solution could effectively and proficiently support the detection of malwares in RFID systems.

As concluding remarks, it is relevant to observe that the approach described in this paper represents only a preliminary step of an ongoing research, because, at the moment, an experimental prototype has been tested only over proof cloning attacks. Next step of our research will be to minutely investigate the feasibility of the approach in real cases, in terms of performance evaluation and experimental assessment.

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# XML Database Storage for Web based Application

**Puspha Rani Suri and Neetu Sardana**

**Abstract** With XML rapidly gaining popularity as the standard for data exchange on the World Wide Web, a variety of XML data management systems are becoming available for maintaining web information residing in web pages of their respective websites. Earlier mostly XML documents were stored in XML based relational database systems. Later XML Native data management systems came in existence that captured all the characteristics of XML data representation. We have applied the same practice and are using XML Native database for web-based applications dealing with time series data. Choosing the right XML native data management systems has become difficult, as every database has its own functionality, performance and expressibility. Databases perform differently for different XML Documents. This paper is an effort directing towards using Native XML database for web-based application dealing with time series. An architectural details related to XML document storage are discussed.

## 1 Introduction

WWW is a huge encyclopedia of information and communities share this common data on web for the execution of various applications like stock marketing, forecasting, risk analysis, portfolio generation, e-commerce application etc. Extensible

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Markup Language (XML) is commonly accepted standard used for exchanging data on web. As huge information is shared, so we need a place to store this information that is residing in web pages.

Traditionally, relational database management systems have been used to store and maintain highly structured and rigid data, until the advent of XML. As XML allowed arbitrarily describing and structuring information that was previously unstructured. As far as websites are concerned these have number of prose-oriented XML documents that are mostly semi-structured or unstructured by nature. Document-centric XML, intended to be read and maintained by humans, have proven to be difficult and expensive to manage using relational databases. This led to the development of a new type of database, Native XML Databases. Native XML Databases are efficient when used to maintain XML documents as it is specifically designed for storing and managing XML documents in databases [1].

We have chosen an open source Native XML database. Several studies are being done to compare the performance of various open source Native XML databases [2–4]. For web based application, major concern is the response time required for querying and retrieving the data whenever required. As storing is a one time effort, but basic purpose behind creation of database is querying or retrieving the data whenever required. So response time matters. It is being observed in literature that eXist takes longer to create a database but at the same time it was discovered that eXist had the best response time. eXist is a very popular and commonly used open source XML database. eXist-db provides a powerful environment for the development of web applications based on XQuery and related standards [5]. eXist only allows the existence of one database but does support multiple documents, collections of documents and collections of collections. For illustration we had taken web-based application containing gold prices. This paper will explain, the detail architecture of storing web pages containing time series gold data in Native database: eXist.

Paper is divided into following sections. Section 2 describes various available options for XML Web Document database storage. Section 3 discusses Native XML storage using eXist. Section 4 describes storing for web based gold price application in eXist. Section 5 ends with the conclusion.

## 2 Available Databases for XML Document Storage

XML has diverse forms ranging from data centric to document centric, so there is no one size fits all storage model to give the best performance and flexibility for each of these cases. As far as web contents are concerned, Most of them have number of prose oriented XML documents.

Moreover the web contents changes over time with the change in real world business systems. In other words web contents are dynamic in nature. Changing the structure of the XML document (it’s possible for attributes to become elements and vice versa)—which is easy, natural, and useful to do in XML—forces a redesign of the database More and more information is communicated daily and is being created every day and hence becomes the part of web.

Access management of XML documents and querying the XML database can be done by various means. We had to consider certain issues while choosing a right way to handle XML documents in web. Let's explore that various options available for storing web XML documents.

There are two basic strategies for storing XML documents: store them in the file system or in a relational database and accept limited XML functionality, or store them in a native XML database [6].

## *2.1 Storing Documents in the File System*

If we have a simple and small set of documents, the easiest way to store them is in the file system. In this case complete text searches of XML documents are obviously inaccurate, as they cannot easily distinguish markup from text and cannot understand entity usage. However, in a small system, such inaccuracies may be acceptable.

## *2.2 Storing Documents as Blobs in Relational database*

A slightly more sophisticated option is to store documents as Binary Large objects (BLOBs) in a relational database. This provides a number of the advantages of databases: transactional control, security, multi-user access, and so on. In addition, many relational databases have tools for searching text and can do such things as full-text searches, proximity searches, synonym searches, and fuzzy searches. Some of these tools are being made XML-aware, which will eliminate the problems involved with searching XML documents as pure text. Storing data as BLOBs, we can also implement simple XML-aware indexing, even if the database cannot index XML.

## *2.3 Storing Documents Using Native XML Storage*

Native XML databases Native XML Storage (NXD) are the containers that can store XML documents and data. XML is its fundamental unit of (logical) storage. NXD appeared in the XML data processing areas, is specifically designed for storing and managing XML documents in databases. NXD defines a logical model for an XML document, relative to XML document and stores and retrieves documents according to that model. The model must include elements, attributes, PCDATA, and document order.

We have to consider various issues while choosing the appropriate database for web application consisting time series. If web size estimates indicate more than 1000 XML files or 200 MB of XML data, the file system isn't the right tool for the job. File systems are not built to manage large numbers of files in a single directory or huge directory hierarchies. In case of time series application we have files that continuously increase. In that managing concurrency, out of disk space conditions, and other common problems will plague our application unless we use a database [7].

Although relational databases fit a lot of problems very well, they don't really fit XML documents, at least not in their full generality. While we can shred an XML document enough to stuff it into a relational table or just treat it as one big *blob*, neither approach really lends itself to indexing and fast queries. Moreover, shredding leads to the loss of details like element order, processing instructions, comments, white space, and other elements. Field and record boundaries just don't match the boundaries of an XML document. Applications such as time series that care about these details need to look beyond the relational database for their information storage needs [8].

A better solution for storing, retrieving, and processing persistent XML documents is the native XML database, NXD, which understands the structure of XML documents and so preserves their data hierarchy and meaning. As defined by the XML: DB Initiative, an NXD defines a model for an XML document and stores and retrieves that document according to that model. XML documents conforming to a DTD or XML Schema maintain a high degree of flexibility with NXD when compared to relational schemas [9].

It is also widely believed (if not exactly proven) that native XML databases can significantly outperform traditional relational databases for tasks that involve heavy document processing, such as newspaper publishing, Web site management, and Web services.

## 3 Native Storage Using Exist 0

Database is a collection of various documents i.e. files. Documents are basically arranged in hierarchical form. Query languages like Xpath or Xquery are used to extract data residing in these documents. Both of these languages use path expression to navigate through the logical, hierarchical structure of an XML document.

To perform queries on large, unconstraint document collection more efficiently, index structures are required. The most significant purpose of the indexing scheme is quick identification of structural and value based relationships between nodes and to determine the relationship between any pair of given nodes, so that whenever node is required, node itself should specify details related to its ascendants-descendents.

Value based relationship between nodes can be easily done using indexing scheme such as B+ tree algorithm. Determining the structural relationship between the nodes is beyond the scope of B+ tree algorithm, it's much harder to deal with. We need indexing scheme that will speed up the processing of path expression in order to identify the structural relationship between nodes. Considerable amount of research is going on to design XML indexing system to meet this requirement.

### 3.1 Indexing Schemes

eXist indexing system uses numbering scheme to identify XML nodes and the relationship between them. Numbering scheme assigns a unique identifier to each XML node. Identifiers are used as an indexes as a reference to the actual node. The indexing approach adopted by the eXist has been inspired by various contributions.

One of the schemes suggests that each XML document can be represented as a tuple consisting of doc-id, start–end position and nesting level [10, 11]. Here document id is a unique number given to each document, start and end position can be generated by counting word positions from start of document and nesting depth (level) to get actual node position. Using above three tuple's, ancestor–descendant relationship can be determined between pair of nodes by the preposition. If we have to find descendent relationship between one node X with three tuple (D1, S1:E1, L1) and another node Y with three tuple (D2, S2:E2, L2) X will be descendent of Y if and only if D1 = D2 (both belongs with same document)

$$\begin{array}{ll} (i) & S2 > S1\,(Starting\ position\ of\ Y\ is\ before\ then\ the\ Starting\ position\ of\ X) \\ (ii) & E1 > E2\,(Ending\ position\ of\ X\ is\ later\ then\ Ending\ Position\ of\ Y). \end{array} \tag{1}$$

Like this we can find out the sibling relationship between node X with three tuple (D1, S1:E1, L1) and another node Y with three tuple (D2, S2:E2, L2).

X will be sibling of Y if and only if

$$\begin{array}{l} (i) D1 = D2 (both\ belongs\ with\ same\ document) \\ (ii) L1 = L2\,(both\ node\ are\ at\ same\ level) \\ (iii) S1 > S2\,(Start\ position\ of\ Y\ is\ before\ then\ Start\ position\ of\ X) \\ (iv) E1 > E2\,(End\ position\ of\ X\ is\ later\ then\ End\ Position\ of\ Y). \end{array} \tag{2}$$

Problem in this technique is that we have to do a lot of comparison to get XML structure and element to satisfy Xpath query. Updations in document cannot be done easily. Time in finding ancestor-descendent relationship will never be constant.

Another scheme sproposed in XISS (XML Indexing and Storage System) system by Li and Moon [12]. This is based on extended preorder scheme. This scheme determines the ancestor–descendant relationship between nodes in the hierarchy of XML data in constant time. In this scheme each node is assigns a pair of numbers $<$ order, number $>$ to each node. Ordering and numbering is done in such a way that for a tree node Y, X will be parent if

$$\begin{array}{ll} (i) & order(x) < order(y) \\ (ii) & order(y) + size(y) <= order(x) + size(x). \end{array} \tag{3}$$

*X will be sibling of Y if*

$$\begin{array}{ll} (i) & X\ is\ predecessor\ of\ Y\ in\ preorder\ traversal\ and \\ (ii) & order(x) + size(x) < order(y) \end{array} . \tag{4}$$

Ordering is done as per preorder traversal of node. Size is total number of descendant of current node. X will be ancestor of Y if and only if

$$Order(x) < order(y) << = order(x) + size(x). \tag{5}$$

The ancestor–descendant relationship for a pair of nodes can be determined by examining their order and size values.

The numbering schemes proposed by Lee, view XML document as a complete k-ary tree where k is equal to maximum number of child nodes of an element in the document. This implies every node in the tree will have equal number of children. Any node having less than k children, spare nodes will be inserted. Each spare node will be given a unique identifier. In other words, a tree is assumed to be complete by inserting spare nodes having spare ids at various locations. Unique node identifier enables to calculate its parent id using given function [13, 14].

$$Parent\_id = floor\,[(i-2)/k + 1]. \tag{6}$$

where, k is number of child nodes and i is unique node identifier.

To get the unique identifier of the j-th child of the node with identifier i we use the function

$$Child\_id = k\,(i - 1) + j + 1. \tag{7}$$

Problem with this scheme is completeness constraint that is each node should have same number of children. This constraint imposes a major restriction on maximum size of document. In normal scenario tree grow in such a way that top level node have less child nodes and bottom node have more child nodes but to make tree complete, we need to insert lots of spare nodes at top level. Due to completeness issue, node may run out of index for even a small document. So here we need a lot of memory to represent our data in the form of tree.

Seeing this problem the completeness constraint is being partially dropped by eXist. Here document is not viewed as a complete k-ary tree. Instead completeness constraint is imposed at each level. In other words, two nodes at same level will have equal number of children. We will compute the number of children at each level as node x and y of a tree, size(x) = size(y) if level(x) = level(y) where size (n) is number of children of a node n. and level (m) is length of path from the root node of the tree to m. For each level, along with a node identity, additional information about number of children of a node is stored with the document in a simple array.

This scheme doesn't affect properties of the assigned level-order identifiers. From a unique identifies we are still able to compute parent, sibling and child node identifiers using the additional information the numbers of children each node may have at every level of tree.

### *3.2 Index Organization*

For storage implementation, eXist uses four index files at the core of the native XML storage backend. Four index files are collection, dom, element and word.

*collections.dbx*: The index file collections.dbx manages the collection hierarchy and maps collection names to collection objects. Due to performance considerations, document descriptions are always stored with the collection object they belong to. A unique id is assigned to each collection and document during indexing. Indexes for elements, attributes and keywords are organized by collection and not by document.

*dom.dbx*: The XML data store represents the central component of eXist's native storage architecture. All document nodes are stored in it according to the W3C's DOM (Document Object Model). The data store is backed by a multi-root B+-Tree in the same file to associate the unique node identifiers of top-level elements in a given document to the node's storage address in the data pages. Only top-level elements are indexed by the B+-tree. The storage address consists of page number and the offset of the node inside the page. Attributes, text nodes and elements at lower levels of the document's node hierarchy are just written to the data pages without adding a key in the B+-tree. Access to these types of nodes is provided by traversing the nearest available ancestor found in the tree.

*elements.dbx:* Element and Attribute names are mapped to unique node identifiers in file elements.dbx. Each entry in the B+-tree index consists of a key - <collection-id, name-id> and each key correspond an array containing an list of < document-id, node-id>.

*word.dbx:* This database corresponds to an inverted index as used in relational information retrieval system. Each entry in the value list, points to a text or attribute node where the keyword occurred.

## 4 Storing Web Based Gold Price Application in Exist

In this section we will illustrate database storage for web based application dealing with gold price. Generally gold price is characterized by various key elements like its exchange, format, date, its price. Gold price can be described using XML file as shown in Fig. 1.

Here in Fig. 1 the gold XML file, we have elements as goldexchange with attribute "kitco.com" that has got elements as format, date and price. Date has

**Fig. 1** Gold.xml

```
<dailygoldprice>
  <goldexchange = “kitco”>
      <format> USD </format>
         <date>
               <day> 21 </day>
               <month> January </month>
               <year> 2010 </year>
        </date>
        <price>
               <min> 320 </min>
               <max> 500 </max>
               <open> 250 </open>
               <close> 389 </close>
       </price>
   </goldexchange>
</dailygoldprice>
```

further sub elements as day, month, year and price have further details as its sub elements as min, max, open, close price.

With respect to gold price web application, each day gold data is a separate XML web page and these web pages are normally available at various gold trading websites like for instance kitko.com, gold.org, goldprice.com etc. Every XML page has information about complete day gold price with respect to year and month.

It has price related details like minimum, maximum, opening and closing price for that specific day. Here is fraction of one day gold price XML file in Fig. 2.

## *4.1 Indexing of Gold Prices Application*

Tree representation of XML files (Fig. 3) is given. Following the completeness constraint, we have added spare nodes in it. Resultant tree is shown in Fig. 3.

Following the completeness constraint at each level by adding spare nodes we have the resultant tree represented in Fig. 4.

## *4.2 Implementation Details of Gold Data and Index Organization*

For implementing web based XML application consisting gold prices in eXist “Native XML database”, four index files are required at the core of the native XML storage backend to generate relationship between data and index. Here is detail implementation of each of these four files with respect to gold price web application.

```
<Goldprice>
        <Goldexchange = "Kitko">
                <format> USD</format>
                <Price>
                        <min>   312     </min>
                        <max>   350     </max>
                        <open>  320     </open>
                        <close> 340     </close>
                </Price>
        </Goldexchange>
</Goldprice>
```

**Fig. 2** Partial XML file for single day gold price

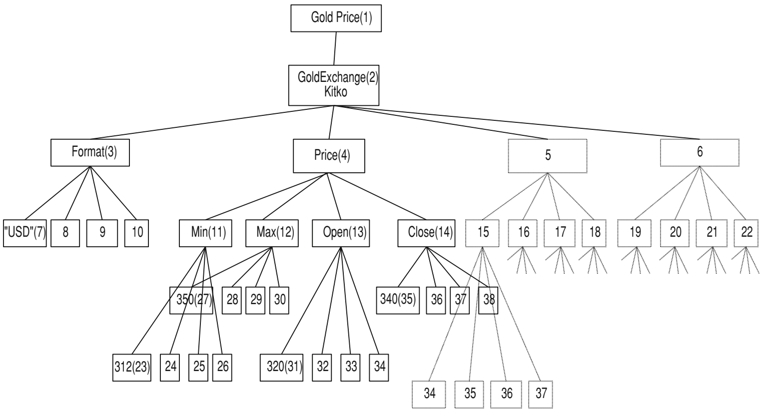


**Fig. 3** Representation of gold data in complete tree format

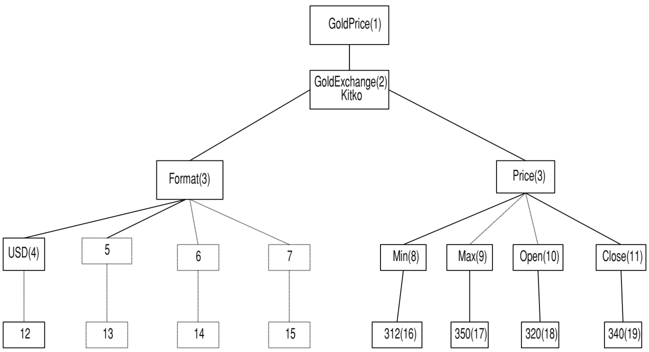


**Fig. 4** Representation of gold data in level balance tree format

*Collections.dbx:* Collection.dbx file maintains indexes for collection of files. All files in a specific year will have same collection year index same way all month will also have month index but each day XML file will have unique index.

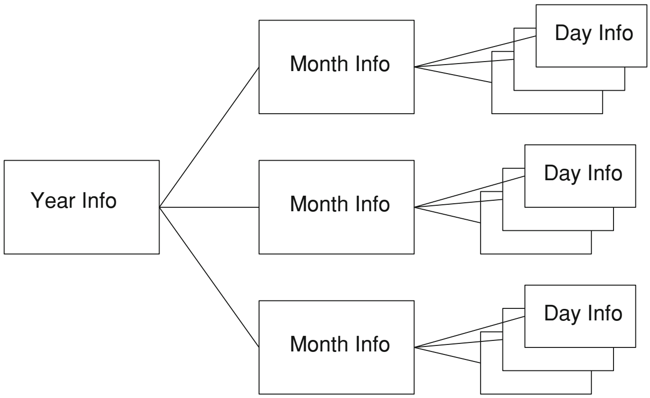


**Fig. 5** Collection Id for years and each day data

Here, for instance, w.r.t. each year we have twelve different collection-ids of months and thirty collection-ids of days. Using Collection index (combination of Year, Month and day) database gets root path for specific day file. In other words, each collection-id is associated with name-id containing the XML page having the gold price details. Name-id corresponds to document-id that has various nodes. Here we have name-id consist various XML pages in the form shown in Fig. 1 (Fig. 5).

*Dom.dbx:* Every document represents each day XML data page. Only top level node indexes are stored as document id. Here top-level nodes are goldexchange, format and price. Other information is stored in a DOM as data pages. Mapping between Data pages and Parent page can be determined by DOM.dbx. Data pages consist of index value of children of the DOM, where each child index in the form of single array. Here price is stored in the form of single array containing min, max, opening and closing price and exchange consist of various exchanges (Fig. 6).

*Elements.dbx:* Element.dbx file have mapping of element and attribute name w.r.t unique node identifier. Each entry in B+ tree index consists of a key -<collection-id, name-id> is represented in corresponding array by document-id, followed by node-id. For gold price each date represents doc-id and node-id's are with respect to contents of goldexchange, format and price for example (13/03/99(doc-id), node-id (1), node-id (2)).

*Word.dbx:* Word.dbx looks for the word occurrences. With the set of documents, in which word has been found, it notifies the exact position where it occurred. It uses <collection-id, keyword> pair to locate any word in a document. Each entry in the value list points to a text or attribute node where the keyword occurred. In gold example it will give mapping like keyword "GoldExchange" belongs to Node 2.

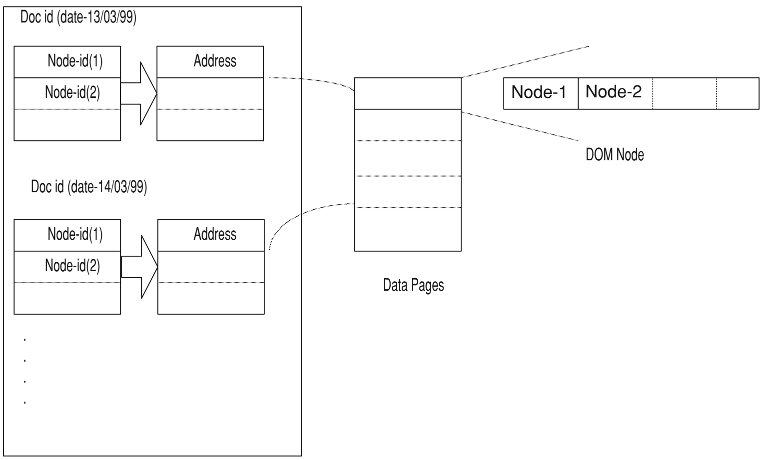


**Fig. 6** XML data store organization

## 5 Conclusion

We have considered an open source native XML database "eXist" for storing data of web based XML application having gold price. It is noted fact that eXist has better response time for data retrieval as compare to other open source databases. All data storage and retrieval using eXist is as much efficient as it provides inbuilt indexing and retrieving technique. Improved indexing technique in database will give significant improvement on overall system.

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# Towards C# Application Development Using UML State Machines: A Case Study

**Anna Derezińska and Marian Szczykulski**

**Abstract** Using a state machine for modeling a class behavior can assist effective development of an application. We discuss a model-driven approach to building a C# application based on UML class models and behavioral state machines. A case study addressed in the paper is devoted to a social network of mobile users. The core of the system is a presence server for the status services in the network. There are three main tasks performed by the server: subscription of a status of another user, publication of a new status with given rules and notification another user about a status. The system architecture and exemplary state machine models are presented. Model to code transformation and development of an executable application was realized by a Framework for eXecutable UML (FXU). Verification of the application was supported by tracing of program execution in terms of model elements using FXU Tracer. On the basis of the gathered experience, we discuss design guidelines for carrying out the approach.

## 1 Introduction

Human comprehension of graphical models can be more effective and less error-prone than a direct code analysis. Therefore model driven engineering (MDE) technology promotes application development based on a model to code transformation [1]. A leading proposal for MDE is the initiative of model driven architecture (MDA) [2, 3] that encourages different ideas and tools around the UML notation.

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There are various strategies to cope with models and their execution. A model can be directly executed according to its virtual machine as, for example, one given in the foundation subset for executable UML models (FUML) [4]. Another strategy is transformation of a source model into a target code. It can be completed in several steps. In the first step, a target level can be an intermediate model level. For instance, a level between UML models and a programming language is used in order to simplify transformation to a desired programming language [5]. Transformation can also be defined as a direct translation of a model to a code given in a general purpose programming language, e.g. Java. C++, C# [6–10]. This paper addresses the later approach.

Complex problems can be modeled with behavioral state machines. It is beneficial to support the development process with a tool capable to transform advance state machine features and to build a reliable application. We discuss this problem in a case study.

A social network deals with a set of mobile users with time and space dynamic relationships. Social networking services support different context-aware features. *Internet protocol multimedia subsystem* (IMS) is an environment that provides a developer with multimedia services based on the internet protocol. The environment was used for the implementation of presence services presented in [11]. The specification was tested using an emulator of IMS. In this work, we propose another solution using UML class and state machine diagrams [12]. Further they were transformed to a C# code and executed using a FXU [6].

In the next section, we present the background of transformation of UML state machines to a C# code. The system considered in the case study and its modeling is introduced in Sect. 3. Section 4 discusses technology of application development and design guidelines. Finally, Sect. 5 conclude the paper.

## 2 State Machine Transformation to C# Code

Providing with modeling facilities, CASE tools also support a model to code transformation, which can assist building a final application reflecting principles behind the model. However, as far as UML is concerned, a transformation is mostly restricted to a structural model, namely a class diagram as, for example, in rational modeling extension for .NET [7].

Some tools also support the code transformation from behavioral diagrams, especially state machines. They usually consider only a subset of state machine elements, whereas such advanced concepts as orthogonal regions, deep and shallow history pseudostates, deferred events or internal transitions are omitted.

An exception is the IBM Rational Rhapsody tool [8] (previously Telelogic and I-Logic) that takes into account the entire state machine during transformations aimed at different programming languages, although it does not support C#.

The FXU, introduced in [6], performs transformation from UML class and state machine models into a corresponding C# code. It supports creation and execution of the resulting application that is intended to reflect the modeled behavior.

The framework, in the opposite to the most of similar tools, implements a complete specification of state machines, including all kinds of states, such as simple states, composite states, orthogonal states, *entry*-, *do*- and *exit*- activities, and submachine states. It also takes into account all possible pseudostates, i.e. initial psudostate, deep and shallow history, join, fork, junction, choice, entry and exit points, terminate, as well as different kinds of events (also deferred events).

In FXU several variation points of the UML state machine specification [13] had to be resolved in order to obtain an unambiguous interpretation of a model behavior [14].

In order to improve the usability of the framework a new FXU version was released. It was equipped with GUI, Application Wizard and FXU tracer assisting comprehension of an application behavior in terms of state machine elements [15].

In some solutions, the code created as the target of a model transformation includes a mapping of the state machine structure as well as of the logic supporting a model execution [16]. Recently, Sparx Enterprise Architect [9] was extended with code generator from a state diagram to various programming languages, including C#. Also in this case, a subset of state machine concepts is transformed into predefined code extracts that are placed directly into a considered class. In case of many state machines the amount of generated code can be significant, aggravating evolution and maintenance of a program.

The approach implemented in FXU is different. The entire logic of state machines is hidden in the library code (runtime environment) and for each class is only generated a simple code defining a structure of its state machine and its initialization.

# 3 Presence Server Modelling

This section describes the basic idea of the system used in the case study (*A*) and its modeling with UML structural and behavioral diagrams (*B*).

## *3.1 System overview*

The system under consideration was devoted to a status service for a social network. A user status is understood as information about a current user's presence and its context. A context is defined by a location, communication possibilities, occupation of a user, its activities, mood, etc. There are different relationships between users. The relations can be divided into various categories, like family, friends, coworkers, acquaintances of a common hobby.

A user description is specified according to a format FOAF (*friend of a friend*). This specification is based on the XML syntax and the *Resource Description Framework* structure (RDF)—a standard used for defining data in the net.

A presence service, which is offered in a social network provides users with a required data about a status of a given, selected user. The main job of the service is filtering of information in accordance to different inter-user relationships.

The services are supported by *Session Initiation Protocol* (Sip)—an open standard for creating a session between one or many clients proposed by *Internet Engineering Task Force*. Application of the SIP protocol for subscription and distributing presence information is described in [17].

A user, let called X, registers directly in a SIP server where information about its status is stored. Another user, so called observer, can request a subscription of the status of user X. Therefore the observer communicates with the *Presence Server* sending an appropriate message. The presence server communicates with the SIP server fetching a current status of user X. The presence server also connects to the XCAP server (*XML Configuration Access Protocol*) where rules defining a resulting status drawn on a current state and a relation between a user and his/her observer are gathered. Therefore the observer can be notified about the real status of user X.

In the case study, we focused on *Presence Server* that constitutes the main part of the system and is responsible for completing of the business logic. A presence server should realize the following main tasks:

– Status creation—creation of a predefined presence status that controls an access to presence information.
– Status publication—making known selected information to users subscribed in a contact list, according to rules of a formerly predefined status.
– Status subscription—requesting information about a presence state of an observed user.
– Delete subscription—deletion of a presence status. A user is no more registered in the service because do not want to be informed about changes of statuses of other users from the contact list.

## *3.2 System model*

The system was divided into three main layers devoted to:

– Communication with a client,
– Controlling of presence statuses,
– Communication with other systems

Each layer is modeled by a package comprising its classes and other subpackages, if necessary. A rough class diagram of *Presence Server* is shown in Fig. 1.

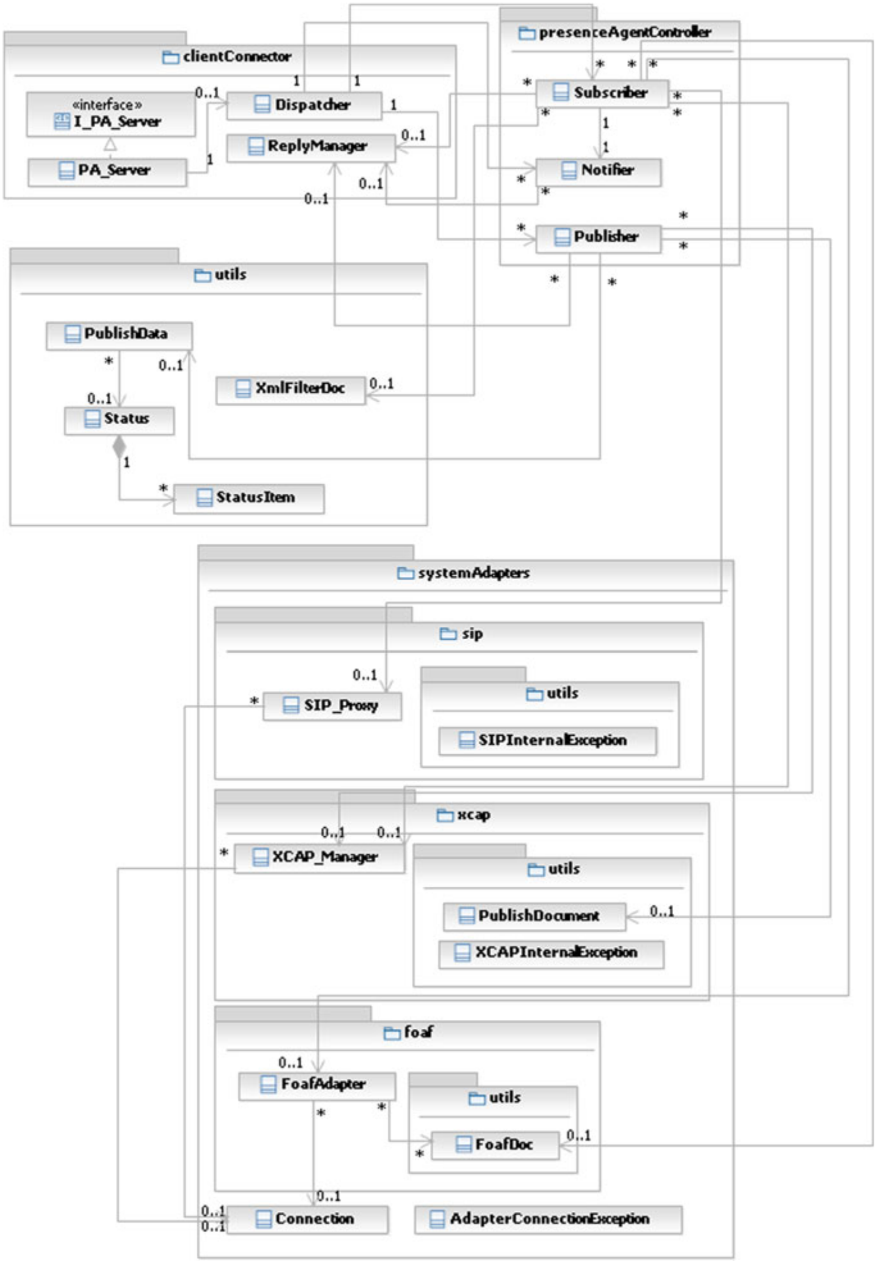


**Fig. 1** Class diagram of the *Presence Server* system

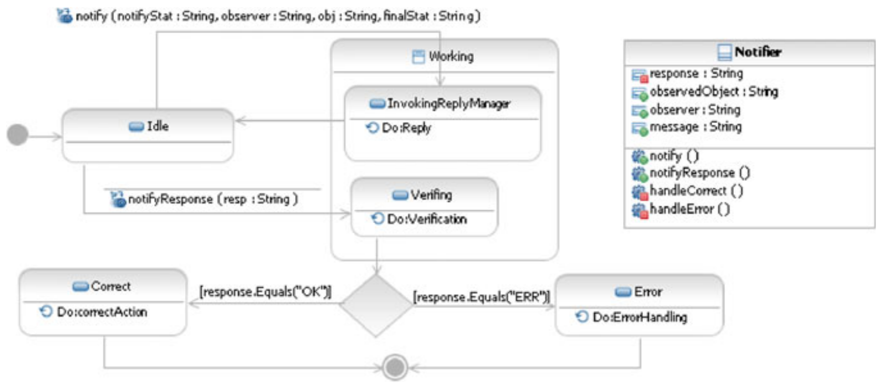


**Fig. 2** Class *Notifier* and its state machine (a member of package *presenceAgentControler*)

Package *clientConnector* consists of four classes and is responsible for receiving client requests. It performs a preliminary preprocessing of requests and forwards them to further handling by package *presenceAgentController*.

This package is the core of the system. Its classes fulfill the basic functional requirements of the presence server. The package uses adapters, stored in package *systemAdapters*, for communication with other systems. Each adapter is created in a separate subpackage. There are three following adapters: an adapter for the server SIP, the server XCAP and the server FOAF. Finally, package *utils* comprises auxiliary classes used by the system.

For each class of the model a state machine was created that specifies a behavior of the class. A state machine complexity varies from a simple two-state model to a more complex state machine that uses different modeling techniques (history pseudostates, parallel execution with forks and joins, composite states, orthogonal regions, etc).

The whole presence server model consists of about twenty classes and interfaces and about seventeen state machines. Two exemplary classes and their state machines are presented below. In the state machine diagrams some less important details are omitted in order to keep the figures legible enough.

The central part of the system constitutes package *presenceAgentControler* with its classes *Subscriber, Notifier* and *Publisher*. Class *Notifier* is responsible for distributing a notification about a subscribed user status. It handles NOTIFY request. For this purpose, it uses an object of class *ReplayManager*. The structural and behavioral model of class *Notifier* is given in Fig. 2. Class *Notifier* has an operation for notifying a state of a user that subscription was requested. Other operations of the class acknowledge a correct or erroneous notification accordingly; or handle a notification.

The given state machine specifies a notification process. The process is divided into several phases. Initially, an object of class *Notifier* is idle, waiting for a request. Once an appropriate request is received, a transition is triggered and the object enters a corresponding substate in the complex state (*Working*). It should be noted that events that are not handled in a state are omitted in the model. It is generally assumed that an occurrence of such an unexpected event will be skipped during execution of the model and the model remains in the unchanged state.

Calling of operation *notify()* launches the major part of the notification process. The configuration of *Notifier* switches to <*Working, InvokingReplyManager*>. A notification comprising a subscribed status of a user is sent to an observer. An object of class *ReplyManager* is invoked. It replays whether the notification was successful. An object of *Notifier* returns to the idle state.

The next activity phase is triggered by a request of sending a response about a notification status. The automaton enters another substate of the complex working state. Verification of correctness of a response is performed. In dependence on the verification result, the object activity is modeled by two states that correspond to a correct response and an erroneous one. One of the states is chosen and an action that is appropriate to a correct situation or an error handling is performed. It finishes activity of the object and therefore the notification process.

Two remaining classes of package *presenceAgentControler* are dealing with publishing information about a client's presence and subscribing of a status of another user. They handle requests PUBLISH and SUBSCRIBE, accordingly. Classes *Publisher* and *Subscriber* are more complex than *Notifier* and have about 12–16 operations each. Their state machines include several complex states with substates, choice selections, and forks for parallel actions.

Package *systemAdapters* comprises subpackages responsible for particular adapters. The main classes placed in those subpackages, namely *SIP_Proxy, XCAP_Manager* and *FAOF_Adapter* are related to appropriate remote servers. The remaining classes of the package are devoted to supplementary functions. There are also classes handling exceptions that can occur during communication with the servers.

An example of adapter classes with its state machine is shown in Fig. 3. An object of class *XCAP_Manager* is responsible for the proper communication between an agent controller and the XCAP server, which keeps the rules regarding statuses of users. *XCAP_Manager* stores the current status of the connection to the server. The class owns operations for managing connection with the server, publishing rules of a status and evaluating the final user's status.

The behavior of any *XCAP_Manager* is specified by its state machine. Communication with the XCAP server is run in several steps. First, a manager object is initialized and connection parameters are collected. If the parameters are set, the manager tries to connect with the XCAP server.

In the next step, the connection status is checked. If the connection was established the manager moves on to state *ConnectionActive*. In this state, the final state of a user is evaluated according to the status document and the relation between users. The document is taken from the SIP server whereas the relation from the FOAF server. Then, the rules about the client status are published in the XCAP server.

Otherwise, when the connection is disabled, state *ConnectionInactive* is entered. In this state the object waits for the appropriate time delay before it tries

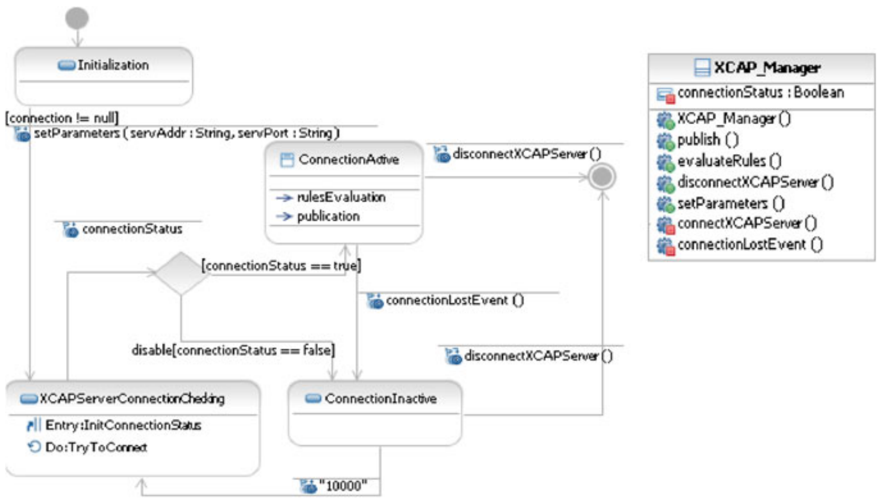


**Fig. 3** Class *XCAP_Manager* and its state machine (an example of a system adapter)

again to establish a connection. This situation is modeled by means of a time event. It labels a transition outgoing from state *ConnectioInactive* to *XCAPServerConnectionChecking*.

Finally, when a disconnection of the manager is requested, regardless in an active or inactive state, the object ends its activity. A new manager object is created if re-connection with the XCAP server is required.

## 4 Presence Server Application Development

In this section we discuss briefly how the application was constructed from the *Presence Server* model and comment on good design practices.

### *4.1 Technology*

The system of *Presence Server* was modeled using a CASE tool. For this purpose we used the IBM Rational Software Architect [10]—a tool that is run within the Eclipse platform [18]. The model, exported in the UML 2.1 format of Eclipse, was forwarded to FXU Generator.

The generator extracted all information of classes and their behavioral state machines and transformed into a corresponding code in the C# language. Using Application Wizard, which is a part of the FXU generator, a project of Microsoft VS was built. At this stage, we declare objects that cooperate within the model, initialize their state machines and define required event occurrences.

Apart from the created code the project was coupled with an FXU Runtime Library. The library provided the application with a code implementing the behavioral logic of all concepts of the UML state machine.

The application was supplemented with the code, written directly in the C# development environment that implemented body of particular operations.

The correctness of class and state machine models was, to some extent, verified during the model to code transformation [19]. Moreover, some checking of selected dynamic features of state machines is incorporated in the library and was completed during application runs.

The developed application was further tested to verify correctness of business logic built-in the designed automata. The testing concentrated on handling of three main requests: PUBLISH, SUBSRIBE and NOTIFY. Each publishing request pointed at a user who produced it and the user's status. A subscription request was associated with data identifying two users: an observer that demanded subscription of a status, and a subscribed object. A notification request comprised identification about an observer, a subscribed object, and a status of the object.

Traces of application runs were stored in log files. They were further analyzed with assistance of FXU Tracer [15]. Application behavior was examined in terms of visited states and other elements of state machines constituting the *Presence Server* model. The observation was advanced step by step or using appropriate breakpoints if necessary. The application behavior was consent to the primary assumptions behind the presence server's activity.

## 4.2 Design guidelines

Basing on the experience gathered during system development the following design guidelines can be addressed.

- Each class should be specified by its behavioral state diagram. In some cases the diagram will be very simple, e.g. comprising only two simple states, but the whole generated code will be more completely and cover the application logic as much as possible.
- Nondeterministic transitions in state machines should be avoided or used very carefully. Otherwise the application can behave in an unexpected manner. If there is no synchronization provided state machines of various classes, but also different regions in orthogonal states can be scheduled in any possible order.
- It is helpful to document all elements of a state machine with associated names. It refers not only to states but also transitions, events, *entry, do* or *exit* actions. They can by further easily localized in the source code, e.g. in order to correct them.
- It is a good practice to specify *entry, do* or *exit* actions with a short code extracts. This code should be brief and not complicated, as it is not verified before the compilation. It can be advised to call a private operation as an action.

The operation can be further implemented in the code development environment. It can also be changed or substituted without interfering into the model.

– Each operation in a class model should be specified with its arguments and their types, unless a default type is consciously accepted. If a type is not determined it will be generated with a default type. The default type might be not consistent with intentions of a designer of a particular model.
– It is worthwhile to comment important diagram elements, filling in an appropriate "description" section. However, in case of an operation, the comments should obey the rules of a programming comment, i.e. be either proceeded by "//" sign or encompassed by "/*" and "*/". The description will be a part of the operation body and can be compiled properly as a comment.
– Writing too much code implementing an operation directly as its textual description in a model should be avoided or at least made very carefully. The code will be transformed and appropriately placed in the resulting source code, but its correctness will be not checked until the program compilation time.
– It is not recommended to use modeling constructions that are variation semantic points of the UML specification [13]. Variation points are especially characteristic to state diagrams, and can be implemented in different ways in various tools, being still consistent with the UML specification. If necessary, a designer should check a solution selected in the tool (FXU) for a desired variation point in order to prevent an unexpected application behavior.
– While verifying a developed application, it is beneficial to interpret its trace in terms of elements of state models. It can be completed using FXU Tracer [15].

## 5 Conclusions

We have presented an approach to model-driven development of an application. The approach is intended to support projects which are built around concepts of behavioral state machines. It was illustrated by a case study of predefined presence status services for social networks. The considered process is supported by the FXU environment aimed at C# applications.

Our future work is focused on extending the environment with various implementations of selected semantic variation points of UML. We also plan to deploy model transformation and state machine execution in accordance to detailed time specification provided in a model with appropriate stereotypes of a UML profile.

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# Visualization of Verilog Digital Systems Models

**K. Jelemenská, M. Nosál' and P. Čičák**

**Abstract** Nowadays the digital systems design is almost exclusively realized using hardware description languages (HDL). Verilog belongs to the HDLs that are the most widespread especially in the United States. However, the textual HDL representation of structural model is less understandable compared the schematic one. Therefore a transformation of the structural HDL description into its graphical schematic representation is a useful function for hardware designers. In this paper the HDL Visualizator is described that was designed and implemented to support this function for Verilog structural models. The paper addresses several problems of visualization process and their possible solutions. The design and implementation of visualization tool that is able to display the schematic view as well as the simulation results of structural Verilog model is also presented.

## 1 Introduction

In the process of complex digital systems design hardware description languages (HDLs) have an irrecoverable role. They provide designers the possibility to describe the hardware behavior and structure on the various abstraction levels.

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However, the structural description in HDL form is often unreadable for the persons not familiar with this kind of design. In these situations the tools for graphical visualization of HDL structural description are very useful.

There are several applications, design tools or development environments that are capable of graphical visualization of a design structure. This possibility is usually only one of many other functions available in the expensive and often too complex solutions for certain group of users, e.g. students or beginners in HDL design. There are very few, if any at all, easy-to-use and affordable applications offering HDL models visualization especially when they are written in Verilog. Our aim was to overcome this gap.

The problem of digital system Verilog structural description visualization is the main subject of this paper. The paper covers application design, its implementation and testing results.

## 2 Related Work

The digital systems design methods have evolved dramatically over the last 30 years. The traditional design methods, based on mathematical equations or schematic approach to the hardware design, became impractical or even useless in the process of complex digital systems design.

Modern design methods based on HDLs and design automation tools brought the effectiveness into the design process and sped it up substantially. Another tremendous advantage was the replacement of prototyping by simulation. The designers can model hardware structure and behavior on various abstraction levels using HDLs and simulate the model to verify its properties. Nowadays, a lot of professional automatic design tools provide several ways to describe digital system behavior and structure together with its optimization. They support various types of graphical and textual editors e.g. to enter the state diagrams, truth tables, logic diagrams or simply to describe the circuit in HDL. The most commonly used HDL languages are VHDL, Verilog and SystemC.

There are many implementation tools with wide spectrum of functions to make the design process easier, more effective and faster. However, most of the software tools capable of structure visualization described in Verilog are the commercial ones. To the most widespread belong Visual Elite, Active-HDL and HDL Author [1–3].

*HDL Author* is the product of Mentor Graphics company [1] that replaced the previously supported HDL Detective. The main goal of this tool is the improvement of team work and data exchange among team members therefore it was designed for data management in all phases of design process. The HDL code visualization function is just one of its many functions and enables also Verilog code conversion into a Block Diagram, IBD, State Diagram or Flow Chart. The objects layout, color, style, and font can be modified i.e. the non-logical edits can be applied that will not influence the original code in any way. However, HDL Author is a robust application, which is very complex and quite expensive.

*Visual Elite* was originally developed by Summit Design company and later bought by Mentor Graphics [2]. This is another complex and universal application to design and build products. It offers a variety of HDLs and other design entry methods including block diagrams, state diagrams and connectivity tables. It also provides automatic mapping of source code into graphical representation. However, the quality of code visualization is not as high as in HDL Author. On the other hand the user interface is very comfortable and easier to manage by new users, than relatively complicated HDL Author's user interface.

Another complex design system supporting HDL code visualization is Aldec's *Active-HDL* [3]. It is a suite of many tools covering all phases of FPGA design and verification. In the context of this paper the tool called Code2Graphics is an interesting one. This tool enables the HDL code conversion into a graphic representation that can be further edited. Unlike in HDL Author or Visual Elite, the altered graphic representation can be converted back to the text form of arbitrary supported HDL using Graphics2Code tool. Moreover, Active-HDL also supports the visualization of simulation. During the simulation an actual state of every module in the block diagram is visualized and the values of all variables are visible in the waveforms. In many other ways Active-HDL is comparable to Visual Elite.

All the mentioned tools and systems are the commercial ones. They all provide many functions, including visualization, and support several HDLs. The main issue is their excessive complexity and the price which is often not affordable for beginners and students.

Since the problem of lost clarity in textual description of structure is especially relevant to students and beginners, we decided to dedicate our effort to the development of simple and easy to use tools for HDL structural description visualization. Several solutions have been developed at the Faculty of Informatics and Information Technologies, Slovak University of Technology (FIIT STU) in Bratislava, most of them in the frame of diploma theses [4, 6–8].

*VHDL Vizualizer* [4] is the tool dedicated to the VHDL structural description visualization. The architecture of this solution consists of six components (see Fig. 1). The VHDL parser was built by ANother Tool for Language Recognition (ANTLR) that provides a framework for arbitrary language parser generation based on its grammar definition [5]. The graphic user interface is based on Netron Graph Library and an Extensible Markup Language (XML) format is used to represent the visualized VHDL description internally.

The tool is able to check the VHDL source code syntax and to visualize the VHDL structural description preserving its hierarchy. It also supports basic non-logical editing of the resulting visualization like modules layout modification, modules connections formatting, notes insertion etc. The created diagrams can be exported into jpeg files or saved in XML file. The main limitation of this solution was the quality of the displayed layout of modules and especially the

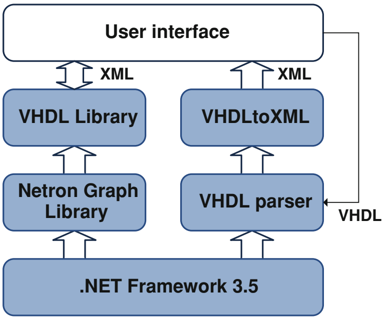


**Fig. 1** The VHDLVisualizer architecture

interconnections which was far from ideal. This issue was discussed and partially solved in [6].

Another solution with the functionality similar to VHDLVizualizer was called *VHDL Visualizator* [7]. The system architecture is basically the same but this tool was implemented on Delphi and Java platforms. An internal representation of visualized structure is also based on XML format. Although the quality of visualization is a bit higher in this case, the tool supports smaller subset of VHDL.

An interesting solution represents [8] that was focused on the SystemC models visualization, based on the modifications of SystemC library itself. However, the SystemC nature is substantially different from other HDLs, therefore the approach adopted in this solution can not be used for Verilog models visualization.

The visualization tools already developed at FIIT STU Bratislava were devoted to VHDL and SystemC HDL languages. The third commonly used HDL—Verilog was not yet supported. This work is supposed to overcome this gap.

## 3 Visualisation of Structural HDL Description

In the context of HDL structural description visualization, the important language constructs are module definitions, port definitions, module instances and their mutual connections. In schematic representation each module is represented by a graphical entity with ports that are connected with ports of other modules. The visualization process is illustrated in Fig. 2. There are three main problems that have to be solved in the visualization process: syntactic analysis of Verilog code, internal data representation, and graphical layout of the visualized data.

The first step in the visualization process is a conversion of Verilog source code into its internal representation. During this step two issues have to be addressed: Verilog code *syntactic analysis* and *internal representation* selection. An appropriate internal representation should be able to keep the information about the modules and connections position, size and general layout. From this step the third issue results: the optimization of modules and connections *graphical layout*.

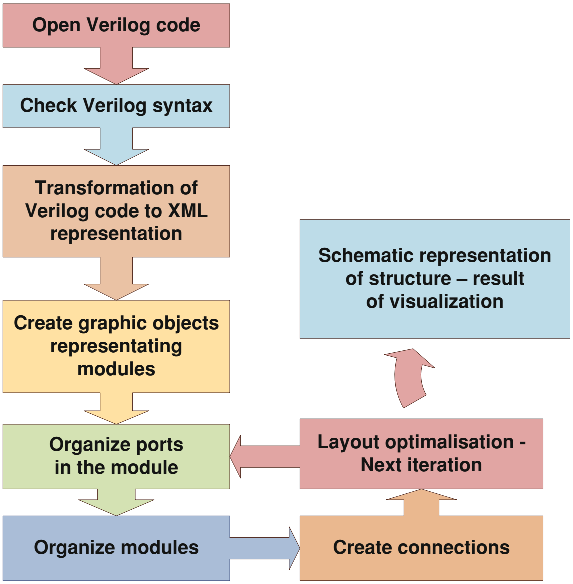


**Fig. 2** The visualisation process of HDL structural description

## *3.1 Syntactic Analysis of Verilog Code*

Syntactic analysis is relatively complicated but an unavoidable step in the visualization process. However, there is a possibility to use an existing parser for this purpose. Several freeware tools are available supporting among other functions Verilog syntax checking [9]. *Icarus Verilog* is a tool for Verilog simulation and synthesis. *Source Navigator for Verilog* is an open source development environment for Verilog which has a built in parser. *CvSDL* represents C++ libraries for Verilog simulation. *GPL Cver* denotes another Verilog simulator with full support of IEEE 1364-1995 Verilog standard and partial support of Verilog 2001. *Verilog2C++* is a tool performing Verilog code transformation into its C++ equivalent. Finally, *Verilator* stands for Verilog simulator suitable for large projects, where simulation performance is the primary concern.

From the available freeware tools the *Icarus Verilog* was identified as the most suitable for our purpose, since in addition to the syntactic analysis it enables also to use the simulation results in our visualization tool.

The next step in the process of visualization is the transformation of Verilog description into its internal representation, what should be done by parser. Since we were not able to find a suitable open source parser for Verilog language, we were considering the available parser generators that can generate a specific language parser based on the language grammar definition. The parser generators like *Gardens Point Parser Generator* (GPPG) [10], *GRAMMATICA* – Parser Generator [11], *ANTLR v3* [5] and *Compiler Generator Coco/R* [12] have been analyzed and the *ANTLR v3* parser generator was chosen as the most suitable one for our purpose.

### 3.2 Internal Representation of Structural Description

There are two basic approaches for internal data representation: an object-oriented approach and the XML based approach. An example of the *object-oriented structure representation* format is The Advanced Intermediate Representation with Extensibility/Common Environment (AIRE/CE) [13], a specification originally designed for the representation of VHDL description that can potentially be used for Verilog description as well.

In general, the internal structure *representation based on XML* is more flexible than the object-oriented one. There are several specific XML schemes that could be used for our purpose including: Hardware Description Markup Language (*HDML*) [14]—an XML scheme created for hardware description, *VXML* [15]—the VHDL Markup Language scheme which is more suitable for VHDL description, Modeling Markup Language in XML (*MoML*) [16]—the XML scheme created for hardware design description like HDML. However, each of them would require some modifications to be tailored to Verilog language and our specific needs. Therefore we decided to design our own XML based representation. The reason was its higher flexibility and potential interoperability with third part XML editors. The resulting XML scheme is given in Fig. 3. The internal data representation will contain information about visualized structure as well as simulation results.

### 3.3 Graph Drawing Algorithms

Graph drawing, including optimization of modules and connections layout, is quite a complex problem. Several rules and algorithms are known for graph drawing and optimization that can be used for Verilog models visualization. The good graph look is very subjective issue, often it is just a matter of aesthetic taste, not the exact parameters. Therefore it is difficult to choose the best algorithm. In spite of this there are a few criteria for graph layout evaluation [17]:

*Minimize crossing*: keep the number of lines cross to a minimum.
*Minimize area*: keep the graph area to a minimum.
*Minimize the sum of edge lengths*.
*Minimize the difference between edge lengths*: keep the edge lengths as same as possible.
*Minimize bends*: keep edge bends to a minimum.

## 4 Visualisation of HDL Simulation

HDL model simulation is much more complicated than HDL model structure visualization. A testbench has to be developed to simulate the Verilog digital system model.

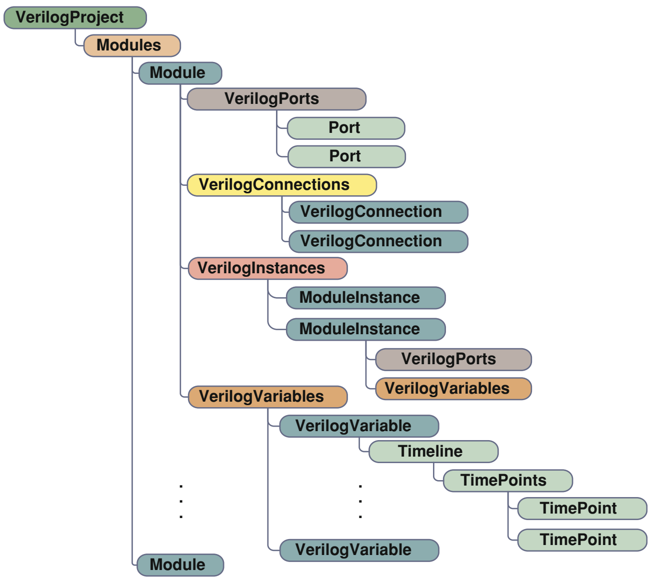


**Fig. 3** The XML scheme of internal data representation

In the visualization process of Verilog model simulation a few basic steps can be identified. The first one is the Verilog code integrity and syntax checking. The second step is simulation itself and the third one is the transformation of simulation results into the internal representation and their visualization. There is also the possibility to visualize the simulation results from external VCD[1] (Value Change Dump) file. In this case the integrity of this file must be checked as well.

## 5 System Architecture

Based on the previous analysis the system architecture was designed that is illustrated in Fig. 4.

*The Icarus Verilog* was used to perform the syntactic analysis of Verilog model for its structure visualization as well as to simulate the model for simulation results visualization.

The syntactically correct Verilog model is passed to the *Verilog parser* that was implemented using the ANTLR v3 parser generator [5]. Only the Verilog language constructs relevant to structural description are parsed and transformed into the internal data representation: module definition, ports definitions, instantiations of modules and their mutual connections represented by “net” construct.

[1] Standardized format of simulation results.

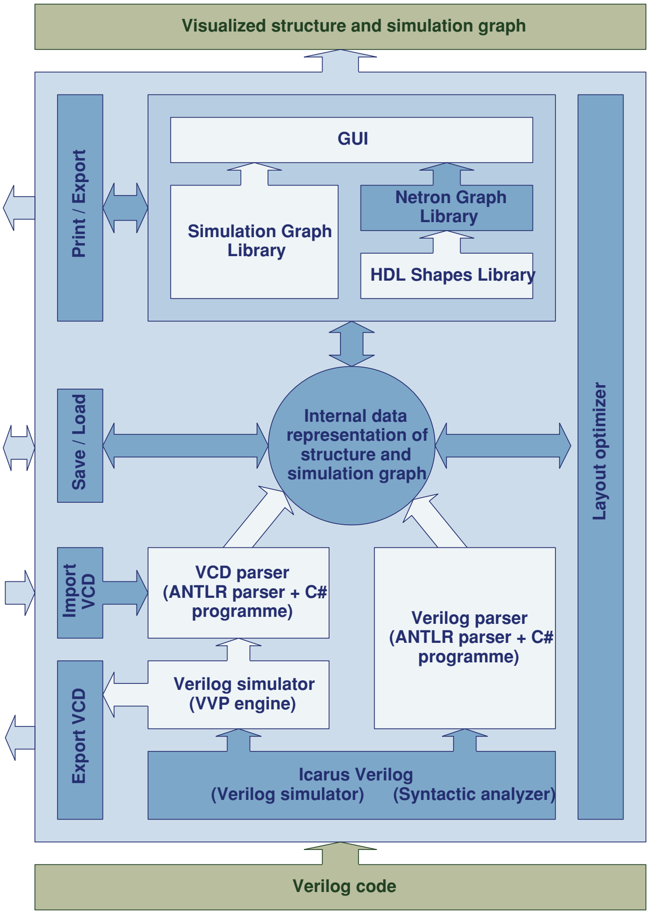


**Fig. 4** The system architecture

Icarus Verilog simulator generates the simulation results in the form of VCD file—a textual description of variable values changes throughout the simulation time. A *VCD parser* is then used to perform the transformation of VCD data into the internal XML representation that was described in the previous section.

The *Layout optimizer* can be applied to the internal data to optimize the graphical layout of the visualized model. The goal of this optimization is symmetrical and well-arranged modules alignment and connections layout.

All the required application functionality is provided to the user by means of *Graphic User Interface* (GUI). To fulfill this task GUI cooperates with other components.

*Simulation Graph Library* component is used for drawing simulation results (Waveforms). It transforms the simulation results from internal XML form into an interactive simulation graph. The functions like zoom, time cursor, waves reordering and redrawing, image exporting or printing are supported by this library.

*Netron Graph Library* component is the core of the visualization. It carries our the actual drawing of modules, ports and interconnections and provides functions like objects moving, objects multi-selection, connections forming, graph printing and exporting, grid and snap to grid functions etc.

*HDL Shapes Library* component is an extension to Netron Graph Library. It defines the shapes of modules, connections, notes and pin labels. The basic classes for visualized objects: VerilogModule, VerilogPort and VerilogConnection are defined here. The objects of these classes represent the basic building elements of graph drawing. HDL Shapes Library is an interface between the Netron Graph Library and the internal XML representation. The classes for handling XML representation, modifying Verilog model visualization, and layout optimization are also defined here.

## 6 System Implementation

The system was implemented in C# language under the.NET Framework 3.5 in Microsoft Visual Studio 2008 SP1 under the operating system Windows 7 Professional. The purpose of Verilog parser component is Verilog code parsing into the internal XML representation. It consists of three parts: VerilogLexer, VerilogParser, and VerilogToXML. The source codes of VerilogLexer and VerilogParser were generated by ANTLRv3 parser generator [5].

The VCD parser component is similar to the Verilog parser component. This component consists of three parts: VCDLexer, VCDParser, and VCDToXML. VCDLexer and VCDParser were also generated by ANTLRv3 parser generator.

HDL Shapes Library contains the definitions of classes like VerilogModule, VerilogPort and VerilogConnection that were derived from Netron Graph Library classes Shape and Connection. Other classes were implemented for handling XML representation, visualization and layout optimization.

The Simulation Graph Library provides an engine for creating interactive simulation graph (waveforms) user interface. This functionality is ensured by four main classes: Stamper, SimGraphControl, Wave and Header.

## 7 Results and Experience

All the implemented components have been tested during the implementation process and after that entire application was tested again. All found bugs have been fixed.

```
...
module SUM8bit (IN1, IN2, OUT, CO);
  output [7:0] OUT;
  output CO;
  input [7:0] IN1;
  input [7:0] IN2;
  wire [6:0] carrysignal;
  SUM sum0(IN1[0],IN2[0], 0,OUT[0],carrysignal[0]);
  SUM sum1(IN1[1],IN2[1],carrysignal[0],OUT[1],carrysignal[1]);
  SUM sum2(IN1[2],IN2[2],carrysignal[1],OUT[2],carrysignal[2]);
  SUM sum3(IN1[3],IN2[3],carrysignal[2],OUT[3],carrysignal[3]);
  SUM sum4(IN1[4],IN2[4],carrysignal[3],OUT[4],carrysignal[4]);
  SUM sum5(IN1[5],IN2[5],carrysignal[4],OUT[5],carrysignal[5]);
  SUM sum6(IN1[6],IN2[6],carrysignal[5],OUT[6],carrysignal[6]);
  SUM sum7(IN1[7],IN2[7],carrysignal[6],OUT[7],CO);
endmodule
module main;
  reg [7:0] a,b;
  wire [7:0] y;
  wire co;
  time tim;
  SUM8bit s1(a,b,y,co);
  initial begin
          $dumpfile( "SUM8bit.vcd" );
          $dumpvars( 3, main );
          a = 0;
          b = 0;
          #1 a = 2;
          #1 b = 15;
          #1 a = 8;
          #1 b = 137;
          #1 a = 119;
  end
endmodule /* main */
```

**Fig. 5** Fragment of Verilog structural model

## *7.1 Illustrating Example*

To illustrate the features of the implemented visualization tool a simple example will be presented here. In Fig. 5, there is a fragment of a simple Verilog model representing the structural description of 8-bit binary adder that was the input of the HDL Visualizator. The Verilog code is analyzed, simulated and transformed into an XML representation that is then visualized. The resulting visualization of Verilog structural description and its simulation illustrates the screenshot in Fig. 6.

## *7.2 Restrictions*

The application is able to recognize the following Verilog language constructions: module definition with module name and ports declaration, port type definitions, all types of net definitions (supply0, supply1, tri, triand, trior, tri0, tri1, wire, wand, wor), module instantiations, UDP (User Defined Primitive) definitions and UDP

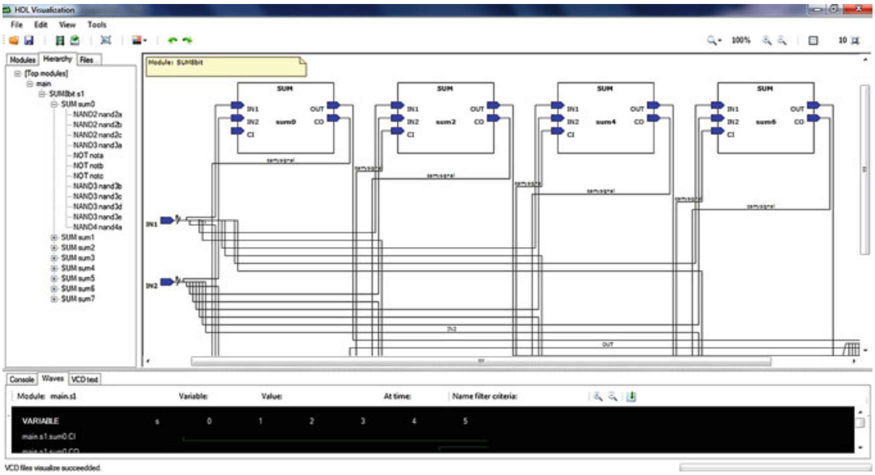

**Fig. 6** Screenshot of HDL visualization tool

instantiations. Verilog parser can handle implicit port mapping or named port mapping in the module or UDP instantiation.

The vector type port can be assigned each vector element separately using curly brackets like in .portname ({sig1, sig2, sig3…}). Verilog parser doesn't support block assignment of signal arrays to the array of module instances.

VCD parser supports four state VCD file format according to the IEEE standard [18], but it does not support extended VCD file format.

## *7.3 System Scalability*

The system architecture is designed with the idea of component independence in mind (each component can be replaced by a new one in case the character of interface was kept). The components are implemented as independent projects and their interfaces are well documented.

The significant space for improvements is in the Verilog parser. As it was mentioned before, the Verilog parser does not support all the Verilog language constructs and its performance is not ideal. Its performance is given by ANTLR characteristic not by an efficiency of Verilog syntax description.

For simulation purpose an external tool Icarus Verilog was used that generates the VCD file that is afterwards imported into the XML file. It is very simple and efficient solution. It has, however, one disadvantage. The VCD output is generated based on the commands specified in the input Verilog code, therefore there is a need to modify it each time we need to change the variables we would like to trace. This disadvantage is compensated by the simplicity of this solution but represents the potential space for system improvements.

**Table 1** The HDL visualization tool efficiency in terms of Verilog code processing

| Verilog file size (number of lines) | Processing time (s) | Memory consumption (MB) |
|---|---|---|
| 630 | 4 | 150 |
| 1050 | 8 | 200 |
| 1995 | 15 | 400 |
| 3254 | 60 | 1500 |

The significant improvements can also be done in the visualized structure layout optimization. We could provide various optimization algorithms to get the layout as close to the users expectations as possible so that almost no manual layout editing would be necessary.

The HDL visualization tool could also be extended by a textual editor to input Verilog code. This extension would transform it into the simple development environment for Verilog projects. The application like that would be capable of writing Verilog model of digital system, checking its syntax, compiling and simulating it and visualizing its structure and simulation results.

### *7.4 Performance Tests*

In order to find out the efficiency of the developed HDL visualization tool it was exposed to several performance tests. The components Verilog parser and VCD parser turned out to be the weakest parts in the chain especially when large Verilog or VCD files are to be parsed. Some experimental results for larger Verilog code compilations are given in Table 1.

The experimental results prove the inefficiency of the Verilog parser. The similar problem arises over the VCD parser performance. For example to import the VCD file of 0.5 MB takes about 20 s. This size of file corresponds approximately to the simulation time of 2,000 time slices.

To conclude the tests for the reasonable processing time the input Verilog file should not exceed 1,000 lines and the VCD file should not exceed 0.5 MB. The HDL visualization tool is therefore no suitable for large projects but it can meet the needs of students and beginners in Verilog design that are working on smaller projects.

## 8 Conclusion

The paper is devoted to the problem of visualization of structural digital system models described in Verilog. Some design alternatives and the possibilities of using the existing freeware tools have been discussed at the beginning. The core of the paper forms the design and implementation of the new HDL visualization tool.

The resulting application called HDL Visualization supports Verilog input and is able to visualize digital system structural description. It is also possible to simulate the design and to display the results in a waveform view. The GUI of the application is intuitive and simple. The internal representation of schematic in the XML format can be stored and later loaded and edited again. The XML file contains also the simulation results. The visualization results can be printed or exported to an image file. The developed tool can be used for smaller project and therefore is especially suitable for education purpose. However, the simultaneous visualization of structural model and its simulation is useful for verification purpose as well.

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# Expert System Aided Power System Reinforcement with Reliability and Voltage Sag Consideration

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**Abstract** The aim of this paper is to introduce a practical way to find an optimal plan for electric power system reinforcement through line addition. Adding a line to the existing network is needed to improve system reliability and/or to raise its loadability. On the other hand line addition results in worsening voltage sag immunity of the system. In order to reach the most appropriate schedule, both system reliability and voltage sag must be considered. This paper assesses the effect of the line addition by comparing the cost gained from raising the overall system reliability with that lost due to worsening the voltage sag immunity. A novel approach to calculate the global reliability of the power system is proposed. This approach is capable of calculating the reliability of all power system nodes following one straightforward procedure which avoids repetition of calculations and drastically reduces the number of steps and execution time. Voltage sag immunity is evaluated by identifying the area of vulnerability caused by short-circuit (S.C.) on the system. The paper suggests using a knowledge-based expert system (E.S.) to help in selecting the appropriate reinforcing line. Representative case study is discussed to demonstrate the effectiveness of the proposed approach.

## 1 Introduction

Electric power system is a complex structure and has many inherent contradictory features. When the planning engineer tries to improve one of these features he may

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be faced with one or more contradictory feature which will be badly affected by this improvement. One of recent emerging contradicting problems is the reliability–voltage sag problem. Both reliability and voltage sag issues are crucial in power system planning. The reliability indices reflect the ability of sustaining service of power supply and the level of customer satisfaction.

Voltage sag is a short duration reduction in voltage magnitude. It occurs due to short duration increase in current magnitude, in most cases somewhere else in the system [1].

Short-circuits are the main cause of voltage sags at transmission and distribution levels. The area of the system affected by the voltage sag is known as vulnerability area. Protective devices are triggered when the rms voltage drops below predetermined value for certain duration. Triggering value of certain load depends on the way by which this load is affected by voltage sag.

The area of vulnerability caused by S.C. is so wide that it affects the operation of equipment located tens kilometers away. Some of this equipment may trip as soon as voltage drops to about 90 % of its normal value for only one or two cycles, other equipment may trip when the voltage drops to less than 80 % for about 1 or 2 s [2].

The most widely cited reliability problems are:

(1) *Terminal-Pair Reliability*: It is a commonly used measure of connectivity between the source node and the sink node. It does not consider the connection between other nodes. Several techniques have been adopted to assess the terminal pair reliability such as minimal path/cut set techniques, inclusion–exclusion method, and sum of disjoint products [3]. These conventional methods have been used for several decades. However they lack simplicity and need large execution time. The new trend is to utilize the advantages of artificial intelligence (A.I.) such as genetic algorithm, particle swarm optimization, fuzzy system techniques and expert system [4, 5]. These techniques are simpler and need less calculation time.
(2) *K-Terminal Reliability*: it is the probability that all nodes in some specified set k of target nodes are joined by paths of non-failed lines. This problem has limited application in power system.
(3) *All-Terminal Reliability (Global Reliability)*: it is the probability of existence of a minimal set of up–state connections such as all nodes of the network are joined by paths of non-failed edges. Such a minimal set is known as spanning tree of the network [6]. To get this probability all spanning trees must be considered which is tedious for even medium size network. Some researchers tried to overcome the high dimensionality of the problem through “tearing” the original network to a number of smaller subnetworks [7]. Proper power system planning should rely on both terminal-pair and global reliability of the power networks.

Considerable attention has been devoted to the combined problem of reliability and voltage sag criteria in power system during the last decade. The researchers invaded this new field of research by two different ways; unifying supply

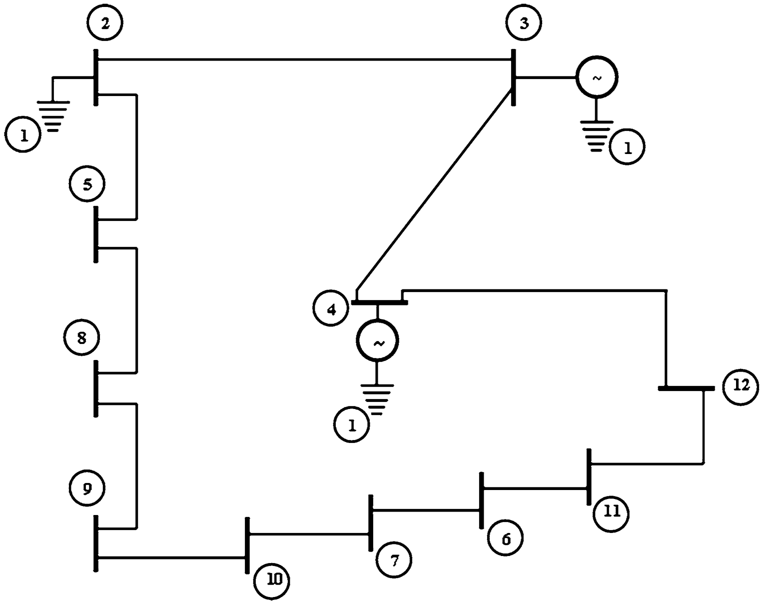


**Fig. 1** 11-Bus system

reliability and voltage sag indices, and studying the contradictory features between reliability and voltage sag [8]. While the first way gained relatively more attention, the second still remains more effort from researchers.

Improving the reliability of power network can be achieved by adding one or more line to the network to gain more redundancy and to release overloading of some network lines. However line addition results in raising the S.C. level of the network which directly reflects as worsening the voltage sag problem. In order to reach judicious reinforcing schedule, the planning engineer has to consider the effect of line addition on both reliability and voltage sag. This effect can be economically assessed by comparing the cost gained from raising the overall network reliability with that lost by worsening the voltage sag immunity of the network. A network cost function has been suggested in this work by adding the two costs to the cost of the line erection. The planning engineer has to seek after line selection which achieves the maximum possible benefit.

As the domain of the line selection is generally very wide in practical power systems, the paper suggests a suitable E.S. to help in this selection. The problem, of appropriate line selection can be better tackled by using E.S. rather than other conventional optimization techniques since the overall cost function does not contain explicit state variables. Some heuristic rules are suggested in the present work. Other rules may be used according to the experience and judgment of the planner.

## 2 Nomenclature

(1) *Reliability*:

| | |
|---|---|
| $e$ | Number of network elements (lines and generating units). |
| $n$ | Number of network nodes (including ground). |
| $b,l$ | Number of branches and links, respectively. |
| $P(i-j)$ | Availability of the element connecting nodes i, j. |
| $R(k)$ | Reliability of node (bus) k, k = 2,3,…….,n. |

(2) *Voltage Sag*:

| | |
|---|---|
| $VS(i-j)$ | Voltage at bus $j$ under S.C. on bus i, in per-unit. |
| $NS(i)$ | Estimated number of S.C. occurring on bus i per year. |

(3) *Loads*:

For i = 1, 2, 3.

| | |
|---|---|
| $PL(i,j)$ | Three load categories at bus $j$ in kW, classified according to trip voltage. |
| $VC(i,j)$ | Critical trip voltages of the load categories at bus j. |
| $F(i,j)$ | Cost of interruption of the three load categories per kW at bus j. |

(4) *Functions*:

| | |
|---|---|
| $CR$ | Total cost of interruption for the whole system due to forced outage, per year. |
| $CS$ | Total loss cost caused by load tripping due to voltage sag, per year. |
| $CL$ | Cost of line erection, per year. |
| $CT$ | Total overall loss cost. |

## 3 Problem Statement

It is required to select the most appropriate line to be added to an existing power network which achieves maximum possible economical benefit. Mathematically, Minimize:

$$CT = CR + CS + CL \tag{1}$$

where

$$CR = \sum_{k=2}^{n} \left\{ (1 - R(k))(\sum_{j=1}^{3} PL(i,k)hF(j,k)) \right\} \tag{2}$$

**Table 1** Reliability of tree nodes

| Step | Added element *i−k* | Node reliability *R(k)* |
|---|---|---|
| 1 | 1−2 | P(1−2) |
| 2 | 1−3 | P(1−3) |
| 3 | 1−4 | P(1−4) |
| 4 | 2−5 | R(2).P(2−5) |
| 5 | 5−8 | R(5).P(5−8) |
| 6 | 8−9 | R(8).P(8−9) |
| 7 | 5−6 | R(5).P(5−7) |
| 8 | 6−7 | R(6).P(6−7) |
| 9 | 7−10 | R(7).P(7−10) |
| 10 | 6−11 | R(6).P(6-11) |
| 11 | 11−12 | R(11).P(11−12) |

$$CS = \sum_{k=2}^{n} \sum_{j=2}^{n} CVS(j,k) \tag{3}$$

$$CVS(j,k) = NS(k) \sum_{i=1}^{3} A(i,j) \tag{4}$$

$$A(i,j) = \left\{ \begin{array}{lll} 0 & if & VS(j-k) > VC(i,j) \\ \sum_{i=1}^{3} PL(i,j)F(i,j) & if & VS(j-k) \leq VC(i,j) \end{array} \right\} \tag{5}$$

The steps of solution are as follows:

(1) Calculate the reliability of each bus in the existing network following the steps explained in Sect. 4. Use (2) to calculate CR.
(2) Carry out three- phase S.C. calculations on all network buses, one-by-one, to determine the vulnerability area for each S.C. Use (3) to get the value of CS.
(3) Get the value of CT from (1).
(4) Follow the four heuristic rules given in Sect. 5 to select the most appropriate line to be added to the network.
(5) Check the economical benefit gained by line addition.

## 4 Calculation of Bus Reliabilities

The proposed method for calculating bus reliabilities is based on building up the power network by adding element-by-element. The reliability of the uncompleted (partial) network is re-evaluated after each element addition until all network lines are added.

The following steps describe the proposed methodology.

(1) Represent the original system with its stochastic network, a network in which all the system buses are represented by the nodes, whilst all the generators are represented by elements originating from a single node (source node) and directed towards the nodes they are supplying. The nodes themselves are connected by elements representing the lines and the components connecting them.
(2) The stochastic network is then broken into two sub-networks; tree and cotree. The tree has all nodes but no closed path; its elements are called branches. Elements of the original network not included in the tree form the cotree and are called links.
(3) Begin by calculating the reliability of all nodes in the tree. Start from source node 1 which is assumed to have 100 % reliability. Generally, if an element (i−k) is added to the partial tree containing node i, a new node k will be added with reliability R(k) as

$$R(k) = R(i).P(i - k) \tag{6}$$

(4) Links are then added to the completed tree, one-by-one. The effect of adding a link on the nodes reliability is evaluated until the original network has been completely built. To illustrate, consider the 11-bus system of Fig. 1. Its stochastic network, tree and cotree are given in Fig. 2. Table 1 explains how reliability of each node in the tree is calculated

Links are then added to the tree, one-by-one. If for example link 9-10 is to be added, this will create one and only one closed loop and it will give new values for both R(9) and R(10) as

$$R_{\text{new}} - (9) = R(9)//\,(R(10).P(10 - 9)), \tag{7}$$

$$R_{\text{new}}(10) = R(9)//\,(R(10).P(9 - 10)), \tag{8}$$

Where // means parallel combination.

The common preceding node of both 9 and 10 is 5. The reliability of this node and of its all preceding nodes in the tree will not change. Reliabilities of other nodes in the created closed loop will take new values as follows:

$$R_{\text{new}} - (9) = R(8)//(R_{\text{new}}(9).P(9 - 8)) \tag{9}$$

$$R_{\text{new}}(7) = R(7)//\,(R_{\text{new}}(10).P(10 - 7)) \tag{10}$$

$$R_{\text{new}} - (6) = R(6)//\,(R_{\text{new}}(7).P(7 - 6)) \tag{11}$$

Moreover, reliabilities of nodes 11 and 12 have to be also updated as

$$R_{\text{new}} - (11) = R_{\text{new}}(6).P(6 - 11) \tag{12}$$

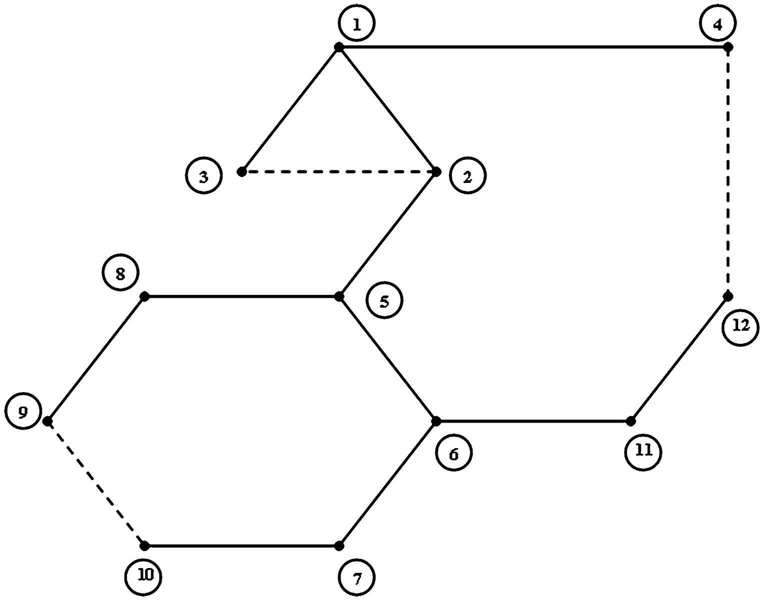


**Fig. 2** Stochastic network, tree and cotree. —Branches —Links

**Table 2** Changes in interruption and voltage sag costs

| Added Line from Node-to-Node | Increase in voltage sag loss, per-unit money | Decrease in interruption loss per-unit money | Net benefit; per-unit money |
|---|---|---|---|
| 6–11 | 0.093 | 0.125 | +0.032 |
| 5–6 | 0.106 | 0.122 | +0.016 |
| 6–8 | 0.110 | 0.110 | +0.000 |
| 4–5 | 0.141 | 0.008 | −0.133 |
| 3–4 | 0.161 | 0.152 | −0.009 |

$$R_{\text{new}}(12) = R_{\text{new}}(11).P(11 - 12) \tag{13}$$

Now, delete link (9–10), add another link, say (4–12), and repeat with the last values of node reliabilities until all links are added.

## 5 Expert System

Expert system is an artificial intelligent system created to solve problems in a particular domain. It has been developed to assist in finding quick pragmatic answers for problems that defy effective solution. In the field of power system planning, E.S. is helpful when the mathematical model of the problem cannot be easily derived or when its solution is cumbersome.

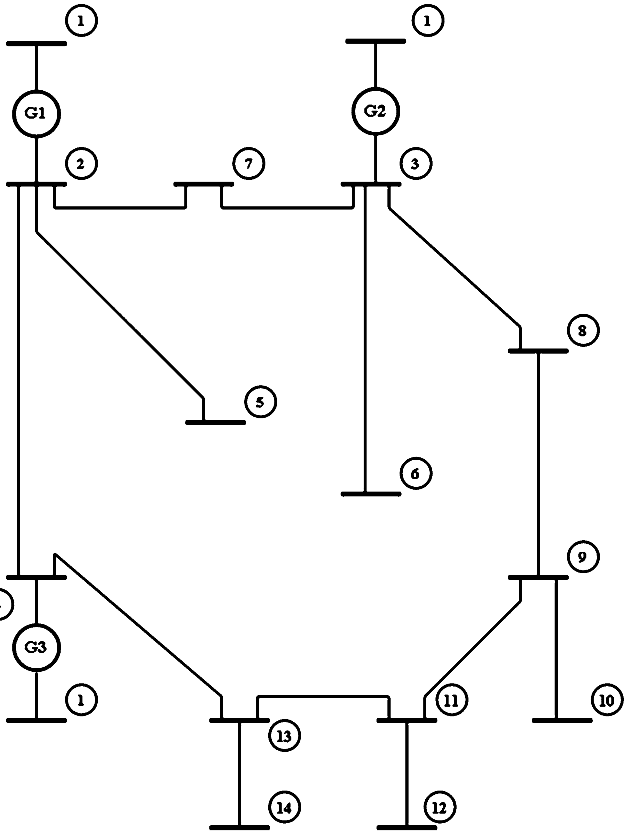


**Fig. 3** Network of case study

E.S. is not an optimization technique rather it helps in getting adequate solution to the problem under study. To create an E.S. for a certain problem a team consisting of experts and knowledge engineers gathers the facts, rules, and heuristic rules for the domain of the problem and organizes them into an A.I. program. The same problem may find different solutions according to E.S. used in this problem.

In the present work, a rule chain containing four heuristic rules is adopted to help in getting preference to the reinforcing lines used in calculating the net overall cost function.

Rule #1: (IF the node has high voltage sag frequency) THEN
–Avoid line connection to this node.
Rule #2: (IF the node has low S.C. level) THEN
–Connect this node with another one having low S.C. level.
Rule #3: (IF the node has high reliability and low S.C. level) THEN
–Connect this node with another one having high cost of interruption.

Rule #4: (IF the node has low voltage sag loss cost and high reliability) THEN –Connect this node with another one having low reliability and low voltage sag frequency.

## 6 Case Study

The power system of Fig. 3 is investigated. System data are given in Appendix A. Cost of line erection is ignored in this study. Changes in interruption and voltage sag costs are given in Table 2.

## 7 Conclusion

A General procedure for evaluation of the economical benefit gained by line addition to reinforce power system has been presented. It is demonstrated that not in all cases addition of reinforcing line is economically beneficial. This is clear from the results of Table 2. Combining reliability and voltage sag costs in one problem is the main target of this paper. It is the authors' experience that many engineers who are working in industrial firms believe that reliability study is hindrance and the benefit gained from this study does not justify the effort expended. However, reliability study is crucial and cannot be ignored in many cases.

In this respect, the paper introduces a novel approach for global reliability calculation of power network. The approach is simple, straightforward, and does not have any inherent approximation.

## Appendix A: Data of Case Study

**Table A.1** Generator data

| Element | From Node *i*–to Node *j* | Rated MVA | Impedance (p.u.) | Availability |
|---|---|---|---|---|
| G1 | 1–2 | 400 | 0 + j0.30 | 0.85 |
| G2 | 1–3 | 200 | 0 + j0.28 | 0.86 |
| G3 | 1–4 | 400 | 0 + j0.30 | 0.85 |

**Table A.2** Line data

| From Node *i*–to Node *j* | Impedance (Ohm) | Availability *P(i–j)* |
|---|---|---|
| 2–4 | 37.5 + j100 | 0.951 |
| 2–7 | 22.5 + j60 | 0.98 |
| 2–5 | 30 + j80 | 0.94 |

(continued)

**Table A.2** (continued)

| From Node *i*–to Node *j* | Impedance (Ohm) | Availability *P(i−j)* |
|---|---|---|
| 3–7 | 22.5 + j60 | 0.98 |
| 3–8 | 15 + j40 | 0.99 |
| 8–9 | 15 + j40 | 0.99 |
| 9–10 | 7.5 + j20 | 0.995 |
| 9–11 | 22.5 + j60 | 0.98 |
| 11–13 | 22.5 + j60 | 0.98 |
| 13–14 | 12 + j32 | 0.995 |
| 4–13 | 22.5 + j60 | 0.98 |
| 11–12 | 22.5 + j32 | 0.995 |
| 3–6 | 30 + j80 | 0.995 |

**Table A.3** Bus data

| Bus #k | *PL(1,k)* kW | *PL(2,k)* kW | *PL(3,k)* kW | *F(1,k)* × 1000 | *F(2,k)* × 1000 | *F(3,k)* × 1000 | *NS(k)* |
|---|---|---|---|---|---|---|---|
| 2 | 20 | 50 | 100 | 60 | 75 | 40 | 10 |
| 3 | 20 | 50 | 100 | 30 | 35.5 | 20 | 1.6 |
| 4 | 20 | 50 | 100 | 60 | 75 | 40 | 1.0 |
| 6 | 800 | 490 | 870 | 1200 | 32 | 15 | 0.09 |
| 10 | 1080 | 700 | 1080 | 20 | 32 | 15 | 0.07 |
| 11 | 2250 | 1600 | 1800 | 20 | 32 | 15 | 0.09 |
| 13 | 760 | 507 | 1950 | 20 | 32 | 15 | 0.06 |
| 14 | 386 | 410 | 615 | 20 | 32 | 15 | 0.04 |

For all buses
$VC(1,k) = 0.95$ p.u.
$VC(2,k) = 0.9$ p.u.
$VC(3,k) = 0.8$ p.u.

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# A TSK Fuzzy Approach to Channel Estimation for 802.11a WLANs

**Laura Ivanciu, Ligia Chira Cremene and Gabriel Oltean**

**Abstract** The paper presents the performance analysis of a Takagi–Sugeno–Kang (TSK) channel estimator integrated in a complex, OFDM-based system—the IEEE WLAN 802.11a transmit-receive chain. The main goal is to see to what extent may fuzzy logic tools be integrated into end-to-end wireless transmission chains and to asses their performance. The fuzzy channel estimation solution was tested with monitoring of overall transmission parameters such as: packet error rate (PER), signal-to-noise ratio (SNR), and bit rate. Considering the fact that the fuzzy solution was integrated in a complex end-to-end transmission chain, the results may be seen as satisfactory and encouraging. The exploring nature of this implementation makes it a starting point for evaluating the opportunity and benefits of integrating fuzzy logic techniques in complex wireless transmission systems.

## 1 Introduction

The rapid evolutions of wireless communications in the last decade lead to an increase in user expectations regarding the quality of the provided services. The requests are focused upon high bit rates and good quality (low error rate). Data is sent over the radio channel, which can be highly unstable and variable in time, and is subject to fading and multipath propagation. The characteristics of the radio channel are fully or partially unknown. This state of ambiguity turns the channel estimation process into a candidate for fuzzy modeling.

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Fuzzy sets theory was introduced by Lotfi A. Zadeh in 1965 [1]. Fuzzy logic tools are efficient in situations where the characteristics of the system to be modeled are unknown or too difficult to predict using classical methods. Fuzzy techniques have proved to be robust even when implemented in non-linear or variant systems [2, 3]. Moreover, fuzzy techniques have been successfully combined with other types of computational intelligence methods such as neural networks or genetic algorithms.

Fuzzy logic applications in wireless communications systems so far have been focused on enhancing the performances of channel estimators and adaptive equalizers.

The paper studies the performance of a Takagi–Sugeno–Kang (TSK) channel estimator for a complex, OFDM-based system—the IEEE WLAN 802.11a transmit-receive chain. The goal is to see to what extent may fuzzy logic tools are integrated in end-to-end wireless transmission chains and to asses their performance.

The paper is organized as follows: Section II is an overview of the related work, Sect. 3 compares the traditional and fuzzy approaches for channel estimation in multi-carrier systems. Sect. 4 describes the integration of the proposed solution on the IEEE 802.11a PHY platform, Sect. 5 discusses the testing conditions and the results, and finally, the conclusions and future developments are stated in Sect. 6.

## 2 Related Work

In OFDM systems, two types of estimation are used: (i) blind estimation—where the channel is totally unknown, and (ii) pilot assisted estimation—where the channel is explored by pilot signals, known at the transmitter and at the receiver [4].

A pilot assisted channel estimation using TSK fuzzy systems is proposed in [5]. The pilots are used to train the initial fuzzy system and to continuously update its parameters, throughout the transmission. Simulations prove that this estimation method comes close to the performances of the minimum mean square error (MMSE) estimation, whilst having the major advantage of lower computational complexity.

This concept was extended to MIMO-OFDM systems, in [6], specifically for a configuration consisting of two antennas at the transmitter and two at the receiver.

An adaptive variable step size algorithm, based on fuzzy inference, is proposed in [7] to estimate the channel characteristics over the low voltage power line. Channel estimation for WiMAX systems, using a fuzzy logic reasoning engine, is described in [8]; the number of pilots changes during transmission, together with the characteristics of the channel.

Adaptive modulation for OFDM systems is also subject to applying fuzzy techniques [9, 10] and results show better adaptation to channel current conditions, while maintaining fair bit error rates and processing speed.

## 3 Traditional and Fuzzy Channel Estimation in OFDM Systems

In wireless communication systems data is sent over the radio channel, which can be highly unstable and variable in time, and is subject to fading and multipath propagation. Also, considering the fact that the characteristics of the channel are generally unknown, the performances of the receiver are affected, and this causes the effective bit rate to decrease. To avoid such loss of performance, adaptive techniques are used in the transmission chain, in general for selecting the most appropriate modulation and coding scheme or for channel equalization and estimation.

Traditional solutions for channel estimation are based on MMSE, least squares (LS) or least mean squares (LMS) algorithms. The main disadvantages of these techniques are high computational complexity, for MMSE and LS, and relatively low convergence speed for LMS [5, 6].

The process of channel estimation using fuzzy logic uses one or more fuzzy systems to estimate the channel coefficients [5, 6].

A TSK fuzzy system is defined by a set of rules [1, 11]:

$$R_i: \ \textit{if} \ x \, \textit{is} \, A_i \textit{then} \, h = f(x, a_i) = a_{0,i} + a_{1,i}x, \; i = 1..C \tag{1}$$

where $C$ is the number of rules;
$A_i$ is the membership function for the *ith* rule;
$a_i$ is the set of parameters for the *ith* rule.

The predicted (estimated) output of the system is:

$$\hat{y} = \frac{\sum_{i=1}^{C} h_i w_i}{\sum_{i=1}^{C} w_i} \tag{2}$$

where $h_i$ is the output of the *ith* rule;
$w_i$ is the activation degree of this rule

The basic concept of channel estimation using TSK fuzzy systems is presented in Fig. 1. The channel estimation scheme in Fig. 1 uses two identical fuzzy systems, one for the real part of the channel transfer function, and another for the imaginary part.

Building a fuzzy logic channel estimator involves a training stage, in which the initial fuzzy system will be defined based on a frame consisting of pilot subcarriers. This stage is necessary only at the beginning of the transmission. The fuzzy systems developed in the training stage are constantly adjusted during

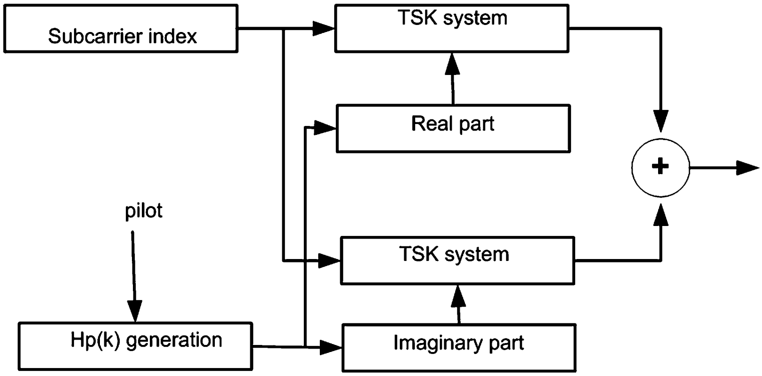


**Fig. 1** Channel estimation using TSK fuzzy systems [5]

transmission, in the updating stage, by means of pilot symbols, inserted at specific slots (positions) in the OFDM frame.

The initial fuzzy systems are defined in the training stage using adaptive neuro-fuzzy inference system (ANFIS). ANFIS is a combination of a TSK fuzzy inference system and an adaptive neural network, and is most commonly used in fuzzy data modeling [12]. ANFIS was successfully integrated as a part of the channel estimation process for OFDM systems [13].

## 4 TSK Channel Estimator Integration into the IEEE 802.11a Phy Platform

The IEEE WLAN 802.11a physical layer (PHY) simulation platform, provided by Matlab/Simulink [14], was chosen for integrating and testing the fuzzy channel estimator.

The IEEE WLAN 802.11a standard was released in September 1999, as a part of the 802.11 family for wireless local area networks. 802.11a is designed to operate in the 5 GHz frequency band and is able to transfer data at 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. The 6, 12, and 24 Mbps bit rates are compulsory for both the transmitter and the receiver, whereas the other available bit rates are optional. The system uses 52 OFDM sub-carriers, which can be modulated using BPSK, QPSK, 16-QAM or 64-QAM. Three coding rates are allowed by the convolutional encoder, specifically ½, 2/3 or ¾.

The simulation platform was developed considering the following simplifying assumptions: the model is a baseband one (without RF conversion), spreading is not implemented, the number of symbols per packet is constant (no “pad bits”), the transmission power level and SNR are specified, synchronization is considered perfect and no convolutional encoding and synchronization algorithms are used.

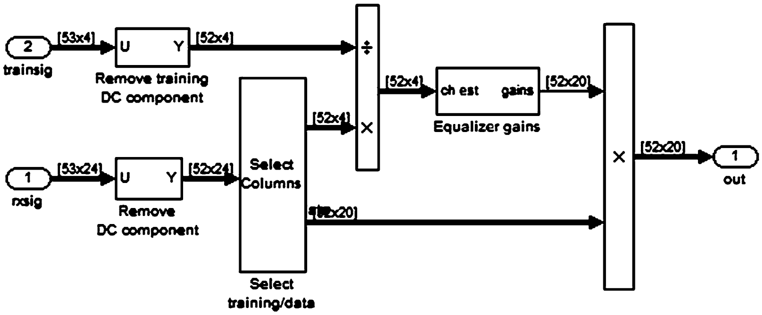


**Fig. 2** The ‘Frequency Domain Equalizer’ block of the IEEE WLAN 802.11a PHY simulation platform

The IEEE 802.11a PHY platform allows the adaptation of the transmission (modulation) scheme to channel conditions. At a certain time, the system chooses one of the 8 available modulation and coding schemes.

The estimation method is based on determining the effect of the channel upon the training sequence. The training sequence is extracted at the receiver and divided by the transmitted training sequence (Fig. 2). The result is the estimated transfer matrix of the channel. The equalization coefficients are computed within the ‘Equalizer gains’ subsystem. The estimated received matrix is the product between the equalization coefficients’ matrix and the received data matrix.

Several changes were made in the original transmission scheme in order to accomplish the training stage, for the fuzzy estimation process. The training stage uses ANFIS to define the initial fuzzy systems for channel estimation. The received data (pilots) is stored in a workspace variable and, together with the transmitted data, they are grouped into corresponding input–output pairs.

The initial versions of the two fuzzy systems are generated from these data sets, using the *genfis1* Matlab function. These systems are then trained until the output is convergent or the maximum number of epochs is reached. The adaptation degree of the output systems can be evaluated by computing the root mean square error (RMSE) (3):

$$\sqrt{\frac{1}{k}\sum_{k=1}^{k}\left(y_k^d - y_k\right)^2} \leq \varepsilon \tag{3}$$

where $y_k^d$ is the desired output,
$y_k$ is the computed output,
$\varepsilon$ is the accepted (tolerated) error,
$K$ is the data set size

Once the ANFIS training has ended the resulted fuzzy systems are used to estimate the real and imaginary parts of the channel transfer function and are constantly updated during transmission.

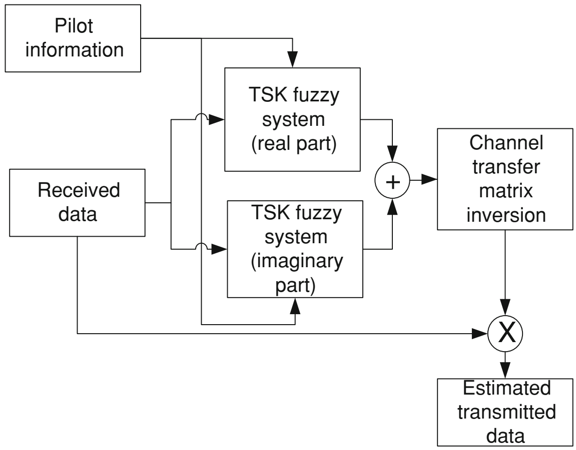


**Fig. 3** TSK channel estimator and data equalizer

The TSK channel estimation subsystem is composed of a series of blocks and embedded functions. According to the operating principles described above, its functionality can be graphically described in a concise manner in Fig. 3.

## 5 Simulations and Results

Testing of the fuzzy channel estimation solution, described in the previous section, was performed by monitoring transmission parameters such as: PER, SNR, and bit rate.

The simulations are set to stop when PER reaches 10 %. The simulations cover the 2, 3, 4, 6, 8, 10, and 12 propagation paths scenarios. The corresponding delay and gain vectors inside the 'Rayleigh Fading' block are set according to Table 1.

The simulation settings are listed below [15]:

- OFDM symbols per transmission block: 20
- OFDM symbols in the training sequence: 4
- SNR threshold vector: [10 11 14 18 22 26 28] dB
- Hysteresis: 3 dB
- Viterbi traceback depth: 34
- Multipath Channel block settings:
  - Fading mode: Dispersive fading
  - Maximum Doppler shift: 10 Hz
  - SNR: 30 dB

The mean values for PER, SNR and bit rate are presented in Table 2, for both the classic receiver, and the receiver integrating the TSK fuzzy channel estimator, for various numbers of propagation paths.

**Table 1** Delay and gain vector values for the simulation scenarios

| No. of paths | Delay vector (us) | Gain vector (dB) |
|---|---|---|
| 2 | [0.04 0.2] | [0 −3] |
| 3 | [0.04 0.1 0.2] | [0 −3 −4] |
| 4 | [0.04 0.08 0.15 0.2] | [0 −3 −3 −4] |
| 6 | [0.04 0.06 0.09 0.13 0.16 0.2] | [0 −3 −3 −4 −6 −10] |
| 8 | [0.04 0.06 0.09 0.13 0.16 0.18 0.19 0.2] | [0 −3 −3 −4 −6 −10 −7 −8] |
| 10 | [0.04 0.05 0.06 0.09 0.13 0.14 0.16 0.18 0.19 0.2] | [0 −1 −3 −3 −4 −6 −10 −7 −8 −5] |
| 12 | [0.04 0.05 0.06 0.09 0.10 0.13 0.14 0.16 0.17 0.18 0.19 0.2] | [0 −1 −3 −3 −4 −6 −10 −7 −8 −5 −10 −9] |

**Table 2** Mean values for per, SNR and bit rate, for the classic and the tsk fuzzy approaches for channel estimation

| No. of paths | Mean PER | | Mean SNR (dB) | | Mean bit rate (Mbps) | |
|---|---|---|---|---|---|---|
| | Classic | Fuzzy | Classic | Fuzzy | Classic | Fuzzy |
| 2 | 0.13 | 0.14 | 50.08 | 38.62 | 53.98 | 52.34 |
| 3 | 0.15 | 0.15 | 48.66 | 37.70 | 53.98 | 52.12 |
| 4 | 0.13 | 0.14 | 49.16 | 37.15 | 53.98 | 50.29 |
| 6 | 0.13 | 0.14 | 48.99 | 26.53 | 53.99 | 47.72 |
| 8 | 0.12 | 0.18 | 48.73 | 25.35 | 53.99 | 39.06 |
| 10 | 0.15 | 0.20 | 49.34 | 24.57 | 53.98 | 38.05 |
| 12 | 0.11 | 0.27 | 48.83 | 24.19 | 53.98 | 35.98 |

The mean PER for the fuzzy estimator solution is 1–2 % higher than for the original scheme, when tested for 2, 3, 4 and 6 propagation paths. When increasing the number of paths over 6, the differences are higher, reaching a peak value for 12 propagation paths.

The mean values of the SNR are lower for the fuzzy solution, than for the original scheme; even for two propagation paths, there is a difference of approximately 12 dB. For 12 propagation paths, the average SNR reduces to half, for the fuzzy solution.

The mean bit rates for the receiver integrating the fuzzy estimator stay close to the ones obtained for the classical scheme, for 2, 3 and 4 propagation paths. From 6 paths on, although the classical scheme maintains its bit rate almost constant, to the value of almost 54 Mbps, integrating the fuzzy solution brings the bit rate down to as low as 36 Mbps, for 12 propagation paths.

The four graphs in Fig. 4 present the probability distribution functions (PDF) of SNR values for 2 and 12 propagation paths, for the classic 802.11a scheme (a), (c) and for the 802.11a receiver integrating the fuzzy estimator (b), (d). For 2 propagation paths, the distribution of the SNR values is concentrated around 50 dB for the original scheme, whereas for the fuzzy estimation scheme, the SNR line drops to a central value of around 39–40 dB, which was also confirmed by the average

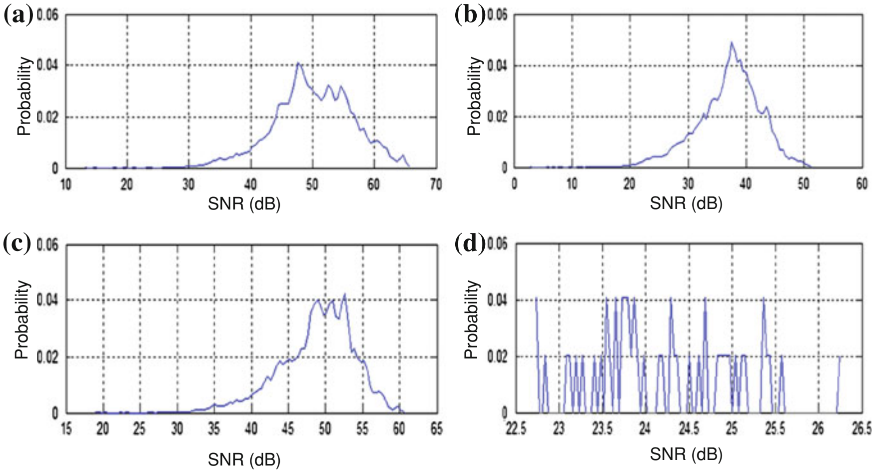


**Fig. 4** **a** The pdf of SNR values for 2 propagation paths for the classic 802.11a scheme **b** The pdf of SNR values for 12 propagation paths for the 802.11a scheme with fuzzy estimator **c** The pdf of SNR values for 12 propagation paths for the classic 802.11a scheme **d** The pdf of SNR values for 12 propagation paths for the 802.11a scheme with fuzzy estimator

value in Table 2. For 12 propagation paths, the SNR values for the fuzzy solution are scattered over a range of values between 22 and 26 dB, lower than for the original scheme.

In the situation were the type of modulation is set (the adaptive modulation process is disabled), the PER vs. SNR curves obtained for 6 and 12 propagation paths are displayed in Fig. 5. The modulation was set to 16 QAM, corresponding to a bit rate of 24 Mbps. The SNR of the channel varies between 10 and 24 dB. The other simulation settings remain the same as described above.

For 6 propagation paths, the PER curve for the TSK fuzzy estimator goes side by side with the one for the Frequency Domain Equalizer, for a SNR between 10 and 14 dB. From there on, the two curves continue with different slopes, the former being lower than the latter's. The PER for the TSK fuzzy estimator reaches a minimum value close to $10^{-3}$, for 24 dB.

For 12 propagation paths, the PER curve for the TSK fuzzy estimator begins at approximately $10^{-1}$ for 10 dB, whereas the one for the Frequency Domain Equalizer has the starting point at $5 \times 10^{-2}$. This trend is maintained until 14 dB, and from there on, the curves separate significantly, with a minimum of $2 \times 10^{-3}$ for the fuzzy estimator.

## 6 Conclusions and Future Work

The principles of fuzzy logic provide efficient tools to use in situations where the characteristics of the system to be modeled are unknown or too difficult to predict by means of classical methods. The applications of fuzzy logic in wireless

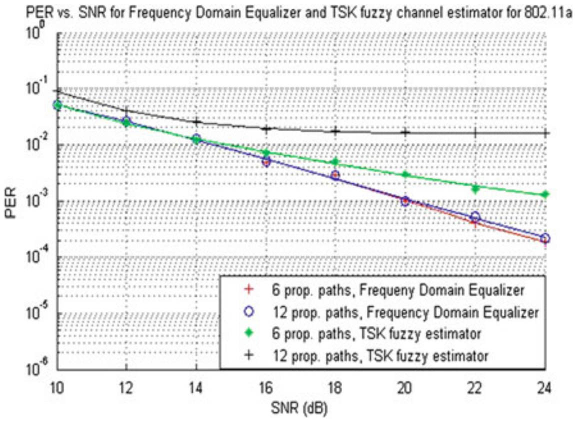


**Fig. 5** PER versus SNR for frequency domain equalizer and TSK fuzzy channel estimator, for various number of propagation paths and fixed modulation (16 QAM)

communications systems are focused on channel estimation, channel equalization, and adaptive modulation.

The paper describes the integration and testing of a fuzzy channel estimator in a complex OFDM-based system—the IEEE WLAN 802.11a PHY. The implementation was made in the Matlab/Simulink environment and two identical fuzzy systems were needed to estimate the channel transfer function. The fuzzy systems are first developed in the initial stage, and will change their properties permanently along the transmission, making use of the information provided by the pilot symbols, which reside in predefined slots (positions).

The fuzzy solution was tested under specific conditions. The performances were compared to the ones of the classical scheme, in terms of SNR, bit rate and packet error rate, for both adaptive and fixed modulation.

Considering the fact that the fuzzy solution was integrated in a complex end-to-end transmission chain, the results may be seen as satisfactory and encouraging. Furthermore, the exploring nature of this implementation turns it into a good starting point for evaluating the benefits brought by integrating fuzzy logic techniques in the channel estimation process of a complete wireless transmission system.

Future directions of study include not only investigating the effect of the fuzzy systems parameters (number of rules) upon the overall performances, but also extending the fuzzy channel estimator for a MIMO–OFDM system, with multiple antennas, specifically 802.11n [16].

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# Comparison of Bootstrapping and Finite State Machine Simulations of a Scheduling Benchmark

**George Anderson, Tshilidzi Marwala and Fulufhelo Vincent Nelwamondo**

**Abstract** This paper compares simulation of a scheduling benchmark using two different approaches. The benchmark mimics the behavior of a chat application, with sender and receiver threads. One approach involves representing the benchmark as a Finite State Machine (FSM), in which the various threads could have different states, and move from one state to another until they complete. Another approach uses a benchmark performance approximation method known as bootstrapping, introduced in the AKULA scheduling simulator. The benchmarks are simulated in the LinSched Linux scheduler simulator. Our results show that bootstrapping produces results (actual runtime figures) closer to those obtained when running the actual benchmark on an operating system. The simulation also completes much faster with bootstrapping. However, the FSM results in a better model of scheduling, with higher significance.

## 1 Introduction

The operating system is a very important part of the computer system. Its job is to manage the resources, such as the storage devices, the main memory, and the CPU [1–3]. The component of the operating system responsible for managing the CPU is the process scheduler, which we will refer to as the "scheduler" from now on.

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There any many different scheduling algorithms in existence. Each algorithm works well for certain workloads, while others work better for other workloads. Scheduling algorithms are judged on their suitability for handling workloads based on various performance metrics, such as *throughput* (the number of processes that complete per unit time), *turnaround time* (the time it takes for a particular process to complete, from start to finish), CPU *utilization* (fraction of time the CPU is doing useful work), and *response time* (the time it takes for a process to respond to some event, from the time the event occurs, to the time the response is produced) [1–3].

Developing and testing schedulers is time consuming and involves modification of operating system kernel source code, followed by compilation, and then rebooting and restarting of the operating system [4]. Bugs present could be hard to detect and could bring down the system, since the scheduler code runs in the kernel and has high privileges, enabling it to affect other components. Debugging the operating system is also difficult.

Because of these reasons, simulators are used, in order to isolate the scheduler. These simulators enable convenient development and testing of schedulers. However, whether using a simulator or not, the scheduler must be supplied with a workload, i.e., a set of processes, which will execute, and by which one can judge the scheduler's performance. Such workloads are called benchmarks. In operating system scheduler simulation, the benchmarks can also be simulated. In this paper we compare two approaches to simulating a well-known scheduling benchmark. One approach uses a Finite State Machine (FSM) implementation of the benchmarks, while the other approach uses implementation based on bootstrapping, a simulation approach introduced to the scheduling community in 2010.

This paper is organized as follows. In Sect. 2, we discuss some prior work on simulation and benchmarking of schedulers; Sect. 3 discusses process scheduling in the Linux operating system; Sect. 4 discusses the simulator we modified for this study, LinSched; Sect. 5 discusses our two approaches to implementing a scheduling benchmark in LinSched; Sect. 6 has our results, and Sect. 7 has our conclusion.

## 2 Related Work

AKULA is a scheduler evaluation tool developed by Zhuravlev et al. [5]. It is Java-based and offers easy coding of algorithms together with rapid evaluation using a novel method known as *bootstrapping*, described in more detail in Sect. 5.2. AKULA can also execute a scheduler on a live platform by tying process tasks to cores on multicore CPUs and evaluating their performance. AKULA is mainly useful for evaluation of schedulers for multicore architectures. We chose to use LinSched as our simulator because it already incorporates the Linux scheduler code, which would take time to port to AKULA. We also have more experience with it. Also, at the time of writing this paper, some critical components of AKULA had not yet been released.

Magnusson et al. describe Simics [6], a full system simulator. This provides for a detailed simulation of an entire system, complete with a base hardware layer. Such simulators are capable of executing instructions and can therefore run actual binary images of programs; no need to simulate benchmarks. However, they are slow, and require fast platforms to run. They can also be difficult to work with. They also model many details not required to evaluate operating system schedulers [5]. Our use of LinSched avoids these disadvantages.

CMPSched$im is a tool developed by Intel for studying scheduling and interaction with caches [7]. It combines a binary instrumentation tool, Pin [8], LinSched, and a cache simulator. It is capable of executing benchmark binaries and evaluating performance, which is dependent on how the tasks are scheduled. It is a very powerful tool, but unfortunately Intel chose not to make it available to the research community at this stage. Hence, we have to develop our own tools or modify existing tools.

## 3 Process Scheduling in the Linux Operating System

Starting from Linux kernel version 2.6.23, a scheduler known as the Completely Fair Scheduler (CFS) has been used as the default Linux scheduler [9, 10]. The CFS tries to ensure all tasks have a fair share of the CPU i.e., process A should not be kept waiting for a long time while process B keeps getting opportunities to use the CPU. The CFS scheduler maintains a red–black tree (a binary search tree) that orders tasks according to how unfairly they are being treated. A task that is being treated unfairly because it has been kept waiting for a long time will move to the "front" of the red–black tree, and will soon be selected to execute on the CPU. The CFS scheduler is easily extensible.

## 4 The Linsched Simulator

LinSched is a Linux scheduling simulator developed by Calandrino et al. [4]. It is based on the Linux 2.6.23 CFS scheduler. The CFS scheduler has been extracted from the Linux kernel source code, including all the C header and source files and kernel configuration files. Additional simulation code has been written to handle the execution of tasks. An Application Programming Interface (API) has been created to enable users to create their own tasks and run the simulation for a specified period of time. When a task is created, the scheduler is made aware of this, since it needs to schedule it. Once the simulation has started, the simulator advances the virtual time and for each advance, the scheduler is invoked to select and execute tasks for each CPU in the system.

LinSched has many advantages for use as a research tool over a live operating system. The scheduler can be modified and tested easily. LinSched runs as a process in user space, just like any other application. A bug in the scheduler's code only affects this process. In the worst case only this process crashes and can easily be restarted. The cycle of code, compile, reboot, benchmark, debug, commonly used for live operating system kernels is not present, since there is no need to reboot. Debugging is also easier. LinSched allows fast validation of the scheduler, since the scheduler is isolated. Other simulators exist, such as AKULA [5], but require the CFS scheduling algorithm to be ported to them. With LinSched, the CFS algorithm is already part of the software. There are currently projects to update LinSched to incorporate more recent CFS versions.

## 5 Benchmark Simulation

In order to evaluate the performance of a system, a workload has to be used to stress the system. Such a workload should be similar to live workloads that will run on the system when it is in operational use and is called a benchmark [11]. When using a simulator for performance evaluation, the benchmark is usually simulated i.e., it does not involve use of live processes with instructions, which the CPU will execute. Rather, it uses a trace of events obtained when the benchmark was running on a live system, or characteristics of tasks, such as the points in time when they are created, and the amount of CPU time each of them requires in order to do its work.

The benchmark we selected for our study is hackbench [12]. It has been used extensively to benchmark the CFS scheduler by the creator of the CFS scheduler, Molnar [13–14, 15]. Hackbench mimics the behavior of a chat server. By default it has five groups of 20 senders and 20 receivers each. Each sender sends a fixed number of messages to each receiver in its group, all 20 of them. Each receiver receives messages from all the senders in its group, all 20 of them. When the sending and receiving is done, the senders and receivers exit and the benchmark completes. Porting hackbench to LinSched presented a challenge since LinSched by default only handles simple tasks that do not have much logic in them. Our study involved the following modifications to LinSched:

1. Implementation of a sender task callback and a receiver task callback, which the scheduler invokes when these tasks are selected to use the CPU. For FSM, these implemented the finite state models. For bootstrapping, a single callback function was used for both senders and receivers, which kept track of the progress.
2. Implementation of some helper functions e.g., to convert strings to integers, which was necessary because the C library for this function could not be linked because of conflicts with the kernel code.
3. Functions to check when all tasks have finished. These are lacking in LinSched, since benchmark tasks that run to completion were not catered for.
4. Data structures to keep track of various task states and groupings in FSM.

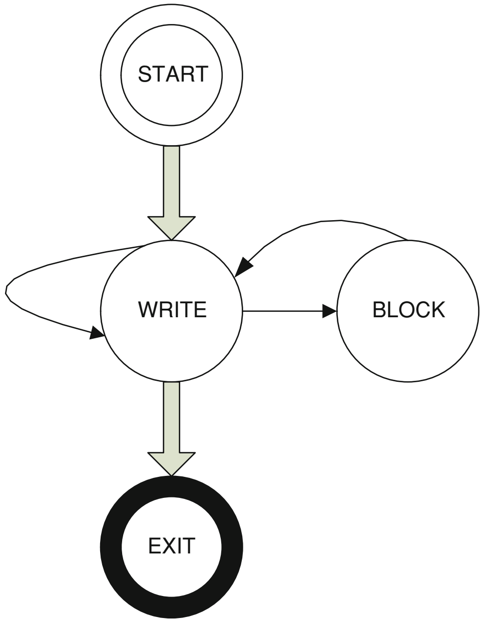


**Fig. 1** Finite state machine for sender

5. Data structures to keep track of progress and groupings in bootstrapping.

The following two sections describe our approaches to implementing hackbench in LinSched.

## 5.1 Finite State Machine Approach

A Finite State Machine is a model of a system, where the system is described as being in one of several states. There is a start state, and then for each input, the system either remains in the same state, or moves to another state. Eventually after one or more such transitions, the system exits. This model maps very well to the way the sender and receiver threads in the hackbench benchmark work. Figure 1 shows the FSM model for the sender and Fig. 2 shows that for the receiver.

The sender is created in the START state, and then it moves to the WRITE state, in which it tries to WRITE to a receiver. If the receiver is not ready e.g., it is busy receiving from another sender, the sender moves into the BLOCK state where it waits. If the receiver accepts the data, the send remains in the WRITE state. If the sender is blocked and the receiver it was trying to write to becomes available i.e., it is no longer busy, the sender again moves to the WRITE state to continue writing. After the sender has written (sent) all its messages to all the receivers in its group, it exits i.e., enter the EXIT state.

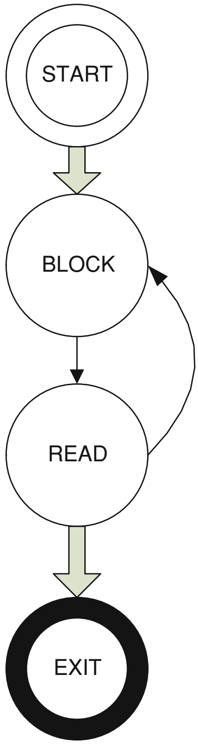


**Fig. 2** Finite state machine for receiver

The receiver also starts in a START state. It then moves to a BLOCK state to receive data. When the data arrives it reads it in the READ state, and then BLOCKs again for the next piece of data. Once all data has been read, it EXITs.

## *5.2 Bootstrapping*

Bootstrapping was first introduced in 2010 by Zhuravlev et al. [5]. It is an approach for simulation of workloads running on an operating system with a specific scheduling algorithm. It is aimed at analyzing scheduling algorithm behavior on multicore systems. Such systems consist of one or more memory domains. Each memory domain could contain one or more cores. Each core is capable of executing instructions belonging to a thread. The cores in a memory domain typically share some hardware resources such as a cache, memory controller, and pre-fetch hardware. Since these components are shared, when two or more threads run in the same memory domain, they experience a negative performance impact. Bootstrapping keeps track of progress of various threads by calculating the impact on progress when several threads are scheduled in the same memory domain. The bootstrapping method involves profiling, where a benchmark thread is run first off all on its own in a memory domain, followed by running it together with another benchmark thread. Then the degradation is measured. For tasks X and Y, the formula is shown below.

$$\mathrm{Deg}(X,Y) = \frac{\text{Runtime Alone}(X)}{\text{Runtime Combined}(X,Y)} \tag{1}$$

The simulator keeps track of time using ticks. A tick is an interval of time between when the hardware timer gives control back to the operating system via an interrupt. At every tick, the scheduler is brought into play to decide whether to take the CPU away from a task, or to calculate how the progress of all the tasks. The formula used to calculate the progress is given in [5] and is as follows:

$$P(X) = 100\% \times \frac{\text{tick}}{\text{Solo}(X)} \times \mathrm{Deg}(X, N(X)) \tag{2}$$

P(X) is the progress of task X, tick is the length of the tick interval, Solo(X) is the runtime of X when running alone in a memory domain, Deg(X, N(X)) is the Degradation when X runs together with the Neighbor of X.

In order for our implementation to work, we measured the performance of hackbench when one group runs alone. We then measured the performance when one group is scheduled with another group i.e., two groups of senders and receivers run at the same time. We calculated the degradation. In bootstrapping, one has to measure the degradation for all possibilities of benchmarks running with other benchmarks. In our case, since we were testing on a dual-core machine i.e., it has two cores in the same memory domain, and all the groups are from the same benchmark, we only had to take those two measurements one group solo, and two groups together.

# 6 Results

We conducted our experiments on a machine with Intel Core 2 Duo CPU T8300 (2.4 GHz and 3 MB L2 Cache) and 4 GB of RAM. The operating system was Ubuntu Linux 9.04. We used a configuration of hackbench where each sender sends a 1,000 messages to each receiver.

Figure 3 shows a plot of actual hackbench execution runtimes for 2, 4, 6, 8, …, 20 hackbench groups versus the LinSched runtimes, after modification for FSM. LinSched shows runtime results in Jiffies, which depend on the frequency of the hardware clock. For our implementation, 1 Jiffy = 1 ms. A linear regression model was produced with high significance for the intercept.

The model produced for FSM was significant at the $p < 0.001$ level, showing a good fit. $R^2$ and Adjusted $R^2$ were close to 1 (both 0.9997), also indicating a good model. Figure 4 shows a plot of actual hackbench execution runtimes for 2, 4, 6, 8,

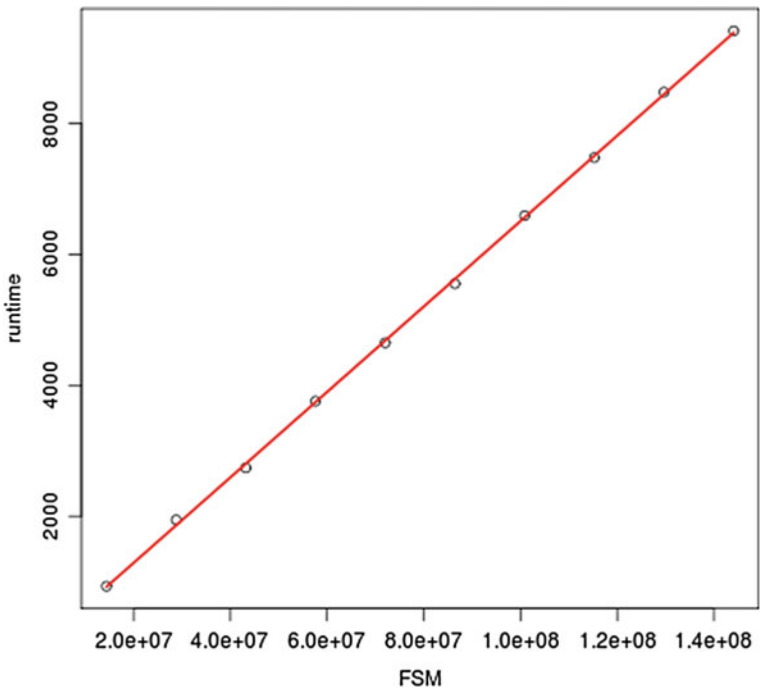


**Fig. 3** Regression model for FSM. Runtime in milliseconds versus FSM jiffies

…, 20 hackbench groups versus the LinSched runtimes, after modification for bootstrapping.

The model produced for bootstrapping was also significant at the $p < 0.001$ level, showing a good fit. $R^2$ and Adjusted $R^2$ were close to 1 (0.9881 and 0.9866 respectively), also indicating a good model. As can be seen in Figs. 3 and 4, the FSM model is a better fit than the bootstrapping model. Note that the Jiffies displayed by LinSched differ in magnitude from live hackbench runtimes because of the operation of the simulator. Hence we need to fit a model in order to be able to translate from Jiffies to actual milliseconds.

Our degradation (see Sect. 5.2) was 0.528, meaning that when two hackbench groups run together, they will finish in just under twice the time for one group. With the largest load (20 groups) FSM LinSched takes 53 s to execute, while Bootstrapping LinSched takes 3 s. Our results show the following:

1. FSM LinSched produces more reliable results than bootstrapping.
2. Bootstrapping LinSched executes much faster.
3. The bootstrapping implementation is shorter than FSM (149 vs. 105 lines of code), making coding and debugging easier.

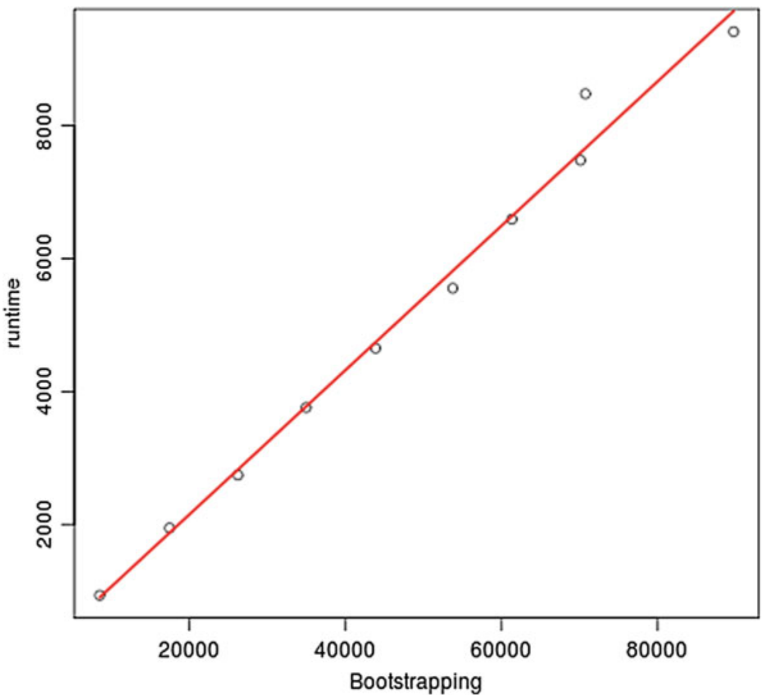


**Fig. 4** Regression model for bootstrapping. Runtime in milliseconds versus bootstrapping jiffies

# 7 Conclusion

In comparison, a bootstrapping implementation of the hackbench benchmark on LinSched produces results (actual runtime figures) closer to those obtained when running the actual benchmark on an operating system. The simulation also completes much faster with bootstrapping. However, the FSM results in a better model of scheduling performance, with higher significance. Therefore, if speed is of the essence, bootstrapping can be used. Its creators, Zhuravlev et al. [5], emphasize that it gives rough approximations of performance, useful for comparing scheduling algorithms together. If accuracy is paramount, the FSM approach is better. The bootstrapping implementation is much shorter than the FSM one, with less code and therefore less opportunity for bugs to creep in.

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# Low Power 8-Bit Baugh–Wooley Multiplier Based on Wallace Tree Architecture

**Xingguo Xiong and Muzi Lin**

**Abstract** In this paper, an 8-bit Baugh–Wooley two's complement multiplier based on Wallace tree architecture is designed and simulated. Baugh–Wooley multiplier is popular for multiplication of signed multiplicands in 2's complement data representation. Baugh–Wooley multiplier can be implemented based on different architectures, such as array architecture or Wallace tree architecture. The strategy of Wallace tree architecture is to combine the partial product bits at the earliest opportunity, which leads to the fastest possible design. Furthermore, carry-save adders (CSA) can be used to reduce the number of addition cycles as well as to make each cycle faster. In this work, both Baugh–Wooley multipliers based on array architecture and Wallace tree architecture were designed and simulated in PSPICE. PSPICE simulation results show that the Wallace tree architecture not only works faster, but also consumes less power than the conventional array structure.

## 1 Introduction

Multipliers are one of the most important arithmetic units in microprocessors and digital signal processing (DSP) systems. Due to their complex structure, multipliers are generally a major source of power dissipation in such systems. The speed of multipliers also limits the overall system performance. With the advance of VLSI technology, the size of transistors is becoming smaller and smaller, so that more and more transistors can be integrated into the same silicon area to achieve

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higher functionality density and performance. On the other hand, higher transistor density also leads to higher power density. This brings great challenge to the thermal dissipation solution of modern VLSI systems. To reduce the burden of thermal dissipation system, power efficiency has become a more and more essential design factor. To achieve higher computation speed and longer battery span of portable compute-intensive applications (e.g., cell phones, laptops, portable audio/video players, electronic organizers, PDAs), reducing the power consumptions of multipliers is key to satisfy the overall power budget of various digital circuits and systems.

Various research works aiming at improving the speed and/or reducing the power consumption of multiplier circuits have been reported [1–6]. Efforts have been made to reduce the power consumption of multipliers in algorithm level, architecture level, circuit level, and device level. For example, software can be used to redesign the algorithms to lower the power dissipation. Parallelism and pipelining are also used in system architecture to reduce glitches and propagation delay. Furthermore, the energy consumption of VLSI circuit can also be reduced by using a different CMOS logic family. Baugh–Wooley multiplier is popular for multiplication of signed data in 2's complement representation. Baugh–Wooley multiplier was first proposed in [7]. After that, various designs based on Baugh–Wooley scheme have been reported [8–11].

Multipliers can be implemented with different architectures, such as array multipliers and tree multipliers [12]. Traditional array multipliers [12] originate from the multiplication parallelogram. In array multiplier, each stage of the parallel adders receives some partial product inputs. The carry-out is propagated into the next row. Due to its regular structure, array multiplier is easy to layout and has smaller area. Furthermore, it is easy to be designed into pipeline architecture to improve its throughput. However, its worst-case delay is proportional to the number of bits of the multiplier, hence it is slow for large N number. In Wallace tree multiplier [12], the multiplicand-multiples are summed up in parallel by means of a tree of carry save adders. As a result, its delay is small, and the number of logic levels required to perform the summation is also reduced. However, Wallace tree multiplier is relatively complex to layout and has irregular wires. In this paper, we implemented 8-bit 2's complement signed Baugh–Wooley multipliers using both regular array architecture and Wallace tree structure. PSPICE simulation is used to compare the speed and the power consumption of both multipliers. Simulation results show that Baugh–Wooley architecture based on Wallace tree structure leads to lower power consumption and higher speed than that based on traditional array architecture.

## 2 Baugh–Wooley Multipliers

Multipliers are one of the most important parts in signal processing and other computationally intensive applications. Therefore, designing multipliers that are high-speed, low power is of substantial research interest. In this paper, we

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $X_7$ | $X_6$ | $X_5$ | $X_4$ | $X_3$ | $X_2$ | $X_1$ | $X_0$ |
| | | | | | | | | $Y_7$ | $Y_6$ | $Y_5$ | $Y_4$ | $Y_3$ | $Y_2$ | $Y_1$ | $Y_0$ |
| | | | | | | | 1 | $\overline{P_{70}}$ | $P_{60}$ | $P_{50}$ | $P_{40}$ | $P_{30}$ | $P_{20}$ | $P_{10}$ | $P_{00}$ |
| | | | | | | | $\overline{P_{71}}$ | $P_{61}$ | $P_{51}$ | $P_{41}$ | $P_{31}$ | $P_{21}$ | $P_{11}$ | $P_{01}$ | |
| | | | | | | $\overline{P_{72}}$ | $P_{62}$ | $P_{52}$ | $P_{42}$ | $P_{32}$ | $P_{22}$ | $P_{12}$ | $P_{02}$ | | |
| | | | | | $\overline{P_{73}}$ | $P_{63}$ | $P_{53}$ | $P_{43}$ | $P_{33}$ | $P_{23}$ | $P_{13}$ | $P_{03}$ | | | |
| | | | | $\overline{P_{74}}$ | $P_{64}$ | $P_{54}$ | $P_{44}$ | $P_{34}$ | $P_{24}$ | $P_{14}$ | $P_{04}$ | | | | |
| | | | $\overline{P_{75}}$ | $P_{65}$ | $P_{55}$ | $P_{45}$ | $P_{35}$ | $P_{25}$ | $P_{15}$ | $P_{05}$ | | | | | |
| | | $\overline{P_{76}}$ | $P_{66}$ | $P_{56}$ | $P_{46}$ | $P_{36}$ | $P_{26}$ | $P_{16}$ | $P_{06}$ | | | | | | |
| | $P_{77}$ | $\overline{P_{67}}$ | $\overline{P_{57}}$ | $\overline{P_{47}}$ | $\overline{P_{37}}$ | $\overline{P_{27}}$ | $\overline{P_{17}}$ | $\overline{P_{07}}$ | | | | | | | |
| $\overline{S_{15}}$ | $S_{14}$ | $S_{13}$ | $S_{12}$ | $S_{11}$ | $S_{10}$ | $S_9$ | $S_8$ | $S_7$ | $S_6$ | $S_5$ | $S_4$ | $S_3$ | $S_2$ | $S_1$ | $S_0$ |

**Fig. 1** An 8-bit Baugh–Wooley multiplication based on array architecture [7]

implement an 8-bit Baugh–Wooley multiplier based on Wallace tree architecture. Carry save adder (CSA) structure is used to add the partial products to improve the speed. A Baugh–Wooley multiplier based on regular array architecture is also implemented, so that it can be compared with the Wallace tree Baugh–Wooley multiplier. The speed and power consumption of both architectures are simulated in PSPICE. The software used for the design and simulation of the multipliers in this project is Orcad PSPICE (version: 16.3).

## *2.1 Baugh–Wooley Algorithm*

The Baugh–Wooley (BW) algorithm [7] is a relatively straightforward way of implementing multiplications of signed digital data. Baugh–Wooley array multipliers are used to multiply positive and negative numbers in two's complement data representation. Figure 1 illustrates the algorithm for an 8-bit case, where the partial-product bits have been reorganized according to Hatamian's scheme [13]. The creation of the reorganized partial-product array for N × N bit Baugh–Wooley array multiplier consists of three steps:

Step 1: The most significant bit (MSB) of the first N−1 partial-product rows and all bits of the last partial-product row, except its MSB, are inverted.
Step 2: A'1' is added to the Nth column.
Step 3: The MSB of the final result is inverted.

The partial-product bits can be generated by using a 2-input AND gate for each pair of operand bits. In the case a partial-product bit should be inverted, a 2-input NAND gate will be used instead. The insertion of "1" in column N is easily accommodated by setting the carry-in of the full adder generating sum bit S8 as "1". The block diagram of an 8 × 8 bit Baugh–Wooley multiplier based on array architecture is shown in Fig. 2.

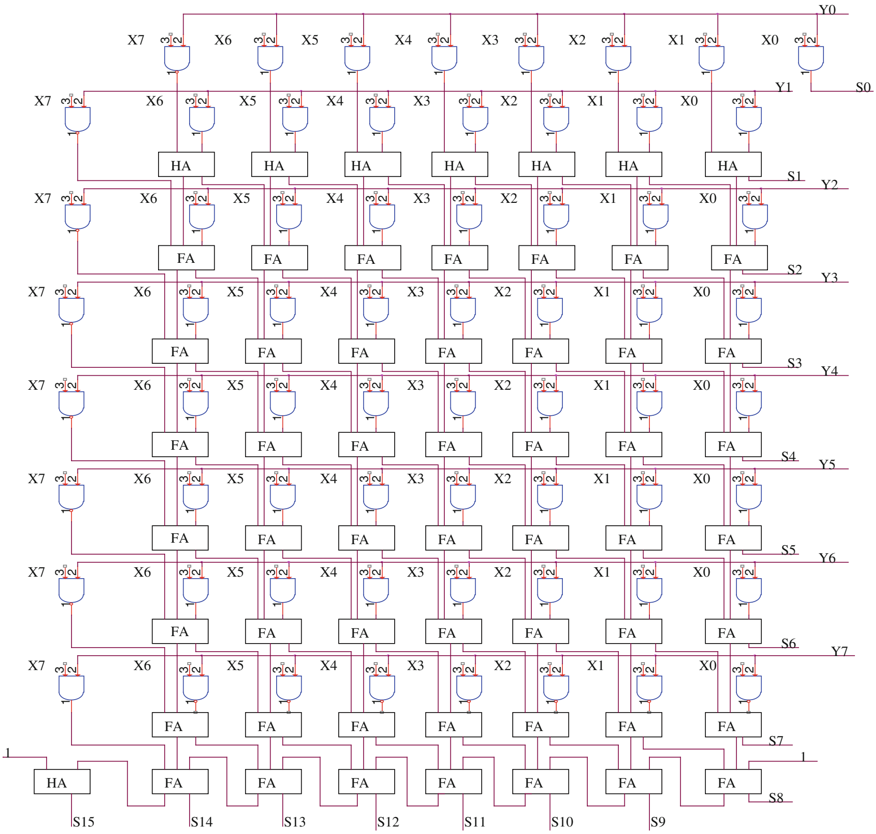


**Fig. 2** Baugh–Wooley two's complement signed array multiplier

## 2.2 *Wallace Tree Architecture*

Wallace tree architecture can be used for signed multiplier. An 8-bit Wallace tree multiplier diagram is shown in Fig. 3. The design of a multiplier can be divided into three stages: partial products generation, partial products addition, and the final addition.

Stage #1: The multiplicand and the multiplier are multiplied bit by bit to generate the partial products.

Stage #2: The second stage is the most important, as it is the most complicated and determines the speed of the overall multiplier. To add all the partial products together, the basic scheme is to add all the partial products serially, reducing the design complexity. But the speed of such multiplier is slow, because the carry-out needs to be propagated in series.

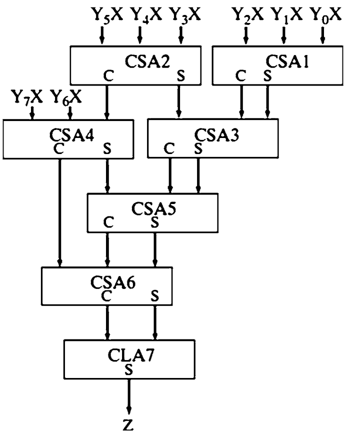


**Fig. 3** An 8-bit Wallace tree multiplier (*CSA* carry-save adder, *CLA* carry look-ahead adder) [13]

Another scheme is to use the Wallace tree structure which adds the partial products in a tree-like fashion in order to produce two rows of partial products that can be added in the last stage. Generally the Wallace tree architecture is much faster than the array scheme.

Stage #3: The two-row outputs of the tree are added using any high-speed adder such as carry look-ahead adder to generate the output result.

## 3 PSPICE Design

An 8-bit Baugh–Wooley multiplier based on Wallace tree architecture is designed and simulated in PSPICE. In order for comparison, an 8-bit Baugh–Wooley multiplier based on traditional array architecture is also implemented in PSPICE. PSPICE transient simulation is used to find out the delay of both multipliers. PSPICE power simulation is used to simulate the power consumption of both multipliers for the same given input pattern sequence. In the PSPICE schematic design, the power sources are set as $V_{dd} = 5$ V, Gnd = 0 V. The size of transistors are set as below:

The size of each PMOS transistor is: $W/L = 9\lambda/2\lambda$,

The size of each NMOS transistor is $W/L = 3\lambda/2\lambda$.

Considering the fact that the mobility of electrons is about 3 times as that of holes, the size of PMOS transistors is set to be three times of the NMOS transistors. In this way, roughly symmetrical rising and falling transitions can be achieved for the multiplier circuit.

The system block diagram of 8-bit Baugh–Wooley multiplier based on traditional array architecture is shown in Fig. 4.

The PSPICE schematic design of the $8 \times 8$ bit Baugh–Wooley multiplier based on traditional array architecture is shown in Fig. 5.

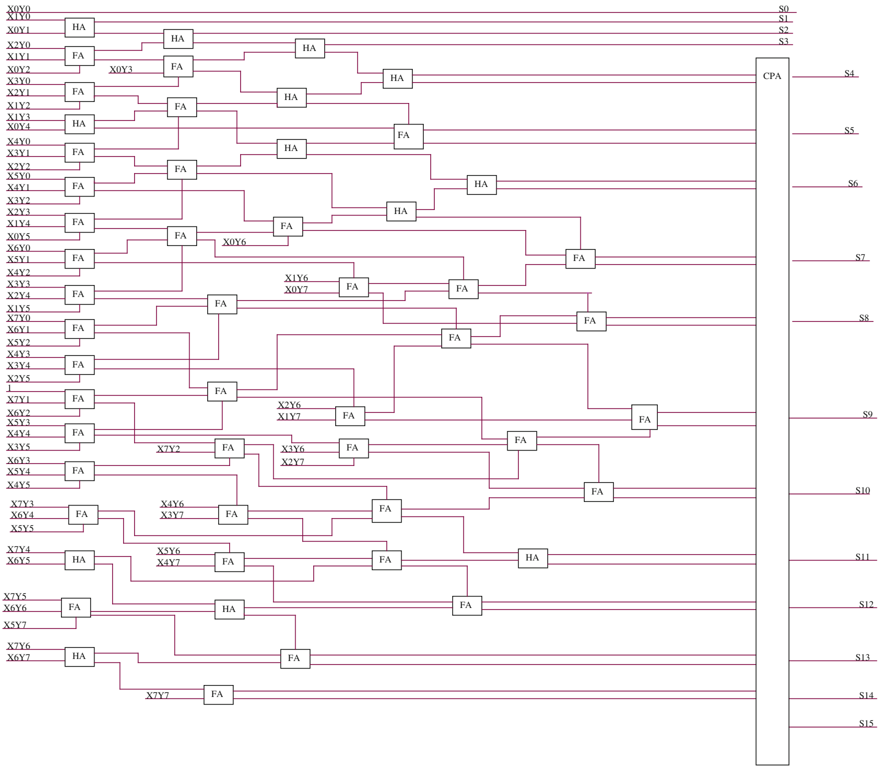


**Fig. 4** Block diagram of 8-bit Baugh–Wooley multiplier based on traditional array architecture

The system block diagram of 8-bit Baugh–Wooley multiplier based on Wallace tree architecture is shown in Fig. 6.

The PSPICE schematic design of the 8-bit Baugh–Wooley multiplier based on Wallace tree architecture is shown in Fig. 7.

PSPICE power simulation is a well-known method to simulate the power consumption of a VLSI circuit in response to given input pattern sequence. Typical circuit simulators (such as PSPICE) can simulate the voltages and currents in a VLSI circuit. However, the power consumption cannot be directly simulated. In order to analyze the average power consumption of a circuit, an auxiliary power testing circuit is ingeniously added in PSPICE simulation, as shown in Fig. 8. The auxiliary power measurement circuit consists of a current-controlled-current-source $(K{*}i_{dd})$, a resistor R and a capacitor C. The resistor R is introduced to help convergence in PSPICE simulation. Generally its value should be very large (> 100 kΩ) to reduce leakage current to the capacitor C.

Assume the current flowing from power source $V_{dd}$ into the circuit under test (CUT) as $i_{dd}(t)$. The average power $P_{avg}(T)$ of the circuit-under-test (CUT) in time period T is

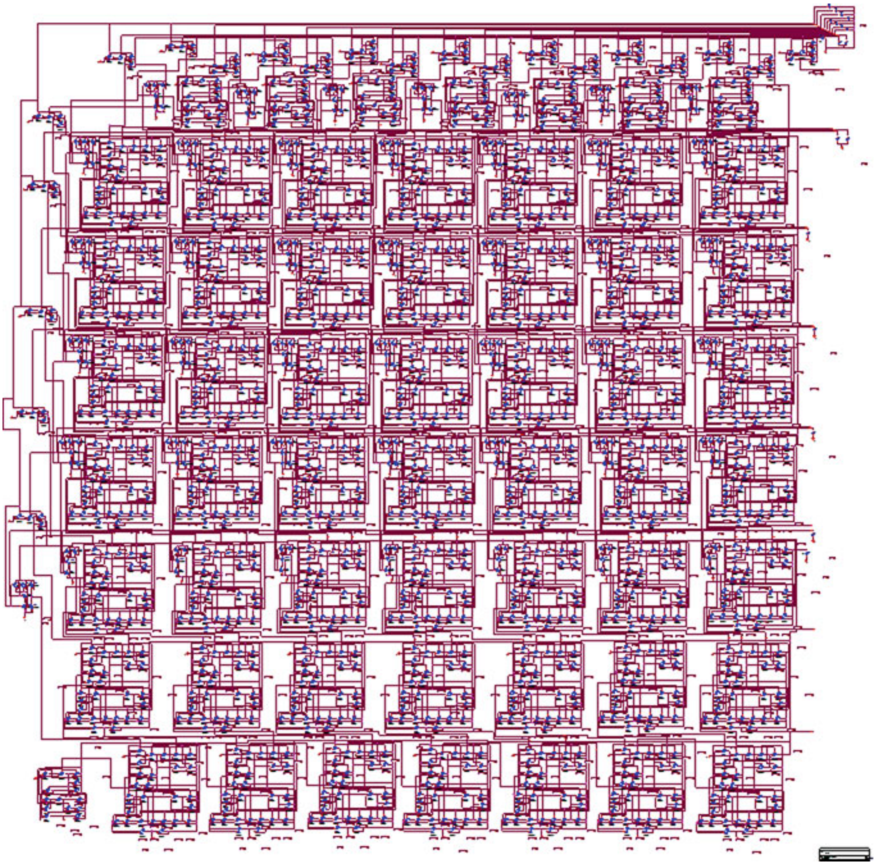

**Fig. 5** PSPICE schematic design of 8-bit Baugh–Wooley two's complement array multiplier

$$P_{\text{avg}}(T) = \frac{E(T)}{T} = \frac{1}{T}\int_0^T P(t)dt = \frac{V_{dd}}{T}\int_0^T i_{dd}(t)dt \tag{1}$$

where E(t) is the total energy consumption of the CUT during time period T, and P(t) is the instantaneous power consumption of the CUT.

In the auxiliary power measurement circuit :

$$K \cdot i_{dd}(t) = \frac{dQ_c(t)}{dt} = \frac{d(CV_C(t))}{dt} = C\frac{dV_C(t)}{dt} \tag{2}$$

where $Q_C(t)$ is the charge stored in capacitor C at time moment t, $V_C(t)$ is the voltage across capacitor C at time moment t. Integrating the both sides of Eq. (2) for time $t = 0 \rightarrow T$, we have:

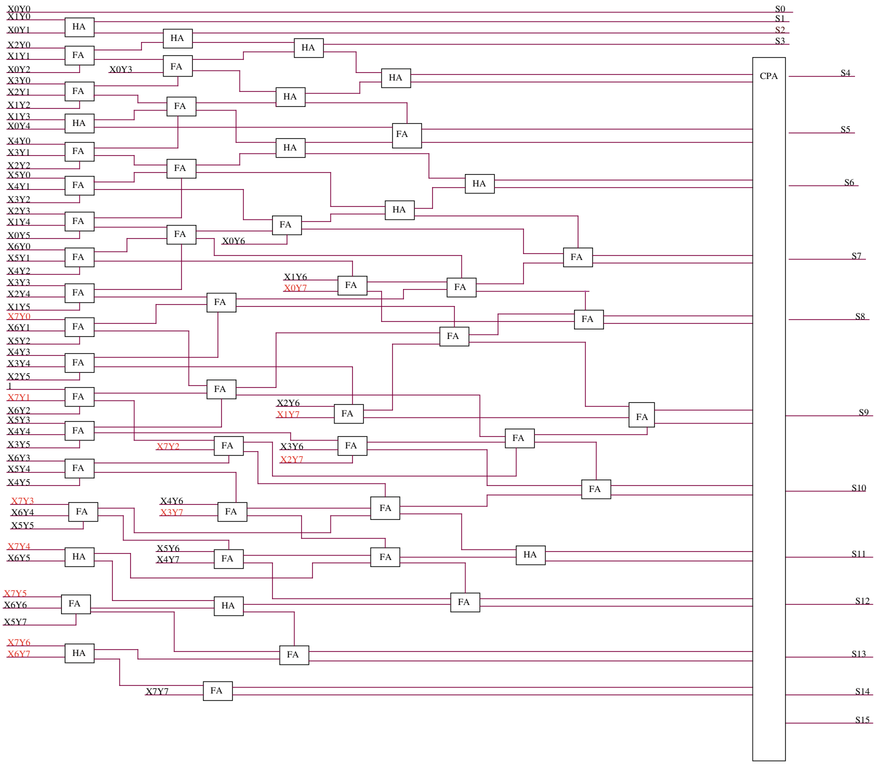


**Fig. 6** Block diagram of 8-bit Baugh–Wooley two's complement signed Wallace tree multiplier

$$V_C(T) = \frac{K}{C}\int_0^T i_{dd}(t)dt \tag{3}$$

Compare Eqs. (1) and (3), if we select Then $V_{dd}/T = K/C$, hence $P_{avg}(T) = V_C(T)$.

That is, if we select $K = V_{dd}{\bullet}C/T$, the voltage $V_C(T)$ in capacitor *C* is numerically equal to the average power $P_{avg}(T)$ of the CUT in time period T. Thus by measuring the voltage $V_C(T)$ in PSPICE simulation, we know the value of $P_{avg}(T)$. In this way, the average power consumption of a circuit can be extracted by PSPICE simulation.

In our work, we want to directly read the average power for t = [0,500 ns], hence the K value of the current-controlled current source is selected as:

$$K = \frac{V_{dd} \cdot C}{T} = \frac{5 \times 100 \times 10^{-12}}{500 \times 10^{-9}} = 0.001 \tag{4}$$

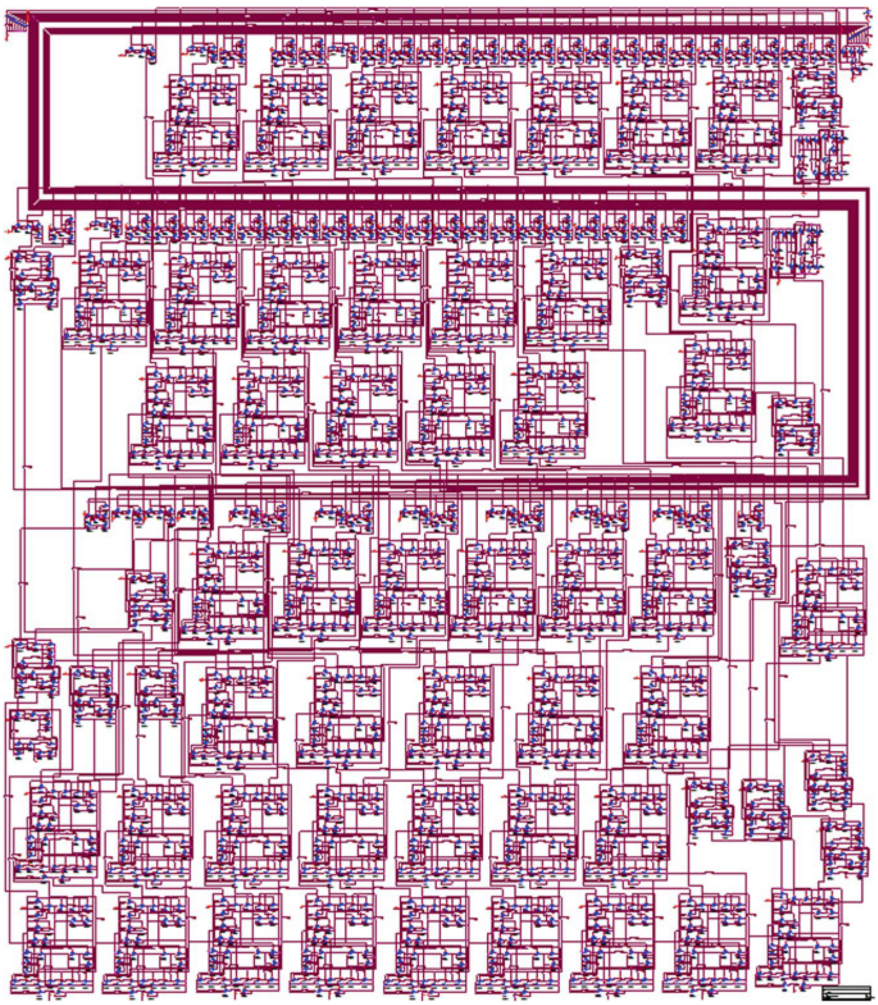

**Fig. 7** PSPICE schematic design of 8-bit Baugh–Wooley two's complement Wallace tree multiplier

# 4 Results and Discussions

## *4.1 Delay Analysis*

In order to for performance comparison, PSPICE transient simulation is performed to find out the delay of both multiplier circuits.

As we can see from the block diagram of the multiplier design, the 16 bits of the multiplication result does not come out at the same time. The least significant bit (LSB) $S_0$ is stabilized first and the MSB $S_{15}$ Is stabilized the last. The delay is

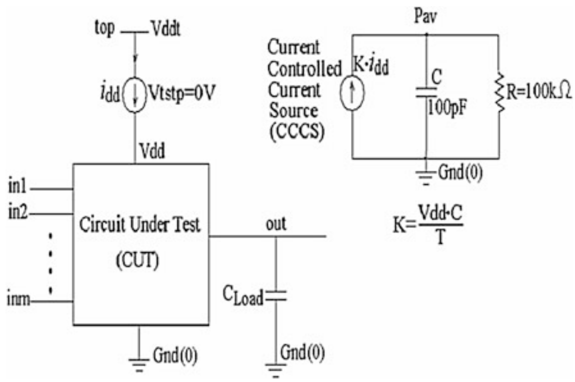


**Fig. 8** PSPICE power simulation using auxiliary circuit

**Table 1** Pattern of delay test for the multipliers

| Input | $X_0$ | $X_1$ | $X_2$ | $X_3$ | X4 | $X_5$ | $X_6$ | $X_7$ | $Y_0$ | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | $Y_5$ | $Y_6$ | $Y_7$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Output | $S_0$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ | $S_{11}$ | $S_{12}$ | $S_{13}$ | $S_{14}$ | $S_{15}$ |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

measured as the time from the moment when a new input pattern is applied to the moment when the MSB $S_{15}$ Is stabilized. In order to test the delay, the initial input pattern is set as:

$$X = X_7X_6X_5X_4X_3X_2X_1X_0 = 00000000$$
$$Y = Y_7Y_6Y_5Y_4Y_3Y_2Y_1Y_0 = 00000000$$

Thus the output of Baugh–Wooley multiplier is

$$S = S_{15}S_{14}S_{13}S_{12}S_{11}S_{10}S_9S_8S_7S_6S_5S_4S_3S_2S_1S_0 = 0000000000000000$$

This pattern lasts for 100 ns. After that, at time moment t = 100 ns, the input pattern is changed to

$$X = X_7X_6X_5X_4X_3X_2X_1X_0 = 11111111$$
$$Y = Y_7Y_6Y_5Y_4Y_3Y_2Y_1Y_0 = 00000001$$

According to previous analysis, the output of Baugh–Wooley Multiplier is (Table 1)

$$S = S_{15}S_{14}S_{13}S_{12}S_{11}S_{10}S_9S_8S_7S_6S_5S_4S_3S_2S_1S_0 = 1111111111111111$$

The input rising/falling ramp (0–100 %) is set as 0.1 ns. The simulated voltage waveforms of input $Y_0$ and output MSB $S_{15}$ for the Baugh–Wooley multiplier based on traditional array architecture is shown in Fig. 9. The corresponding

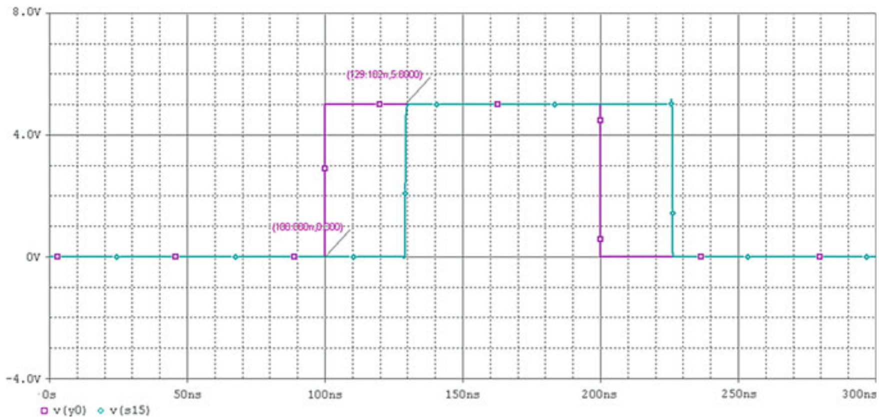


**Fig. 9** Delay test of array multiplier

simulated waveforms for the Baugh–Wooley multipler based on Wallace tree architecture is shown in Fig. 10.

The delay of the multiplier is defined as the time difference between the input transition and output MSB ($S_{15}$) transition. As shown in Fig. 9, the delay time of the Baugh–Wooley multiplier based on array architecture is $t_{d\_array} = 29.102$ ns. Howver, in Fig. 10, the input transition of $Y_0$ and the output transition of $S_{15}$ is almost coincident. That is, the delay time $t_{d\_wallace}$ of the Baugh–Wooley multiplier based on Wallace tree architecture is approximately zero, which is much less than that of the array multiplier. That is, the Baugh–Wooley multiplier based on Wallace tree architecture is much faster than the Baugh–Wooley multiplier based on array architecture.

## *4.2 Power Analysis*

In order to compare the power consumption, an input sequence of ten consecutive patterns is applied to both multipliers, as shown in Figs. 11 and 12. Each pattern lasts for 50 ns, The input rising/falling ramp (0–100 %) is set as 0.1 ns. The simulation time T is set as 500 ns.

The simulated voltage across capacitor ($V_C$) of the both multipliers, which is numerically equal to their average power consumption during time t = 0–500 ns, are shown in Figs. 13 and 14 separately.

From Fig. 13, we can see that at t = 500 ns, $V(P_{av}) = 9.1331$ mV. That is, the average power dissipation of the Baugh–Wooley multiplier based on array architecture during time period of t = 0–500 ns is:

$$P_{avg\_array} = 9.1331 \text{ mW} \tag{5}$$

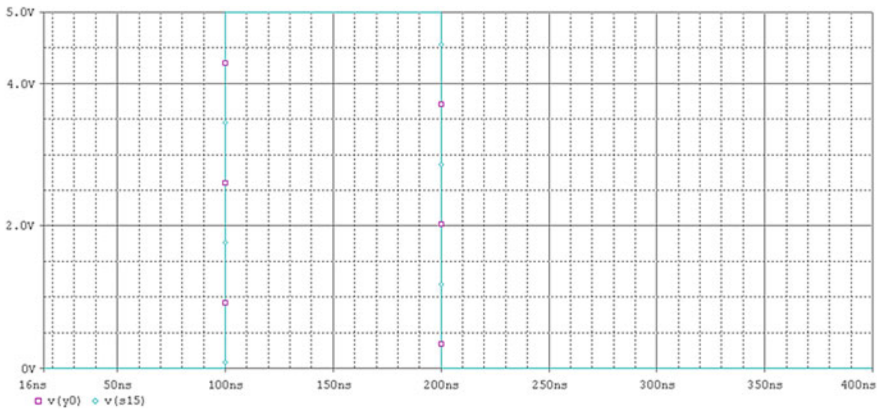


**Fig. 10** Delay test of Wallace tree multiplier

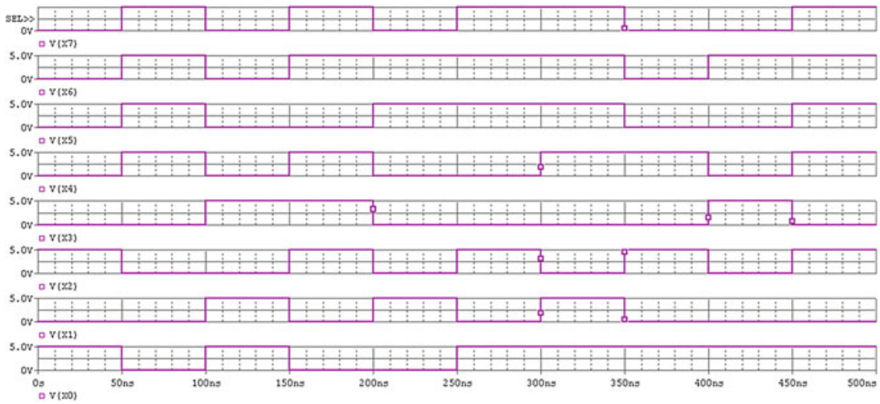


**Fig. 11** Power simulation input patterns for $X_7$–$X_0$

In Fig. 14, at t = 500 ns, V($P_{av}$) = 1.2329 mV, thus the average power dissipation of the Baugh–Wooley multiplier based on Wallace tree architecture for the same given input pattern sequence is:

$$P_{avg\_Wallace} = 1.2329\ \text{mW} < P_{avg\_array} = 9.1331\ \text{mW} \tag{6}$$

Thus for the same given input pattern sequence, the power saving of 8-bit Baugh–Wooley multiplier based on Wallace tree architecture compared to the multiplier based on array architecture is:

$$\begin{aligned} P_{save} &= \frac{P_{avg\_array} - P_{avg\_Wallace}}{P_{avg\_array}} \times 100\ \% \\ &= \frac{9.1331 - 1.2329}{9.1331} \times 100\ \% = 86.5\ \% \end{aligned} \tag{7}$$

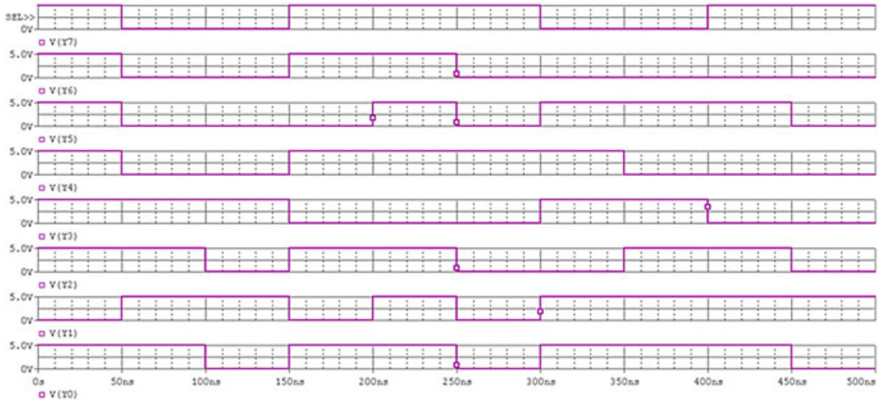


**Fig. 12** Power simulation input patterns for $Y_7$–$Y_0$

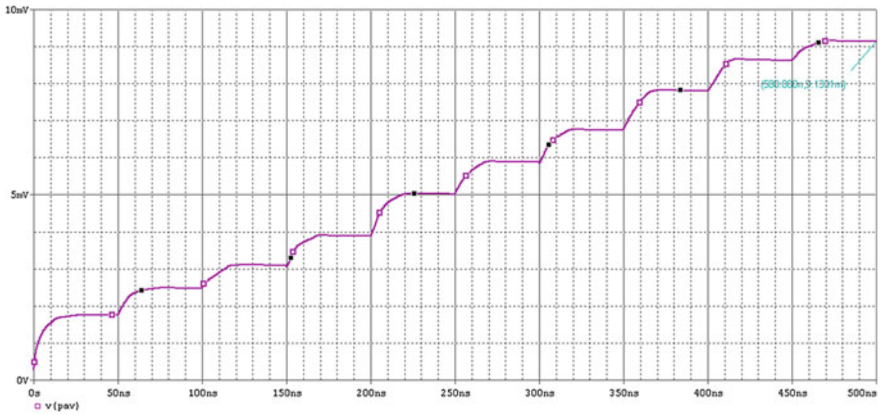


**Fig. 13** Simulated power curve of Baugh–Wooley multiplier based on array architecture

Although the given input pattern sequence is only a special case, it verifies that the Baugh–Wooley multiplier based on Wallace tree architecture leads to lower power consumption compared to the Baugh–Wooley multiplier based on array architecture.

## 5 Conclusions and Future Work

In this paper the design and simulation of an 8-bit Baugh–Wooley multiplier based on Wallace tree architecture is proposed. In order for performance and power comparison, an 8-bit Baugh–Wooley multiplier based on array architecture is also designed and simulated. PSPICE simulation results show that the Baugh–Wooley

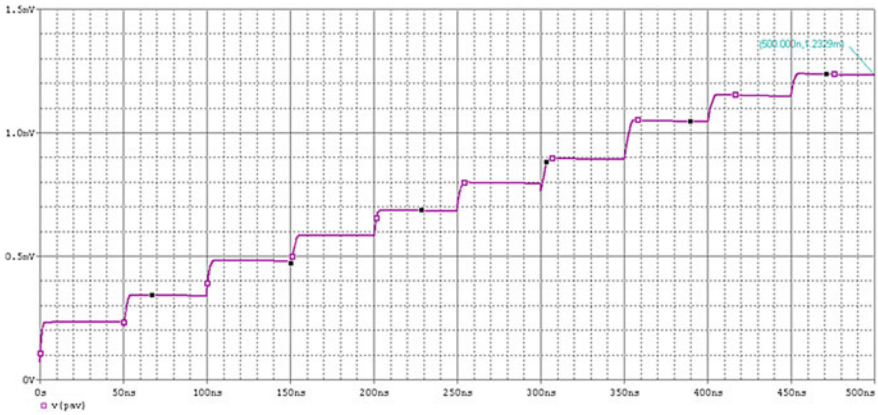


**Fig. 14** PSPICE power simulation of Baugh–Wooley multiplier based on Wallace tree architecture

multiplier based on Wallace tree architecture works much faster than the array multiplier. Furthermore, it consumes much less power than the Baugh–Wooley multiplier based on array architecture.

Although being fast, the Baugh–Wooley multiplier based on Wallace tree architecture has the disadvantages such as larger circuit area and increased complexity. Our future work will aim at further reduce the circuit area and complexity for the Baugh–Wooley multiplier based on Wallace tree architecture.

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# Rapid Prototyping and CAD/CAM in Building Design Education: A Very Early Introduction to Mass Customization

**Neander Silva and Ecilamar Lima**

**Abstract** This paper describes the experience of integrating 3D computer modeling, rapid prototyping, digital fabrication and mass customization into the first-year design studio at the Faculty of Architecture and Urban Design, University of Brasilia. A Problem-based learning approach has been adopted in a progressive exploration of three different architectural languages: a cubist/minimalist, a deconstructive one and a curvilinear one. This provides the students with an early opportunity to explore the paradigm shift from mass standardization to mass customization which is taking place in contemporary architecture.

## 1 Research Problem

The very early introduction of computing in an architectural education curriculum is often met with resistance by many faculty members. The most common argument against this approach is that students must learn how to draw by hand before being introduced to computers [1]. It is believed that students' skills will be hampered if computer techniques are taught before learning hand drawing.

Another common argument is that such early teaching of computing necessarily leads to less creative designers. This argument is usually connected to the first one

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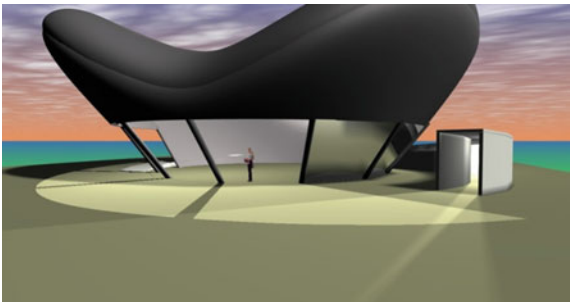

**Fig. 1** Exhibition pavilion by Rubiana Lemos

in which the ability to draw by hand is confused with the very ability of designing [1]. In other words, if you do not draw by hand you are not designing properly. This seems to be a reductionism. First, drawing is not the only way to design and it has never been. The architect's predecessor, the master builder who existed until the end of the High Middle Ages, used many design tools. Robbins, having undertaken a careful examination of that evidence, affirms:

> … the use of drawing in architecture as we know it today is relatively recent and historically situated… whatever the role of drawing in ancient architecture, it was still not a dominant instrument of design… Drawing was one technique among others that architects used… The role of drawing probably did not shift much after the fall of Rome. If anything, its use may well have declined… [2].

These statements are corroborated by the work of other authors [3, 4]. Therefore, the historical evidence from the Ancient World to the High Middle Ages does not support the claim that drawing was always the prevailing way of designing and building.

Second, there is no evidence that early teaching of computing necessarily leads to less creative designers. On the contrary, previous studies have shown [5, 6] that students' creativity actually increased as they became more proficient with 3D interactive computer modeling. Kalisperis states in his early work at Pennsylvania State University:

> Students are encouraged to design in three dimensions from the beginning of conceptualization. Through simulation and testing of the building design students go beyond convention and explore movement in both time and space… The more talented students immediately start using 3D techniques, taking advantage of the visualization capabilities… [5].

These studies have shown that the more the students mastered 3D computer modeling the more venturesome they became. This paper also corroborates these earlier studies as shown in Figs. 1, 2, 3, 4, 5, 6, 7 and 8. The great variety of formal solutions and the lack of repetition refute the idea that computers inhibit creativity.

The argument that computers can hamper the learning of hand drawing is also an anthropomorphic statement. It seems to imply the computer is the designer rather than a tool. We believe that the computer is a design tool, a machine to execute sequences of instructions, not a designer. The best way to illustrate this is

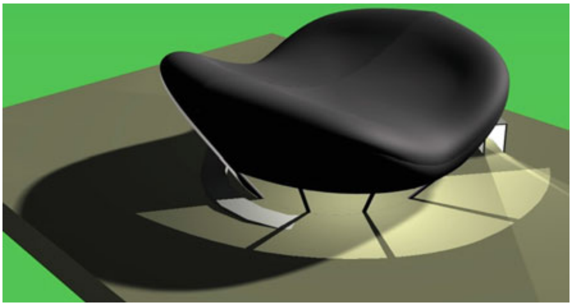

**Fig. 2** Exhibition pavilion by Rubiana Lemos

**Fig. 3** Exhibition pavilion by Júlia de Paula

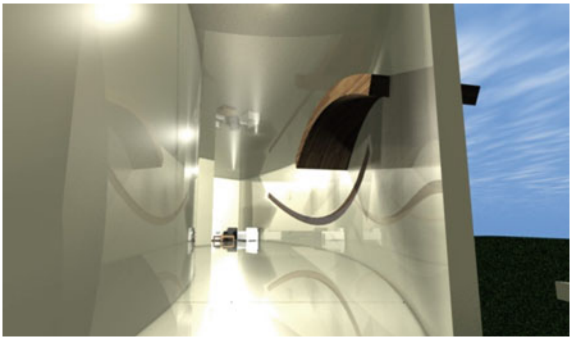

**Fig. 4** Exhibition pavilion by Júlia de Paula

the fact that the computer will take no designing action before told to do so by the user. Sit in front of it and cross your arms and nothing will happen until you tell it to do something. If properly mastered, every shape or form a computer models is the product of the user's sequence of inputs, choices and decisions. The human designer remains the creator.

Certainly the advent of computers did cause the demise of the technical drawing pen and tracing paper in architecture and in engineering. However, it must be stressed this decline can only be attributed to computers if confined to the manual production of 2D orthographic design documentation [7].

Another assumption is that computers only automate activities and procedures that would otherwise be carried out by hand. The assumption follows that they just increase speed and precision but do not allow the user to do different things in relation to those which were done by hand. This might have been true regarding 2D computer-aided design tools, but it is a different matter when we refer to interactive 3D computer modeling. We can only compare like to like. Hand drawing has many things in common with 2D computer graphics, but has substantial dissimilarities with interactive 3D computer modeling. Although they are both intended to represent design, the way they do it makes them two very different things; they do not perform the same roles. They are two different representation systems which allow for different perceptions and analysis of the proposed building.

When a student is introduced to interactive 3D modeling on a computer, he or she is learning to do different things from those that could be achieved by hand drawing. A virtual three-dimensional model is not just an equivalent to a hand drawn representation or even to a scaled model as it has been believed by some in the past [8]. Besides representing the "four dimensions of architecture", width, height, depth and time, as described by Zevi [9], it allows for many experimentations and analysis which cannot be provided by a hand drawing, a scaled model or any other traditional media. A virtual 3D model offers many exclusive resources such as interactive walk-through, real scale and immersive perception of the proposed space, designing complex non-Euclidian geometries [10], solar animation, global illumination calculation, object animation, digital fabrication [11] and mass customization [15], just to mention a few of them. Therefore, it cannot be understood as just another way to do the same old things.

## 2 Hypothesis

At our school of architecture we have decided to challenge those misconceptions. We have decided to introduce very early into the design studio not only interactive 3D computer modeling, but also the concepts of digital fabrication [11] and mass customization [15].

Our decision was driven not only by the conviction that those assumptions were fallacious, but also by our previous experience in teaching interactive 3D computer modeling to third-year students in our school for more than nine consecutive years. During all this time the only type of computing that was taught mandatorily in our school was a 2D drafting system.

3D modeling tools could only be taught as an elective course in the third year of our undergraduate program. Students taking this course have consistently shown great resistance to designing in a 3D environment because the habit of representing in 2D orthographic projections had already become too ingrained into their minds. This led us to the conclusion that the earlier the better for introducing interactive 3D computer modeling.

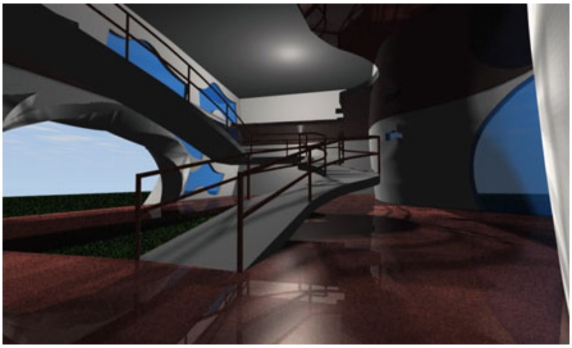

**Fig. 5** Exhibition pavilion by Hernany Reis

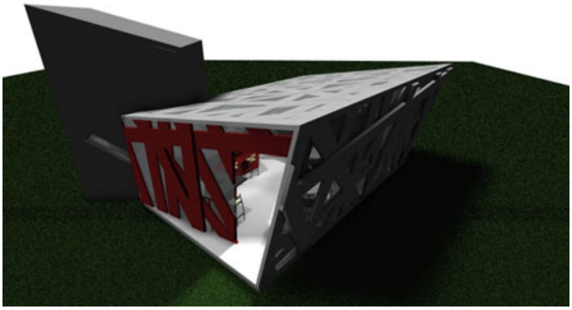

**Fig. 6** Cafeteria by Talita Córdova

**Fig. 7** Exhibition pavilion by Rafael Paula

We decided to do so by adopting a problem-based learning (PBL) approach [12, 13]. The chosen point in the curriculum was the second term of the first year of our undergraduate program. Adopting a PBL approach meant that different courses had to be integrated around the design studio of that semester. Therefore, we started to implement a project integrating the teaching of interactive 3D computer modeling within the second term design studio.

As previously mentioned, the most important issue we wanted to bring to the knowledge and consideration of the first-year design studio students was that of

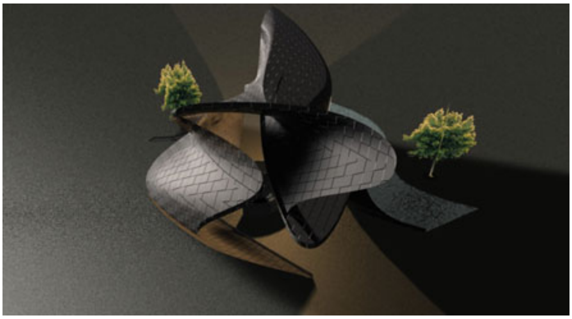

**Fig. 8** Exhibition pavilion by Caroline Barreto

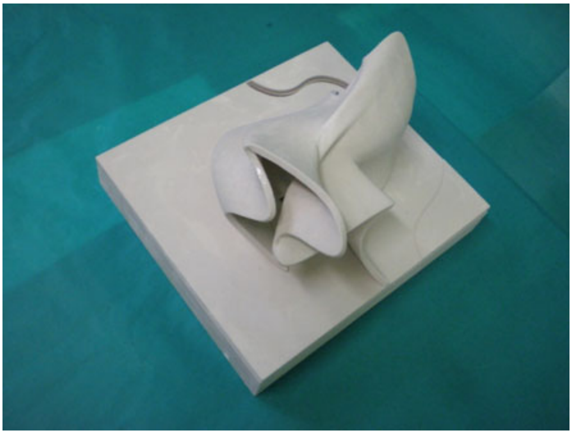

**Fig. 9** Addictive RP model: exhibition pavilion by Caroline Barreto

digital fabrication [11, 14] and its practical implications for architectural design and construction. The most relevant of these implications was the paradigm shift from mass standardization to mass customization in contemporary architecture [15, 16].

## 3 Research Method and Results

This paper describes the ongoing experience of integrating 3D computer modeling, digital fabrication and mass customization into the first-year design studio at the Faculty of Architecture and Urban Design, University of Brasilia. This teaching project takes place in the second-term of our first-year undergraduate architectural program.

This experience has now been carried out for five consecutive semesters and it has involved around 140 students so far. The use 3D solid modeling tools, suitable

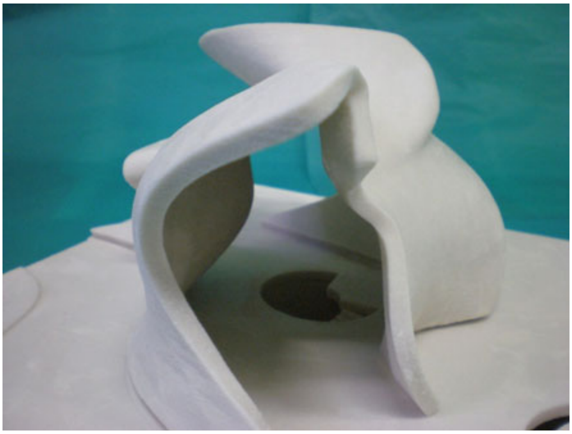

**Fig. 10** Addictive RP model: exhibition pavilion by Caroline Barreto

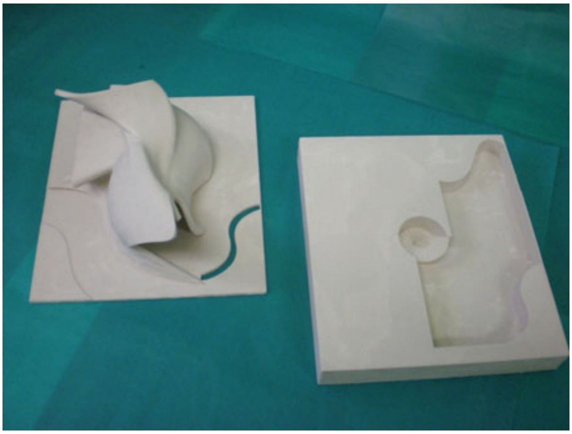

**Fig. 11** Addictive RP model: exhibition pavilion by Caroline Barreto

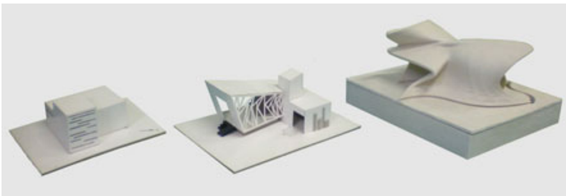

**Fig. 12** Three projects, three languages, one transition from standardization to mass customization, by Caroline Barreto

for free form explorations and digital fabrication, has been paramount in this teaching project.

Significant obstacles had to be overcome in order to implement and develop this teaching approach. However, we found that most of these were not related to technological limitations but rather to the philosophical misconceptions and fallacies described and refuted earlier in this paper.

The students of the first-year, second-term studio are required to develop three projects for a small cultural and entertainment park. The first one is small administrative building, the second one is a cafeteria/snack bar and the third one is a small exhibition pavilion.

The theme of the chosen design studio is architectural languages and expression. For this reason a set of requirements and restrictions was established for each of these design projects comprising not only functional, constructive and environmental aspects, but also formal requirements. The objective of this was to encourage the students to develop three projects exploring the possibilities of three different architectural languages. The first, with predominantly orthogonal planes and using prefabricated standardized components, leads to a cubistic and minimalist architectural language. The second project, with shapes derived from the dislocation of points, segments and faces and using a mix of standardized and customized components, leads to a deconstructive architectural language. The third and last project, with shapes derived from deformations or made out of meshes and NURBS and using predominantly customized components, leads to a curvilinear contemporary architectural language.

The students have also been required to design three-dimensionally by simultaneously making physical and virtual models. The physical models are more often handmade, but rapid prototyping (RP) is also used in the most complex works produced in the design studio course (Figs. 9, 10 and 11). In all cases the role of rapid prototyping is to inform and to show the students, at least, the existence, the feasibility and potential of digital fabrication technology.

The main objective of those three projects with three different languages is to provide the students with an opportunity to gradually develop and apply their computer modeling skills in design, from simple to complex forms and from small to large buildings (Fig. 12), while at the same time gradually breaking the boundaries of mass standardization and shifting to mass customization.

## 4 Conclusions

We believe our contribution resides in the introduction of 3D interactive computer modeling together with digital fabrication and mass customization concepts and processes in very early architectural design education.

We believe our research showed promising results: we found that the students did manage to design beyond the boundaries of cubistic and minimalist architectural languages. There was no evidence of less creativity or repetition. In fact our students' projects showed a large degree of creativity through new and complex forms, no fear of experimentation and a venturesome attitude.

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# Design and Implementation of Nonlinear Control Strategies: A Tutorial

**J. F. Briones, M. A. Paz, J. L. Gallegos, J. I. O. Rodriguez and M. O. Aguilar**

**Abstract** The aim of this chapter is to propose a methodology for the design and implementation of a nonlinear controller for a single input and single output nonlinear system applicable to property which is required to submit the full relative degree. This methodology is validated with the illustration of two examples related to plant first and second order compared to a conventional classical control strategy and applied to solving the typical problem of control (regulation and servo-control).

## 1 Introduction

The control and feedback processes play a crucial role in nature and particularly in the engineering processes, in fact, they could not prevail if there were no control and feedback, even if you had no direct knowledge of their execution or operation. Intuitively, the feedback is information from the system and used to change their behavior, so that when this happens, is running some action to control [1].

From the above, taking into account feedback from the output information of a given process to generate an input signal for the same process, is said to have a closed loop and in the context of control engineering, a closed loop control.

The closed loop is formed, so basic elements such as: sensors and data acquisition systems, digital signal processors, controllers, actuators (see Fig. 1).

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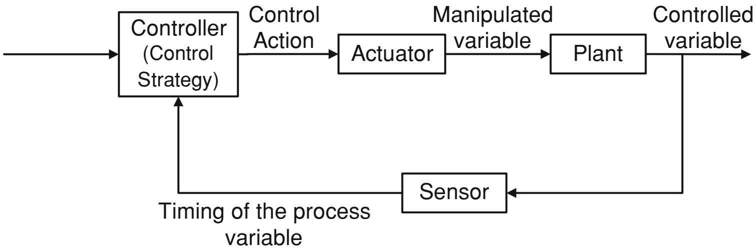



**Fig. 1** Components of a closed loop control

The synthesis of the control strategy (controller) of the control target must be consistent with the nature of the plant, and that it has the proper structure for feedback and control, so in this case is:

1. Consider only one input (i.e. only one variable manipulated to induce a specific dynamics on the plant), and a single output (i.e. only available for a variable output feedback of the plant).
2. Include the nonlinear characteristic of the plant, this because most processes are modeled by nonlinear equations, which for this case are used complex control schemes (e.g. non-linear control), or other control strategies (e.g. classical control), employing an approximate linear operating point the nonlinear system [2].
3. Define the disturbances and parameter variations known [1] (in cases of lack of these can be estimated through the use of observers and the process output variables).
4. Define the typical control problem as [3]: Maintaining the stability of closed loop control, with the appropriate disturbance rejection and robustness to parameter variations of plant (regulation problem), plus the controlled variable reaches the value reference quickly and accurately as possible (problem of servo-control).

Thus, to meet the control objective, this paper follows the steps stated in [1] applied to a first order process (tank level) and second order (two stage heat exchanger tube), and these are:

1. Characterize the plant for control purposes; defining what is expected of closed loop (an objective is to solve the typical problem of control).
2. Selecting the control structure (which in this case is a classic control approach as nonlinear control), and design the control system (statement of the law of control).
3. Tune the control parameters in order to meet the control objective while solving the typical problem of control.
4. Implement and validate the closed loop control, which for purposes of this study is only at the level of simulation software in LabVIEW.

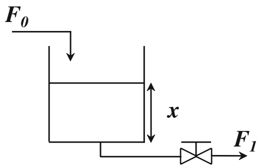



**Fig. 2** Liquid storage system with level change

# 2 Design of Control Strategies

As explained in the previous section, this lays down the processes to be analyzed:

*A. First-Order Plant: Emptying a Tank*

Whether the system shown in Fig. 2 which is considered as the input variable the volumetric flow $F_0$ and the output variable at the height $x$.

The mass balance for this process is defined as Eq. (3)

$$\frac{d(Ax\rho)}{dt} = F_0\rho - F_1\rho \tag{1}$$

Where $t$ is the time variable, $x$ corresponds at the height of liquid in the tank, $F_0$ and $F_1$ are the volumetric flows entering and leaving the tank respectively, $A$ is the sectional area of the tank and $\rho$ is the density of the liquid. Assuming that the density of the liquid and the cross sectional area of the tank are constant, and that the outflow is regulated by the valve which is based on the height of the liquid as:

$$F_1 = a\sqrt{2gx} \tag{2}$$

Where $a$ is the constant of the valve and $g$ is the acceleration of gravity. To which, substituting the Eq. (2) in (1) establishing the first-order dynamic model to control as:

$$\frac{dx}{dt} = \frac{F_0 - a\sqrt{2gx}}{A} \tag{3}$$

## *2.1 Dynamic Evolution Process of Temperature in a Double Pipe Heat Exchanger in a Countercurrent Operating System*

Consider the double pipe heat exchanger depicted in Fig. 3, in which the fluid in the inner tube is at a higher temperature than the liquid in the annular space of the equipment. The process variable vector $x$ is the hot temperature ($x_1$) and cold temperature ($x_2$).

Thus it is assumed that: (i) the evolution of heat exchange is only a function of time, (ii) heat transfer only occurs between the inner tube and annular space (no heat loss to the outside of the external tube), (iii) the flow of hot and cold fluids are

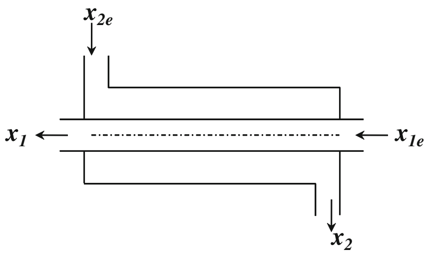



**Fig. 3** Double pipe heat exchanger countercurrent system

piston-type, (iv) the heat capacity of the inner tube wall is negligible (i.e. there is not accumulation of heat in the equipment and the heat is exchanged only between the fluids), (v) the effect of heat transfer in the direction of flow of fluids as well as the entire equipment size is negligible, (vi) the flow, density and heat capacity of the hot and cold fluids are constant.

The energy balance for the system described is [3]:

$$\begin{aligned} \dot{x}_1 &= \left(\frac{2}{M_1}\right)\left(F_1(x_{1e} - x_1) - \frac{U_i A_i}{Cp_1}\Delta x\right), \\ \dot{x}_2 &= \left(\frac{2}{M_2}\right)\left(F_2(x_{2e} - x_2) + \frac{U_o A_o}{Cp_2}\Delta x\right). \end{aligned} \tag{4}$$

Where $t$ is the time variable, $x$ is the vector of temperature given as $x = [x_1, x_2]^T$, $F_1$and $F_2$ are the volumetric flow in the inner tube and annulus respectively, U is the integral coefficient of heat transfer, $A$ is the sectional area of heat transfer, $Cp$ is the heat capacity of fluids, $\Delta x$ is the mean temperature difference which can be varied [4], but in this case is chosen to be logarithmic: $\Delta x = [(x_{1e} - x_2) - (x_1 - x_{2e})]/ln\ [(x_{1e} - x_2)/(x_1 - x_{2e})]$. The subscripts *1* and *2* denote hot and cold temperature respectively, while the subscripts $i$, $o$, and $e$ represent the value of the transport and the thermodynamic property in a certain position of equipment such that $i$ refers to the inner tube, $o$ refers to the annular space, and $e$ refers to the position of entrance in the equipment.

The control objectives to raise both the declared plants (3) and (4) are respectively:

1. The control of the height $x$ through the manipulation of $F_0$ flow.
2. The control of the hot temperature $x_1$ through the manipulation of $F_2$ flow.
3. A common objective for both plants is to solve the typical problem of control previously defined in this chapter.

To achieve the objectives stated above for each plant, in this paper has been proposed a classical control strategy and a nonlinear control strategy.

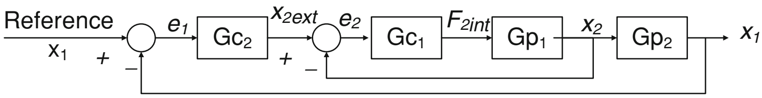



**Fig. 4** Classic control scheme cascade

## 2.2 Classical Control Strategy

For the application of classical control by considering Fig. 1 despising the dynamics of the actuator and the sensor. The analysis of the transfer function of the plant (3) defines this as the first order, however, is not linear in its outflow end of declared $F_1$ (2), and according to Taylor linearization given by [5]:

$$f(x) \approx \sum_{n=0}^{\infty} \frac{1}{n!} \frac{d^n f(x)}{dx^n}\bigg|_{x_0} (x - x_0)^n \tag{5}$$

Using Eq. (5) with $n = 1$ in (2), the outflow $F_1$ has been approximated by:

$$F_1 \approx a\sqrt{2gx_0} + \frac{ag}{\sqrt{2gx_0}}(x - x_0) \tag{6}$$

Where $x_0$ is a point of interest for this case is referred to the initial condition of the height in the tank, i.e. $x_0 = x(0)$, and combining the Eq. (3) to (6) and as stated as the objective of control 1, applying the Laplace transform and be the variable $x$, $F_0$ the output and input in the plant respectively, the transfer function is:

$$G_p = \frac{K_p}{\tau_p s + 1},\ K_p = \frac{\sqrt{2gx_0}}{ag},\ \tau_p = \frac{A\sqrt{2gx_0}}{ag} \tag{7}$$

And defining the action of such classic PI control given by:

$$G_c = K_c\left(1 + \frac{1}{\tau_I s}\right) \tag{8}$$

The fluid flow $F_0$ is calculated using Eq. (8) and thereby guarantees the existence of a control action such that given the control objective 1 can be completed.

In the case of second-order system given in (4), the nonlinear term is given in $\Delta x$, in this case does not apply the definition of (5) in ti but is considered a simple average temperatures $\Delta XMA = [(x_{1e} - x_2) + (x_1 - x_{2e})]/2$, which allows the proposed plant is linear in nature as well as separable variables in terms of temperature vector $x$ and in this case for the application of classical control strategy is part of a cascade control scheme illustrated in Fig. 4.

As outlined in Fig. 4, and applying Laplace transform to system (4) with $\Delta x$ as the arithmetic mean difference temperature is proposed that $Gc_1$ and $Gc_2$ are proportional control strategies, while $Gp_1$ and $Gp_2$ are first order given by:

$$G_{p1} = \frac{K_{p1}}{\tau_{p1}s + 1},\ G_{p2} = \frac{K_{p2}}{\tau_{p2}s + 1},\ G_{c1} = K_{ci},\ G_{c2} = K_{co} \tag{9}$$

Where:

$$\begin{aligned} K_{p1} &= \frac{U_iA_i}{C_{p1}M_1},\ \tau_{p1} = \frac{2F_1}{M_1} + \frac{U_iA_i}{C_{p1}M_1}, \\ K_{p2} &= \frac{2}{M_2(x_2 - x_{2ext})},\ \tau_{p2} = \frac{2F_{2\text{int}}}{M_2} + \frac{U_oA_o}{C_{p2}M_2} \end{aligned}. \tag{10}$$

Both $Kc_i$ and $Kc_o$ are the proportional control gains for internal and external closed loop, respectively, and for practical purposes in cascade control schemes $Kc_i > 3Kc_o$ [6]. And with the overall transfer function ($G_T$) between $x_1$ and the reference value for $x_1^{reference}$ defined as:

$$G_T = \frac{G_{p1}G_{p2}G_{c1}G_{c2}}{1 + G_{p1}G_{c1} + G_{p1}G_{p2}G_{c1}G_{c2}} \tag{11}$$

And replacing in the Eq. (11) the declared into (9) and (10), then exists a control action $F_2$ that stabilizes the $x_2$ to some reference $x_{2ext}$ and, under certain conditions of $Kc_i$ and $Kc_o$ the state $x_1$ tends at the $x_1^{reference}$ by completing the statement in control objective 2:

$$\begin{aligned} x_{2ext} &= \frac{M_1C_{p1}}{U_iA_i}K_{ce}\left(x_1 - x_1^{reference}\right) \\ &\quad - \frac{2F_1M_1C_{p1}}{U_iA_i}(x_{1e} - x_1) + (x_{1e} + x_1 - x_{2e}) \\ F_2 &= \frac{M_2}{2(x_{2e} - x_2)}\left(K_{ci}(x_2 - x_{2ext}) - \frac{U_oA_o}{M_2C_{p2}}\Delta x_{MA}\right) \end{aligned} \tag{12}$$

## 2.3 Nonlinear Control Strategy

The design of a nonlinear control uses the next proposal affine system:

$$\begin{aligned} \dot{x} &= f(x) + g(x)u \\ y &= h(x) \end{aligned} \tag{13}$$

The $f(x)$ and $g(x)$ vector fields are smooth and real valued whereas $h(x)$ is the vector of measurable outputs of the plant [7]. And for the design of the control strategy must be chosen from the plant to be controlled, the variable that will induce the desired dynamics and thus define the vector field $g(x)$, so that later sets if contained in the vector field can influence the rest of the plant given by the vector field *f (x)* and if the chosen output *h (x)* as feedback to the plant can achieve the proposed control objective.

This requires obtaining a scalar value of the projection of the output *h(x)* on the vector field *f(x)* to obtain the influence of such removal on the part referred to the plant, then obtain the projection of the field vector *g(x)* and see whether the choice of the vector fields *f(x)* and *g(x)* can carry out the control of the plant. These projections are made through the application of gradients ($\partial h(x)/\partial x$) and directional derivatives of function *h(x)* along the vector field *f(x)* under the rules of the Lie algebra [8]:

$$\begin{aligned}
&\frac{\partial h(x)}{\partial x} \stackrel{def}{=} \left[\frac{\partial h(x)}{\partial x_1}, \ldots, \frac{\partial h(x)}{\partial x_n}\right], \\
&L_f^0 h(x) \stackrel{def}{=} h(x), \\
&L_f h(x) \stackrel{def}{=} \sum_{i=1}^{n} \frac{\partial h(x)}{\partial x_i} f_i(x) = \frac{\partial h(x)}{\partial x} f(x), \\
&\vdots \\
&L_f^k h(x) \stackrel{def}{=} L_f(L_f^{k-1} h)(x) = \frac{\partial L_f^{k-1} h}{\partial x} f(x).
\end{aligned} \tag{14}$$

And to find the effect of the vector field *g(x)* for control over the remainder of the plant *f(x)* and output *h(x)* is necessary to test the relative degree *r*, which can be done by either graphically and analytically.

For graphic proof, as defined in [9] it is considered that the related system (13) may be associated with a given graph by a set of vertices or nodes and a set of connections given by:

- The set of vertices is connected to the control inputs *u*, and states *x*.
- The connection set consists of lines that connect two or more vertices according to the rules:
  - If $\partial\ _{fi}(x)/\partial_{xk} \not\equiv 0k,\ i = 1,\ldots,\ n,$ then there is a connection $x_k$ to $x_{i.}$
  - If $g_{ki} \not\equiv 0i = 1,\ldots,\ n,$ then there is a connection from $u_i$ to $x_{k.}$
  - If $\partial h_i(x)/\partial x_k \not\equiv 0k = 1,\ldots,\ n,$ then there is a connection form $\mathrm{x_k}$ to $h(x_i)$.

Where $f_i$ and $g_{ki}$, denote the i-th element of the vector fields *f(x)* and $g_k(x)$ respectively. A path of a graph is a particular sequence of nodes and connections, and also defines the length of the route as the minimum number of nodes that the path contains. With this, the relative degree *r* is equal to the *length of the route −1*.

For analytical testing the relative degree *r* must be the smallest integer such that the output effect is reflected in the vector field *f(x)* and *g(x)* [8]:

$$L_g L_f^k h(x) = 0,\ L_g L_f^{r-1} h(x) \neq 0 \tag{15}$$

In this chapter has been considered only the case in which the relative degree $r$ is equal the number of states of the plant to be controlled. Under the considerations of (14) and (15), the related system (13) becomes:

$$\begin{aligned} \dot{x} &= L_f h(x), \\ &\vdots \\ x^{(r-1)} &= L_f^{r-1} h(x), \\ x^{(r)} &= L_f^r h(x) + L_g L_f^{r-1} h(x) u \end{aligned} \tag{16}$$

If the control action has been defined from (16) in order to induce some dynamics to the plant (4), the nonlinear control law is:

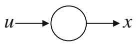
$$u = \frac{-L_f^r h(x) - \sum_{i=0}^{r-1} k_i L_f^i h(x)}{L_g L_f^{r-1} h(x)} \tag{17}$$

Where $k_i$ is the vector of control gains, and these are chosen from the error system formed by the substitution of (17) in (16) has a Hurwitz polynomial $\lambda^r + k_{r-1}\lambda^{r-1} + \cdots + k_1\lambda + k_0 = 0$. To illustrate this, we analyze the first-order system (3) and the second-order system (4).

For the first order system (3) and in relation to the related affine system (13) and with the control objective 1 previously raised:

$$f(x) = \frac{-a}{A}\sqrt{2gx},\ g(x) = \frac{1}{A},\ y = h(x) = x. \tag{18}$$

Thus, the relative degree graphical proof can be applied declaring the vertices and related connections:




The minimum length of the route between the control input and state to control is $2$, so that the relative degree is $1$, i.e. $r = 2\text{-}1$, which in this case is considered complete to match that number integer with the total number of states present at the plant to be controlled. Now, apply the Eq. (14) and (15) with definitions (18) we have:

$$\begin{aligned} L_f^0 h(x) &= 0,\ L_f h(x) = \frac{-a}{A}\sqrt{2gx}, \\ L_g L_f^0 h(x) &= \frac{1}{A} \neq 0. \end{aligned} \tag{19}$$

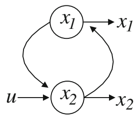
And since $L_g L_f^0 h\ (x) \neq 0$, the relative degree is $1$, i.e. $r\text{-}1 = 0$ such that $r = 1$. Thus, there is a nonlinear control law derived from the expression (17) which allows bringing the affine system (3) to a reference value $x^{ref}$ with a gain $k_0 < 0$:

$$u = \frac{-L_f h(x) + k_0 L_f^0 h(x)}{L_g L_f^0 h(x)} = \frac{\frac{a}{A}\sqrt{2gx} + k_0(x - x^{ref})}{1/A} \tag{20}$$

In the case of second-order system stated in (4), in terms of the affine system (13) and objective control 2 previously established, then:

$$\begin{gathered} f(x) = \begin{pmatrix} \left(\frac{2}{M_1}\right)\left(F_1(x_{1e} - x_1) - \frac{U_i A_i}{Cp_1}\Delta x\right) \\ \frac{2U_o A_o}{M_2 Cp_2}\Delta x \end{pmatrix}, \\ g(x) = \begin{pmatrix} 0 \\ \frac{2}{M_2}(x_{2e} - x_2) \end{pmatrix}, y = h(x) = [x_1, x_2]^T. \end{gathered} \tag{21}$$

The test of the relative degree in graphic is done with the definition of the vertices and related connections:




As described in the previous graph, the minimum length of the route between the control input $u$ and the state to control $x_1$ is $3$, so that the relative degree is $2$, that is, $r = 3 - 1$, that this case is considered complete the entire match that number with the total number of states present at the plant to be controlled. Now, apply the Eqs. (14) and (15) in the Eq. (21):

$$\begin{aligned} & L_f^0 h(x) = x_1, L_f h(x) \\ & L_g L_f^0 h(x) = 0, L_g L_f h(x) = \frac{-4U_i A_i (x_{2e} - x_2)}{M_1 M_2 Cp_1}\frac{\delta \Delta x}{\delta x_2} \neq 0, \\ & L_f^2 h(x) = \left(-\frac{2}{M_1}\right)\left(F_1 + \frac{U_i A_i}{Cp_1}\frac{\delta \Delta x}{\delta x_1}\right) \\ & \left(\frac{2}{M_1}F_1(x_{1e} - x_1) - \frac{U_i A_i}{Cp_1}\Delta x\right) - \frac{4U_i U_0 A_i A_o}{M_1 M_2 Cp_1 Cp_2}\frac{\delta \Delta x}{\delta x_2}. \end{aligned} \tag{22}$$

And $L_g L_f h(x) \neq 0$, the relative degree is $2$, that is, $r - 1 = 1$ such that $r = 2$, then there is a nonlinear control law derived from the expression (17) which allows bringing the system declared (4) to a reference value $x_1^{ref}$ manipulating $F_2$ and a set of gains $[k_0, k_1] < 0$:

**Table 1** Nominal values used in the numercial simulations in concurrent and countercurrent heat transfer

| Parameters | First-order system |
|---|---|
| $F_0$[=] $m^3$/min | 20 |
| $a$[=] $m^2$ | 1.5 |
| $A$[=] $m^2$ | 15 |
| Parameters | Second-order system |
| $Ui$[=] kcal/$m^2$ °C hr | 100.244 |
| $Uo$[=] kcal/$m^2$ °C hr | 89.653 |
| $Ai$[=] $m^2$ | 0.2736 |
| $Ao$[=] $m^2$ | 0.3040 |
| $F_1$[=] kg/hr | 11.279 |
| $M_1$[=] kg | 0.767 |
| $M_2$[=] kg | 3.258 |
| $Cp_1$[=] kcal/kg °C | 0.999 |
| $Cp_2$[=] kcal/kg °C | 0.997 |
| $x_1e$[=] °C | 90 |
| $x_2e$[=] °C | 29 |

$$
\begin{aligned}
u &= \frac{-L_f^2 h(x) + k_0 L_f^0 h(x) + k_1 L_f h(x)}{L_g L_f h(x)} \\
&= \frac{\left(\frac{-2}{M_1}\right)\left(F_1 + \frac{U_i A_i}{Cp_1}\frac{\delta \Delta x}{\delta x_1}\right)\left(\frac{2}{M_1}F_1(x_{1e} - x_1) - \frac{U_i A_i}{Cp_1}\Delta x\right)}{\frac{-4 U_i U_0 A_i A_o}{M_1 M_2 Cp_1 Cp_2}} \\
&\quad \frac{-\frac{4 U_i U_0 A_i A_o}{M_1 M_2 Cp_1 Cp_2}\frac{\delta \Delta x}{\delta x_2} + k_0(x_1 - x_1^{ref}) + k_1\left(\frac{2}{M_1}F_1(x_{1e} - x_1) - \frac{U_i A_i}{Cp_1}\Delta x\right)}{\frac{-4 U_i U_0 A_i A_o}{M_1 M_2 Cp_1 Cp_2}}
\end{aligned} \tag{23}
$$

## 3 Results

This section presents the simulation results of each of the proposed plants and with the control law proposed with the LabVIEW software. To perform the simulations, we assume nominal parameters for each plant illustrated in Table 1.

For first-order plant defined in (3) applies the PI control law given by (8) at time $t = 5$ as shown in Fig. 5, while the nonlinear control law expressed in (23) applies at the same time value and behavior described in Fig. 6. The control problem addressed in the terms described in its definition so that, for the first-order system induces a change in the variation of parameter of 5 to a value of 4 at time $t = 10$, while for the analysis of servo-control problem of inducing a change of 2 to a value of 4 at time $t = 20$.

For second-order plant given by the system (4) applies the classical control law given by P cascade (12) at time $t = 2$ as shown in Fig. 7, while the nonlinear control law defined in (23) applies the same value of time and its behavior is

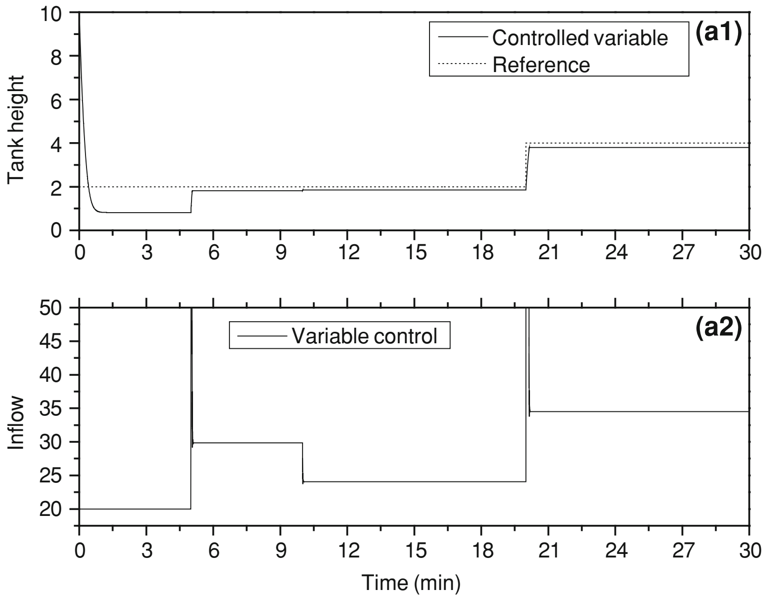



**Fig. 5** Tank level control using a PI control law (8). **a1** Behavior of the tank height. **a2** Behaviour of the inflow and control action with a saturation function with upper limit of 50 $m^3/m$

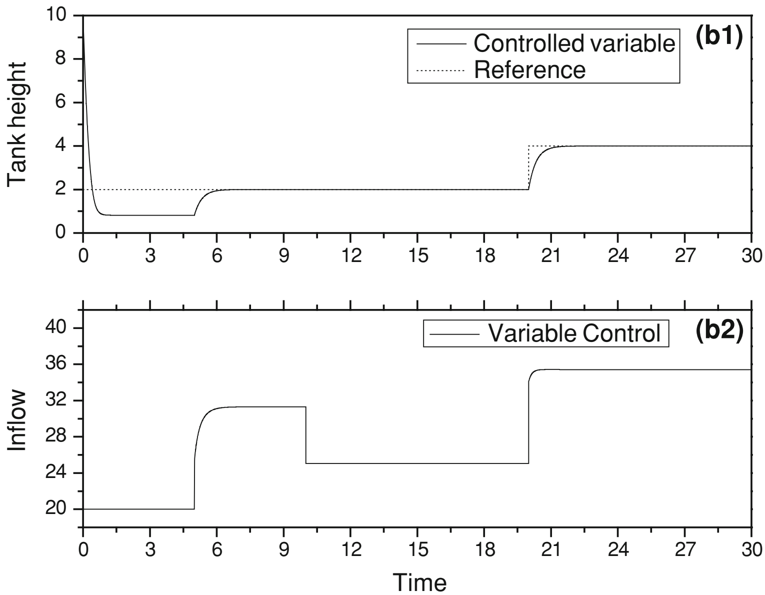



**Fig. 6** Tank level control using a nonlinear control law (20). **b1** Behavior of the tank height. **b2** Behaviour of the inflow and control action with a saturation function with upper limit of 50 $m^3/m$

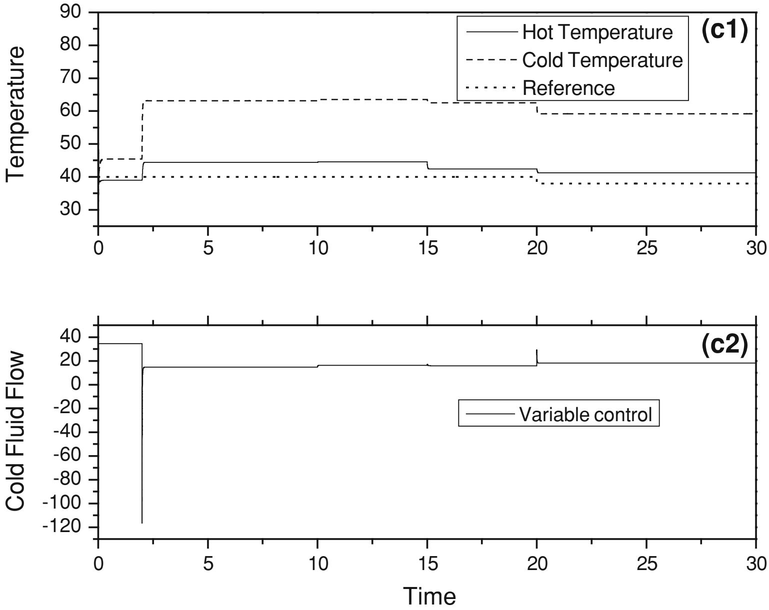



**Fig. 7** Numerical simulation of heat exchange in concurrent regime. **c1** Hot fluid temperature. **c2** Cold fluid temperature

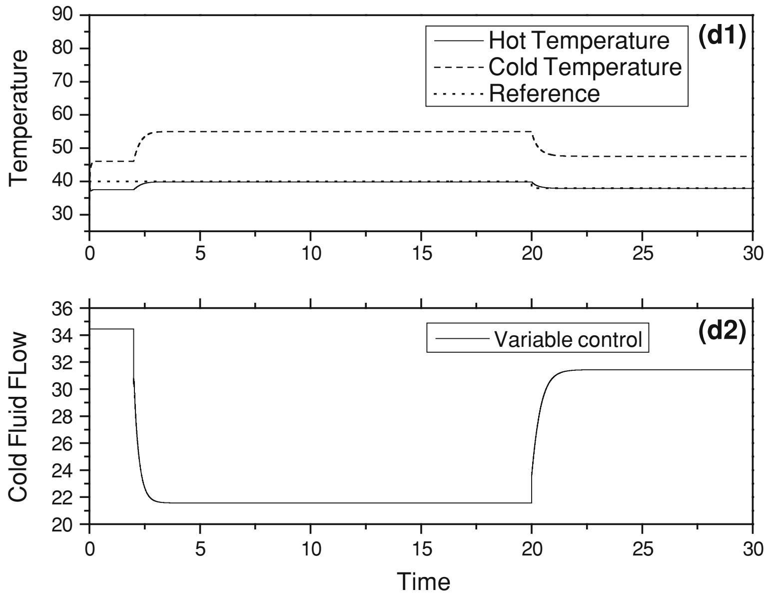



**Fig. 8** Numerical estimation of mean temperature difference. **a** Reference by observation in the inner tube. **b** Reference by observation in the annular space. **c** Definition of logarithmic mean temperature difference

described in Fig. 8. The control problem given in the definition given in previous sections for the second-order system, it induces a change in the variation of the parameter $U_o$ least 10 % of the nominal value of that at time $t = 10$, and includes a disturbance $F_1$ cargo flow of more than 10 % of the nominal value of that at time $t = 15$, while for the analysis of servo-control problem of inducing a change of reference of 40 ° C to a value of 38 °C at time $t = 20$.

## 4 Conclusions

The nonlinear control strategy assumes the nonlinear systems which allows linearising control actions with the exact cancellation of these nonlinearities which gives a better performance when it is compared with other closed-loop control strategies (e.g. those arising from Classical Control Theory), but it assume that the nonlinearities of the plant using algebraic approaches (e.g. Taylor linearization), its performance is not quite optimal.

This implies that control actions arising from a nonlinear control strategy are feasible to be physically realizable since they have no significant overshoot and its implementation implies gains control of small magnitude, and have a good performance against the problem of control, which does not happen at all in cases related to classical control.

Finally, the nonlinear control strategy allows for custom control actions to the plant type control (which is an unfavorable factor against the universality of the Classical Control strategies), and its synthesis involves laborious algebraic developments and considerable computing time, but by his performance justifies its application in plants, by nature nonlinear and their implementation in processes, control actions requires specialized.

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# Using PRINCE2 Project Management Methodology to Develop SOA Based Applications

**U. Şimşek and H. Gümüşkaya**

**Abstract** Service Oriented Architecture (SOA) is nowadays more stable and more mature considering both conceptual approaches and supporting technologies. SOA must be implemented in an enterprise-widely manner to take the advantages of it. In this paper, we present a novel approach to manage SOA based projects using PRINCE2 project management methodology. We show how the features of PRINCE2 are applied to achieve a better implementation of SOA in enterprise projects. A SOA implementation in an enterprise environment is realized as a Program which is a part of PRINCE2 concept. The Program consists of several projects. Some projects are used to establish the technical and principle SOA environment. Others will be SOA application projects.

## 1 Introduction

According to the Gartner's 2009 Hype Cycle Special Report [1], SOA is now in the "Slope of Enlightenment" area, and in a near future coming to the fruitful period called "Plateau of Productivity". Enterprises are aware of the potential of SOA and they are changing their software policies following the SOA principles and try to get the most valuable advantages of SOA. It is obvious that using a new technology has own risks, costs etc. Therefore SOA must be implemented very carefully for the sake of Return of Investment (ROI) and productivity. SOA is

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neither a product nor a technology. It is an architectural decision made by IT division of enterprises. Therefore using a proven project management methodology to implement SOA is crucial. This paper focuses on implementation of SOA using PRINCE2 (PRojects IN Controlled Environments) project management methodology [2]. We first introduce the important aspects of SOA and PRINCE2, and then state how to apply PRINCE2 principles in SOA based applications.

## 2 Related Work

SOA is sometimes accepted as a new technologic improvement used for enterprise applications. It is sometimes considered as an individual software development project. In fact SOA is an architectural software development concept which should be implemented in an enterprise environment. To implement SOA and get the most of its benefits, there are some conceptual and technology related efforts which must be considered together. One of the concepts is SOA governance. SOA governance is an ideal SOA creation activity to lead an enterprise to better maturity levels of SOA making correct decisions.

There are several software development and life cycle methodologies. These are usually used for realizing any types of software development projects. None of the well known and highly-accepted methodologies are SOA specific. Only SOMA which was emerged recently focuses on this subject [3]. There is an analysis work for the use of agile methods for SOA development [4]. This study presents the fundamentals of agile software development and assesses their suitability for SOA-based systems. Another work is about system dynamics for SOA modeling [5]. The paper offers a framework for SOA projects and shows how system dynamics can be used to enhance the effectiveness and agility of SOA projects. Another framework is proposed to manage SOA projects to determine the scope and estimate cost and effort [6].

PRINCE2 and CMMI are mapped to take the similar or alike features of both methodologies but there are not any analyses or suggestions about using either of these methodologies to manage SOA projects [7]. An MDA and PRINCE2 combined models are proposed from the approach of parallelism in both methodologies in obtain to discuss its advantages and disadvantages [8].

There are still some gaps when considering managing SOA projects and developing SOA-based applications in enterprise environments. What we are trying to do is to examine SOA principles, technologies and development methodologies under one of the proven project management methodology PRINCE2 to establish an SOA environment and implement SOA projects.

# 3 Creating SOA Environments

## *3.1 Establishing SOA Principles*

There must be an analytical study project which analyses and specifies SOA principles in an enterprise environment. This is an almost always necessary procedure because an enterprise always has its own existing and already serving software systems and it is nearly impossible to find an enterprise which does not have any software environment. The implementation should be starting from this point. Enterprise environment, infrastructure and its priority are investigated widely and very well in an initiation project. Besides the vision and any future steps of enterprise and possible technological and methodological trends and inventions should be considered when the SOA environment is created.

There are several very common and wanted-by-everyone principles which are really boasted by SOA as followings:

Agility: We start with one of the most valuable benefits of SOA. There is a common project challenge called *change*. This can be involved in various projects from construction to media sector but when we talk about software development it can become fatal and can cause failure of software projects because software development is abstract, flexible and it changes fast itself with improvements and updates because of its defects and new bringing. Enterprises of present-day are agile and continuously changing and need to find their way through limitless and immense global environment mostly and yet again provided by technology with a companion software. Therefore software should be developed as fast as possible and be responding to new business imperatives. Every brand new software piece should respond to the needs of business and transform or change when every change of business needs before it is too late.

Reusability: Future reusability of SOA components and reuse of existing components of legacy systems should be a principle consideration. There must be a way to find useful services that can be directly used or combined using internal SOA environment. Unfortunately it is really difficult to achieve reusability always. The real need of business does not always match what we have in our hand. The information of future needs is of course only estimation. But this way of thinking brings us reuse of some code via integration and possible reuse of newly created application pieces. Once it is achieved, the developer does not worry about versions, platforms and other incompatibilities. He or she focuses on other issues which assures quality improvement of software.

ROI: Return of investment (ROI) is one of the financially problematic issues of every IT. IT is mostly seen as costly part of serving in an enterprise. Considerably huge investments of enterprise resources go to IT and the ROI of IT can be very difficult task to make satisfying explanations. Therefore ROI should be analyzed very carefully before and after SOA implementation to show the difference. Every SOA project should be realized with a good ROI and its natural advantage on this sphere.

Indeed SOA projects should have better ROI by their own natures. Evolving SOA across the enterprise frees up IT resources so that IT investments focuses on core capabilities aimed at growing the business. Reduced duplications, shorter development times, lower cost of integration, support and maintenance provide better ROI to SOA projects [9].

Integration: SOA cries for integration because of its characteristics. Agility, reusability, simplicity, flexibility and other bricks of SOA can be achieved only if integration environment makes it happen. Therefore integration environment must be considered as a pillar of SOA. As it is decided to implement SOA, an integration environment should be selected and deployed with other enabling technologies.

Security: Because of layered design of SOA, security should be maintained in every layer. The creation of a service layer by definition means that developers have created an additional network interface that can be used by multiple applications. When systems were built using monolithic or client–server methods, security was normally handled on the front-end. Companies often did not even implement database security because it is too hard to maintain multiple security lists. Services on the other hand are used by multiple applications, so they have their own security mechanisms. An application will therefore have multi-level authentication at both the client level and at the service level [10].

Availability: Another useful benefit of SOA is availability. Especially when SOA projects get more mature, availability issues should be considered more carefully. Because of location transparency of SOA, multiple servers may have multiple instances of a service running on them. If a network segment or a machine goes down, a dispatcher can redirect requests to another service without the client's knowledge.

More technical considerations which every SOA project should be aware of are as follows:

Simplicity: SOA is based on industry standards and can reduce complexity when compared with integrating systems on a solution-by-solution basis. They also enable future applications to mesh seamlessly with existing standards-based services.

Flexibility: SOA supports the building of next-generation composite solutions. These performance-driven solutions consolidate numerous business processes from multiple systems in a simple user interface.

Maintainability: SOA has a modular structure and divided into layers. Therefore the effort of maintenance can be focused on much more specific points. Because of simplicity of SOA the maintenance can be easier and faster.

Code Mobility: SOA provides a real transparency between layers, components and services. SOA enabling technology infrastructures provide redundant services which can alter a used web service or component with the others. Client side requests do not even notice the difference. So organizing services moving or spreading to other machines can be achieved stealthily.

Ease of Development: A SOA based application has multiple layers. Therefore every layer can be assigned to its own group of developers having specific roles and responsibilities. This is an advantage for companies because they can deploy more specialized and less experienced developers to develop SOA based applications.

Services which are used by SOA intensively have published interfaces that can be tested easily by developers by writing unit tests. It is possible to run test tools to validate the service independently. An application need not to be tested by a QA tester before the compilation of unit tests [10].

### 3.2 Analysis of Existing Systems

The existing systems of an organization should be investigated carefully in order to obtain to leverage its former investments in the beginning of SOA implementation. There is a need to determine which components of existing systems can be used to give any parts of business demands. To accomplish this task, some preceding steps can be taken:

- Matching current and possible future business service needs with the components of the existing systems. In this case the documentation of the existing systems may help bringing a successful extraction. There can be some work to modify the existing systems to be used in a SOA environment.
- Specification of necessary actions to reuse the existing components. The reuse can be achieved using migration, wrapping the components, changing the internals of the components. IT can be considered to create new interfaces for the components of existing systems.
- Calculating the cost and effort of reusing the components. This calculation should consist of all steps like data-mining, documentation, migration, additional or modification development processes.

The Service Migration and Reuse Technique (SMART) method of Software Engineering Institute can be used to estimate scope, cost and effort of the reuse steps [6].

### 3.3 Deploying Enabling SOA Technologies

Even SOA is considered as technology-independent, there can be cases a basic technology may improve and manage SOA implementation in organizations. Today many global technology leaders come with intensive solution packages for SOA implementations. Therefore it may be a better idea to evaluate this kind of packages. Technologies that enable SOA include:

Web Services: A common misconception is that business services are the same as web services. In fact, while web services are highly interoperable, making them excellent for composite business applications that span business boundaries, they are only one of several options available for SOA. Conversely, adopting web services standards does not automatically give you SOA.

Business Process Management: In general business logic, processes and flow are embedded or hard-coded in an application. So it is difficult or impossible to make changes and mostly needs the participation of IT staff. Some of emerging technologies make it possible to manage business process management by non-technical staff.

Some of SOA enabling technologies provides business process management infrastructure with graphical interfaces which are used for defining business processes.

Integration technologies: In a SOA environment all components like services, composite applications, are communicated with the help of integration technologies.

Enterprise Application Integration (EAI) can play an important role in an SOA environment. In order to achieve a business outcome, various systems which can be in current enterprise environment or provided by business partners, communicate to each other in a seamless and reliable fashion irrespective of geographical location or platform of these components. The communication between the components of SOA is provided by using asynchronous and synchronous message transportation, message acceptation, message delivery, routing and business process management.

Enterprise Service Bus (ESB) products are responsible for performing a function similar to EAI products. ESB is more focused on facilitation of SOA. ESB provides a messaging backbone used for message format transformation, protocol conversion, routing, accepting and delivering messages from various services and components.ESB is more lightweight so this improves its cost-effectiveness, flexibility and scalability.

It is also possible to prefer one of SOA application suites. This kind of suits offer a more complete SOA infrastructure adding portal functionality, workflow engines, business process co-ordination engines and more sophisticated business to business integration on top of EAI and/or ESB [9].

SOA repository: Because reusability is one of the most important advantages of SOA, it should be maintained very carefully. In order to achieve this goal a repository should be created. This keeps inventory of SOA assets like services, SLAs and components. Visibility of SOA ecosystem, flexible meta-models, automation of the collection of assets and lifecycle workflows are some of benefits of the repository. The repository can be very simple and maintained manually. In fact the repository can be maintained with an enabling technology much more successfully. The technology to keep the repository is already available in many SOA packages provided by big vendors.

### 3.4 Monitoring SOA

SOA is not only an independent application framework but a strategic decision of IT. SOA governance is a social change. The enterprise architect plays the role of the teacher or educator, not the policeman. The policing can be performed by the review board. Your role as the mentor to the application teams is to show them the value of governance; how they can benefit from the governance processes, policies, and tools in place; and how the additional work involved in following these policies can help them be more productive and deliver more business value. You must become a salesperson who tries to understand the application team's perception of pain from all these new policies and helps them work governance into their process. Be sympathetic about how they feel—but be ready to answer the tough questions. You need to understand and appreciate the value of governance before you can help others do so.

Another job of the enterprise architect is to continually monitor the SOA governance policies. You must keep an eye on which policies are working, which aren't, and which need to be tweaked. You need to be in touch with the review board to make sure policies are amended or created as needed. You must also ensure that policies are documented clearly and that the community of application architects and developers is kept abreast of the latest policies.

The success of the governance program lies on the shoulders of the enterprise architect. If your interactions with the application architects and developers get off on the right foot, you'll help the entire project move ahead more smoothly [11]. Periodically review the architecture.

## 4 Implementation of SOA

### 4.1 SOA Implementation Program

OGC, the owner organization of PRINCE2 states differences between projects and Programs as seen in Fig. 1. In our case "Driven by vision" of 'end state' will be SOA paradigm. SOA projects will be driven by business deliverables within SOA principles. As explained before SOA Program will be tending no pre-defined path but SOA projects will have defined start and finish. We will have two types of projects. Some projects will be responsible for establishing, controlling and maintaining SOA; others will be focused on business needs.

"Defined start and finish" will be very carefully maintained. SOA projects have certain and agile business outcomes. Business changes can affect the flow of Program but SOA output should be clear and well defined. The deliverables of Program are SOA Projects, deliverables of SOA projects are business products. Benefits of SOA should be realized along the Program but every closure of SOA project. A SOA Program can go on several years but a SOA project can have very

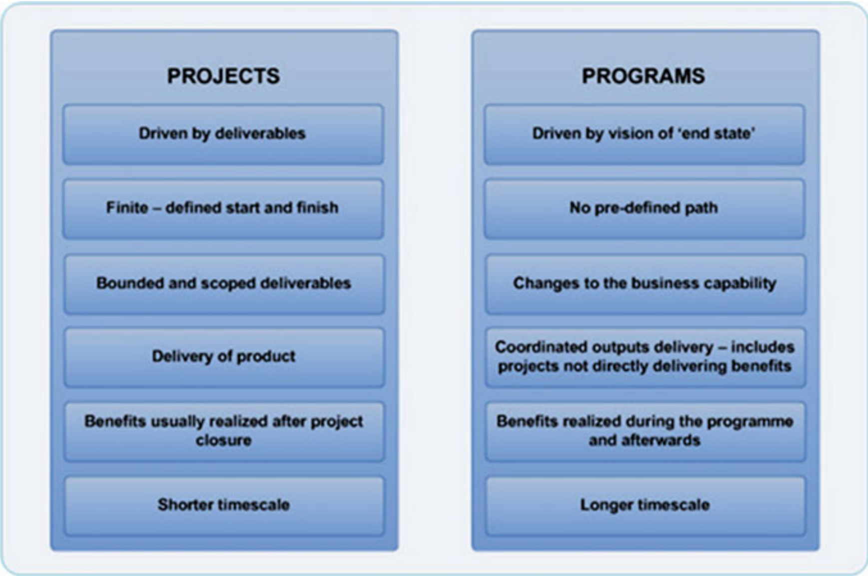



**Fig. 1** Differences between projects and programs

short timescale. Because business alignment is vital in this type of projects, projects closure day can be demanded yesterday of project initiation [12].

Finally SOA must be related to an SOA implementation Program. As you can see in Fig. 2, SOA implementation Program can consist of several projects:

SOA Initiation Project: The SOA principles of an enterprise should be analyzed and established. The SOA principles should be thought related members of SOA projects and realized by every SOA project. The processes and specifications of SOA should be determined in this step. After that it can be really useful to analyze existing systems. Finally an SOA implementation roadmap is created.

SOA Enabling Technologies Project: Before starting an SOA project having business outcome a technology which enables SOA should be deployed.

SOA Monitoring Project: After some SOA projects are implemented a monitoring project can be realized to measure, report and realign SOA projects.

SOA Projects: After realization of SOA Initiation and SOA Enabling Technologies Projects individual SOA projects which bring business outcomes can be realized. This type of projects can be parallel or one by one or with considerable time gaps.

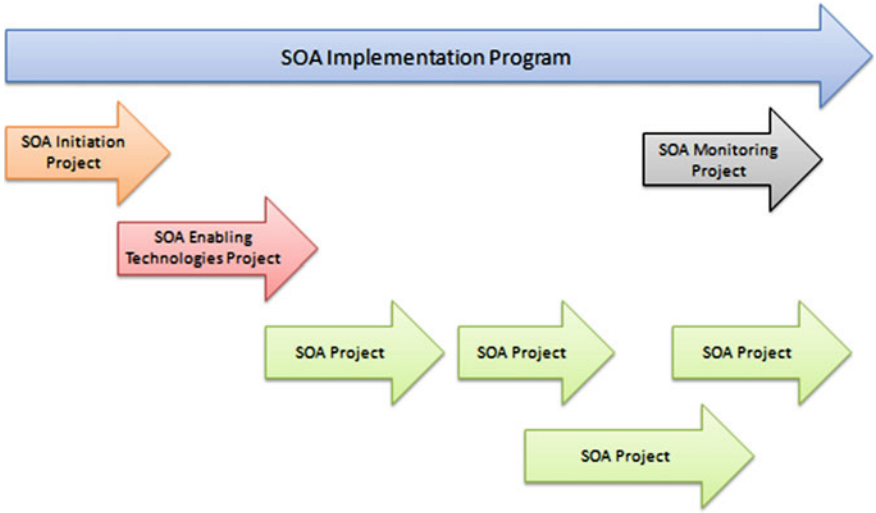



**Fig. 2** SOA implementation program layers

## *4.2 Using PRINCE2 Principles with SOA Principles*

Continued business justification and focus on products and their quality: These two principles of PRINCE2 should be important, but when we talk about SOA which serves business agility and productivity, PRINCE2 and SOA meets this exact point.

Learning from experience: This can be used when creating SOA services and composed applications. The creation process must look for experiences to decide a better balanced composition of SOA components. SOA looks forward to be keep its reusability and integration specifications.

It is tailored to suit the particular product environment: PRINCE2 is highly tailorable and this has a great importance when we talk about software development as well as different SOA applications. SOA projects can vary with their technical use, analytical use level, maturity.

## *4.3 Using PRINCE2 Themes to Gain More SOA Benefits*

The seven themes of PRINCE2 should be applied in every project, but some of them can bring SOA projects success.

Business case: One of the most matching concepts of both PRINCE2 and SOA is business focus. A PRINCE2 project is based on business case and keeps watching the business value of project in all circumstances. SOA is valuable because it provides business agility. Therefore one of the best starting points of SOA implementation is to specify a focus on delivering early business benefit. As stated before the principles of SOA should be included every single SOA project and the very starter project of SOA implementation which is the first state to create a fruitful environment for the implementation of SOA projects.

Organization: The purpose of the Organization theme of PRINCE2 is to define and establish the project's structure of accountability and responsibilities. PRINCE2 is based on a customer/supplier environment. It assumes that there will be a customer who will specify the desired results and probably pay for the project and a supplier who will provide the resources and the skills to deliver that result.

The PRINCE2 principle of defined roles and responsibilities states that a PRINE2 project will always have three primary categories of stakeholders. And the interests of all three must be satisfied if the project is to be successful. Figure 3 shows the three project interests. As it can be seen in Fig. 2 PRINCE2 methodology is focused on business and users and this is really important if the project is a SOA based application which has the same focus.

The products of the projects should meet a business need which will justify the investment in the project. The project should also provide value for money. The business viewpoint therefore should be represented to ensure that those two prerequisites exist before a project commences and remain in existing throughout the project. PRINCE2 makes a distinction between the business interests and the requirements of those who will use the projects' outputs [12].

Quality: The "product focus" principle is central to PRINCE2's approach to quality. This approach and SOA share the same goal. The quality theme of PRINCE2 is defined as meeting business expectations and enabling the desired benefits to be achieved subsequently.

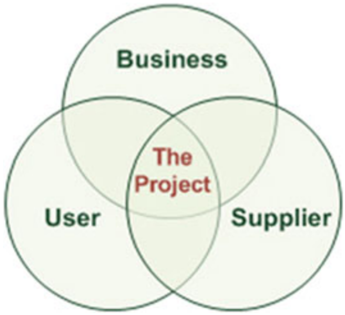
Change: If SOA is the answer to agile, responsive and service-oriented software development, it must be implemented in an agile and responsive manner. To achieve this, an SOA project should have a change mechanism. PRINCE2 provides the Change theme to identify, assess and control any potential and approved changes to the baseline.

Change is inevitable during the life of a project, and every project needs a systematic approach to the identification, assessment and control of the issues that may result the change. As changes may arise from project team members, stakeholder requests, complaints or a wide range of other factors, PRINCE2 provides a common approach to issue and change control. PRINCE2 provides both systematic and common approach, which ensures that issues possibly affecting the project's performance targets are appropriately managed.

### *4.4 Using PRINCE2 Processes for SOA Projects*

SOA implementation of an SOA project can be controlled and monitored thorough the project with the help of PRINCE2 processes.

**Fig. 3** The three project interests




The Project Board of an SOA project is defined by "directing a project" PRINCE2 process. Regular reports of the project are used for information of the project board. The project should be approved by the Project Board in "Initiating a Project" PRINCE2 process. Because PRINCE2 is based on delivering a product, an SOA based application should be delivered using "Managing Product Delivery" process. The project is divided into stages. Each stage should be completed and approved by the project board with the consideration of SOA principles using "Managing Stage Boundaries" process of PRINCE2. According to PRINCE2 a project must be closed down in a controlled and orderly way which means recorded learned lessons, completed handover document and post implementation review are created based on SOA concept.

## *4.5 Tailoring PRINCE2 toFit SOA Projects*

One of the PRINCE2 principles is to be tailored to suit project complexity, scale, culture etc. Tailoring is defined to using PRINCE2 appropriately on any project with correct amount and planning, control, governance and uses of the themes and processes.

PRINCE2 provides "Special aspects" mechanism with its flexibility and emphasis on the subject. Because it is generic, industry specific activities and methods are not available. Therefore PRINCE2 opens the gate of using necessary methods to implement SOA based and software development specific methods and techniques. All these aspects are categorized by PRINCE2 as "specialist work" meaning that these should be considered to be identified and included.

In our case some of object oriented software development methodology can be used to complete the implementation. To be more specific "service-oriented modeling and architecture" can be considered to mature our SOA based projects.

## 5 Conclusion

With the rich methodological approaches like principles, themes and processes and business intuition, PRINCE2 can bring big advantages to any SOA projects. PRINCE2 supports management of several projects which aims same business initiatives with the program mechanism which is highly capable of implementation of SOA projects.

SOA Implementation Program supports creation of SOA environment. This environment consists of principles, rules, templates and technical infrastructure bricks. Once SOA environment established, individual SOA projects which are focused specific business cases can be easily implemented. SOA projects can be realized sequentially or parallel. SOA monitoring works or projects can be applied in regular basis or before important business milestones in order to keep SOA in form to perform its best.

The future work could be on adding and bringing together additional features of other methodologies like CMMI, PMBOK, Object Oriented Analysis and Design techniques to establish a more advanced implementation framework. Every enterprise which has decided to implement SOA in its own specific business goals, can improve its business responsiveness, agility, cost-effectiveness etc. maturing SOA-based applications using a dynamic and progressive and maturing SOA implementation environment.

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# Logical Circuits Design Education Based on Virtual Verification Panel

**P. Pištek, R. Marcinčin, T. Palaj and J. Štrba**

**Abstract** The paper presents a novel method for teaching courses about logical circuits. Attracting students' interest is an issue that is being addressed in all courses. In general, students are more interested in doing practical exercises then learning theory and calculating or designing things on a piece of paper. In courses devoted to logic circuits design it is especially important that the students have the possibility to verify their designs and to experiment with various variations. Using universal virtual verification panel, the lessons can be more understandable. Our solution has limitation for logical gates as formerly had physical verification panels but also many other features which can be used during education. Experimental results show, that 90.2 % of students think that our solution is better than the old one [1].

## 1 Introduction

Universal virtual verification panel of logical circuits is a software tool for personal computers providing functionality to design logical circuits and verify the correctness of their function. Virtual verification panel is the successor to hardware verification panels. In the past, these panels were mainly used for educational purposes.

Hardware panels contains limited amount of logic gates of one or several types which can create one complete sets of logic. Students are expected to design the

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logic circuit filling the required function. Circuit can be constructed by interconnecting the gates with conductive links. Logic gates are placed on the printed circuit board with their inputs and outputs accessible from outside. The board contains circuit input points with both positive and negative value available. There are also circuit outputs represented by bulbs. User can connect gates to each other using bundled metallic cables.

These panels are no longer used for several reasons. The basic problem is strict area of usage. Specific panel is required for every complete set of logic. In addition, more than one panel of each type is needed in the education process to give students possibility to practice their skills. The second reason is the limited lifetime of these panels. As the interconnections between logic gates are not permanent as well as they are not being established in contactless way, considerable means for maintenance are required to keep the verification panels in good condition.

Given the continuing growth in the share of modern information technologies in the field of education, it would be the idea of hardware simulation at a computer program, which has indisputable advantages especially as concerns the financial as well as the functional side.

Although there are many logic simulators available, there is no solution providing the exact functionality of virtual verification panel with all its advantages. Logic simulator is typically complex software with amount of logic units giving possibility to create almost any circuit. User can choose one of many ways of construction with no limitations. There are two different approaches for logic simulators: a desktop application or a web application. Software Log [1] is a desktop application. It is quite outdated but for some of its functionality served us as a basic example. Log serves for design and verification of extensive circuits supported by rich library of logic gates. Compared to Log, LogicSim [2] has congenial user interface although the functionality is similar. One of the best find solutions (from desktop applications) is Multisim [3]. It is worth mentioning because it contains square drawing canvas which facilitates design of a circuit. It has many features such as extensive library, support of 3D circuit's design and so on. Main disadvantage of this solution is that it is commercial product and it is not freeware. On the other side Simcir [4] is a web application. This project is still not finished so it has some errors but it has good attitude to error states—user can't create error state in a circuit. Other solution is Logicly [5]. This web application is suitable only for beginners because it features are very limited and contains only a few basic gates. Simulators like Log, LogicSim or Multisim are widely-used and their functionality is fully sufficient in the area for which they are designed. On the other side, virtual verification panel simulates as many of the functionality of its hardware predecessor as possible. The great benefit is the option to limit the types of logic gates as well as their number. This option requires the user to be more creative and to find new ways of circuit's design. In addition, he is forced to utilize the resources more effectively.

Our goal was to create software (called HTP [6]) serving as an operational tool to simulate the behavior of the designed logical circuits including the advantages of verification panels. HTP also includes a simple way to define the user's own components identified by number of inputs, outputs and logical function. One of our sub-goals was also to generate logical expression [7] for designed circuit. The HTP was developed based on our experiences from description languages [8] and Petri Nets [9] which are basically another form of design of circuits.

However, the main benefit of this system is its component for distribution of tasks created by teacher to the specified group of students. This function supports e-learning as the effective way of education.

## 2 System Design

Universal virtual verification panel is expected to be, as the title says, universal. This means that it contains all the basic logical gates [10, 11] and complete sets of logical gates [12]. Moreover, our solution is universal to be used with any hardware and software platform supporting Java Virtual Machine.

### *2.1 User Interface*

User interface in our solution is clear and intuitive [13]. It is divided into three parts. The first part is the main desktop determined for design and verification of logical circuits. The second part is the side panel offering all the necessary logical gates and other user define components sorted in structured tree. The third part is the top panel including action icons e.g. *Save the circuit*, *New circuit*, *Load circuit* or *Activate/deactivate verification process*. There is also the standard menu bar above this panel with standard.

### *2.2 Functionality*

Our solution provides possibility for creating logical circuit from logical gates and components [14]. These are placed in the side panel and can be added to the desktop using drag and drop technique [15]. Interconnections are made by drawing lines between designated components. Verification process operates in real time; however it is possible to deactivate it, what can be useful in some special situation. The system differentiates all connections according to driven logical value.

The created logical circuit can by whenever saved to binary file being ready for next use. Next functionality provides possibility for adding the created circuit to the library of external logical circuits. After this addition the new circuit is shown in separated section in side panel between other logical gates and this external logical gate is available for use in other logical circuits. This function represents easy way to define own logical gates or modules of advanced logical systems.

In addition, our solution offers possibility to get logical expression representing designed logical circuit, what can be useful especially in process of back-checking or debugging.

Other functions like logic gates labeling or exporting the circuit into vector graphics (SVG) are implemented to make this solution more useful in process of publishing logic circuit schemes.

## 2.3 HTP Architecture

Architecture of our solution is divided into seven components ensuring all the functionality. These components are same in both student's and teacher's version, but there are some differences in the inner structure of the components.

The main component is *Graphical User Interface (GUI)* which is displaying the main window of the system including the desktop area, components panel and all the necessary controls.

*GUI* closely interacts with *Verificator*—component responsible for logic function verification. Implemented self-designed verification algorithm is based on recursive transition of logical value starting from the outputs of circuit. Three-state Boolean logic including the states of *Low, High* and *High-Z* is provided to simulate real conditions.

*Saver* and *Loader* components are used to save designed circuit into the binary file and to load it back when necessary. For this purpose they both use serialization technique [16, 17].

*Sender* with integrated *Timer* contains all the functionality necessary to send tests and example tasks and samples to the students. *Receiver* is responsible for receiving the tests from students. For detailed information about the functionality of these components see chapter Student Testing.

## 2.4 HTP Versions

### 2.4.1 Student

In addition to the standard modules for design and verification of logical circuit this version contains also modules for tests receiving, tests development (this module is special modification of module for logical circuits design) and sending tests back to teacher for evaluation (Fig. 1).

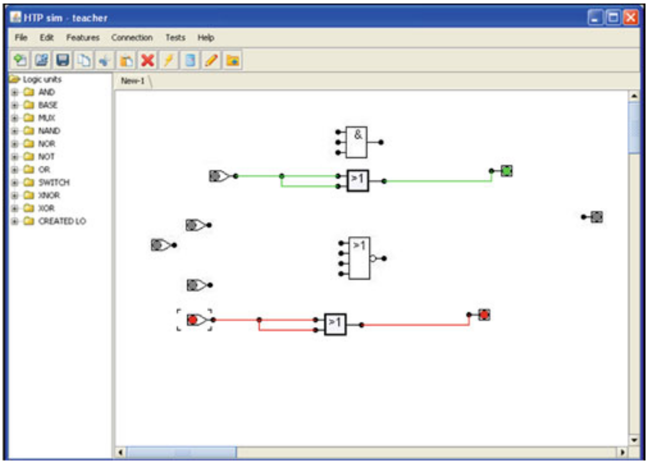



Fig. 1 Student's interface—solving of a task

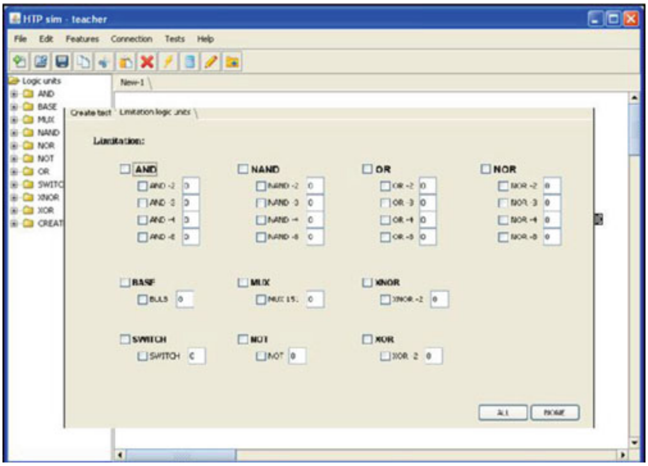



Fig. 2 Teacher's interface—a test creation

### 2.4.2 Teacher

Final system is implemented in two versions. The first version is created for students and the second one is edited for teachers. Each version is fully utilized for designing and verification of logical circuit.

This version contains also additional modules for creating tests, sending these tests to students and receiving them (difference between this module in student's and teacher's version is that teacher is expected to receive more than one tests back) and tests evaluation (Fig. 2).

# 3 Communication

As the distribution of the tests as well as collection of the answers is based on network communication, it is necessary to define the network protocol. We decided to create our own protocol providing desired functionality.

## 3.1 Communication Protocol

Our protocol is based on client–server architecture although the data will be transferred through peer-to-peer network. We decided to use client–server architecture because the client (HTP for students) will communicate only with one network entity (HTP for teachers). A peer-to-peer connection was chosen because these two parts of HTP are within one network segment with no server or another controlling device.

The protocol working on local area network is socket-based [18]. A socket is software that establishes bidirectional communication between a server and one or more client side of the HTP. The socket associates the server program with a specific hardware port on the machine, where it runs, so any client program anywhere in the network with a socket associated with that same port can communicate with the server program.

As number of client software are running at the same time is expected, system uses the technique of multi-threading (division into multiple threads). The server creates a thread for each newly created communication channel with client. Without this technique, the client would block the entire server in their communication. In our case, the server HTP can continue to receive requests from the other client while it is communicating with one client.

Communication is established only between server and client, so the exchange of information between clients is not allowed. Each client has a unique identifier which identifies it to the server. Unique ID is get from a random combination of numbers and name of the student. Every attempt to anonymous connection is ignored by the server.

## 3.2 Connection Establishment

Communication is based on two ways: broadcast and then direct communication between server-client and client–server.

At the beginning, server sends the hello packet to identify itself through broadcast and waits for a response. Client's HTP which has received this packet answers it. In response it sends its unique identifier (name of student) and waits for confirmation. If the answer arrives to the server, the address of client is saved and confirmation is sent. Hello packets are sent periodically to make it possible to discover the new clients connected later.

After creating a table of addresses on the server side and depositing the server address on the client side, server communicates directly with the client. Likewise, the client does not send data through broadcast, but directly to the server address.

# 4 Student Testing

Our solution creates a virtual classroom [19] in which students are able to obtain study materials and test their knowledge. This process takes place in several steps.

## *4.1 Registration*

Each student, who wishes to attend a course, has to register. The teacher has the opportunity to see all registered course participants. Registration is necessary for correct identification of student in order to his evaluation. Registration data including username and password are stored in the separate file. There can be as many files as necessary, i.e. one for each course, group etc. The teacher is able to select the file for the certain group.

## *4.2 Creating Example Tasks and Tests*

Teacher can create and edit tasks and tests for students on the course in the editor present only in the teacher system. Teacher has few options when he or she is designing tasks. He or she can either define the logic function while students have to design the circuit, or he or she can design an incomplete scheme and students are expected to complete it to provide required function. The teacher can limit the full set of logic which can be used to solve the example task or test.

## *4.3 Taking the Tests and Example Tasks*

Designed test or task is automatically sent to selected group of students and it is forcing them to close all the other open schemes and it is starting the timer after student's confirmation. After the time limit expires, tests are automatically sent back to teacher and stored as binary files being available to reopen for the purpose of back-check and assessment.

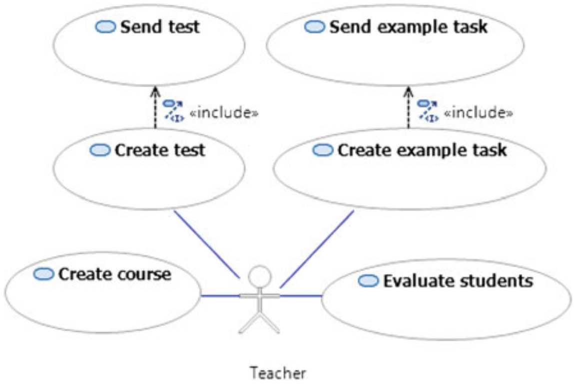



**Fig. 3** Use-case diagram of actor teacher

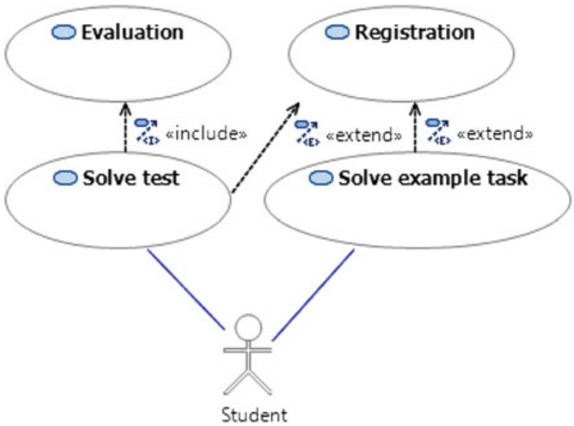



**Fig. 4** Use-case diagram of actor student

### *4.4 Test Evaluation*

To simplify the process of assessment, the simple tool for test evaluation is integrated. This tool generates the logic function of designed circuit and compares it with the function pre-defined by teacher. Based on the result, the status of test is changed to either Passed or Failed.

In the Figs. 3 and 4, there are shown brief diagrams of use-cases for both student and teacher.

## 5 Experimental Results

We tested our solution on one course on our faculty which is about basics from logical circuits and their design. On this course, students design specific logical combinational circuits (i.e. with NOR, NAND, AND-OR-NOT gates only) in

**Fig. 5** Question 1: Did you manage to create required circuit scheme?

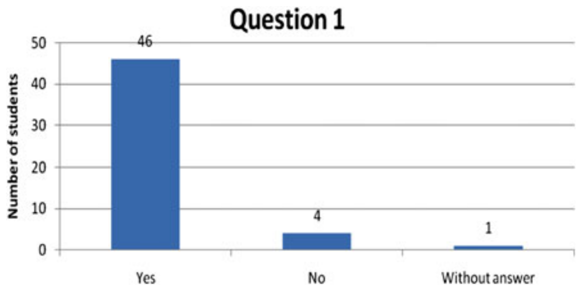
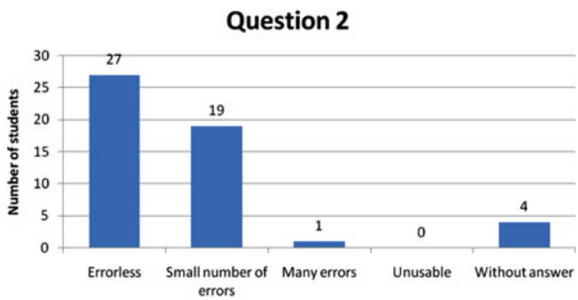



**Fig. 6** Question 2: How do you assess functionality of HTP program?




program Log. We prepared an assignment for one lesson. It was based on the first assignment which students solved a few weeks before. Basically, students should create scheme of a circuit from previous assignment and verify it in our solution. At the end, they filled a survey, which consisted of six questions and place for improvement proposals—we pick up 5 of them to this paper. This assignment was implemented on 3 different groups with 51 students together.

As you can see on Fig. 5, there were only four students who were not able to create circuit's scheme. Those students wrote reason why they didn't succeed. We understand their notices as their superficial work and insufficient work with manual because they made basic mistakes during using of our solution.

Figure 6 shows presence of errors. In this figure, quantity of errors during using of the program is shown. This was the first test of our solution with students we are glad that only 20 of them find an error, only one of them find more errors during working with the program and 27 of them didn't find any error.

One of our aims was also to create a well arranged graphical user interface. 32 students (see Fig. 7) thought that we succeed in this aim. Rest of the students wrote their observations about GUI improvements which were analyzed and some of them will be implemented.

There are a few complete sets of logical gates which can be use to design whole circuits (i.e. NOR, NAND, AND-OR-NOT). We implement some of these sets to our solution but not all of them—i.e. set NAND-AND-OR-NOT is not usually used in education but it can be added if necessary. In Fig. 8 you can see that all students who answer to this question think that our solution contains all basic sets compared to program Log which has all type of gates together in libraries.

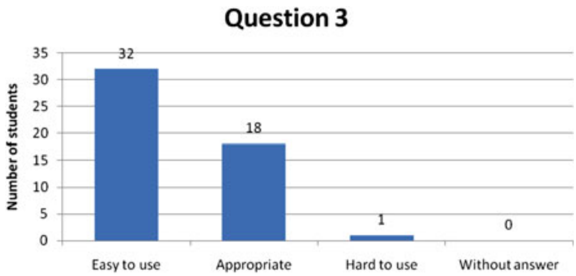



**Fig. 7** Question 3: How do you asses ease of use of HTP program?

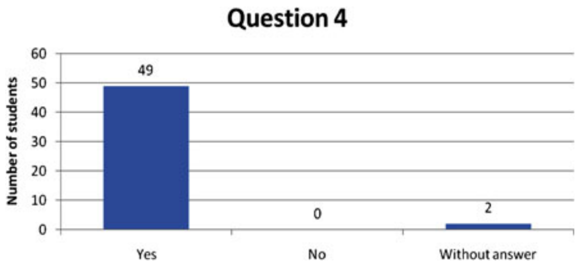



**Fig. 8** Question 4: Do you think that groups of logical gates in this solution completely cover all basic methods of circuit design?

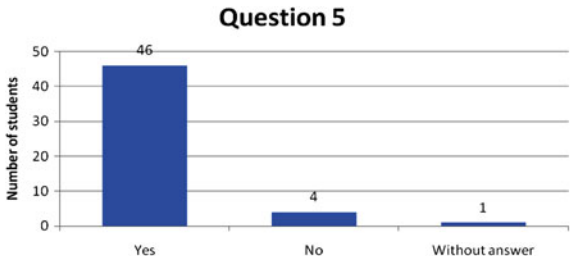



**Fig. 9** Question 5: Do you think that this solution is better than the present solution? (despite the potential errors)

The most important question was at the end of the survey (see Fig. 8): "Do you think that this solution is better than the present solution? (Despite the potential errors) ". Absolute majority of students think that our solution is better than the current one. Only four students have different opinion and this is caused by a few errors and their objections to GUI so this can be eliminated during integration of their observations (Fig. 9).

Besides this answers, we also obtain large number of suggestions for improvement. We plan to implement these suggestions till summer term and use our solution as the main one on the course of Logical circuits.

## 6 Conclusion

We design and implement solution which can be used as successor of physical verification logical panels. This solution was made as computer program and is independent on operating system. The system can be used as a tool for teaching and creating logic circuits, which will be verified in real time, or creating their own logic gates which will be saved and then re-opened and used. Students can be limited to specific sets of logical gates (i.e. NAND, NOR, AND-OR-NOT) but of course there is still option to use all gates together. This depends on actual teacher's needs during education. Testing on students and following survey show that this solution is easy to use (62.75 % of students) and it is better than the current one (90.2 % of students).

As a future work we also implemented network support for online testing of students but this feature will be used in the next term (due to restriction on courses in this term). In addition, we plan to implement students' suggestions which will improve this solution.

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# Extending LR Parsing to Implement Rewriting Semantics in Extensible Programming Languages

**Ernesto Ocampo Herrera and Leonardo Val**

**Abstract** Extensible programming is a software development technique where the programming language allows the developers to add new syntactic constructs. Consequently, developers can use this technique to enrich their programming language with new syntax specifically tailored to the problem domain in which they are working. However, the creation of an extensible programming language poses a series of implementation challenges and requires the use of specialized parsing algorithms. Although much discussion has taken place, there exists little information on precisely *how* extensible programming can be implemented, especially using LR parsing. This chapter presents a complete and operational set of implementation steps and the precise alterations to the LR parsing algorithm that are needed in order to create an extensible programming language.

## 1 Introduction

Extensible programming languages allow developers to extend the language by defining new syntactic constructs [1–4]. Special statements or declarations are used for this. After processing them, new constructs that were not valid before become supported. The following example illustrates a simple syntax declaration

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on a hypothetical extensible language lacking a 'for' loop construct, which becomes available after the declaration:

```
syntax Statement ::=
'for' '(' Statement:init ';' Expression:term ';'
Statement:inc ')' Statement:body {...}
//'for' construct now available
for (int i = 0; i < 10; i ++) {print i;}
```

In order to create new language constructs, the programmer must provide two specifications: the *syntax* and the *semantics*. Syntax specifications are expressed very similarly across most extensible languages: by using BNF or equivalent definitions. This owes to syntax definitions having been a very stable and mature area of knowledge for decades.

However, there exists little consensus regarding how the semantic specifications are to be expressed, as can be inferred from several publications [5–9]. That is, how to specify the *meaning* of a construct (intentionally omitted in the previous example). This chapter focuses on *rewriting,* which allows the programmer to state the semantics of a new construct using other constructs of the language being extended. This introduces changes in the parsing algorithm, which can be particularly challenging when using LR parsing. LR is interesting because it is the most general deterministic parsing algorithm known. Introduced by Knuth in the 60 s [10], its use is very widespread across programming languages.

Despite much work has been done on the concept of rewriting, not much information is available regarding *precisely how* it should be implemented, especially when trying to use an ascending parser, like LR. This chapter presents one possible solution: an enhancement to traditional LR parsing that enables rewriting, so as to implement an LR based extensible language.

## 2 Semantic Specifications

Techniques for expressing the meaning of a construct can basically be categorized into two main groups: a) those which involve extending the language processor[1] and b) those in which new syntax constructs are translated into older existing syntax constructs, reusing their semantics. The latter group is commonly called *rewriting*.

For example: let us assume that our extensible language has a 'while' loop construct but lacks a 'for' loop construct. The 'for' loop construct shall be added using the extensible capabilities of our language. To do so, we need to provide both a syntactic and a semantic specification, even though we will focus on the latter more deeply.

[1] We use the term 'language processor' to refer to either a compiler or an interpreter.

Using the first approach involves extending language processor so that it knows what to do with the new syntax. In a language like C, this would mean doing some programming and recompiling on the C compiler. In a language like Java, this would mean extending the compiler and possibly the JVM as well. However, languages designed for extensibility allow better mechanisms, such as linking dynamic libraries to find how to process a specific construct. The syntax extension declaration could look like the following in our hypothetical extensible language:

```
syntax Statement ::=
'for' '(' Statement:init ';' Expression:term ';'
Statement:inc ')' Statement:body
{
ForLoop(init, term, inc, body);
}
```

The syntax declaration, expressed in standard BNF notation, tells the language processor that a new syntax rule exists for statements. The processor then modifies its parsing algorithm in order to continue, since '`for`' statements are now valid. The declaration specifies that the construct is composed of other constructs: an initialization statement, a termination expression, an increment statement and a body. After processing each '`for`' statement, the parser has knowledge of four variables which represent parts of the construct: init, term, inc, and body.

Finally, the semantic specification between curly brackets tells the processor that the meaning of this construct is specified by '`ForLoop`'. This might be a class name, method, or function, depending on the processor implementation. The processor should use that logic whenever the '`for`' loop is to be executed (if interpreting) or compiled (if compiling). The main problem with this strategy is that '`ForLoop`' runs as part of the language processor. So in order to write it, the programmer needs extensive knowledge of the processor's internal structures and mechanisms, and some good knowledge on compiler design.

On the other hand, by using the rewriting approach, the semantics are defined based on already-existing constructs. In this case, the 'while' loop construct is suitable for the task. The syntax extension declaration could look like the following:

```
syntax Statement ::=
'for' '(' Statement:init ';' Expression:term ';'
Statement:inc ')' Statement:body
[
init ';' 'while (' term ') {' body ';' inc '}'
]
```

This specification is written using the same language that we are extending, thus reusing the semantics of the while construct. The specification comprises references to partial parsing results (variables init, term, inc, and body) and text fragments of code. When the parser processes a '`for`' construct, it will have those program parts available in the variables, and should behave as if the rewrite specification had been parsed.

This is not a text-level search-and-replace operation, like in the C preprocessor macros. Program parts being handled can be of arbitrary complexity and the full strength of a parsing algorithm is needed to determine their boundaries. Also, the rewrite definition is clearly not expressed in exactly the language being extended, but one with augmented capabilities to allow expressing how those program parts are to be combined with additional text code. As a consequence, parsing and using the rewrite definition requires multiple adaptations to the parsing algorithm.

## 3 Parsing Algorithms

A brief introduction to parsing algorithms is provided for the purpose of context. Nevertheless, readers are encouraged to refer to [11, 12] for further clarification.

From the theoretical point of view, parsing a given string (e.g. a program source) means deciding whether it belongs or not to a particular language. Since the language is defined using a grammar, the parser is inferred from it. Grammars are derivation systems which use both the alphabet of the language being defined (called terminal symbols) and other special symbols to represent concepts of the language (called non-terminal symbols).

From a compiler design point of view, a parsing algorithm is also expected to i) given a valid input, return a data structure that represents it (usually a tree like structure called AST - Abstract Syntax Tree) and ii) do it quickly.

The first point has lead to the use of grammars with additional specifications that build the structure (usually called semantic actions of the parser), while the second point has lead compiler designers to sacrifice generality for performance. This means that the most used algorithms enforce restrictions on grammars and are limited in the syntactic richness that they can process.

Deterministic parsing algorithms have evolved into two main categories: descending -especially LL($k$)-, and ascending -especially LR($k$)-, where $k$ is the look-ahead level. Both LL and LR are table-driven, linear time and space algorithms. However, while LL enforces many more restrictions on the grammars and can process fewer languages,[2] LR is remarkably more complicated to implement, understand, and modify.

[2] Both LL and LR can process an infinite amount of languages. However, LR can process all LL languages but LL cannot process all LR languages.

# 4 Rewriting Implementation

This section describes one possible solution, a set of enhancements to the LR parsing algorithm with which a rewriting mechanism can be implemented.

In this chapter, we shall call *token* to a symbol-value pair resulting of the parsing process. The symbol is either a terminal or a non-terminal, and the value is either the matched text—for terminals—or the AST built from parser actions—for non-terminals.

## *4.1 Extending the LR Parsing Tables*

When using rewriting, the semantic specification is written with an augmented version of the language, which allows defining how to transform one construct into another. These specifications must be validated first, to ensure that they rewrite to something syntactly correct. In order to do this, the ability to process non-terminals as input has to be added to the parsing algorithm.

Traditional parsing only expects terminals as input. It becomes clear from the previous example that *init*, *term*, *body* and *inc* are variables that represent tokens which symbols are non-terminals.

```
init ‘;’ ‘while (’ term ‘) {’ body ‘;’ inc ‘}’
```

Since the grammar comprises only symbols (not symbol-value pairs), only the symbol parts of these tokens are relevant to verify the syntactic correctness of this line of code. Conversely, as ASTs comprise only values, only the value parts of them are relevant to build the correct AST.

Every time that the parser receives a non-terminal, it must accept it only if there exists an arc in its automaton from the current state labeled with that non-terminal. That is, it must behave exactly as if the entire text that originated that token was at the input, but much faster—without re-parsing. This can be achieved by extending the LR ACTION table.

This table traditionally contains a column for each terminal—i.e. each possible input symbol—and we shall add a column for each non-terminal as well. All actions that were applicable to terminals now become applicable to non-terminals. Shifts for non-terminals symbols are to be calculated in the same way that shifts for terminals are: from the arcs in the LR automaton. This is different from standard LR, where arcs labeled with non-terminal symbols are considered to build the GOTO table.

Reduce actions in the table are calculated in the standard way (see [11] pp. 234), but as non-terminals may appear in the input, they must be considered in the lookup. Lookup is obtained from the *first* and *follow* sets, which calculation must suffer a minor change. Let $P$ be the set of grammar rules, *first* set $Fi$ and *follow* set $Fo$ are calculated as follows (changes are underlined).

$$Fi(\alpha) = \begin{cases} \{a\} & if\ \alpha = a\beta \\ Fi(A) & if\ \alpha = A\beta \wedge \lambda \notin Fi(A) \\ (Fi(A) - \{\lambda\}) \cup Fi(\beta) & if\ \alpha = A\beta \wedge \lambda \in Fi(A) \\ \{\lambda\} & if\ \alpha = \lambda \end{cases} \tag{1}$$

$$where \quad Fi(A) = \{Fi(\gamma)/A \to \gamma\} \cup \{A\}$$

$$\begin{aligned} Fo(A) = \ & \{Fi(\beta) - \{\lambda\}/B \to \alpha A\beta \in P\} \\ & \cup \{Fo(B)/B \to \alpha A\beta \ \in \ P \wedge \lambda \in Fi(\beta)\} \end{aligned} \tag{2}$$

The actual algorithm for calculating the ACTION table remains unchanged (see [11] pp. 234), but its results are different with these modified sets.

These changes also eliminate the need for the LR GOTO table, since all its information is now covered in the augmented ACTION table. To perform a reduce operation, the parser should remove the rule tail symbols from the stack and then proceed as if the non-terminal at the head of the rule was the next input symbol. This is called an *unshift* operation, and followed by a corresponding shift operation it has the same result that a standard reduce operation.

## 4.2 Creating Parsers for Rewrite Definitions

While the rewrite definition of the previous example is a valid statement, it is certainly not a valid program. Since the parser only accepts valid programs, it will fail to recognize the rewrite definition. The need arises for a specialized parser which is able to process statement. To obtain it, it is necessary to rebuild the parsing tables from the same grammar, but this time using '`Statement`' as the initial symbol.

In general, separate parsing tables are needed for each non-terminal with a rewrite definition, and each rewrite definition needs to be processed using the proper parsing table. The parsing tables may vary greatly, and no possibilities of reuse have been studied.

## 4.3 Building Rewrite Templates

Processing the rewrite specifications every time that a construct defined using that mechanism appears in the source code would be excessively time consuming and inefficient. Instead, it would be convenient to process each definition once and keep some structure that represents it. That is what we call rewrite templates: intentionally incomplete ASTs with empty placeholders to be filled when processing source code.

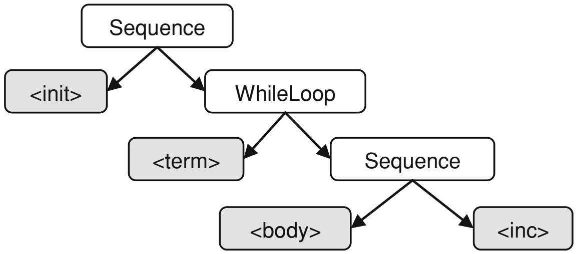


**Fig. 1** Rewrite template attached to rule as semantic action

In the preceding '`for`' example, a template is to remain attached to the '`for`' rule, as depicted in Fig. 1 (note that construct names in the AST need not match their syntax).

The operation of 'applying' a template implies filling the placeholders with values returned by the parser when it is to perform a reduce operation. It is rather straightforward since the template indicates which token value each placeholder is to be filled with (these are named *init*, *term*, *body* and *inc* in the example). Building the templates correctly is a more challenging task.

Let us analyze all the steps that the parser undergoes to process a rewrite definition in this scenario. For that purpose, we shall suppose that the following grammar rules exist for the language, and that precedence rules have been properly defined.

```
(a) Statement → Statement:s1 ';' Statement:s2
{Sequence(s1, s2)}
(b) Statement → '{' Statement:s '}'
{s}
(c) Statement →'while' '(' Expression:e ')'
Statement:s
{WhileLoop(e, s)}
```

When the parser performs a reduce operation with, for instance, rule (c), it creates a new token which symbol is Statement and which value is built according to the specification between brackets (rule semantic action). In this case, the action indicates to get the values referenced by variables `e` and `s`, and return a new `WhileLoop` AST node, composed by them.

The parser fetched the e and s values from the parser stack, which elements are tokens. Precisely, the e variable means *"get the value of the token which is found in the 3rd topmost position of the stack"*, while s refers to the value of the token at the very top of the stack. By that moment, the entire rule tail has been pushed into the stack from left to right.

Those values exist because they were built from previous parsing of the source code. However, when processing a rewrite definition there is no previous parsing of any code. Consider the parsing of the rewrite definition (previous example copied below for reference).

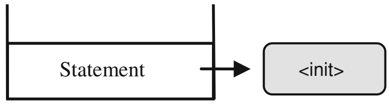


**Fig. 2** Parser stack after shifting rewrite token

```
syntax Statement ::=
'for' '(' Statement:init ';' Expression:term ';'
Statement:inc ')' Statement:body
[
init ';' 'while (' term ') {' body ';' inc '}'
]
```

What should the value of the 'init' token be? It is required to implement a mechanism to express that its value means *"fetch the value of the token at the 8th topmost position of the stack, but not now"*. The reference must certainly not be resolved yet, since there are not 8 elements in the stack; it is a reference that should only be resolved when parsing source code, not the current rewrite definition. Thus, a delayed reference resolving mechanism is required. Figure 2 shows the parser context after shifting token '`init`', where $<$ `init` $>$ represents the unresolved reference.

After inputting all symbols but the last '**}**', the parser is in a state from which a reduce with rule (a) must be performed, thus replacing the stack tokens from (body, '**;**', inc) with one token *t* which symbol is `Statement` and which value, *a,* is the AST `Sequence`(body, inc). For this to hold true, `s1` and `s2` references must be resolved immediately.

Shortly after, the parser shifts lexeme '}' and arrives at a state from which a reduce with rule (b) is to be performed, therefore replacing the tokens from ('**{**', *t*, '**}**') with a new *u* token which symbol is Statement and which value is *a* (*t*'s value), as specified by (b)'s action. Next, the parser reaches a state from which a reduce with rule (c) must take place, replacing the tokens from ('**while**', '**(**', term, '**)**', *u*) with one token *v* which symbol is `Statement` and which value is the AST `WhileLoop`(term, *u*). Finally, the last reduce operation, with rule (a), replaces stack tokens from (init, '**;**', *v*) with a *w* token which symbol is `Sequence` and which value is the AST `Sequence`(init, *v*).

Figure 3 illustrates the parser context exactly before the final reduce operation. Performing the final reduce operation will assemble the rewrite template.

The resulting AST is incomplete, since some nodes do not have values, but rather not-yet-resolved references to values which will later be found in tokens in the parser stack. This way, we have created an AST template that represents the semantics of the 'for' construct with a combination of the loop, sequence, and statement blocks structures.

After processing the rewrite definition, the resulting template remains attached to the '`for`' syntax rule and becomes the rule's action to be used when parsing source code. Consequently, having declared the '`for`' construct using that rewrite definition would have had the same effect as the following declaration, but without required the programmer to know the internal details of the language processor:

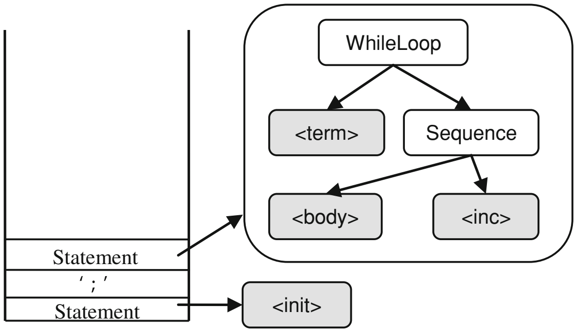


**Fig. 3** Parser context before final reduce operation

```
syntax Statement ::=
‘for’ ‘(’ Statement:init ‘;’ Expression:term ‘;’
Statement:inc ‘)’ Statement:body
{
Sequence(init, WhileLoop(term, Sequence(body, inc))
}
```

It should be considered that unlike grammar symbols, which are known to the programmer, Sequence and WhileLoop are names used by the language processor for building its internal data structures (e.g. function or class names).

It should be noted that a rewrite definition may use other constructs which are also defined using rewriting; in that case, they should be processed recursively. Consequently, cyclic rewrite definitions must be checked for. This can be easily achieved by marking a rewrite definition while under process and unmarking it when finished.

Finally, we shall present in insight into the process of parsing source code using the ‘`for`’ construct, as of our template strategy. Let us examine the following code:

```
…
for(i = 0; i < 10; i = i+1)
k = k*2;
…
```

When the parser reads the ‘`for`’ lexeme, if at that point it is expecting a Statement, it will begin shifting tokens according to the ‘for’ syntax rule. The whole statement is syntactically valid according to the rule. Figure 4 depicts the parser context exactly before performing the reduce operation with the ‘`for`’ rule.

At this point, all tokens in the parser stack have concrete and complete values, since actual source code is being processed, as opposed to rewrite definitions. The rule action to be performed is to apply the rewrite template, i.e. resolve all variable references in the template with the real values found in the parser stack. Figure 5 shows the resulting AST after performing that final step.

This structure, let us call it *f*, is the result of that ‘for’ statement, and may be used as part of a larger tree. It does not contain any unresolved references, and is

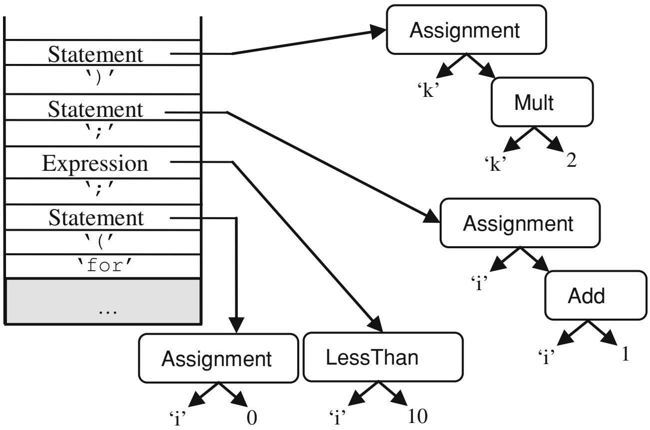


**Fig. 4** Parser context before reduce with 'for' rule

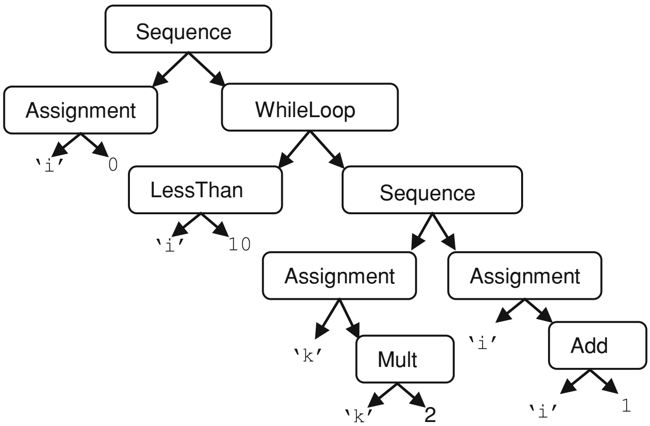


**Fig. 5** Parser context before reduce with 'for' rule

ready to be executed or compiled. The parser proceeds to remove all tokens that correspond to the rule tail from the stack, create a new (Statement, *f*) token, push it onto the stack, and continue parsing.

## 5 Conclusion

In this chapter it has been proposed and analyzed a complete set of modifications to the traditional LR parsing algorithm that enable the implementation of LR based extensible programming languages. The set of alterations described in this work can be summarized as follows:

i. Extend the definition of *first sets* and *follow sets* to allow non-terminals at the parser input.
ii. Generate the LR *action* table using the standard algorithm but considering those extended definitions; remove the *go-to* table.
iii. Implement a parser generation mechanism that allows creating multiple parsers using any non-terminal of the grammar as its initial symbol.
iv. Create a delayed reference scheme that allows storing unresolved token references from a rule's semantic action to the parser stack.
v. Implement template generation for rewrite rules (optional, for performance and scalability).

Under this scenario, the processing of extension definitions and source code comprises the following steps. First, starting from a basic or original language, read the syntax part of every extension definition and update the underlying language grammar. Next, for each extension definition: if its semantics are expressed using rewriting, then parse the rewrite definition and, if syntactically valid, create its rewrite template and replace the rule's action with it.

After processing all rewrite definitions, the meaning of every syntactic construct has been translated into constructs of the original, basic language. At this point, the language processor is ready to accept and process source code that uses the extended syntax.

Finally, it should be considered that additional implementation steps, outside the scope of this chapter, are required in order to achieve better rewrite flexibility and further syntactic richness. This chapter provides one set of implementation steps that enable creating a simple, yet operational, extensible programming language. Most importantly, this research demonstrates that creating extensible languages using LR parsing is not only possible, but also perfectly feasible from a pragmatic standpoint.

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# Neuro-Fuzzy Model Related To Job Assignation

**Marius Pislaru and Silvia Avasilcai**

**Abstract** An important problem that many organizations have to face nowadays, especially in the context of technical and economical changes, is the job assignment problem. The hiring of new staff and the assignment of current staff to specific tasks represents a crucial decision, since the very survival of the enterprise can depend upon an appropriate choice being made. This is true in all areas of the economy, but is even more so in those in which turbulent trading conditions or cut-throat competition in the business makes it vital to have personnel with sufficient flexibility and adaptability. In these circumstances the correct choice of staff has yet a greater influence over future development of the company. This paper is an attempt to supply a satisfactory solution to a real staff management problem with linguistic information using Adaptive Neuro-Fuzzy Inference System. The system's purpose is to optimize decision making regarding the job assignment problem inside an organization.

## 1 Introduction

Fuzzy logic is often referred to as a way of "reasoning with uncertainty." It provides a well-defined mechanism to deal with uncertain and incompletely defined data, so that one can make precise deductions from imprecise data. The fuzzy theory provides a mechanism for representing linguistic constructs such as "many", "low", "medium", "often", "few". In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities [1–3].

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In practice, fuzzy logic means computation of words. Since computation with words is possible, computerized systems can be built by embedding human expertise articulated in daily language. Also called a fuzzy inference engine or fuzzy rule-base, such a system can perform approximate reasoning somewhat similar to but much more primitive than that of the human brain.

Fuzzy modelling techniques, namely, the construction of fuzzy rule-based inference systems, can be viewed as grey-box modelling because they allow the modeller to extract and interpret the knowledge contained in the model, as well as to imbue it with a priori knowledge. However, the construction of fuzzy models of large and complex systems—with a large number of intricately related input and output variables—is a hard task demanding the identification of many parameters [4]. Fuzzy logic is capable of representing uncertain data, emulating skilled humans, and handling vague situations where traditional mathematics is ineffective. Based on this approach our aim is to attempt to devise a model for staff selection in conditions of uncertainty, such that it will both reduce to a minimum the risks arising from performance of tasks by unsuitable personnel and also maximise the capacity of the firm by means of optimal assignment of workers. This system will allow incorporation of all information which may be to hand, however ambiguous or subjective it may be, and cope with the lack of precision that is a concomitant of this sort of decision making process. Staff selection for the varying activities performed by enterprises requires a coherent approach, which cannot be simplistic, to the information held. The use of fuzzy membership functions is convenient because it allows the problem to be recognised as it is in real life. All this makes the job assignment challenging, yet a crucial task to perform. A lot of companies have experts who are responsible for the job assignment. Currently, the job is done manually and we think that every technique meant to automate this process can prove invaluable for all the companies. We propose an Adaptive Neuro-Fuzzy Inference System (ANFIS) which can learn to make human-like decisions and uses fuzzy membership functions to point out satisfaction degrees [5]. The goal is to achieve most suitable solutions for matches between employs and jobs. Further on we try to extract a small number of fuzzy rules, which are still very effective without disturbing the robustness of system.

After the system is trained, we can adapt it to environmental changes in order to increase its efficiency. Moreover, using the information provided by experts from time to time, the system may learn to make better and up to date human-like decisions. This system can be easily used by the experts in job assignment, due to the implementation of the fuzzy membership functions, being able this way to easily express their decisions in terms of linguistic descriptions (such as good, average, low) regarding the constraints as well as the overall fitness of the match between workers and jobs [6]. However, there is another problematic issue because different experts may provide fairly diverse decisions, due to their personal experience, current environmental situation, not to mention emotions and mistakes. Moreover if the same data would be presented to the same expert at a different time, it is estimated that 20 % difference would occur. Consequently, such subjective component makes the optimization a very sophisticated task to perform. From the point of view of the business, the problem as described is essentially one of optimisation of one relationship: the efficiency of labour and the costs arising from its use. Nevertheless, no company, when choosing the best candidate for a post, can avoid the fact that workers interact with one another and do not perform their duties in isolation. This gives rise to the idea of forming teams able to carry out the work allocated, even if all their members are not great ability or possessors of a range of skills [7].

Thus, when the selection of a candidate is done, there shouldn't be taken into consideration only his capacities to perform a good quality job, but also his personality, because if they are chosen they will belong to a team made up of people with who must get along in order to achieve a common goal. It is clear that personnel managers and others, charged with determining the standards attained by each candidate in the skills needed for the job, prefer to use natural language for this, whatever the tests used (aptitude tests, personality questionnaires, role-plays evaluation workshops, interviews and others). This is because it is quite divorced from reality to express these standards in terms of strict numerical values. Using normal language may lead to the loss of the precision that numbers can give, but there is a positive counterpart in greater closeness to the problem.

## 2 Staff Selection

For the purposes of this paper, it will be assumed that the selection of staff consists of choosing a person for a job with a given profile. This profile can be defined by a set of measurements or values which can be compared with any candidate's capacities.

The schemes used in staff selection can be affected by a certain dose of subjectivity (because they are conceived by human resources experts who can also make mistakes). These schemes take the form of a succession of stages, during which candidates seen as less suitable are successively eliminated. In the same time an attempt is simultaneously made to grasp what capacities those who are most suited to performing the tasks defining the job will have [8].

### *2.1 Determining a Profile for the Post*

Establishing a profile is done by means of an analysis of the tasks to be assigned and possible objectives to be attained. The profile also includes a list of skills that the candidate must possess in order to carry out the activities involved in the job correctly, together with indications of the weight that skill has in the specific post concerned.

In practice it is usual to set up a list of all the necessary skills, with these being understood as meaning an essential characteristic of any individual who can do the work efficiently or better. This definition would include all the abilities, personal characteristics, motivations and other features as self-image, social standing, knowledge the individual has, and so forth. Anyway, certain values have been used to fix the skills needed for the job. Nonetheless, it is obvious that for most of them thee degree of compliance does not have to be rigid, and therefore modelling by means of normal linguistic variables can find an interesting application here.

Further, in establishing the post profile, it is necessary to include relationships with other staff, since organizations are not made up of people carrying out their work in isolation but rather interacting with one another. So, it may be more urgent to get a "good team" rather than "good individuals".

In addition, if it is a question of selecting staff for several posts, then those jobs which are of greatest importance to the management of the firm should be weighted in some manner, as these are the ones should be most effectively matched to the ideal candidates.

## 2.2 Candidate Evaluation

There is an extensive range of choices in respect of the tests that can be used (forms, interviews, examination, tests and so on). All try in one way or another to determine the level of aptitude of a person in respect of specific capacities that are deemed needful in order to perform the duties of a post correctly. However, it is also advisable to keep in mind not just the requirements for the post but also the conditions surrounding it, and especially those concerning the team of staff into which the holder must be incorporated.

It is during this phase that analysis of potential interactions between individuals comes into full play. The reason is that when tasks or jobs in which there is person-to-person contact or which are performed by teams are considered, it is essential to ensure that the workers involved co-operate, that is, that they are compatible when it comes to carrying out their joint work.

This justifies looking into the possible relationships between tasks, and into the level of compatibility between individuals, during the selection process. Such considerations are often made in a subjective way, so that the use of linguistic labels would allow greater closeness to the realities of the decision-making procedure being investigated.

## 2.3 Match of Candidate to Profile

Once the degree to which each candidate has a given ability is established, this is compared to the capacities stated in the profile set up for the job in question. This shows how far each candidate matches up to them, and allows an order of preference among candidates to be drawn up, though not without taking into account inter-personal compatibility, which is an objective in parallel with the good match of candidates to posts. The data was extracted from the Human Resources Management databases. The database contained 350 workers and 115 possible jobs for the given environment. From all the attributes regarding each candidate will be selected those which are most important for the decision making process. Various hard constraints will be applied to these attributes complying with organization policies. Every candidate along with his possible jobs satisfying the hard constraints is assigned to a unique group. The numbers of jobs in each group were counted and normalized to fit the [0,1] unit interval; this will be used later for decision refinement. This is important because the output (decisions given by experts) were highly correlated: there was typically one job offered to each candidate. We considered three widely soft constraints, but they can be changed or modified according with firm policies:

- Job priority match: The higher the job priority, the more important to fill the job
- Candidate location preference match: It is better to send a candidate to a place he/she wants to go
- Pay grade match: The worker's pay grade should exactly match the job's required pay grade

Note that decisions were made sequentially and independently. This simulate the typical task an expert normally faces: offer a job to a given candidate at the given time from a given list of possible jobs, not considering other candidates, jobs which will be available in the future, etc. Of course the worker doesn't have to accept the offered job and various other things might happen before the job actually gets posted to the worker, but these situations are not relevant from the viewpoint of our decision-making problem [9].

## 3 Adaptive Neuro-Fuzzy Inference System

ANFIS uses a hybrid learning algorithm to identify the membership function parameters of single-output, Sugeno type fuzzy inference systems (FIS). A combination of least-squares and backpropagation gradient descent methods are used for training FIS membership function parameters to model a given set of input/output data.

Applying a neuro-fuzzy inference system to model this real life problem is quite natural, because of the similarity to real life human decisions-making. Some design issues were set up based on information from human resources experts, while others were learned and experimented. Some of the design issues were the following:

- Number of input membership functions: the fuzzy membership functions were set up based on knowledge on expert decisions. We determined four membership functions (low, rather_average, average and high) for each of three soft constraints model.

- Type of input membership functions: based on the properties of the soft constraints we consider gaussian membership functions.
- Type of output membership functions: we used a single output, obtained using weighted average defuzzification. All output membership function had the same type and were either constant or linear [10].
- The number of output membership functions: it ranged from 2 to 81.
- The number of rules: for a well defined fuzzy system we need to define control actions (fuzzy output) for every possible combination of input membership function values. In our case three constraints, each with four membership functions result (64) fuzzy rules, where the linguistic values were not negated, and they were connected with "and" relation.
- Performance function: some of the widely used performance functions in neural networks are Sum of Squared Error, Mean Squared Error, and the following cost function:

$$\mathrm{J} = \mathrm{SSE} + \lambda \sum |\mathrm{w}| \tag{1}$$

where SSE is Sum of Squared Error, $\lambda$is a penalty factor and w is weight.

- Optimization methods: back-propagation and hybrid (mixed least squares and back-propagation) methods had been used as optimization methods
- Then we have to partitionate the data into training, cross-validation and testing sets. The range of the training data set size is between 5 and 90 %. The cross-validation and testing data sets each will take half of the rest of the data (5–25 %). The use of cross-validation is optional but in our implementation is important, to avoid overtraining.
- Number of epochs: we think that 400 are good enough for a good network performance.

Through an adaptive neuro-fuzzy inference system the range of the membership functions are learned, fuzzy rules are created and their weights are adjusted in order to better model the training data. The performance function values are calculated, and classification is provided [11].

## 4 Work Methodology

To implement the methodology we used programming language Matlab environment with fuzzy logic toolbox [12]. From the multitude of membership functions we have been tried the triangular membership functions performed best followed by trapezoid. Also Gaussian curve and generalized bell-shaped membership functions performed well.

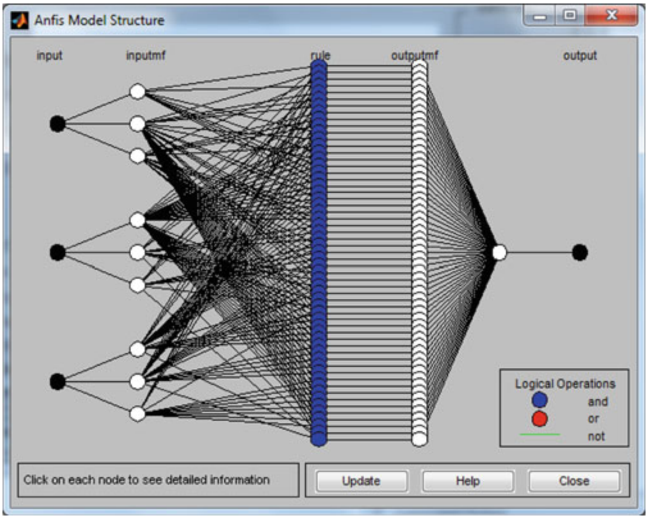


**Fig. 1** ANFIS network architecture

As optimization method we used the back-propagation method. Figure 1 shows the generated ANFIS model structure. Its layered structure from left to right is the following:

- Layer1. Input neurons: for input neurons we used the three soft constraints.
- Layer2. Input membership functions: three gaussian membership functions for each input neuron
- Layer3. Fuzzy rule left hand sides: each connected to 4 input membership functions.
- Layer4. Output membership functions (right hand sides): the right hand side rules are in one to one relation with the left hand side rules.
- Layer5. Aggregated output: each output membership function gets aggregated with the weight they carry.
- Layer6. Output (decision)

To avoid overtraining we used cross-validation. In some cases the minimum cross-validation error occurred within the first epoch because the given set of membership functions were not a good choice for modeling the training data. This also indicated that either more data needed to be selected for training, or it was necessary to modify the membership functions (both the number of membership functions and their types). For four gaussian input membership functions, 400 epochs, linear output membership functions, the Sum Squared Error between the actual and desired outputs was 0.315.

In Fig. 2 the thick line represents training and thin line represents cross-validation. It can be easily observed that both the training and the cross validation curves are still decreasing after 400 epochs, but the decrease rate is very low.

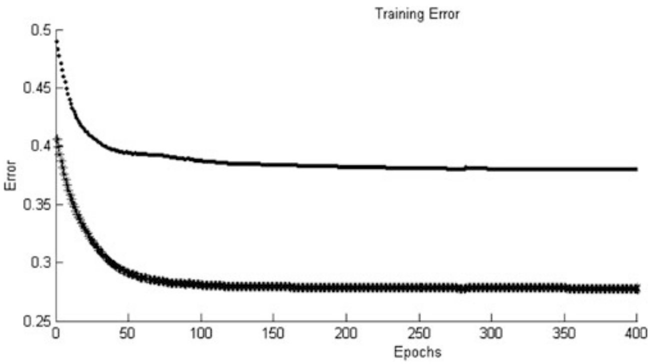


**Fig. 2** Learning curve for gaussian membership functions

Once the ANFIS is trained it would be useful to extract a small number of rules, which can reliably predict jobs to be offered based on fuzzy membership function values. Of course extracting rules cannot further improve performance, but will increase speed and efficiency for further training.

A very important thing is the indeterminate nature of human resources expert decisions. This is why we cannot expect a very high accuracy of classification. The same expert may easily make different decisions on the same data at different times. It is widely believed that different experts are also likely to make different decisions even under the same circumstances. Moreover environmental changes may have their own influence on decision making, so periodic training on as recent data as possible is required. Therefore the values coming from observation and which are reported can't give us information also about the quality of the decisions our system makes, but only about the performance of following the decisions launched by the surveyed expert. This problem is present in firm practices as well: they don't have a given model or formula to effectively evaluate expert performance.

## 5 Conclusions

In this paper we have proposed an adaptive neuro-fuzzy inference system for solving the problem of job assignment that can be encountered in many firms. Also we believe that human like-decisions can be achieved with the model.

Because of the current firms practices and also due to real world limitations time to time training of our system is imposed by our desire to keep pace with continuously—evolving environmental factors.

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# Time-Based Location Prediction Technique for Wireless Cellular Networks

**Joshua Bradley and Sherif Rashad**

**Abstract** In this paper, we are introducing a time-based location prediction technique for wireless cellular networks. This technique is based on a two dimensional sequence mining algorithm. We have taken concepts of data partitioning methods and modified SPADE algorithm (Sequential PAttern Discovery using Equivalence classes), which has been implemented over a mining model known as mining mobile sequential patterns, and called Dynamic MobileSPADE algorithm. This algorithm mines for mobile sequential patterns based on dynamic-length item sets. In mining for mobile sequential patterns in a mobile environment, we use base stations ID data from a dataset constructed by the reality mining project at the MIT. Experiments were conducted to study and evaluate the performance of the proposed techniques. The experimental results show that the proposed technique is promising and it can be used effectively to predict future locations of mobile users with high accuracy using the generated mobile sequential patterns.

## 1 Introduction

In a world where mobile devices are becoming more popular and one of the leading factors to an end-user in choosing a mobile network carrier is cell coverage for a particular area, advancements in wireless communication technologies and

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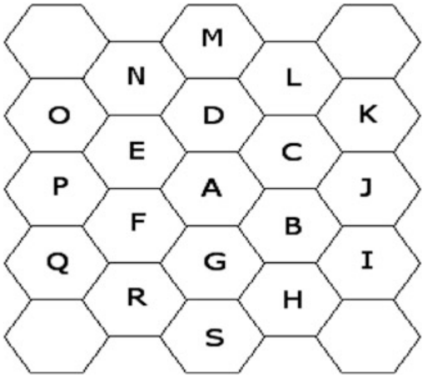


**Fig. 1** Grid of cells in cellular networks

routing protocols is often advantageous to a network carrier in order to gain more customers. Due to the extent of applications now available for mobile devices, there have been many studies on Location-Based Services (LBS) in the past couple of years, but one important research aspect that has gained more interest in upcoming network technologies is the tracking and prediction of a mobile user's movement pattern in a cellular network via data mining. Mobile network carriers currently implement a method that distributes all available resources evenly across the network.

Using Fig. 1 as an example, when a mobile user is in cell A, the mobile network carrier will distribute and allocate resources required by the mobile user evenly throughout the surrounding cells or base stations (B, C, D, E, F, G). This allows for the network to be readily prepared to continue the node's data connection if the mobile user continues using the mobile device and relocates to an adjacent cell. Disadvantages to this strategy include producing unnecessary overhead by distributing resources to cell towers that will not be used by the mobile user, thus not allowing the mobile user full employment of all available resources. One alternative solution being extensively researched has been sequence mining, which effectively mines for frequent sequential patterns in a temporal database. In this paper, frequent sequential patterns refer to the frequent movement patterns of a mobile user.

Finding these frequent sequential patterns could allow for a network carrier to calculate with some probability where a mobile user will go next, based upon his/her past movement history. Using this innovative mobile sequential pattern model and referring to Fig. 1 again, when a mobile user resides in cell A, the network carrier could allocate more resources of a certain service requested by the user to the cell where the end user is most likely predicted to move to. For example, based upon a mobile user's past history, if a mobile user is predicted to have a 75 % chance of going from cell A to cell D, then the network could then reallocate/distribute a larger percentage of its resources to cell ID as compared to the other surrounding cells, in order to provide better quality of service to the end-user via a more efficient use of its resource allocation methods and routing protocols.

This paper presents a novel location prediction technique that can be used to enhance the overall performance of the wireless cellular networks. The proposed prediction technique is based on using Dynamic MobileSPADE algorithm that we developed to work in mobile environments and it takes into account the different behaviour for mobile users during the week days and weekend days. Also, the prediction will be based on a 6-h time frame that can be used to enhance the prediction during the day. The remainder of this paper is organized as follows. Section 2 reviews definitions and preliminary concepts used throughout this paper. Section 2 discusses related work that has been done concerning data partitioning methods and the original SPADE algorithm. The dataset used for testing is briefly discussed in Sects. 4 and 5 discusses the Dynamic MobileSPADE algorithm and how it is used to discover frequent sequential patterns from the dataset. Section 6 presents prediction results of future locations for mobile users and Sect. 7 discusses conclusions and future research plans.

## 2 Preliminary Concepts

Let $D = \{t_1, t_2,\ldots,t_m\}$ represent a set of $m$ transactions from a data set $D$. Cardinality of each $t_n$ transaction is independently determined by the formation of non-repeating sets of items, termed itemsets in this paper.

Each $t_m$ transaction is defined as a sequentially ordered set of literals $t_m = \{i_1, i_2, i_3,\ldots,i_h\}$ known as items, or node movements in the context of node prediction within a cellular network. For purposes of this paper and prediction analyses, we only consider transactions $|\mathrm{t_m}| \geq 2$.

Given that our data mining algorithm performs with data from a cellular network, we assume that each node movement $\mathrm{i}_h$ occurs with a time stamp. We define the local support of an itemset by the occurrence of that itemset within the group of all itemsets generated during a user-specified local time period (e.g. 6:00–10:00 a.m.), referenced here on out as time frames.

## 3 Related Work

In [1], one pre-processing method discussed was data fragmentation (partitioning). The original partition algorithm was proposed in [2] and adheres to the following principle. Referring to Fig. 2, a fragment $\mathrm{P}_n \subseteq \mathrm{D}$ is defined as any subset containing $\mathrm{t}_m$ transactions found in $D$. Also note that any two fragments are non-overlapping, such that no two fragments contain the same transaction. Local support for an itemset is then determined by the fraction of transactions in that data fragment containing that specific itemset. In [2], Savasere et al. considers the idea

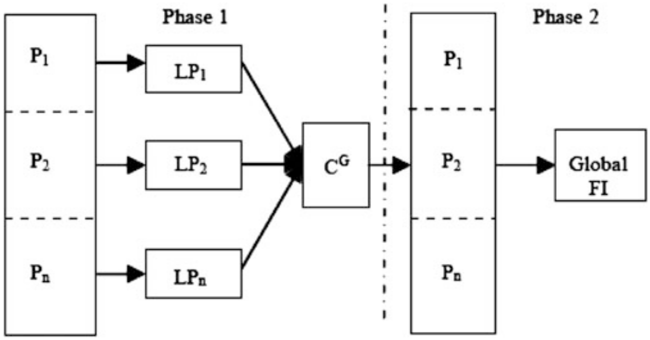


**Fig. 2** Data partitioning approach

of splitting un-ordered data up into fragments and processing each data fragment one at a time to determine *local frequent itemsets* that must pass the minimum user-specified support threshold in order to be considered frequent. After each fragment is processed, the algorithm then concatenates all *local frequent itemsets* ($LP_n$) into a set of *global candidate itemsets* ($C^G$). The partition algorithm then scans the database a second time recalculating the support for all *local frequent itemsets* in $C^G$ to finally determine *global frequent itemsets* which are then used to construct association rules.

An extension of the original partition algorithm is reviewed in [1], in which the idea of utilizing "skipping fragments" to minimize the number of *global candidate itemsets* is evaluated. Nguyen discovered that there is a relationship between the density and composition of each fragment and its overall computation time.

By employing "skipping fragments" in which the transactions in a database are split up into various fragments randomly instead of ordered, he was able to minimize the number of global candidate itemsets that are checked during the second scan of the database, thus minimizing the computation time. A series of data pre-processing methods such as the introduction of new clustering and similarity algorithms was also applied across the data to show that the performance of the algorithm increases by initially partitioning the data.

In [3], Zaki developed SPADE algorithm (Sequential PAttern Discovery using Equivalence classes), a sequential mining algorithm designed for the accelerated discovery of sequential patterns that essentially ascertains associations within a temporal database and presents a new approach to mining for frequent sequential itemsets by employing a vertical id-list format of a database. SPADE algorithm reduces I/O cost be reducing the number of database scans to three and utilizing properties of combinatorics to decompose the original problem into smaller subproblems that results in a smaller time complexity.

**Table 1** A sample dataset with starttime and celltower_oid data columns for user number 94

| User 94 | |
|---|---|
| Starttime | Celltower_oid |
| 2004-07-23 12:22:34 | 38 |
| 2004-07-23 12:23:56 | 39 |
| 2004-07-23 12:25:10 | 38 |
| 2004-07-23 12:26:15 | 39 |
| 2004-07-23 12:27:24 | 40 |
| 2004-07-23 12:28:36 | 38 |
| 2004-07-23 12:28:51 | 40 |
| 2004-07-23 12:29:14 | 39 |
| 2004-07-23 12:33:40 | 41 |
| 2004-07-23 12:34:37 | 40 |
| 2004-07-23 12:37:16 | 39 |
| 2004-07-23 12:38:22 | 38 |
| 2004-07-23 12:38:49 | 41 |
| 2004-07-23 12:40:21 | 39 |
| 2004-07-23 12:41:01 | 40 |
| 2004-07-23 12:48:37 | 41 |
| 2004-07-23 12:49:29 | 40 |
| 2004-07-23 12:51:50 | 38 |
| 2004-07-23 12:53:20 | 41 |
| 2004-07-23 12:55:18 | 40 |

## 4 Mobility Dataset

The dataset used in this research is a result of the reality mining project carried out by the MIT Media Lab [4]. It is the result of one of the largest mobile data collection initiatives in academia and industry to obtain objective data that accurately reflects various mobile user behaviour patterns in a dynamic mobile environment. This is one of the first datasets to provide physical evidence of the patterns and relationships that form within various types of social networks (e.g. work, school, lunch, private life) around individual users/groups on a daily basis and represents over 500,000 h (approximately 60 years) of data. The dataset represents data collected from 100 cell phones for a period of 9 months, in which each device recorded data related to location proximity, data type, time duration of data usage, etc. Table 1 shows a sample of the collated dataset with the corresponding *starttime* and *celltower_oid* data columns for mobile user number 94 after sorting with reference to *timestamp* value. The timestamp is defined by the values in the "starttime" column of the dataset. A mobile user's movement path is defined as the tower ID utilized for each logged event.

**Table 2** Example of data set

| TID | Time | List of items | TID | Time | List of items |
|---|---|---|---|---|---|
| $t_1$ | 06:23:32 | 1,5,12,14 | $t_6$ | 10:03:02 | 2,4,6 |
| $t_2$ | 08:23:45 | 1,5 | $t_7$ | 12:45:57 | 2,6,8,10 |
| $t_3$ | 12:46:59 | 1,9,41 | $t_8$ | 12:44:12 | 4,9,41,13 |
| $t_4$ | 17:25:34 | 2,9,51,62 | $t_9$ | 07:56:18 | 20,24,51 |
| $t_5$ | 23:24:32 | 2,9,41,3 | $t_{10}$ | 02:19:13 | 1,5,53,78 |

## 5 Dynamic MobileSPADE Algorithm

Similar to SPADE algorithm [3], Dynamic MobileSPADE algorithm is an Apriori-based sequential pattern algorithm that utilizes characteristics of combinatorics and adapts a vertical data format of the original dataset. The original SPADE algorithm [3] was not designed to work in mobile environment. It did not account for consecutive sequential order as a parameter when finding frequent itemsets. Also, SPADE algorithm was designed to utilize all candidate subsets of a transaction when calculating the support and confidence of each itemset. In our problem, it is important to keep consecutive sequential order of the items (the networks cells in this case). It is important to note also that when calculating the confidence of each itemset, the item at the end of each transaction is not considered by Dynamic MobileSPADE algorithm, because there is no succeeding movement beyond that item (or that cell). Two defining characteristics of Dynamic MobileSPADE algorithm lie within its ability to incorporate data attributes into a consecutive sequentially ordered list, based upon timestamp values, and its capacity to only consider itemsets of length two or greater, in order to find frequent sequential itemsets.

Notation used throughout the paper is as follows:

- Let T = $\{t_1, t_2,\ldots,t_n\}$ be a set of n transactions over data set D
- Transactions can be of variable length
- Each transaction consists of a sequentially ordered set of items $\{i_1, i_2, i_3,\ldots,i_m\}$ $T_n$, referenced as tower ID numbers in this paper.

### 5.1 Intuitive Example

Given a dataset *D* as in Table 2, unlike many authors we do not assume that the itemsets are ordered by item ids, but by time ids (TID). Rather, we view database *D* as shown in Table 3.

From this, if we define the day to have 2 time frames (12 h each), then it can be determined that $T_1 = \{t_{10}, t_1, t_9, t_2, t_6, t_8\}$ and $T_2 = \{t_7, t_3, t_4, t_5\}$. If the support

**Table 3** Example of ordered data set

| TID | Time | List of items | TID | List of items | Time |
|---|---|---|---|---|---|
| $t_{10}$ | 02:19:13 | 1,5,53,78 | $t_8$ | 12:44:12 | 4,9,41,13 |
| $t_1$ | 06:23:32 | 1,5,12,14 | $t_7$ | 12:45:57 | 2,6,8,10 |
| $t_9$ | 07:56:18 | 20,24,51 | $T_3$ | 12:46:59 | 2,9,41 |
| $t_2$ | 08:23:45 | 1,5 | $t_4$ | 17:25:34 | 2,9,51,62 |
| $t_6$ | 10:03:02 | 2,4,6 | $t_5$ | 23:24:32 | 2,9,41,3 |

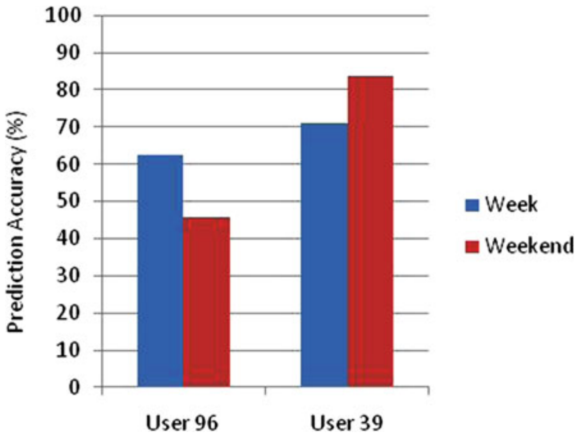


**Fig. 3** Prediction accuracy results for two mobile using 6-h time frame and using 5 % support and confidence thresholds

threshold and confidence threshold are set at 50 %, then it can be seen that frequent itemsets for each respective time frame are {{1,5}} for the first time frame and {{2,9},{9,41},{2,9,41}} for the second time frame.

## *5.2 Explanation of Dynamic MobileSPADE Algorithm*

Using the sample dataset shown in Table 1 as an example, the Dynamic MobileSPADE algorithm is described as follows:

Input: *Transaction database: D*; length of time frame, *support_threshold*; *confidence_threshold*

Output: frequent sequential itemsets

Begin

(1) Sort database D by sequential order, with reference to timestamp value.
(2) Sort T into $t_n$ transactions by creating non-repeating sequences of itemsets. For example,
(3) when using the database from Fig. 3, $T = \{t_1, t_2, t_3, t_4, t_5, t_6, t_7\}$ where:

$t_1 = \{38, 39\}$
$t_2 = \{38, 39, 40\}$

$t_3 = \{38, 40, 39, 41\}$
$t_4 = \{40, 39, 38, 41\}$
$t_5 = \{39, 40, 41\}$
$t_6 = \{40, 38, 41\}$
$t_7 = \{40\}$

(4) For every time frame (TF):

i. Consider each transaction as a sequential itemset, where the length of each itemset must be greater than two *len(itemset)* $\geq 2$. Using the current example, a list of candidate sequential itemsets will be as follows:

$t_1 = (38, 39)$
$t_2 = (38, 39, 40)$
$t_3 = (38, 40, 39, 41)$
$t_4 = (40, 39, 38, 41)$
$t_5 = (39, 40, 41)$
$t_6 = (40, 38, 41)$

ii. Calculate the support $support(i_m)$ of each sequential candidate itemset where:
$support(i_m) = frequency\_count(i_m)/number\_of\_transactions$
where:
$frequency\_count(i_m)$ = frequency of itemset $t_n$ in D *number_of_transactions* = |D|/*transaction_length*.
If $support(i_m) < support\_threshold$, then remove the itemset from candidate sequential itemsets.

iii. Calculate the confidence $confidence(i_m)$ of each sequential candidate itemset where:
$confidence(im) = frequency\_count(A \cup B)/frequency\_count(A)$
where:
A = *itemset[0]* the first element of the itemset
*and* (A ∪ B = *itemset[0:]* is the set of all items in the itemset.
If $confidence(i_m) < confidence\_threshold$, then remove the itemset from candidate sequential itemsets.

End

## 6 Experiment Results and Prediction Analysis

We conducted multiple experiments with the Dynamic MobileSPADE algorithm using different parameters, on the reality mining project dataset. There were many results collected, but we focus in this paper on the results of using a 6 h time

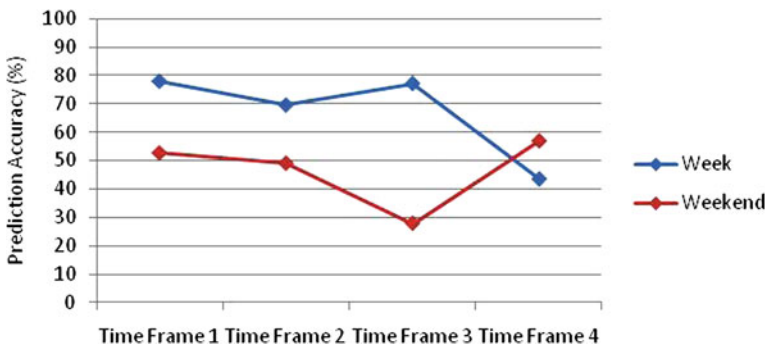


**Fig. 4** Prediction accuracy results for mobile user 96 using 6-h time frame

frames starting at 12:00 a.m. for each recorded day. Therefore we have four time frames for every day in the dataset. Also, we conducted several experiments to study the effect of dividing the week into workdays and weekend days on the location prediction results.

The results of location prediction using the current location, time, and the frequent itemsets generated by Dynamic MobileSPADE algorithm with support and confidence thresholds of 5 % for two mobile users (user 96 and 39) are shown in Fig. 3. The results are shown for week data and weekend data. We used 5 weeks to apply the Dynamic MobileSpade algorithm and generate the frequent itemsets of cells (base stations) and we used one week to test the location prediction accuracy. This results show that this algorithm is promising and we can have high prediction accuracy for mobile users during the weekdays and weekend periods. Also, the results for certain time frames for each user was high compared to the overall results. This results show also that the hypothesis of having different behavior of mobile users during the weekend is correct. We can see the location prediction accuracy for weekend periods is higher than the weekday. This will be different for different mobile users based on their different behavior during the weekends.

The change in perdition accuracy during the four time frame periods for both users is shown in Figs. 4 and 5. As we can see from these results, both mobile users have higher prediction accuracy in the first time frame. This can be returned to the low activity of mobile users during this period of time. Also, we can see that user 39 has higher prediction accuracy during the weekend period for three time frames.

Other experiments were conducted to see the effect of changing the support and confidence thresholds on the prediction accuracy using three different sets of support and confidence thresholds is shown in Fig. 5 for three different mobile users. We can see from these results and the previous results (for %5 support and threshold) that it is recommended to use low support threshold to include most of the location records in the database. This is because we have a large number of records and 5 % of this number will be still large enough to discover frequent

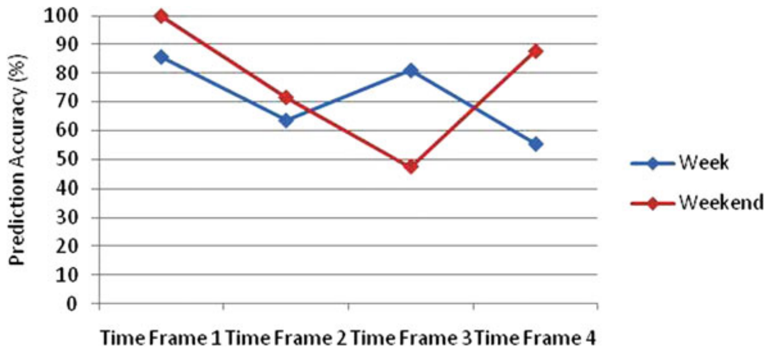


**Fig. 5** Prediction accuracy results for mobile user 39 using 6-h time frame

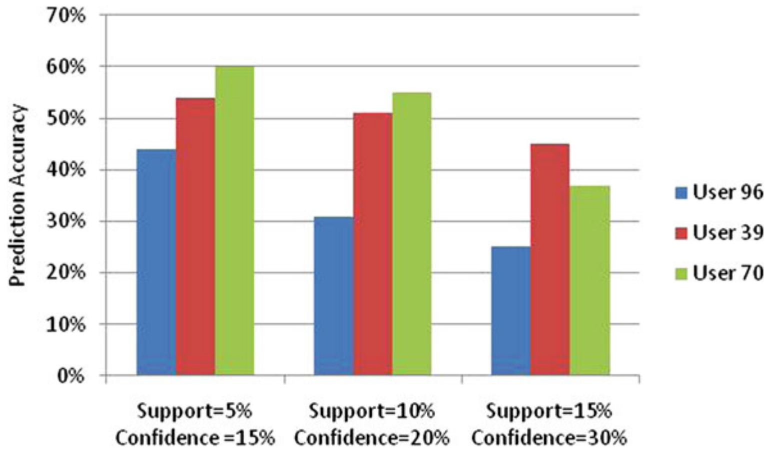


**Fig. 6** The effect of using different support and confidence thresholds on the prediction accuracy results

items. For example if we have 5,000 records and we used 5 % support this will allow us to include items (base stations) that have a frequency of 250 or more. As we can see this is still a large number and it means that this location was visited 250 times or more. If we increase the threshold to 15 % we will not be able to include a number of items although they have been visited 749 times or less. We can say that selecting the best support and confidence thresholds is an important factor to improve the accuracy of prediction. It may be important to select different thresholds for different users based on their behavior and the length of period that was used to record their mobility data (Fig. 6).

## 7 Conclusion and Future Work

We have proposed in this paper a time-based location prediction technique for wireless cellular networks. The proposed technique is based on using the Dynamic MobileSPADE algorithm. The mobility sequential patterns that are generated by Dynamic MobileSPADE is used to predict the future locations of mobile users. This algorithm is a modified versions of the SPADE (Sequential PAttern Discovery using Equivalence classes) algorithm that has been modified to work in the mobile environment. A time frame of 6 h was used. Also, the proposed technique differentiates between the weekdays and the weekend days for mobile users. The proposed technique was evaluated using the mobility datasets that was collected by the MIT reality mining project. The experimental results show that the proposed technique can successfully predict the future locations of mobile users with high accuracy. Prediction accuracy results show that it will be useful to use a time frame of six hours and to divide the week into week days and weekend periods. Also, the results show that it is important to select support and confidence thresholds to enhance the prediction accuracy. It is recommended changing these thresholds based on the users' behavior and the length of period that was used to record the mobility data.

We plan in the future to enhance the prediction accuracy by considering more data characteristics and by sing various time frame lengths for different users' behavior. Also, we plan to develop algorithms that can be used to predict what services will be utilized to improve the performance of load balancing techniques.

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# Computer Simulation Applied to the Design of Urban Public Spaces: Day Lighting in the Squares

**Tatiana Yeganiantz, Neander Silva and Ecilamar Lima**

**Abstract** This work is a study of computer simulation of day lighting applied to the design of urban open public spaces, as squares. Currently environmental computer simulation is often used in interior spaces and facades of buildings. However, it is hardly applied in open urban spaces. The contribution of this study is to assess the application of environmental simulation to public spaces and to encourage architects and urban designers to use programs to evaluate day lighting and other environmental factors in the process of design of urban public spaces. Our hypothesis is that the lack of the environmental assessment in a design of public squares reduces considerably the use of these places. The results obtained through computer simulation show the need and the potential for its use for assessing comfort of the open public spaces.

## 1 Introduction

The environmental assessment of open squares is a need of design because it allows for a better control of weather variables. Nowadays we can count on a large variety of tools for thermal, lighting and acoustic simulation that aid the designer in forecasting the environmental performance of the proposed space. If they would be used from the beginning of the design it would contribute to avoiding the loss of

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materials, energy, time and labor and the need of remodeling and reconstruction. These tools of simulation have been practical and efficient, allowing performing analysis that would be possible only through complex calculation or through measurement *in loco* using scale models (Amorim C (2006) A Avaliação Ambiental Integrada e Simulação Computacional: interfaces, limitações e potencialidades, "unpublished").

A city or town square may be defined as "an open public space commonly found in the heart of a traditional town used for community gatherings" [1].

The environmental comfort depends on the urban design. The urban architect can transform a square into a pleasant or unbearable space that, as a result, will be used or not by people.

It is possible to take advantage of or to avoid the light and heat of the sun in a designed space and the best criteria to use to make decisions is to have as basic principles the thermal and visual comfort of the users and the energy savings [2].

There have been efforts in the design of urban areas to avoid that a building cause day lighting obstruction to others [3]. On the other hand, it should be observed that the use of materials that reflect radiation instead of absorbing it and rapidly returning it to the outside, allows keeping the temperature low inside a building. However, this use can be of little help for an open public space, because it receives direct sun radiation and sums up the emissions causing thermal and visual discomfort [4].

The habitant of Brasilia, where our environment study takes place, has an intense relationship with the sky that is constantly in it's scenery. The sky is the protagonist of the landscape. It is not easy to ignore it, because it is in each perspective and in each view.

Considering the role played by the day lighting in an open public square, the main aim of this study is to demonstrate the need for better thermal and lighting assessment of such places, particularly at design stage. A square situated in the North Entertainment Sector in Brasilia, was used for an environmental simulation experiment.

## 2 The Context of the Square of the North Entertainment Setor

The urban design of Lucio Costa for Brasilia maximizes open public spaces and large green areas offering many opportunities of contact with natural resources. However, in the majority of the designs of squares in urban spaces in Brasilia there is no concern in controlling the day lighting that in general is very intense. Owning to this lack of concern these open spaces are inadequate for the users.

In the same way that the environmental conditions in a building can be assessed, it also can be carried out in relation to the performance of open spaces of a public square through specific computer applications.

In this context, aided by ECOTECT, in this article, we aim to assess the use of day lighting in the open public square of North Entertainment Sector, a central public area of Brasilia. As a result we expect to demonstrate the need for such a type of simulation on a regular basis and contribute to encourage the architects to include the assessment of comfort in the design of public squares.

## 3 Hypothesis

Our hypothesis is that the lack of the environmental assessment in a design of public squares in modern cities like Brasilia reduces considerably it’s use as a place for leisure.

In order to verify this hypothesis there will be used a computer simulation that, in general, can aid the architect in the decision making in the process of design of urban squares, allowing forecasting of its environmental performance before construction. In the case of designs already executed this procedure can aid in correcting possible mistakes and allow improvements in order to make the environment more comfortable for the users.

## 4 Research Method

ECOTECT was used to assess the environmental performance of the public squares due to its simplicity, smooth learning curve and good quality results. Besides it is one of the few programs that can perform simulation of the open spaces. This software was used to assess day lighting during the year.

The procedures adopted to develop the simulations involved the following steps:

1. Verification if the CAD files from the local authority met with the real dimensions of the square under study, North Entertainment Sector.
2. Importing these files into ECOTECT.
3. Creation of zones with tridimensional information including volume and height of two buildings located near the square under study (“Conjunto Nacional” and “Teatro Nacional”).
4. Importing of files with data about Brasilia’s climate into ECOTECT.
5. Creation of zones to facilitate the use of the space under analysis.
6. Calculation of the predominant winds in the ECOTECT.
7. Simulation of the best position for the square.
8. Calculation of the thermal performance of the square.
9. Calculation of shadows cast in the summer and winter solstices besides the vernal equinox (of September) in different hours of the day such as 9:00, 12:00, 15:00 and 17:00.


**Fig. 1** Location of "Conjunto Nacional" Square. (*Source* Brenofontes, 2008)

10. Interpretation of the images obtained through the simulation process of ECOTECT.
11. Assessment and conclusion of the study.

The shopping mall "Conjunto Nacional" is located in the central area of Brasilia and has become a reference point in the city. Its construction was carried out from 1966 to 1972, in the north side of the central bus station of Brasilia, facing the National Theatre ("Teatro Nacional"), in the so called entertainment area. It was designed by the architect Nauro Esteves. Its construction is particularly important to the square under analysis because it is the only source of shade over the square in this tropical dry climate.

The climate of Brasilia is characterized by two seasons: one dry and the other rainy. The dry season ranges from the beginning of May to the end of August, lasting for more than one hundred days without rain. In this period, the highest temperature can reach 35, 8 °C during the day, while at night the temperature may drop to 8 °C. On the other hand, in the rainy season the humidity reaches numbers characteristic of humid tropical regions.

Situated in the north entertainment sector (Fig. 1), the Square of Conjunto Nacional has six thousand and five hundred square meters. It has six fountains that can mitigate the effects of the hot and dry climate of the square. It also has eleven wooden benches that are unfriendly to the passerby because they are exposed to the sun all day throughout the year. The ground of the Square is predominantly of grass, surrounded by concrete sidewalks that also cross it diagonally forming a cross in the center.


**Fig. 2** "Conjunto Nacional" Square. *Source* author own file

It should be noticed that this square has been used mainly as a pedestrian cross way. However a small part in its west side is used for a longer period by the passerby because at a certain time of the day there is some shade provided by the building of Conjunto Nacional. There are also small trees that do not offer enough shade but reduce the visual and thermal discomfort. The proximity of the building seems to offer a feeling of security and shelter that in the later afternoon attracts some users.

In the square there are only two large trees and some palm trees that offer a little bit of shade for the users (Fig. 2). However these trees are situated near Conjunto Nacional and that is a place already receiving more shade. In reality, in the areas of more radiation there are no barriers to protect against the sun. There are some trees recently planted with the potential to offer some shade in the future (Fig. 3).

As the last figure of the Square shows, it is exposed to sun radiation on three of its sides. Its protected side corresponds to the west orientation, where the Conjunto National shopping mall, which is twenty meters high, is located. In some periods of the day, it offers much shade. The square receives a considerable amount of sun light and in addition the reflections of the glass façade of Teatro Nacional, situated in the east side. The photo below shows the shadow produced by Conjunto Nacional in the month of November at 4:00 pm.

**Fig. 3** "Conjunto Nacional" Square. *Source* author own file

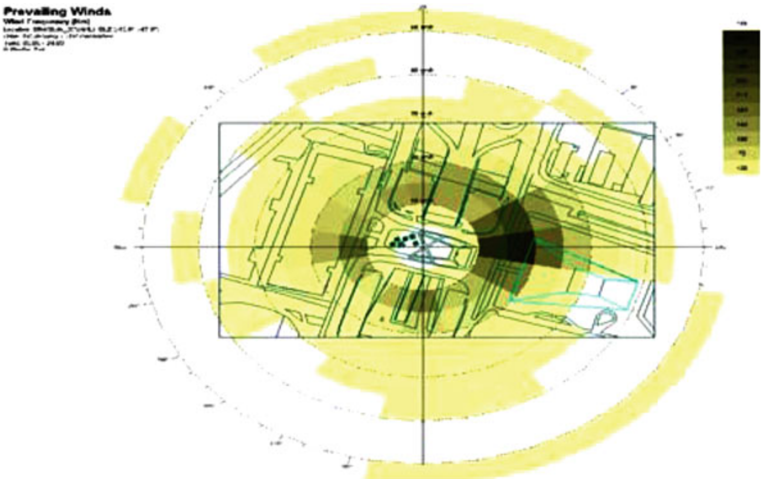



**Fig. 4** ECOTECT simulation of the speed of winds

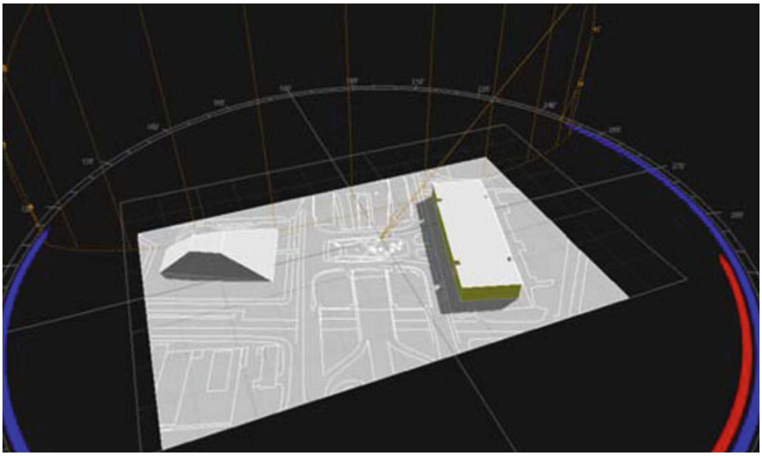


**Fig. 5** ECOTECT simulation of the direction of urban space

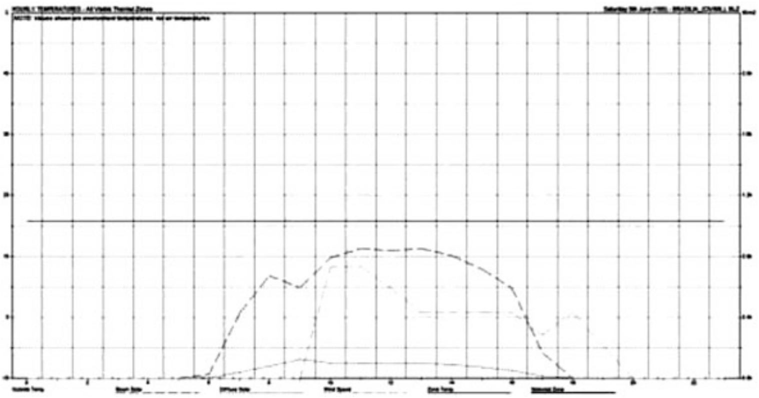


**Fig. 6** Shows ECOTECT simulation with the average of the coldest days, which temperature is represented by the *blue dashed line*

## 5 Environment Assessment Using Ecotect—Simulation of the Speed and Direction of the Winds

Figure 4 shows a graph of the predominant Wind in the Square, from which one can conclude that the winds of more speed are from the East. The National Theater building makes a small barrier for the winds in the east direction; however the largest part of the Square is exposed to the predominant winds (Fig. 5).

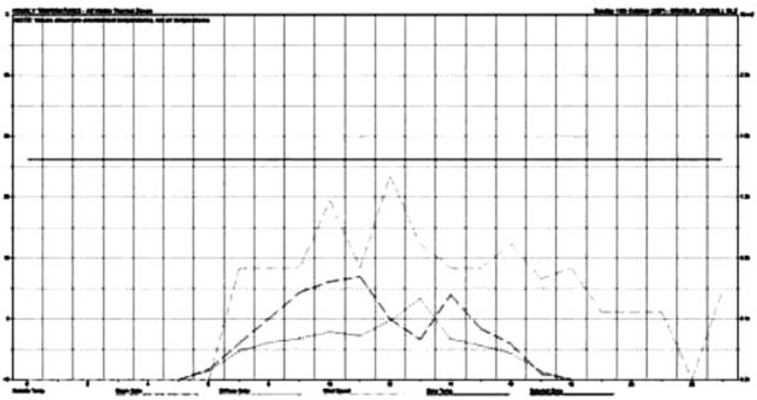


**Fig. 7** Shows ECOTECT simulation with the average of the hottest days of the year, in which the temperature in the open space is presented by the *dashed blue line*

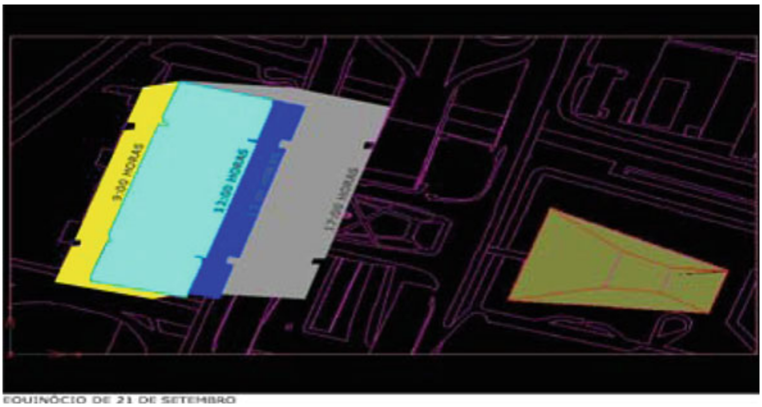
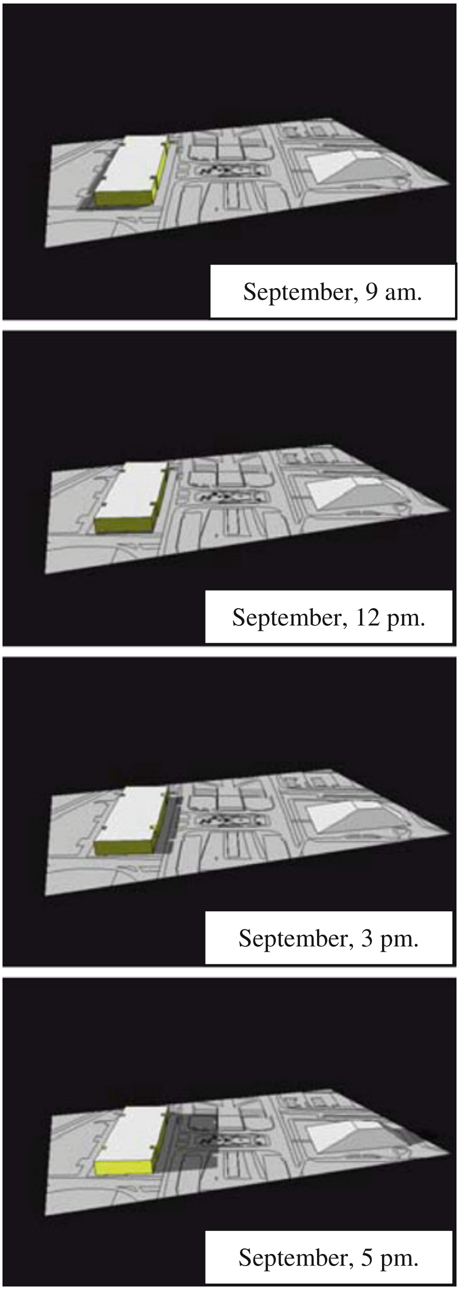



**Fig. 8** ECOTECT simulation in which the shadow projected by Conjunto Nacional in the vernal equinox in different periods of the day

## 6 Simulation of the Best Orientation

According to the simulation carried out in ECOTECT, the best direction to build a building would be Northwest at 330°. However, this assessment would be important for vertical surfaces, based on the average of occurrence. For this reason this kind of simulation is not useful for aiding design of squares since they are made of horizontal surfaces (Fig. 6).

**Fig. 9** ECOTECT simulation of equinox of September



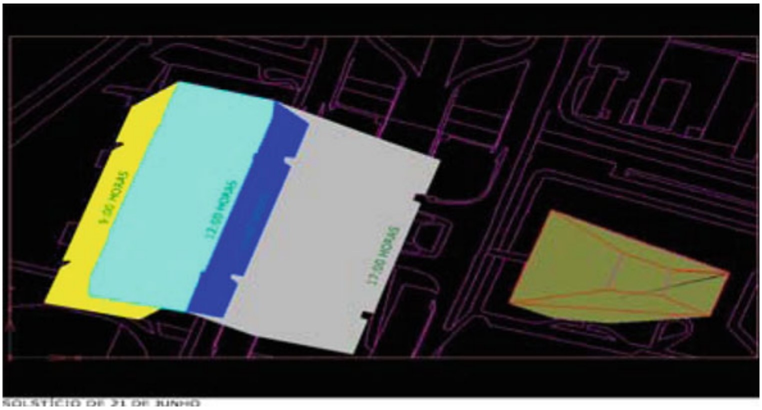



**Fig. 10** ECOTECT simulation in which the shadow projected by Conjunto Nacional in the solstice of June in different hours of the day

## 7 Thermal Simulation

In order to understand the thermal performance of the Square, two simulations were carried out: one with the average coldest day in Brasilia and other with the average hottest day.

The results above show that considering the average of the coldest days of the year, in an open space such as this square, the lowest temperature would be 8 °C and the highest 24°. The coldest temperature varies between 8 and 9 °C, from 5:30 to 6:30 am. The highest temperature occurs between 1:30 and 5:30 pm, varying from 22 to 24 °C.

The simulation of the average hottest day shown by Fig. 7, the highest temperature is 33 °C and the lowest is 21 °C. Also the highest temperature occurs between 12:30 and 16:30 pm, varying between 32 and 33 °C. The lowest temperature take place between 3:30 and 5:30 am, varying between 21 and 22 °C.

The data also show that the highest temperatures of the Square take place during the largest part of the year, when there is very little barrier of the direct radiation that causes discomfort to the users.

## 8 Simulation of Shadows Casted

Although the Square of Conjunto Nacional is an open urban space that receives sun radiation all over its surface, in certain times of the day some parts are protected by the shadow of Conjunto Nacional.

In order to simulate these shadows we chose some periods of the year related to the southern hemisphere's winter solstice (21st June), summer solstice (21st

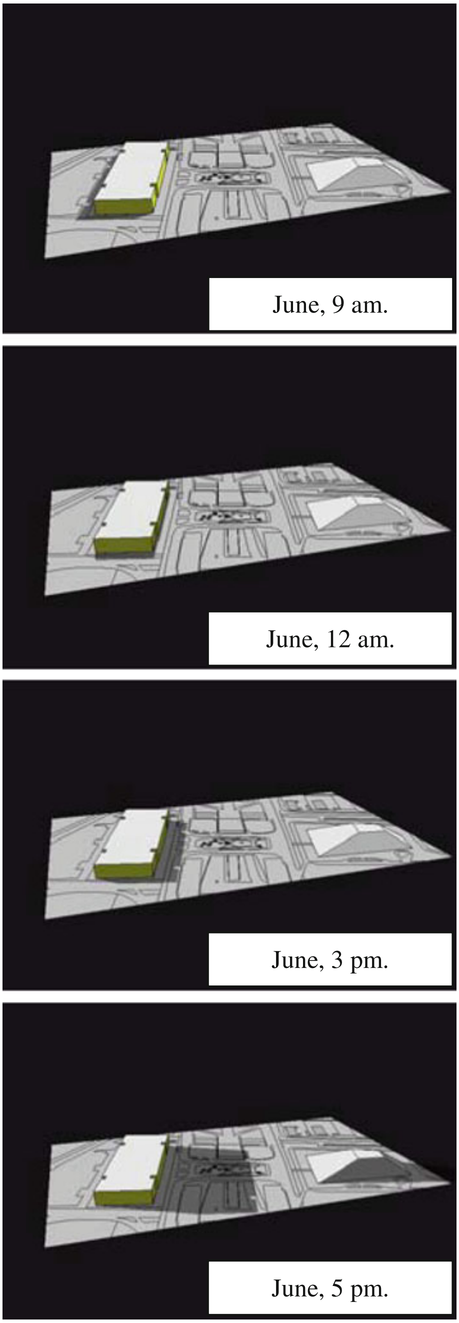



**Fig. 11** ECOTECT simulation of the solstice of June

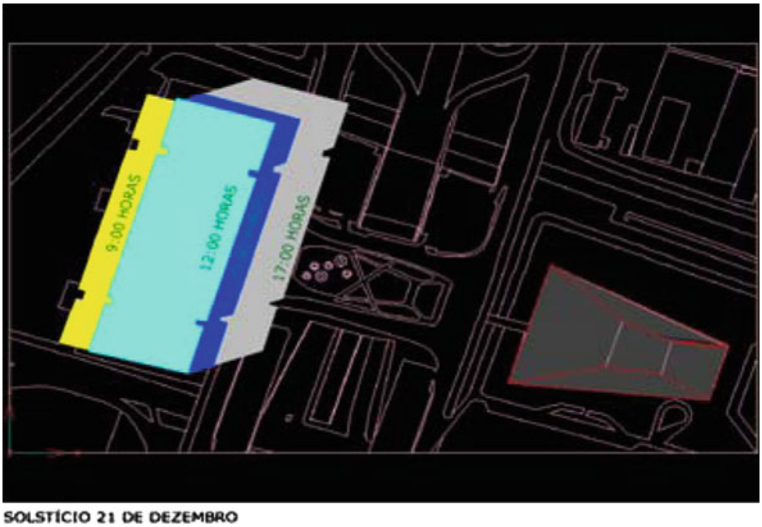



**Fig. 12** ECOTECT simulation in which the shadow projected by Conjunto Nacional in the solstice of December in different periods of the day

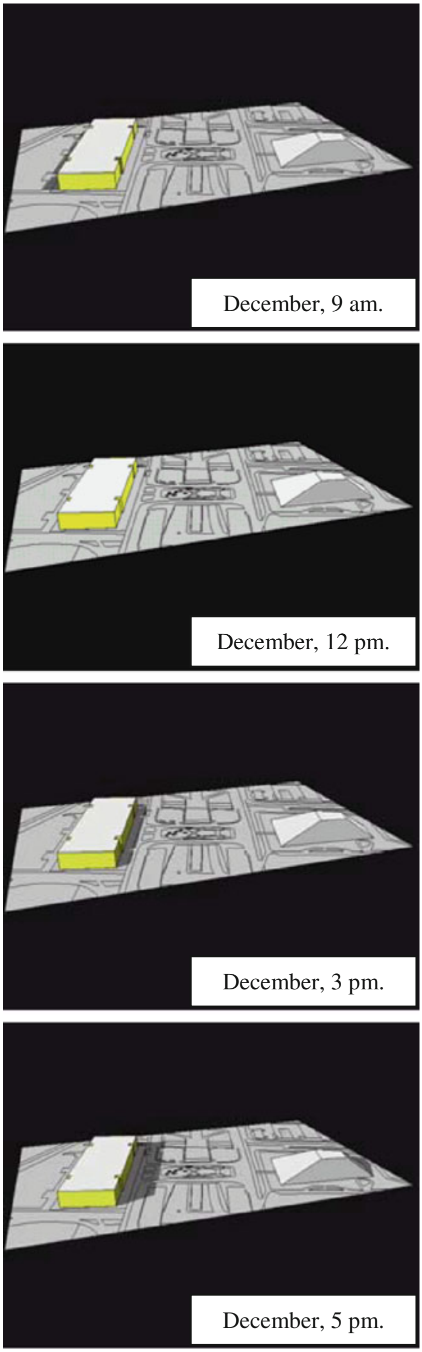
December) and vernal equinox (21st September). In this sense we present the following images of simulations carried out with ECOTECT. The Figs. 9 and 10 show that in the vernal equinox, at 9 am, the shadow is situated in the opposite direction of the Square, not offering any protection to the possible user. In the same way, at 12 pm there is no projection over the Square. However, at 3 pm there is some shadow in the west part and at 5 pm the shadow covers almost half of the Square.

In the winter solstice (21st June) at 9 am, the Conjunto Nacional building projects a larger shadow than that from the equinox in the opposite side of the Square, in its west façade. At this time there can also be seen some shadow in the south façade. At 12 pm there is a small shadow in the South and West façades that does not reach the Square. However, at 3 pm there is some shade in the West façade, and at 5 pm the shade covers almost the whole Square (Fig. 10).

In the solstice of 21st December, at 9 am there is no shade over the Square, only over the west façade of Conjunto Nacional (Fig. 11). At 12 pm there are no considerable shadows in any of the façades. At 3 pm there is a small projection of shadow in the west part of the Square. And at 5 pm there is some shadow projected in the Square but much smaller compared with the equinox of September and winter solstice (Fig. 12).

The simulations show that the winter solstice is the time in which the Square is more unnecessarily protected from Sun radiation, i.e., when the coldest days and nights of the year occur. It can be observed that the shadows increase from June to December, when it is more exposed to the sun radiation. It is worth noting that the

**Fig. 13** ECOTECT simulation of the solstice of December



National Theater building offers some shade that cannot reach the aforementioned Square I don't understand why under was used here (Figs. 1 to 13).

## 9 Conclusion

These simulations confirm our hypothesis that the design of open public squares without taking into consideration environmental conditions may lead to an unsuccessful result. They point to the main cause by which an uncomfortable environment does not attract users. They show that during most of the year the square of "Setor de Diversões Norte" is unprotected against sun radiation. They also show that during the months with the lowest temperature, i.e., from May to July, in Brasilia, it is exactly the time of the year in which there is more shade from "Conjunto Nacional" over the Square. In addition there are no barriers against the predominant winds what increase the discomfort of the users.

It also can be observed that the shadow projected by "Conjunto Nacional" decreases from June to December and increases from January to June. The projection of shadows is smaller in December and January and largest in May and June.

Therefore the urgent need for the architect to adopt tools for the assessment of comfort from the beginning of the design process for open public spaces is clear. Rather than the way it has been done more commonly in relation to buildings.

The lack of use of assessment tools in the urban design results in loss of control over the design. These tools can be used to forecast the discomfort and to aid the decisions to prevent it.

The use of these procedures in the process of urban planning can maximize the location and the orientation of the open spaces by identifying the negative and positive results from the simulation during the various periods of the year and in different hours of the day.

As a result of these simulations the open public spaces can be better used through the planning of structures, choice of materials, and urban equipments such as kinds of trees, benches, percolators, fountains and etc., in the right places.

Owing to the fact that the Square of "Setor de Diversões Norte" is situated on a fly over, makes it difficult to plant trees with deep roots. For this reason we suggest planting trees of medium size near the planned places of permanency where the benches are. The fountains could be located closer to the equipment of permanency and the passage of pedestrians, because the water in movement could increase humidity and the feeling of comfort. The floor could be colored instead of the white one used that causes sun glare. More attractive urban equipment could be chosen to encourage the permanency of people in the Square. After these changes we suggest feeding the data into environmental simulation tools to verify again the level of visual and thermal comfort. I'm unfamiliar with the term 'fly over' could that be 'viaduct'?

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# Some Results in Automatic Functional Test Design for Processors

**Ján Hudec**

**Abstract** This paper deals with the design and implementation of a universal functional test generator for VLSI circuits, such as microprocessor and processor cores. Our approach to test generation—the functional test generation method–is based on knowledges and functional description of VLSI systems at functional VHDL level and the algorithm for automatic generation of test (normal executable test sequence of instructions) and arrangement, is used in very flexible and effective tool - functional test generation software system. Also a short methodology overview for the test synthesis of VLSI circuits using an automated process of the VHDL synthesis simultaneously with Automatic Functional Test Generator (AFTG) is presented. The determination of the test efficiency of instructions mixes is discussed.

## 1 Introduction

As a consequence of exploiting the ever more advanced technologies, the complexities of electronic-based products have increased significantly and there is a great need to incorporate design for testability and test generation into the development of these products. One from many important problems in this area is to create a powerful tool for automatic test design of digital systems, which supports automated test pattern generation. In recent years, functional testing has been presented as a suitable solution to the problem of test generation for complex

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VLSI systems, such as microprocessors, specially designed ASIC systems and processor cores. In this area, a number of functional level test approaches for VLSI systems have been proposed [1, 2].

The AFTG (automatic functional test generator) project provides a consistent set of tools for definition of a test method for complex programmable systems, functional test generation, test verification, determination of test efficiency, fault simulation and testability analysis.

## 2 Methodology of Test Synthesis, Simulation and Verification

Once the designer has described the design, the design must be verified to check that the specification has been followed. The commonest verification method is to apply input stimuli signals during a simulation and then read the outputs signals from the system design. A major disadvantage of using the simulator's input stimuli language is that it depends from simulator. Another method of verification is to write the test model generation and the output signals check in VHDL. This means that you design a testbench which both provides input signals and tests the output signals from the design. The recommendation is to use both the VHDL testbench and to verify the components using system simulation.

The major advantages of the VHDL testbench are its speed and the fact that it is platform-independent, as it is described in VHDL language.

The disadvantage is that the VHDL testbench can contain the same logical errors as the design [3]. For our purpose, it may be beneficial to build a test environment in full or in part in specific VHDL functional diagnostics tool.

Naturally, the basic question is how effective test programs (testing mix—is the meaningful sequence of instructions) can be created automatically and what AFTG design rules must be followed in VHDL code in order to make this possible.

Our methodology–the AFTG approach to functional testing is based upon the following principles:

- Use of an identification test method (no extra fault model of system is needed),
- Use of a system for the automated generation of test programs for actual VLSI systems.

We consider this approach as most effective mainly because it is used the knowledge-based method that is very close to the identification test method and is a combination of heuristic and random pseudotrivial approach [2].

The architecture and behaviour of the system is described in VHDL language divided into some basic parts (such as ALU, memory, control unit, I/O unit, block of registers, etc.).

In addition to generating instruction mixes we developed method, in which we used:

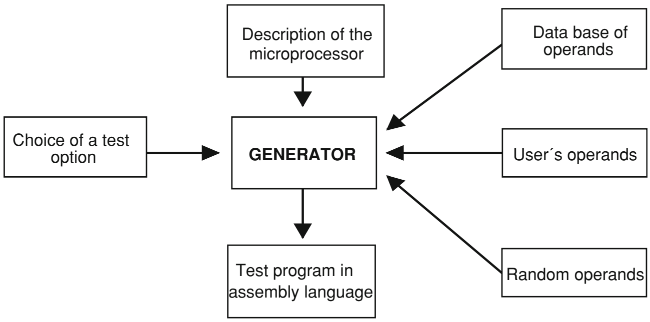



**Fig. 1** Design flow of AFTG

- Solid state choice of instructions,
- Standard computer system random number generator, which is capable to fetch instructions from appropriate groups using choice algorithm and to add suitable operands.

Such a way, we obtained that **the ability of system's testing is the property of generated testing mix**. We concentrated our effort on this idea.

The methodology (called Grouping) of test synthesis was briefly introduced in [4, 2] and the procedure of obtaining of testing mixes consists from following steps:

1. Analysing and partition of instruction set to groups (G–number of groups).
2. Establishing number N of instruction in each group.
3. Random generator RNG generates a number ni from 1 to Ni (Ni is maximal number of instruction in each group i).

This is a pointer to instruction in actual group of instruction. Number of register combinations for each instruction is Q.

OPER is field of pointers for estimating of access index to field with appropriate operands.

4. For each fetch instruction in actual group, random generator RNG generates number from interval 1 to Q for establishing pointer OPER for access to field with operand for this instruction.
5. Repeat this procedure for desired number of instruction in testing mix.

System AFTG (Fig. 1) generates a test programs (program composed from various parts of testing mixes) in assembly language according to the user's choice of:

- Test generation option (used method, number and type of mixes),
- VLSI system test (number of blocks, instructions), using the reported methodology.

AFTG provides test programs in assembly language, which are easy to use during diagnosis experiments (leads to readable programs), but AFTG has also a possibility for generating the executable code and watching the internal states of system and simulating the function.

AFTG fully makes extended arrangement of instructions and automatic test generation of test mixes for whole system.

## 3 Some Implementation Results and Test Verification

The whole AFTG system is implemented in C# language in environment of Visual Studio.NET. The ModelSim simulator was used due to very good property for incorporate it to the whole AFTG design. The verification of the efficiency of the generated tests of systems (VLSI microprocessor type circuits) is obtained from the diagnostics efficiency tool, which is integrated into the product. The set of tools in AFTG test program generator is open and can be easily extended because of the description parameter's versality of representing system model.

For configuring the parameters of test generation, simulation and verification we assumed some arrangements for the selection of:

- Reference system description in VHDL (i.e. processor),
- Various descriptions of systems in VHDL with fault function assumption,
- Method of composition of testing mixes (i.e. the number of instructions in each testing mix),
- Validation by simulation process (what kind of comparison),
- Test efficiency result.

Some previews from AFTG system graphic interface menu are in Figs. 2, 3, 4.

We concentrated on the comparative method of the test evaluation (comparison with a reference ("gold") system) in two ways:

- Comparison of the memory contents after simulation of the whole testing mix,
- Comparison of simulation runs that means comparison of registers of processors after each instruction of testing mix.

The part of the whole VHDL-based design was the automatic functional test generation to several systems, such as family iAPX 86 microprocessor (from 8086 to 80486–Intel, AMD), Pentium, Motorola 68000 family (68020, 68030, 68LC040), neural TNP processor and hypothetical 32-bit DP32 processor.

*Some results of test efficiency verification of iAPX86 system*—Ten functional errors are modelled in processor: Stuck-at- zero/one on zero bit of address bus or data bus, zero bit of address bus is equal to first bit of data bus, register AX have zero value and some errors in execution of instructions MOV, STC, CWD, NOT.

The number of detected faulty processors with 15 testing mixes composed from 6 instructions is shown from Fig. 5. It was 9 processors from 10. We have used the

**Fig. 2** AFTG input data (XML scheme)

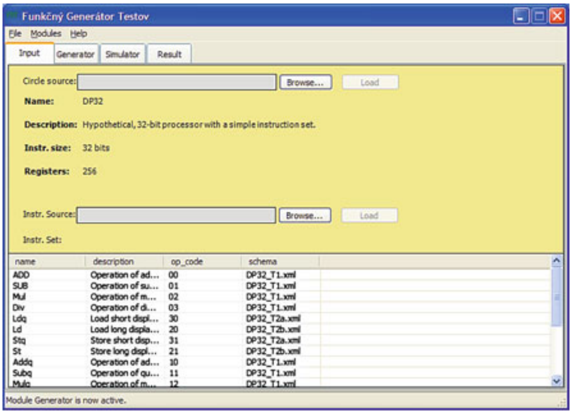



**Fig. 3** AFTG module generator

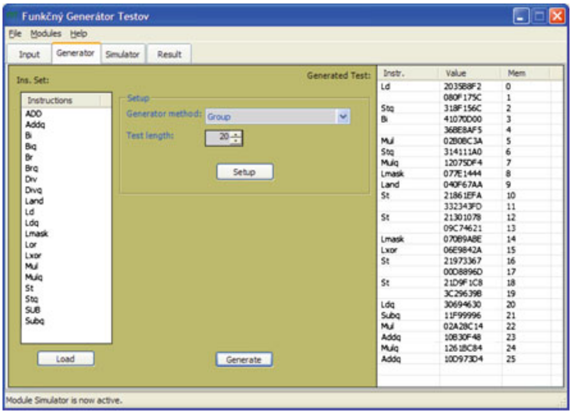
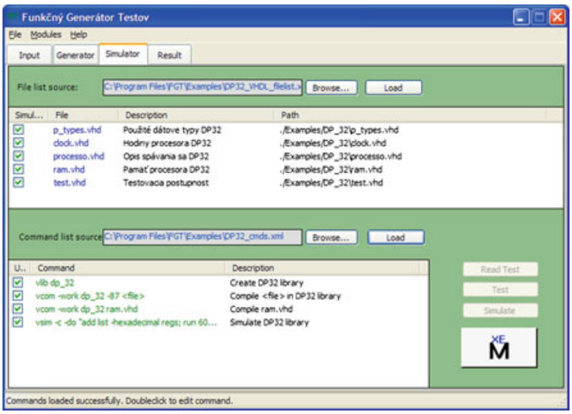



**Fig. 4** AFTG module simulator



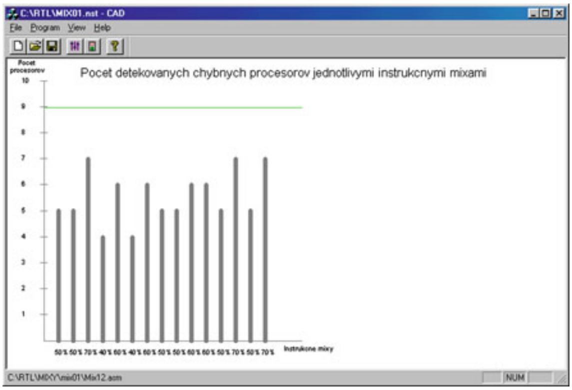



**Fig. 5** 15 mixes from 6 instructions

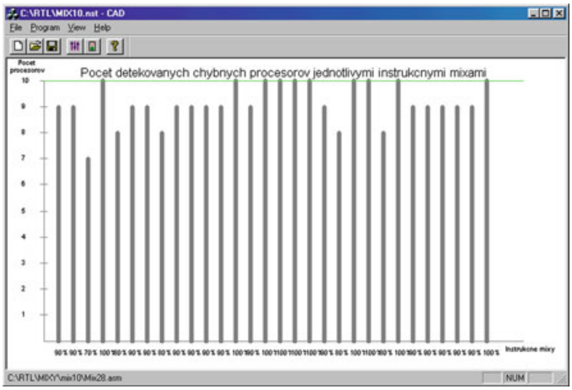



**Fig. 6** 30 mixes from 72 instructions

comparison method of registers contents of reference and faulty processor after each instruction of testing mix.

The validation result from 30 testing mixes composed from 72 instructions is on the Fig. 6. The number of detected faulty processors in this particular arrangement was nearly 10, i.e. 100 %.

Based on the simulation process validation we affirm that the longer testing mix gives high efficiency in detection of faulty systems. The major effort in preparing each system test comprised its precise system description, while the realization was automated by AFTG components of whole VHDL synthesis system.

After these practical experiences we implemented the sophisticated module for extended test efficiency analysis, which we first used for the DP32 processor [5] (Figs. 7, 8).

The extended analysis compares the difference in longitude of compared files, the difference in number of characters and the average of these values. Additional information about the simulation process is also displayed.

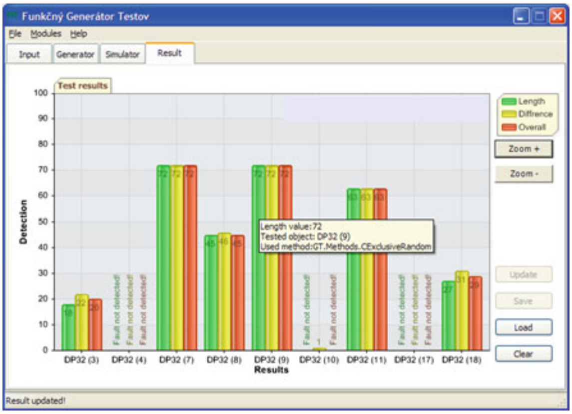



**Fig. 7** Extended test efficiency analysis

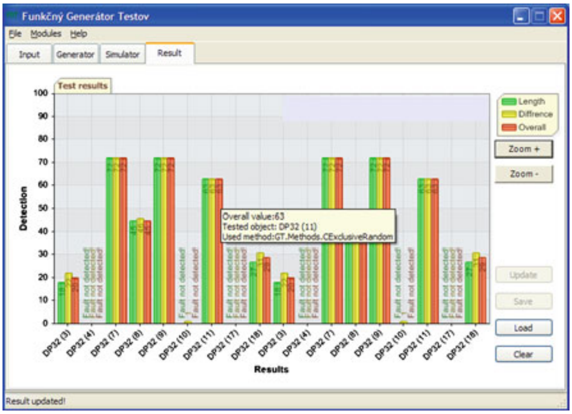



**Fig. 8** Test result of 50 faulty processors

## 4 Conclusion

On the basis the above specifications and methodologies we developed and implemented a system with computer-aided tools for processor functional test synthesis, simulation, fault simulation, verification of efficiency of testing mixes together with solving different test design tasks. The AFTG test design software for systems described at the VHDL level consists of tools for circuit description, multi-valued simulation and testability analysis, test mix generation and test efficiency verification.

Our recent work is focused to the development of the new sophisticated methods based on new algorithms, which takes advantage of evolution strategies. The generated testing mix forms the basis for the next generation of testing mix with use of genetic algorithms.

On higher level the AFTG system supports design and synthesis from various CAD environments, including those of OrCAD, Synopsis, Viewlogic, Mentor Graphics FPGA Advantage and Xilinx Design Suite Technology. Such a way, the

CAD synthesis system with AFTG forms the basis of a VHDL functional diagnostics tool (VFDT). AFTG with supporting synthesis tools is a flexible and versatile tool for

automated design of comprehensive test programs for complex VLSI circuits, such as intelligent chips, dedicated and specific microprocessors, embedded processor cores.

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# Enhanced Classroom Presenter

**K. Jelemenská, P. Koine and P. Čičák**

**Abstract** Nowadays perhaps the most widespread teaching style at the university lectures is based on slides presentation using computer and data projector. Compared to the previously used "blackboard and chalk" style, data projectors brought a substantial loss of interactivity between students and teacher into the teaching process. Students are often taking notes without even thinking what they are writing down. This can in no way develop their creative thinking. Recently the "active learning" teaching style emerged and is becoming more and more preferable. To use this style in conjunction with computer and data projector the interactive presentation system is one of the basic assumptions. Among the available open-source presentation systems supporting interaction the Classroom Presenter, developed at the University of Washington, seems to be one of the most promising. The article describes the extensions that were designed and implemented to this presentation tool at the Faculty of Informatics and Information Technologies, Slovak University of Technology in Bratislava mainly to enhance the editing, import, and export possibilities of the tool.

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# 1 Introduction

Human interacts with his environment on a daily basis. Even as children, we learn through communication with other people and through processing information others show us. It is the easiest way for us to learn. To completely understand a subject however, we need to discuss.

Over the years the teaching styles have evolved from the "blackboard and chalk" through the "whiteboard and board marker," "overhead projector and transparencies" to the nowadays most widespread data projector presentations. Although the data projector brought a lot of advantages like cleaner environment, better visibility especially in large classrooms, possibility of projection screen duplication, higher flexibility etc. a number of issues occurred as well. The most important include one-way static transfer of information from teacher towards students, uncomfortable ways of active entries into the presentation, and static or no access to presentation materials.

A lot of lecturers noticed the declining students' engagement and an inability of students to follow the lecture content. When taking the notes most of the students do it without knowing what they are writing. There was an urgent need to make the lectures more attractive. However, the loss of the possibility to annotate the presentations using handwriting made it difficult. The only way of attracting students' attention was the laser pointer which is hardly visible in huge lecture halls. These were the main reasons that encouraged the development of interactive presentation systems that would support things like attention catching marks for emphasizing slide content, writing illustrating examples, annotating diagrams, drawings or pictures as well as promoting the audience interaction [1]. That means the system that can give audience the possibility to interfere directly with the presentation itself. Therefore, as the whole product it can help students to understand the problem by presenting the subject, discussing it and interacting with it.

# 2 Related Work

There are several interactive presentation systems that give us the functionality mentioned above. They include freeware, shareware, as well as the commercial applications [2].

## *2.1 DyKnow Vision*

DyKnow [3] stands for Dynamic Knowledge. Created at the DePauw University by Dr. Berque to help students learn new things it was later commercialized and its functionality widely extended. It has client–server architecture and supports both wired and wireless networks. The whole communication is encapsulated into the HTTP protocol. DyKnow Vision allows students authentication and provide some monitoring capabilities. To get students' feedback, teacher can create little tests that are sent to the client applications where the students solve them and send them back to the teacher. Another interesting possibility is to give the student a control over the teacher's working space to fill in some information.

## 2.2 Classroom Presenter

Classroom Presenter (CP) was designed and implemented by students at the University of Washington [4]. It is an open source tool that has many useful functions. It has the object oriented architecture. The slides are divided into several sheet layers: image sheet layer, text sheet layer and ink sheet layer. Several commonly used stylus types are supported e.g. pen, highlighter, erase pen etc. CP provides quick poll (voting for an answer to multi-choice question) as well as the possibility to send the whole-slide solution to the teacher.

Concerning the possibility to extend the system there is one important disadvantage: the CP software documentation is far from perfect therefore making any changes would not be an easy task

## 2.3 Ubiquitous Presenter

This system is an extension to Classroom Presenter version 2 (the latest available version is 3.1). It has been developed at the University of California, San Diego [5]. One of the main extensions was the implementation of a web based java applet which allows the user to connect to the presentation using a web browser. Students' submissions are sent to the teacher's application through a central server. It supports ink as well as other annotation techniques and a new submission style—short message service (SMS) should be available soon.

## 2.4 NetSupport School

NetSupport School [6] is not exactly an interactive presentation system. Its main purpose is the class management. It can manage the whole computers and their running processes. However, it has some capabilities that allow the users to present slides and to save the presentation and solutions as a Portable Document Format (PDF) journal. It also allows students to submit their contributions and to perform the tests.

The main disadvantage is the initial high cost investment into the application itself and into the class equipment with tablet PC or other computers.

### 2.5 InkSurvey

InkSurvey [7] is a completely web based application, freeware tool. The teacher can ask questions during the presentation and the students can answer them using ink or keyboard. When submitting the answers the students can choose how certain they are with the answers. However, only Mozilla Firefox web browser is fully supported.

### 2.6 eBeam Projection

eBeam Projection by Luidia [8] is more a hardware solution than a software one since to be functional a hardware package is needed. This contains an interactive stylus that behaves like a mouse, an eBeam receiver that can be mounted on almost any surface (wall, whiteboard etc.) to turn it into an interactive whiteboard, and a data projector. The receiver catches the stylus position and the actions on the projected screen and transfers it back to the computer. eBeam Projection is accompanied with an eBeam Interact software package including an eBeam Scrapbook – the presentation tool with content sharing and collaboration features using an Internet connection.

The comparison of the mentioned tools is summarized in Table 1.

## 3 Classroom Presenter Extensions

After experiencing several interactive presentation applications we found out that none of them satisfies our expectations completely. All the tested applications can be characterized by poor import possibilities. If ever a tool supported other than its own natural format then it was PowerPoint presentation. So the lecture materials prepared in other format can not be reused with these systems. Since we believe this is an important restriction we decided to concentrate on this issue. There were two possibilities: to design and implement a completely new interactive presentation tool or to improve one of the existing ones. The University of Washington's Classroom Presenter 3.1 (CP3) was chosen for this purpose [11] simply because it is the only open source tool. Based on the CP3 license it can be extended and redistributed by anyone providing that the license conditions will be met. We realized the potential of this application consisting mainly in its quality interaction support.

**Table 1** Comparision of interactive presentation systems

| | DyKnow Vision | Classroom Presenter | Ubiquitous Presenter | NetSupport School | InkSurvey | eBeam Projection |
|---|---|---|---|---|---|---|
| Hardware compatibility | All | All | All | All | All | Need of eBeam HW |
| Central server | By producer | No | Yes | Yes | Yes | Local host or by producer |
| Controlled authentication | Yes | No | No | Yes | Yes | By producer |
| Microsoft Power Point integration | Yes | No | No | Yes | No | Partialy |
| Stylus preasure support | Yes | Yes | Yes | – | – | Yes |
| Network communication | Yes | Yes | Yes | Yes | Yes | Partialy |
| Multimonitor support | Yes | Yes | Yes | Yes | – | No |
| Price per license | \$30-\$108 | Free of charge | MSR-SSLA | \$546.00 per 10 licenses | Free of charge | Free with eBeam HW |

### *3.1 Classroom Presenter Original Features*

The main feature of Classroom Presenter 3.1 is its role based choosing system. It supports two different role types. The first one is standalone, the second one is networked. In the standalone type you can choose to work only as an instructor.

In the networked type, there are 3 roles. The first one is the student role. As the role implies it was designed to provide the students with a possibility to connect to the presentation. After the successful connection they can download the presentation, browse it, and annotate it with their own notes. They can also be allowed to send their solution slides to the teacher and to answer the quick polls.

The second role is the instructor role. This role is identical to the standalone instructor. The only difference is that it creates a TCP based server which the students are connecting to.

The last role is called public display. This role was created only to give the teacher the possibility not to be connected directly to the projector. In this case another computer with public display role is connected to the projector and is used as a middleman to the teacher who can roam freely in the classroom.

Other features of CP3 include pen stylus and highlighter stylus. The user can change the stylus color and in case it is supported by the computer technology the application can recognize the stylus pressure too.

As it was mentioned above, CP3 has a completely object based architecture. The object slide consists of multiple sheet

layers: image sheet layer, text sheet layer, and ink sheet layer. The layers themselves are objects too.

*Image sheet layer*—holds an image which can be resized and moved. Resizing keeps the aspect ratio, therefore we cannot change only its height or width. This is the bottommost layer.

*Text sheet layer*—gives us the opportunity to insert normal text into the presentation. Font, size and color can be set.

*Ink sheet layer*—stores all the strokes the user draws. It is the topmost layer, therefore it is always redrawn as the last one and is always visible.

CP3 supports dual monitor output and is able to export slides in the form of images and Hypertext Markup Language (HTML) documents.

As an input it is able to open its native format and the Microsoft Power Point presentations. Primarily devoted to presenting and annotating the presentations prepared in advance in Microsoft Office PowerPoint, the presentation editing capabilities of CP3 are very poor compared to other environments. It does not even support the basic editing features like slide movement or copying which one would say are indispensable when reviewing the older presentations.

Among the editing options we can find the zoom out button. Zooming out scales down the slide size and an extra space is available for additional notes.

Except for PowerPoint presentations there are no other import possibilities. So the materials prepared in other formats can not be reused with Classroom Presenter.


**Fig. 1** Role selection wizard

## *3.2 Enhanced Classroom Presenter*

While using the CP3 during lectures presentation several issues occurred that could or even should be solved to improve the comfort and the efficiency of the Presenter. Some extensions were designed and implemented into the CP3 in the frame of diploma thesis [9, 10] and will be described in this section.

## *3.3 Role Selection Wizard*

The first one was the role selection wizard. This wizard simplifies the role choice using a step by step user interface (Fig. 1). The original login window was not very practical on the monitors with low resolution. It caused the login window to show up outside the working area. This wizard corrects the problem. It allows teacher to simply create a TCP session and to start the presentation. The students can then easily join the selected session.

## *3.4 Presentation Publishing*

Another feature that was implemented is the presentation publishing. To accomplish that we export the current presentation to the PDF format, fill in the server IP address and publish the document. Of course, to publish the document the central server has to be created first. The server allows the teacher to divide students into classes and to sort the published materials. The connection to the server needs an authorization which recognizes the privilege level of the logging in person. The paths to the documents are not absolute, instead they are computed using an MD5 hash algorithm.

## *3.5 Import and Export Extensions*

The possibility to import and export the *PDF documents* was implemented as well. To export the PDF document we took the advantage of CP3 to export slides as images. We take these images and create a PDF document from them. Just before

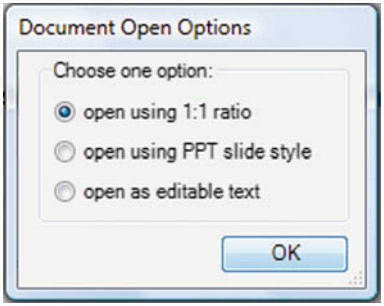


**Fig. 2** Word document open options

the document creation, we can add some metadata like author, title etc. The resolution of the used images can also be changed setting up the DPI (dots per inch).

Another document type we can import is the *Microsoft Word document*. The supported formats are.doc,.docx and.rtf. To open these types of documents we need to have Microsoft Word installed. The supported versions are Word 2003, Word 2007 and Word 2010 Beta edition.

The document can be opened using one of the three options (see Fig. 2):

1. *1:1 style:* this opens the document in CP3 as a one to one copy i.e. as we can see it in Microsoft Word. This style does not allow the slide content to be edited afterwards.
2. *PPT style:* this style is very similar to the Power Point presentation. The Word document is resized, rescaled and then used to create the slides. The resulting slide content cannot be edited either.
3. *Editable text:* the last style enables to open the Word document as an editable text. It uses the PPT style format, but it is then parsed to CP3. For each document page we parse its text and create a text sheet layer, for each picture in the page we create an image sheet layer and for each table we create an additional text sheet layer.

## 3.6 Basic Editing Features

An effort has been made to implement some basic editing features. The original CP3 did not support the *slide position change*. Therefore, we changed the default behavior of the mouse when entering slide miniature. According to the original behavior to see the slide preview it was necessary to hold down a mouse button. We changed it to a more intuitive behavior. Entering the slide miniature the preview is shown immediately. After five seconds without any movement the preview closes automatically.

Holding down a mouse button over a slide miniature the slide movement is possible. We can move it down or up to another slide position and then release the

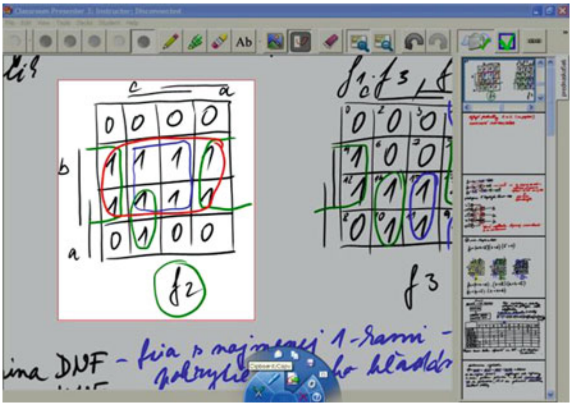

**Fig. 3** Snipping tool on zoomed in slide

mouse button to move the slide to the new position. To show where the slide is going to be moved a graphic marker was added showing us the current position.

The original CP3 did not support the *copy/paste* function either. As it is widely used, the functionality of CTRL+C and CTRL+Vshortcuts was added as well. To differentiate between copying the whole slide or just one sheet the stylus selection is used. In case the pen or the highlighter stylus is selected the shortcut CTRL+C will add the whole slide into the clipboard. In case the text stylus is selected the copy shortcut will place the topmost text sheet layer into the clipboard. Finally, in case of image stylus selection the copy shortcut will place the topmost image sheet layer into the clipboard.

The paste functionality is made more versatile. According to the clipboard content the corresponding slide or sheet will be pasted. The possibility to paste images from the clipboard directly to the slide was added too. In this case the new image sheet layer is added into the current slide. This feature makes for example the use of snipping tool more comfortable.

The next new feature is the possibility to *zoom in*. This feature gives us the opportunity to show the audience some detail in the slide (see Fig. 3). It can be useful when for example a large picture should be included into the presentation and the small details are not perfectly visible.

The last new feature is the *reflector stylus*. This stylus will create a gray half transparent layer on the top of the slide. Using a mouse or other selecting device we can then select the region we want to see normally. In other words a window is created through which the selected part is visible. Two reflector styles were implemented: rectangle style and custom shape style.

With rectangle style stylus the selection is reshaped to a rectangle which is then removed from the layer. With custom shape reflector stylus the selection is transformed into a closed curve which is then removed from the layer. Figure 4 shows us the custom shape reflector style. This allows the teacher to show the students only a part of the slide and to focus on a specific problem.

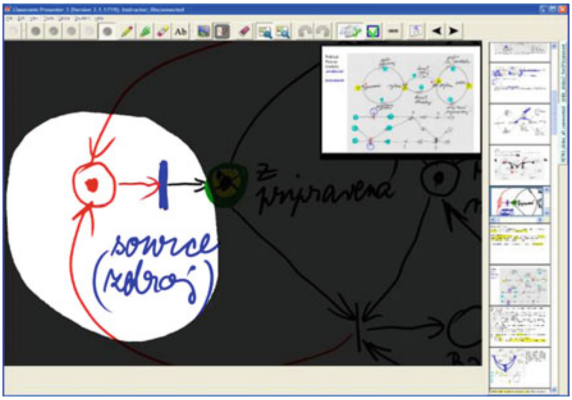

**Fig. 4** Custom shape reflector on zoomed in slide


**Fig. 5** Toolbar extension in Enhanced Classroom Presenter

Two new tools were appended to the original Toolbar – Reflector and Zoom in and the icon of the former Zoom out tool was modified. The differences are illustrated in Fig. 5.

## 4 Conclusion

In this paper the interactive presentation system called Enhanced Classroom Presenter was presented. The system is based on the Classroom Presenter 3.1 [11] using its basic functionality and expanding it to meet our needs. The main extensions include: PDF documents import and export, Word document import, presentation publishing, zoom in, reflector, and slide movement functions. The possibility to copy the whole slide or just the image or text sheet layers and to paste the content of the clipboard into the presentation or current slide is also supported. The role selection was simplified, replacing the original one with a step by step role selection wizard.

The Enhanced Classroom Presenter is an open source product just like the original one and is used for lectures presentation at the Faculty of Informatics and Information Technologies, Slovak University of Technology in Bratislava.

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# A Textual Domain Specific Language for User Interface Modelling

**Mart Karu**

**Abstract** User interface development is one of the hardest parts of the software application development. It could be made more efficient by introducing model-driven development approaches and user interface modelling. This paper introduces a textual domain specific language and a corresponding meta-model for describing user interaction using abstract UI patterns that can be transformed into more platform specific UI patterns during application generation. The language also follows use case description format and provides possibilities to add free-form documenting context to the formal constructs used in the language, making the models described in the language suitable both for model driven engineering and requirements elicitation.

## 1 Introduction

User interface (UI) development is one of the hardest parts of a software development, especially in a world where the success of a software application can be attributed to the quality and consistency of its UI. Targeting UI development with model driven development (MDD) methods can:

- reduce the effort needed to implement and maintain reoccurring UI patterns in general purpose languages, by abstracting out the patterns to the meta-model and to the corresponding modeling language.

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- raise the quality and consistency of the application UI, by applying code generation techniques that will always produce similar implementations of the patterns across the target application.

The goal of this paper is to introduce an additional language and a corresponding meta-model to the existing user interface modelling languages and meta-models, that could raise the quality of the viewpoint taken on a model and on the general domain of UI modelling and model driven UI development.

This paper is organised into six sections. Section 2 explains the other related works in this field and motivation behind the work. Section 3 describes the proposed language and the concept space the language covers. Section 4 will give an exemplifying overview of the language usage. Section 5 discusses the results of the work and the final section will conclude the work.

## 2 Related Work and Motivations

Current modelling languages used in MDD-specific UI modelling can be divided into three categories based on the modelling approach:

- UML-based languages and UML Profiles
- Graphical Domain Specific modelling languages
- Textual Domain Specific modelling languages

The UML-based approaches rely on using standard UML concepts like class and interaction diagrams [1] or specific UML profiles [2] that further restrict the generic UML language by applying domain specific constraints. While the approaches do manage to capture the most essential parts of the UI and there is mature tool support available, the complexity of the UML meta-models and the inflexibility of the standard diagram formats to be tailored to match the domain make them not the most optimal choice for the MDD in general [3].

Non-UML based graphical languages have the freedom to use the most suitable language representation for UI modelling and there are several works [4–6] that utilise graphical modelling languages or visual toolsets. While the graphical languages are prevailing approaches to the UI modelling and there are clear benefits of using graphical languages, there are also disadvantages when compared to textual languages [7].

On the existing textual languages side, there are domain specific languages (DSL) for developing web-based user interfaces like WebDSL [8] attempts to describe the UI domain using functional languages [9]. Also the UsiXML approach [10] can be considered to be based on the textual XML language, although in practice the XML is being generated from the graphical modelling tool front-ends [11].

Concept-space wise, many model driven approaches employ meta-models that include concepts that are based directly on a specific technical target platform or

UI style. For example, in the WebDSL approach the UI aspects are describe by using idioms and UI elements widely known in the web-based UIs. There are works that express the importance of using more abstract ways of marking UI concepts and using intelligent transformations [12, 13] or abstract UI modelling in general [10].

Based on the previous works and the benefits [3] of MDD, it would be reasonable to construct a domain specific textual language that would satisfy the following goals:

- The language needs to present a model as a first class artefact for capturing requirements of all of the aspects of the user interaction.
- The model described by the language needs to be formal enough to be used in user interface generation using MDD approaches.
- The language (and the meta-model) should have extension points for integrating the target model with models that represent other software application domains
- The language should present the user interaction patterns in the abstract form, to facilitate independence from the user interface technology and the interaction paradigm
- The language should be textual because of the many practical benefits of the textual languages, like efficient creation and maintenance, efficient usage of visual space, language integration possibilities, fast formatting, version control and mature tool support [7].

## 3 Overview of the Language

The UI description language and the corresponding meta-model described in this paper operates with the concepts that have a variable nature in the UI domain space. The language and the meta-model consist of two distinct parts. The first part describes the aspects and the granularity of the interaction elements provided to the system user during each interaction step. The second part of the language describes all of the possible interactions provided by the UI.

The meta-model allows inclusion of other UI model instances by using special language construct 'include' and a corresponding meta-model element *Include*.

### *3.1 View-Sets and Interaction Elements*

The limitations of human perception require the user interfaces to quantify the amount of information and interaction possibilities that are expressed to the user interface user. The first goal of the UI description language is to capture the sets or partitions of the user interface elements that are made available to the system user during each interaction step.

The interaction elements that are referenced in the language are expressed as abstract patterns that will be transformed into more precise patterns during model transformations towards executable software application.

The following list of the most basic abstract patterns is incorporated into the language as an example for this paper:

- Data entry—an ability to enter simple stream of data to the system.
- Secure data entry—an ability to securely enter data to the system.
- List of selectable items—a list of items where one of the items can be selected and the corresponding event to be generated.
- Event firing—an ability to produce events to be processed by the system.

When an interaction element is placed into the model, the abstract UI pattern it references will be instantiated with the provided parameters that will configure the variable parts of the pattern. For example, adding the keyword "secure" to the regular input element will denote that the inputs presentations in lower abstraction levels must follow a platform-specific pattern that would guarantee secure entry while inputting the data.

The interaction elements are grouped into viewsets by using the keyword "viewset." The *Viewset* definition and each element can be named and can also have two descriptive strings placed after the definition. The first string denotes a title of the element or the *Viewset* and the second one gives a description of the object.

Both strings are useful during transformations—the title string can show the purpose of the element in the graphical UIs and the description string can be transformed to context-specific help messages accompanying the element.

## *3.2 Navigation and Interaction*

To retain the most common appearance of the requirement artefact, the starting point in design of the interaction description part of the UI language has been the classic use case description format [14]. The use case scenarios are presented as separated interactions with a reference to a viewset that is being used to carry out the interaction. The *Interactions* are contained inside the *UseCase* container to group logically related interactions. Each Interaction contains:

- optional freeform textual description or documentation of the interaction
- markings inside the freeform text to connect events described in the viewsets and the next interactions to be initiated after the events.

The references to the viewset's events are prefixed with the character ":" and references to following interactions or usecases with the character " $>$ ." Together those markings form an event-to-reaction navigation pair that can be used to construct the interaction graph. This syntax enables to describe the navigational graph state-machine in textual form and also provides documentation context to the use case description. If *Interaction* names and use case names are chosen appropriately, a clear, readable and yet formal enough textual description of the user interaction can be specified.

In the meta-model, both *UseCase* and *NavigationRule* elements are defined as special cases of *AbstractInteraction* element. It allows the *NavigationRule* elements (defined by the event-to-reaction syntax) to reference either other interactions or use cases. This allows the navigation targets to be either large scale use cases or interactions inside a specific use case. *NavigationRules* are defined in the *Interaction* and the *Interaction* elements are placed in the *UseCase* elements. The *NavigationRule* element also references the *EventElement* that initiates a navigational change in the UI.

To be usable as a general requirement specification artefact, the other elements of the use case description format can be added to the language. Although only the simplest way of marking the use case interactions is presented in this paper, the other conditions and markings available in use case descriptions could be evolved to be more formal and more tightly integrated with other domain areas, like role-based security or other business domain areas.

### 3.3 Integration with Other Domains

The UI aspects are rarely isolated from the other aspect models that define a software application. The integration with the core business domain models is implemented by referencing the name of the business domain service to be invoked as a response to the event. The returned data of the service can be stored in the named slots and can be used in the viewsets that are displayed after the event. The named slots are stored in the model as the meta-model *Mapping* elements. The parameters given to the business service can be resolved during source code generation by passing the interaction context (the interaction and the corresponding viewset) object as a parameter.

### 3.4 Formal Definition of the Language

Based on the examples and features described above, a grammar (displayed in Fig. 2) and a corresponding meta-model (displayed in Fig. 1) can be expressed to support the language. The grammar definition is expressed using the grammar definition DSL of the Xtext programming language framework [15]. The meta-model is expressed as an instance of the Ecore meta-meta-model [16].

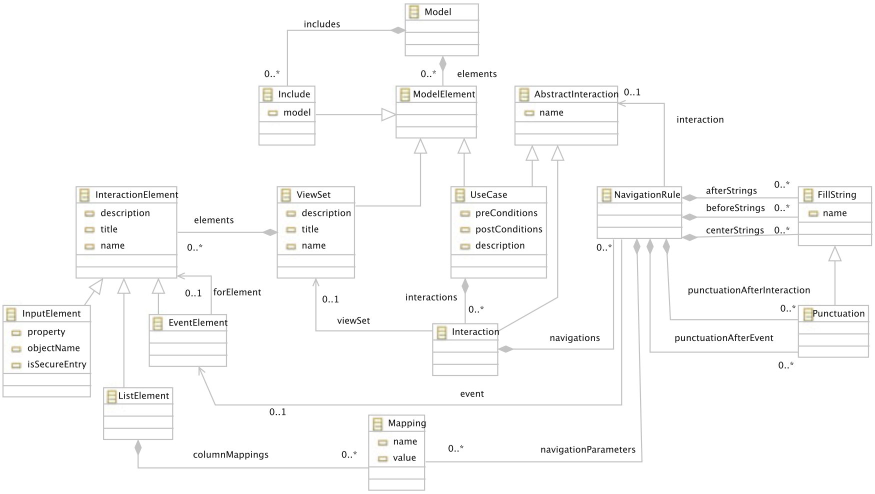



Fig. 1 Meta-model supported by the language

## 3.5 *Integrating with Model Driven Methodologies*

The abstraction level of the language and of the corresponding meta-model enables platform independence from the user interface technology and interaction paradigm. The model can be transformed into both graphical UIs and conversational UIs, like voice based or command-line interfaces. Since the communicational UIs are based on few simple interface patterns like detecting or parsing speech or text and responding with speech or text, the abstract patterns defined in the UI model can be implemented by combining the simple UI patterns supported by the conversational UI platform.

The model described by the language can be used in custom-made transformations or can be applied to other user interface transformation approaches. To use the model with other approaches, a model-to-model transformation is needed to transform the model concepts into the concept space of the target meta-model.

Since the model relies on abstract patterns, the abstract patterns must be transformed into platform specific patterns during model transformations. The Fig. 3 shows some possible transformation paths from the UI model to more reified platform specific models.

# 4 Example Usage

One of the most widely used large scale UI patterns is a simple resource management pattern that includes showing a list of items of interest and means to edit, remove and delete the items. The example displayed in the Fig. 4 shows a

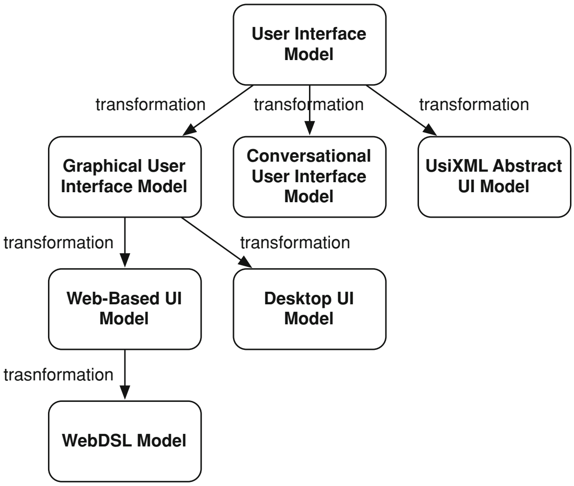
**Fig. 2** Language grammar definition

```
Model:
  (includes += Include)*
  (elements += ModelElement)*;
ModelElement:
 ViewSet | UseCase | Include;
Include:
 "include" model = URI;
ViewSet:
 "viewset" name = ID (title = STRING)?
 (description = STRING)?
 (elements += InteractionElement)*
 "end";
InteractionElement:
 InputElement | EventElement | ListElement;
InputElement:
 (isSecureEntry ?= "secure")?
 "input" name = ID (title = STRING)?
 (description = STRING)?
 ("(" objectName = ID
   ("." property = ID )? ")")?;
EventElement:
 "event" (forElement = [InteractionElement] ".")?
 name = ID
 (title = STRING)? (description = STRING)?;
ListElement:
 "list" name = ID (title = STRING)?
 (description = STRING)?
 "(" (columnMappings += Mapping)* ")";
Mapping:
 name = ID ":" value = ID;
UseCase:
 "usecase" name = ID (description = STRING)?
  (interactions += Interaction)*
 "end";
Interaction:
 "interaction" name = ID
 ("withviewset" viewSet = [ViewSet])?
 (navigations += NavigationRule)*
 "end";
AbstractInteraction:
 UseCase | Interaction;
NavigationRule:
 (beforeStrings += FillString)*
 ":" event = [EventElement]
 ( "(" navigationParameters += Mapping ")")?
 (punctuationAfterEvent += Punctuation)*
 (centerStrings += FillString)*
 ">" interaction = [AbstractInteraction]
 (punctuationAfterInteraction += Punctuation)*
 (afterStrings += FillString)*;
FillString:
  name = ID (Punctuation)*;
Punctuation:
 "." | "," | "!" | "-";
```

implementation of the pattern in the form of a basic phonebook application. The example displays:

- Two use cases (*MainMenu* and *ManagePhonebook*) that contain interaction descriptions.
- Descriptions of three viewsets (*MainMenu*, *PhoneBook* and *EditPhoneBook-Entry*) and the interaction patterns (inputs, events) used in the viewset.

**Fig. 3** Model transformation paths




The textual descriptions of the interactions contain event-to-reaction pairs. For example, the :*open_phonebook* event initiates a business service getpersons and stores the result in the slot named *people*.

Figure 5 displays a fully functional web-based application UI that was transformed from the model described in the example.

## 5 Disussion

The language and the corresponding meta-model are the results of the iterative prototyping work using the Xtext language development framework [15]. The prototyping work also included a development of model-to-model and model-to-code transformation rules that were used to generate working implementations of the UIs on different technological and UI platforms. The target implementations used in the prototype were:

- Graphical web-based UI implemented in the Ruby language [17] and on the Ruby on Rails framework [18].
- Graphical desktop-based UI implemented on the Java Swing framework [19].
- Text-based conversational UI implemented in the Python language [20].
- Voice-based conversational UI implemented in the C# language [21] using the Microsoft Speech voice recognition and synthesis API [22].

The generated target implementations were used as a feedback for verifying the usability and suitability of the language and the meta-model. It also helped to unify the concepts of target platforms as the abstract concepts in the meta-model.

The iterative process of improving the work results has proved the meta-model and the language to be sufficient enough for the narrow context of supporting the

**Fig. 4** Example usage of the UI DSL language

```
usecase MainMenu "Main menu"

  interaction ShowPhoneBook withviewset MainMenu
    User can :open_phonebook(people:getpersons)
    and the >ManagePhonebook section
    will be showed.
  end

end


usecase ManagePhonebook "Phonebook Manager"

  interaction ListOfPersons withviewset PhoneBook
    User needs to :select a person from the
    list of persons to >Edit the person data.
    If user wants to :add_new person then the
    >AddNewPerson form must be filled.  User
    can :exit the phonebook and to return
    to the >MainMenu.
  end

  interaction Edit withviewset EditPhoneBookEntry
    User modifies the Person data and
    initiates :save(people:getpersons) to store
    the changes.  The system responds
    with >ListOfPersons.  If the user wants
    to :cancel(people:getpersons) editing, no
    changes are stored and the user will be
    directed to >ListOfPersons.  To remove a
    person user must :delete(people:getpersons)
    and after that the >ListOfPersons will
    be shown.
  end

  interaction AddNewPerson
      withviewset EditPhoneBookEntry
    To :create(people:getpersons) a new person,
    user enters and saves person data and the
    >ListOfPersons will be shown.  If the user
    wishes to :cancel(people:getpersons) new
    person creation the >ListOfPersons
    will be displayed.
  end

end


viewset MainMenu
  event open_phonebook "Open phonebook"
end

viewset PhoneBook
  list people
    "People in the phonebook:"
      (Name:name Number:number)
  event people.select "Edit"
  event add_new "Add new person"
  event exit "Exit"
end

viewset EditPhoneBookEntry "Person data entry"
  input name "Name" "Name of the person"
  input number "Phone number"
    "Phone number of the person"
  event save "Save"
  event create "Create"
  event delete "Delete"
  event cancel "Cancel"
end
```

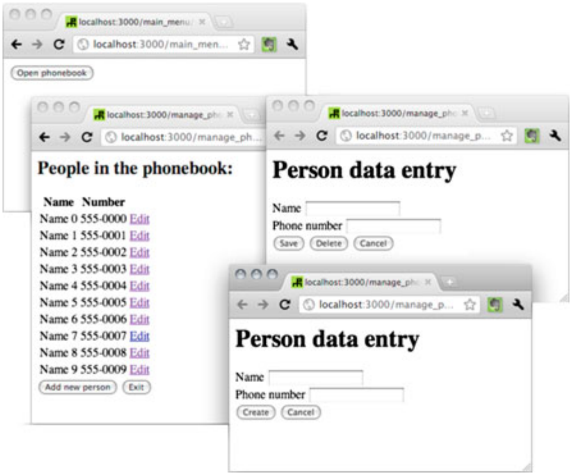



**Fig. 5** Web-based application generated from the example model

code generation of the selected target platform UIs. More thorough assessment of the quality and usability of the language must be measured, based on either of the comparison of other similar languages or the fundamental principles and best practices of language design.

Based on the principles described in [23], the language and the meta-model described in this paper can be evaluated using the following quality aspects:

- **Simplicity**: The proposed UI language and the meta-model provide narrowly focused and minimal concepts for describing UIs. Accidental complexity by adding confusing language elements has been avoided.
- **Uniqueness**: The meta-model consists of unique elements that do not overlap conceptually.
- **Consistency**: The proposed language lets to connect the meta-model concept instances and the instantiated models contain the formal description of the UIs. All the language elements support the initial language development goals.
- **Seamlessness**: The abstractions provided by the language can be used repeatedly throughout the development process and the resulting models can be used to generate working software implementations.
- **Reversibility**: Reverse-engineering the generated models or the source code back to the UI models is orthogonal to the language and meta-model described in this paper. Any reverse-engineering tool capable of detecting the required abstractions could output the collected knowledge as a textual UI model, using the proposed textual language.
- **Scalability**: The language can be used to describe both large and small systems, by separating the model descriptions into different text files.
- **Supportability**: The proposed language can be used both as the requirement artefact for human use and as a model for generating UI implementations.

- **Reliability**: The language facilitates pattern-based software generation, that will always produce similar (and tested) source code footprints for a specific pattern or a model concept.
- **Space economy**: Using the language without textual interaction description contexts could result in very concise textual representations. As the amount of the textual documentation included in the descriptions increases, the space needed to visualise the model also increases.

## 6 Conclusion

A textual domain specific language has been described in this paper that can be used to define aspects of human-computer interaction. The resulting models and their presentations could be used as generic artefacts for documenting software requirements and also as formal models for UI generation. The concept space of UI aspects used in the meta-model consist of the abstract UI patterns that can be instantiated and configured in the UI models. The described models can be used as inputs to various MDD scenarios and approaches that transform the abstract patterns into more platform specific UI patterns in intermediate models and later in the process into working UI implementations.

The example UI patterns in this paper cover only the most basic UI patterns and domain integration possibilities. Also having a language defined based on the use case format is just one possibility to expose the UI interaction model in a domain specific language. The goals for the further work are the following:

- Improving the language to support more complex integration scenarios by providing more integration extension points to the language.
- Mapping patterns and pattern transformations on various platforms so that more abstract patterns could be expressed in the language
- Provide a formalisation approach of similar text-based state-machine descriptions in agile user stories and scenarios, especially in the test automation tools that support Behaviour Driven Development [24].
- Provide more through language quality evaluation based on the good modelling language principles and evaluation approaches.
- Compare the proposed language with other languages expressing similar concepts.
- Test the language and the meta-model in real-life development scenarios.

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# Vehicle Detection Even in Poor Visibility Conditions Using Infrared Thermal Images and Its Application to Road Traffic Flow Monitoring

**Yoichiro Iwasaki, Shinya Kawata and Toshiyuki Nakamiya**

**Abstract** We propose an algorithm for detecting vehicle positions and their movements by using thermal images obtained through an infrared thermography camera. The proposed algorithm specifies the area of moving vehicles based on the variations of pixel values, i.e. the standard deviations of pixel values along the time direction of spatio-temporal images. It also specifies vehicle positions by applying the pattern recognition algorithm which uses Haar-like features per frame of the images. Moreover, to increase the accuracy of vehicle detection, correction procedures for misrecognition of vehicles are employed. The results of our experiments show that the information about both vehicle positions and their movements can be obtained by combining those two kinds of detection, and the vehicle detection accuracy is 96.3 %. As an application of the algorithm, we also propose a method for estimating traffic flow conditions based on the results obtained by the algorithm. By use of the method for estimating traffic flow conditions, automatic traffic flow monitoring can be achieved. In addition, there is a possibility that traffic accidents, vehicle troubles, and illegal parking can be detected with the proposed method. By using the traffic information obtained from the proposed method, we also expect to realize an optimized traffic signal control around the clock even in changeable weather.

## 1 Introduction

It is a pressing matter how to develop the vision-based traffic measurement systems in the field of ITS (Intelligent Transportation Systems). They have the advantage of measuring what could not be measured by conventional vehicle

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detectors: vehicle positions, vehicle lengths, and vehicle tracking on multilane. Therefore, by use of the vision-based traffic measurement systems, we can make up both an automatic traffic monitoring system designed to find traffic incidents without time delay and a new traffic control strategy designed to reduce traffic jams.

The present research level of the vision-based traffic measurement systems is high enough to detect vehicles robustly around the clock [1, 2]. However, there are some defects as follows.

Many of the conventional methods detect the bodies of vehicles only in the daytime, and nighttime detection is adopted in much fewer cases. Yoneyama et al. [2] pointed out that most of the daytime detection methods lose their accuracy when they are directly applied to nighttime detection. Therefore, generally adopted methods have been those of detecting the headlights or the taillights of vehicles at nighttime and of preparing two algorithms separately for daytime and nighttime detection [1, 2]. It is generally difficult to measure the vehicle sizes at nighttime. In the conventional method of detecting taillights [2], the vehicle lengths can be measured only at the limited camera angles because the vehicle length is estimated by the triangle of a pair of taillights and the vehicle front edge detected as the gray level difference between the head of the vehicle and the headlight reflection area on the road. What is the most important for both traffic signal control and traffic simulation is to be able to measure the vehicle sizes and to specify the number of large-sized vehicles in the detected area around the clock. It is especially true because the saturation flow rate used as one of the fundamental values for them is largely influenced by the rate of large-sized vehicle mixing.

Vehicle cast shadows at daytime impair the vehicle detection of the adjoining lane. Therefore, a method of eliminating vehicle cast shadows has already been proposed [3]. However, it has the disadvantage of restricting the elimination of the vehicle cast shadows to limited camera angles.

In the conventional methods of vehicle detection with visible light cameras, it is difficult to detect vehicles with high accuracy in poor visibility conditions such as fog, snow, heavy rain, and darkness. However, traffic accidents and traffic jams are most likely to happen under such circumstances. Therefore, it is a pressing matter for us to develop a method designed to detect vehicles with high accuracy under all circumstances.

In this paper, we propose a method for detecting vehicle positions and their movements by using thermal images obtained through an infrared thermography camera instead of a visible light camera. The thermal images are expected to detect vehicles robustly regardless of changing environments around the clock. Recently, a few vehicle detection algorithms using infrared images have been proposed [4, 5]. However, these algorithms cannot detect the positions of many vehicles in queues under heavy traffic. Therefore, these algorithms are not useful for automatic traffic monitoring and adaptive traffic control systems.

First, we explain our observations using an infrared thermography camera in Sect. 2, in which we show that clear visions of vehicles in snowy and deep foggy weather have been obtained. Second, the proposed vehicle detection algorithm is

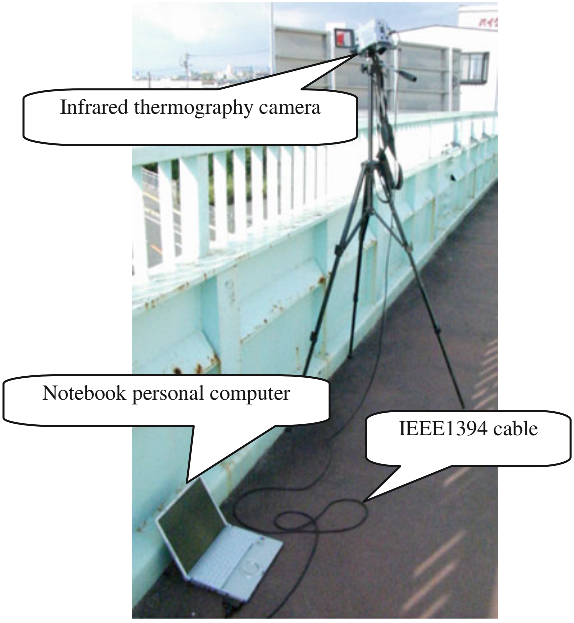


**Fig. 1** The infrared thermography camera and the notebook personal computer on a pedestrian bridge

explained in Sect. 3. Third, our experiments at daytime with vehicle cast shadows are explained in Sect. 4. Then we refer to the experimental results which show that our method offers reliable information about both vehicle positions and their movements without the influence of the vehicle cast shadows. A method for estimating traffic flow conditions based on the vehicle detection results is also explained. Moreover, it is shown that the vehicle detection results are useful for an automatic monitoring of road traffic flows. Finally, we have concluded in Sect. 5.

## 2 Advantages of Thermal Images in the Vehicle Detection Under Poor Visibility Conditions

The infrared thermography camera used in our detection is TVS-200 [6]. The frames of the infrared thermal images are transmitted to a notebook personal computer with the 1/60 s interval through the IEEE1394 interface. The infrared thermography camera and the notebook personal computer are shown in Fig. 1.

We have confirmed through our observations that the obtained thermal images are contrasted highly enough to detect the shapes of vehicles even in poor visibility conditions.

We have obtained both thermal images and visible light images in snowy and deep foggy weather on a mountain road of Aso in Kumamoto, Japan. Images of moving vehicles taken from the infrared thermography camera are shown in Fig. 2a, b and an image taken from a visible light camera is shown in Fig. 2c.

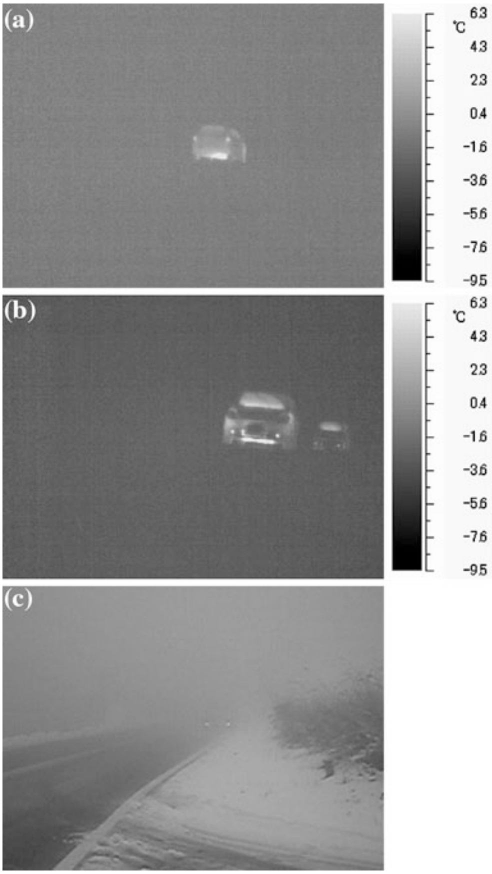


**Fig. 2** Thermal images and a visible light image in snowy and deep foggy weather

The outlines of the vehicles are clearly seen in Fig. 2a, b while only the position of the fog lamps is seen in Fig. 2c. The bars of the right sides in Fig. 2a, b show the temperature scale.

The infrared thermography camera, therefore, can be effectively used for vehicle detection under poor visibility conditions like snowy and deep foggy weather.

## 3 A Method for Detecting Vehicle Positions and Their Movements

The proposed method is applied to the detection of vehicles from the traffic thermal images obtained through the infrared thermography camera set up at the height of a pedestrian bridge. Figure 3 shows one frame of thermal images.

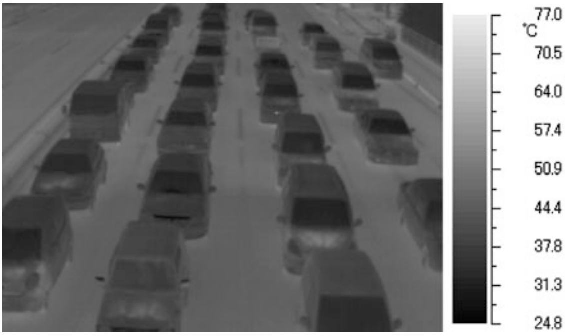


**Fig. 3** A frame of thermal images

### 3.1 Spatio-Temporal Image Processing

Figure 4 shows an example of spatio-temporal images with the inscription of space-axes $xy$ and time-axis $t$. The standard deviations of pixel values for $n$ frames in the past are calculated from the thermal images as follows.

$$\sigma(x, y, r_{tc}) = \sqrt{\frac{\sum_{k=0}^{n-1} \left(f(x, y, r_{tc} - k) - \mu(x, y, r_{tc})\right)^2}{n}}, \tag{1}$$

where $\sigma(x, y, r_{tc})$ is the standard deviation at coordinates $(x, y)$ for $n$ frames in the past from the frame $r_{tc}$ at the current time, $f(x, y, r_{tc}-k)$ is the pixel value at coordinates $(x, y)$ in the frame $r_{tc}-k$, and $\mu(x, y, r_{tc})$ is the mean value at coordinates $(x, y)$ for $n$ frames in the past from the frame $r_{tc}$.

The standard deviations indicate the variations of pixel values along the time direction. By computing the standard deviations of all pixels in the frame, we can distinguish between the area of moving vehicles and that of the background or stopped vehicles based on $n$ frames in the past. In other words, if the standard deviation is not zero, it means that the pixel value is changed by a moving vehicle. Conversely, if the standard deviation is zero, it means that the pixel value maintains the same value in the area of the background or stopped vehicles. When the standard deviation is more than or equal to $sd_t$, the pixel is actually assumed to be in the area of moving vehicles because each pixel value includes a noise.

### 3.2 Vehicle Pattern Recognition Using Haar-Like Features

The pattern recognition algorithm using Haar-like features was proposed by P. Viola et al. [7]. P. Viola et al. proved in their paper [7] the effectiveness of the algorithm concerning the experiments of face detection. By changing the object of pattern recognition, this algorithm can be applied to the detection of other objects like vehicles. To detect vehicles in images, we have used two types of images: the positive samples including a vehicle and the negative samples including no

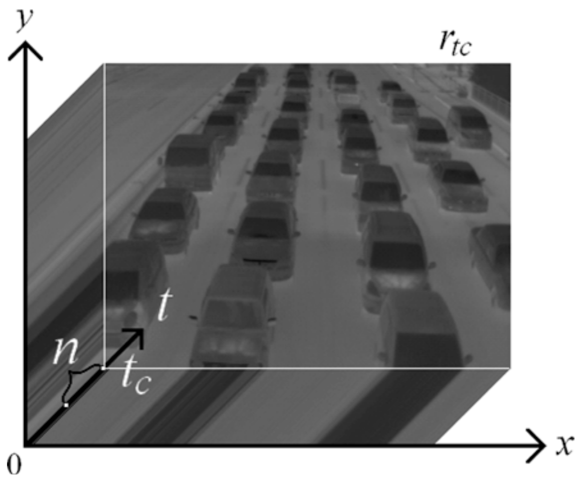


**Fig. 4** An example of spatio-temporal images

vehicle. Then, the machine learning has been done by using them, and a multistage cascade of classifiers has been constructed. We can execute a pattern recognition by using the obtained multistage cascade of classifiers.

The images we have collected contain the windshield and its surroundings which clearly show the front view of a vehicle as positive samples while they contain no vehicle as negative samples. Figure 5 shows some examples of the positive sample images, and Fig. 6 shows some examples of the negative sample images. By using the upper part of the vehicle such as the windshield and its surroundings as the target of pattern recognition, we can make a robust detection of vehicles even when they are stopped one after another with a short distance. We have conducted training with these sample images to obtain a multistage cascade of classifiers, and finally managed to make the pattern recognition of vehicles with the obtained multistage cascade of classifiers. In our vehicle pattern recognition, we have used the extended algorithm proposed by R. Lienhart et al. [8] for the paper [7]. In cases that two vehicles in a queue with shorter distance or a car is following a large truck, the target area is disappeared. In such cases, the proposed method cannot of course detect the vehicle.

### 3.3 Correction Procedures for Misrecognition of Vehicles

In order to increase vehicle detection accuracy, the following three correction procedures are applied to vehicle pattern recognition results.

When the omission of vehicle detection is occurred in the vehicle pattern recognition, the omitted vehicle position is searched from the vehicle position in the previous frame by using pattern matching as shown in Fig. 7. Figure 7 also shows the number of horizontal and vertical pixels in the searched area. When the searched positions are out of the frame, the searched area is restricted to within the frame. In order to match the template against the traffic image with high accuracy,

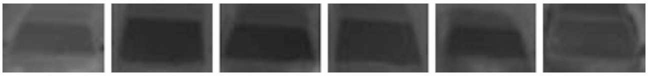

**Fig. 5** Examples of positive sample images

**Fig. 6** Examples of negative sample images

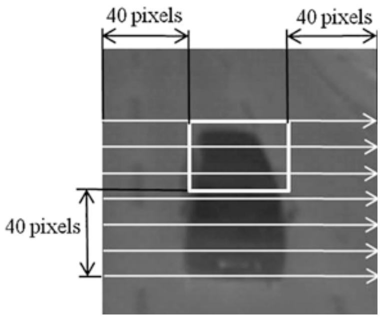


**Fig. 7** The area searched by template matching

we have examined several matching methods. As the result, we have selected the normalized correlation coefficient matching method [9].

The size of windshield is bigger as the vehicle comes nearer to the infrared thermography camera as shown in Fig. 8. So, we have done the regression analysis on the relationship between *y* positions (independent variable) and the sizes of the recognition-target areas (dependent variable). The size of the recognition-target area is calculated from the obtained regression equation after substitution of *y* position. If the size of detected object is less than $S_t$ % of the calculated size, the detected object is deleted as a non-recognition target.

If two rectangles are overlapped on a vehicle as shown in Fig. 9, the smaller rectangle is deleted.

### 3.4 Combination of Two Kinds of Information: Vehicle Positions and Their Movements

By combining the two kinds of processing (spatio-temporal image processing described in the Sect. 3.1, and vehicle pattern recognition with the correction procedures described in the Sects. 3.2 and 3.3) in the same frame of images, the position of each vehicle can be specified, and its movement can be classified, too.

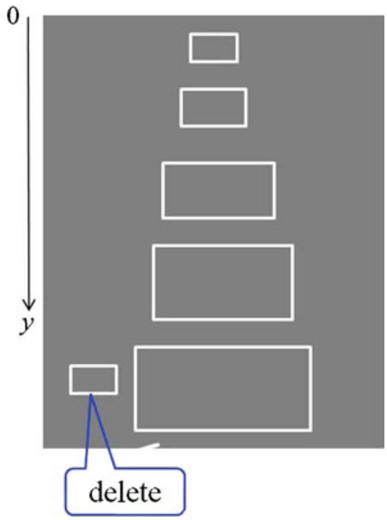


Fig. 8 The correction procedure using a regression equation

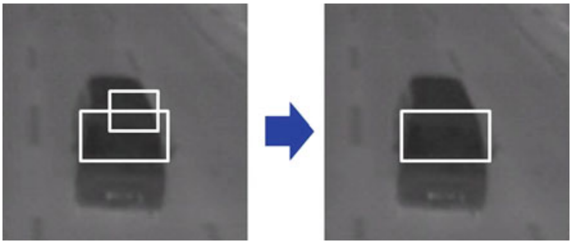

Fig. 9 The correction procedure for two overlapped rectangles

Each vehicle speed can be classified based on the ratio of the area of the moving vehicle in the rectangle which shows the windshield and its surroundings of vehicle. In our method, we have classified the three categories: If the ratio is less than $a_1$ %, the vehicle is assumed to be stopped. If the ratio is more than or equal to $a_1$ % and less than $a_2$ %, the vehicle is assumed to be running at low speed. If the ratio is more than or equal to $a_2$ %, the vehicle is assumed to be running at high speed.

# 4 Experimental Results

## 4.1 Vehicle Detection Experiments

We have developed our algorithm with Visual C++ 2008 and the computer vision library OpenCV [9].

The frame size of collected images is 320 $\times$ 240 pixels. The number of positive sample images and negative ones used in our experiments are 20,984 and 9,500, respectively. In order to secure a long measurement section on roads, the windshield sizes of the vehicles locating at a long distance from the infrared thermography camera are small. For that purpose we have used the smallest rectangle size of $12 \times 8$ pixels for a recognition-target area. Each positive sample image is resized to the $12 \times 8$ pixels for the training. The number of the stages of the classifiers obtained through the training is 14. We have assumed in the experiments that $n$, $sd_t$, $S_t$, $a_1$, and $a_2$ are 30, 3.0, 40.0, 10.0, and 40.0, respectively.

By the regression analysis between $y$ positions and the sizes of the recognition-target areas ($S$), we obtained the regression equation: $S = 15.429y + 96.0$. When calculating the regression equation, we fixed the intercept value as 96.0 which is the minimum value of detected rectangle area.

Figure 10 shows some results of the detections. The three images of Figs. 10 a–c show the interim results we have got by combining the two kinds of processing. The areas of gray pixels show those of moving vehicles specified by the processing described in the Sect. 3.1, and the white rectangles show the outlines of vehicles specified by the pattern recognition with the correction procedures described in the Sects. 3.2 and 3.3. The three images of Fig. 10d–f show the final results of the detection which have enabled us to specify each vehicle position and its movement. The three images of Fig. 10 a–c correspond to those of Fig. 10 d–f, respectively. The dotted lines, the thin lines, and the bold lines in the final results in Fig. 10 show three categories of vehicles: stopped ones, slowly moving ones, and fast moving ones, respectively.

In the interim results of Fig. 10, there is no connected components of gray pixels for stopped vehicles because the standard deviations of pixel values are distributed less than $sd_t$. When a vehicle begins to move at low speed, the pixels with the standard deviations which are more than or equal to $sd_t$, begin to appear in the images. Consequently, a part of the rectangle which shows the result of vehicle pattern recognition with the correction procedures contains the connected components of gray pixels. In addition, when the vehicle runs at high speed, the area of gray pixels spread more widely, and most of the rectangle area becomes gray pixels.

By combining the results of spatio-temporal image processing and the pattern recognition with the correction procedures, we can classify the speed of each vehicle. In our experiments, we classify vehicle speed into three categories as described above.

Figure 10d shows the time soon after the green lights are turned on. Vehicles begin to move and increase their speed gradually from the head to the back of the lines. Figure 10e and f show the passage of time after the green lights are turned on. Figure 10f shows the vehicular queue on the right-turn lane is made longer. As shown in Fig. 10, each vehicle position and its movement can be detected in real time with our algorithm.

Figure 11 shows a visible light image taken at the same time. The vehicle cast shadows extend to the adjoining lane in Fig. 11 while there is no influence of vehicle cast shadows on the detection of vehicles in Fig. 10.

In the experiments, we used 64 images at 60 frames interval (1 s interval) taken from the start of the green lights. The proposed algorithm detects 574 vehicles

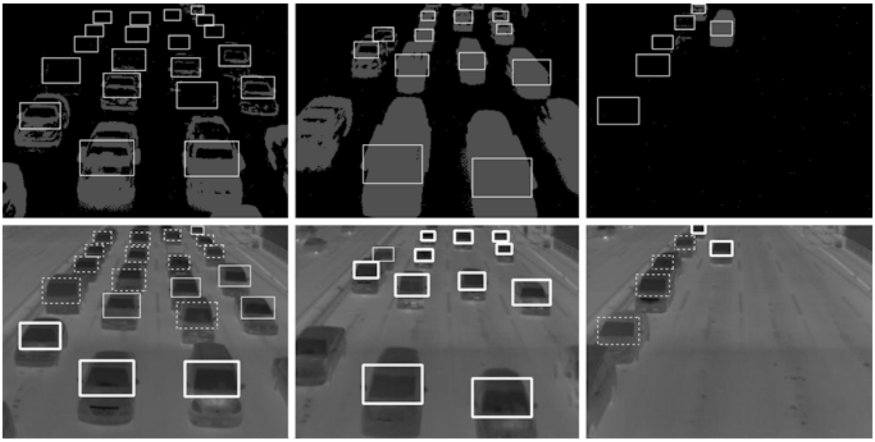

**Fig. 10** Thermal Image detection results. **a** A result of both spatio-temporal processing and pattern recognition with the correction procedures. **b** A result of both spatio-temporal processing and pattern recognition with the correction procedures, **c** A result of both spatio-temporal processing and pattern recognition with the correction procedures, **d** A detection result for vehicle positions and their movementsm, **e** A detection result for vehicle positions and their movements, **f** A detection result for vehicle positions and their movements

**Fig. 11** A frame of visible light images

(96.3 %) of 596 vehicles contained in the 64 images. On the other hand, the number of false detection was eight, which contains detection of two locations on a vehicle and detection of non-recognition targets.

## 4.2 Automatic Monitoring of Traffic Flow Conditions

As an application of proposed vehicle detection algorithm, we propose a method for estimating traffic flow conditions based on the results obtained by the algorithm. The measurement targets are inflow traffic into an intersection.

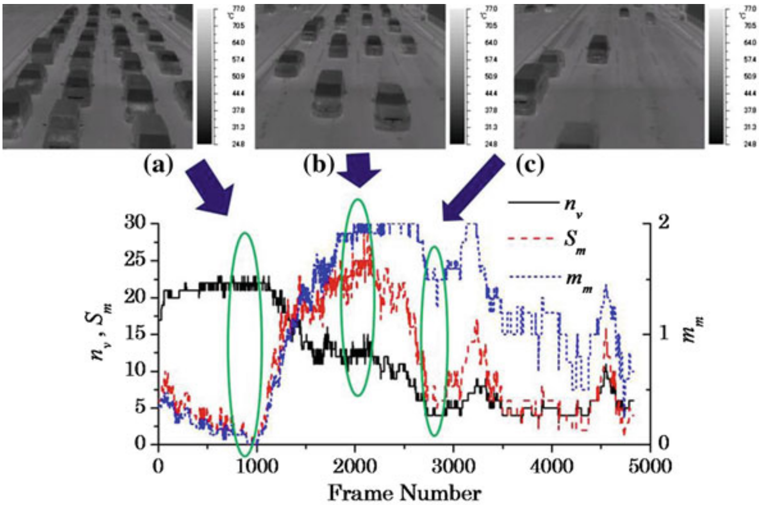


**Fig. 12** Fluctuations of the three variables: $n_v$, $S_m$, and $m_m$

The number of vehicles in the measurement area is $n_v$, and the degree of movement of each vehicle is $m_i$. The value of $m_i$ takes 0, 1 and 2. The 0, 1 and 2 mean stopped vehicle, low-speed vehicle, and high-speed vehicle, respectively. The $n_v$ represents the degree of spatial congestion which is proportional to the traffic density.

$$S_m = \sum_{i=1}^{n_v} m_i\,. \tag{2}$$

$$m_m = S_m / n_v\,. \tag{3}$$

The $S_m$ calculated by equation (2) indicates the instantaneous value which is proportional to traffic volume. The $m_m$ calculated by equation (3) indicates the value which is proportional to the mean speed per a vehicle.

Figure 12 shows fluctuations of these three variables. As shown in Fig. 12a, when $n_v$ maintains a high value and the value of $S_m$ (or $m_m$) is close to zero, vehicle queues are composed in whole measurement area. If these three variables indicate such the values when displaying green lights, the occurrence of traffic jams can be detected. As shown in Fig. 12b, when $S_m$ maintains a high value, traffic flows are smooth and the traffic volume is high. When $n_v$ becomes a low value while the value of $m_m$ maintains near 2.0 as shown in Fig. 12c, it indicates that the traffic green lights may be turned off.

By monitoring the trends and relationships of these three variables, automatic traffic flow monitoring can be achieved. These spatial variables are also useful for the information to control appropriately traffic signal lights.

## 5 Conclusions

First, we have confirmed through our observations that the thermal images obtained through an infrared thermography camera offer the images of vehicles clear enough to detect their shapes even under poor visibility condition like snowy and deep foggy weather.

Then, we have proposed an algorithm for detecting vehicle positions and their movements by using thermal images. The proposed algorithm specifies the area of moving vehicles based on the standard deviations of pixel values along the time direction of spatio-temporal images. It also specifies vehicle positions by applying the pattern recognition algorithm which uses Haar-like features per frame of the images. Moreover, to increase the accuracy of vehicle detection, correction procedures for misrecognition of vehicles are employed. The results of our experiments show that the information about both vehicle positions and their movements can be obtained by combining those two kinds of detection, and the vehicle detection accuracy is 96.3 %. As an application of the algorithm, we also propose a method for estimating traffic flow conditions based on the results obtained by the algorithm. By use of the method for estimating traffic flow conditions, automatic traffic flow monitoring can be achieved. In addition, there is a possibility that traffic accidents, vehicle troubles, and illegal parking can be detected with the proposed method. By using the traffic information obtained from the proposed method, we also expect to realize an optimized traffic signal control around the clock even in changeable weather.

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# Using Data Mining Techniques for Diagnostic of Virtual Systems Under Control of KVM

**Monika Chuchro, Kamil Szostek, Adam Piórkowski and Tomasz Danek**

**Abstract** Analysis of logs of remote network services is one of the most difficult and time consuming task—its amount and variety of types are still growing. With the increasing number of services increases the amount of logs generated by computer programs and their analysis becomes impossible for the common user. However, the same analysis is essential because it provides a large amount of information necessary for the maintenance of the system in good shape thus ensuring the safety of their users. All ways of relevant information filtering, which reduce the log for further analysis, require human expertise and too much work. Nowadays, researches take the advantage of data mining with techniques such as genetic and clustering algorithms, neural networks etc., to analyze system's security logs in order to detect intrusions or suspicious activity. Some of these techniques make it possible to achieve satisfactory results, yet requiring a very large number of attributes gathered by network traffic to detect useful information. To solve this problem we use and evaluate some data mining techniques (Decision Trees, Correspondence Analysis and Hierarchical Clustering) in a reduced number of attributes on some log data sets acquired from a real network, in order to classify traffic logs as normal or suspicious. The results obtained allow an independent interpretation and to determine which attributes were used to make a

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decision. This approach reduces the number of logs the administrator is forced to view, also contributes to improve efficiency and help identify new types and sources of attacks.

## 1 Introduction

Since the 1990s, various data access services have become available through the Internet. It has changed our lives and society completely. On the one hand, it facilitates and speeds up the work, contact with the other hand. But it is also a new source of danger, became a new venue for the development of crime. It is therefore necessary for a design of a system which can analyze logs of virtual machines in real time, to minimize the threat posed by high activity of multiple users using the virtual machines' server at the same time.

The logging itself is a simple activity, but as services still generate more logs, various concerns might appear. They are connected to the storage amount, the time required to analyze the logs and difficulty of that process. Storage requirements is the only hardware concern, which is in fact not a real problem today. All the other results in necessity of human expert analysis, which is unfortunately slow and expensive [1].

With the increasing use of computers in every area of life, the question arose: Is it possible to replace part of the physical machines through virtualization. Nowadays, this idea became possible due to very high performance and low cost hardware. With virtualization and at least one physical machine we can create even a few dozens of full machine ready to work. This idea is also advantageous from the standpoint of environmental protection. The energy consumption due to a single physical machine is used for at least a few posts ready to work. This solution also opens up new opportunities for education (easy adaptation for use in e-learning). Furthermore, lower maintenance costs and operation of machines allow to create more new jobs in places where for reasons of economic problems it was not previously possible. But that explosive growth of machines number could cause high risk due to physical difficulties in the interpretation of the quantity of log supply.

Methods of analysis presented in this paper were inspired by the architecture of workstations of the university computer rooms. Computers in classrooms are terminals for connecting to the server which is, due to installed software, hardware virtualization. KVM allows sharing the same environment for students. The solution is very convenient from the viewpoint of maintaining the system administrator. It does not require so much commitment as the maintenance of the system on a traditional machine. This solution also poses several risks. It is therefore necessity for design a system which can analyze logs of virtual machines in real time, to minimize the threat posed to high activity of multiple users using the virtual machines server at the same time.

Network administrator is today equipped with tools and techniques that might be used to analyze system logs, such as system's text parsers and regular expression searchers, artificial ignorance and intrusion detection system:

## 1.1 Grep

*Grep* is simple and useful tool that can be used to search for patterns in logs, which can improve efficiency of logs analysis in easy way. This solution is simple, intuitive and quite powerful, often used by administrators to obtain relevant information from large amounts of information generated by the computer system. However, this method is inefficient and even impossible to use when handling a larger number of machines, due to the small automation the process of retrieving relevant information (in this case, all decisions must be taken as an administrator).

## 1.2 Artificial Ignorance

Artificial ignorance is a method that filters, orders and valuates logged system events to collect important entries. This technique requires from the administrator of the network knowledge about system and events that occur, to separate them from real threats.

## 1.3 Data Mining Methods

This method boils down to the use of advanced mathematical and statistical methods to forecast future events based on the analysis of data collected in the past. These methods based on genetic algorithms, artificial neural networks and analysis of text can yield much better results because they used cameras to evolve along with the amount of collected and analyzed data [2].

Very frequent security incursions usually do not have specific targets. Worms and malware (malicious software) contain exploits, which are used to create network of compromised machines (botnets) by infecting as much computers as possible. Then this network is used to perform more sophisticated attacks that today are often connected to criminal organizations. These botnets might perform attacks on an enterprise or institution that results in denial of service. What is more, botnets may be used to send unsolicited email (spam) or to hinder identification of the attacker. Analysis and characterization of large amount of data is required by data mining [1].

Useful mechanism to gather information, necessary for the proper functioning of the data mining mechanisms, may be large quantities of logs generated by the services running across multiple machines.

In our case, inference methods will be used for prediction of the possible risks of system failure on the server systems where the virtual machines are located. Also we will try to predict intrusion from the part of users of virtual machines or from outside the system. Application of data mining methods allows one administrator to maintain several machines in good condition.

The virtual servers are often used to share computing power machine on which they are located. This environment allows you to create virtual machines. A network card, hard drive, graphics card are virtualized for every virtual machine. It makes the performance much higher than a purely software solution, because the KVM hardware is using virtualization technology found in newer processors. Under VMs it is possible to install a common action at a time any number of Linux, Windows and other systems.

# 2 Introduction to the Analysis

The data used in analysis were gathered from virtual machines which were used by students. So access to the logs generated by users is huge and the logs are very diverse. With such a huge amount of data, exploration using data mining methods is always the best way to analyze the accumulated information into account of possible risks.

## *2.1 Pre-Processing*

Data mining algorithms require from the dataset to be assembled as well as this dataset must be large enough to contain patterns, which the algorithm will uncover. Pre-process is the most important in multivariate logs before any clustering or data mining. Then the target set is cleaned, which is performed by removing noise and missing data. Then results can be described as feature vectors that are raw data observations' summarized versions.

## *2.2 Tasks of Data Mining*

The tasks of data mining are as follows:

- Classification—The data is arranged into predefined groups. Decision tree learning, nearest neighbor, naive Bayesian classification and neural networks are used in this stage.

- Clustering—The algorithm tries to classify similar items together into groups.
- Regression—Attempts to model the data.
- Association rule learning—Searches for relationships between variables. The purpose of using association rules is to help finding items that imply the presence of the different items in the same moment or transaction. This tool is very useful in a supermarket management; it helps to uncover shopping patterns for groups of customers, for example the most famous shopping rule: men+ friday+ diapers = beer.

### 2.3 Results Validation

The last step of process is patterns verification, which were discovered by the data mining algorithms. The most important is if the patterns exist in wider data sets. Sometimes where process of learning is very advanced, algorithms could found patterns between data sets, which does not exist in general. It is called overfitting. For overcoming this process data sets are divide into three parts, learning data set, testing data set and validation data set. Algorithms are learning on the first data set, after then tested on the second and third, for checking if the founded pattern is real. If the founded pattern does not exist in testing or validation data set, the pattern does not exist or there were some problems with selecting data to each data sets; data sets should have the same percent of each kind of instances.

### 2.4 Kernel Based Virtual Machine

The latest open source virtualization is represented by Kernel-based Virtual Machine (KVM) project, which objective was to produce a modern hypervisor. The idea was to create it on the experience of previous generations of technologies and to increase usability of the modern hardware. Linux kernel can be converted into a bare metal hypervisor thanks to loadable kernel module, which is KVM implementation. KVM project have turned into stable and high performance hypervisor very fast thanks to two key design patterns adoption. These have also made KVM leader between other open source hypervisors [3].

### 2.5 Data Mining Software

The article focused on the analysis carried out in the most popular programs that allow an analysis of data mining. We tried to compare the performance and capabilities of commercial software to those of free, and chose the best solution for our application. Since at the present stage, our project is not yet able to propose a real-time we could afford to identify available technologies and select the best of them both in terms of capacity, speed of calculation and availability. For the analysis of textual data on those referred to in this article are perfect software for data analysis with appropriate modules for data collection and analysis. In our considerations, we focus mainly on:

- WEKA—(Waikato Environment for Knowledge Analysis) is a popular suite of machine learning, developed at the University of Waikato. WEKA is free software available under the GNU (General Public License). WEKA supports several standard data mining tasks, more specifically data preprocessing, clustering, classification, regression, visualization and feature selection.
- Statistica—(trademarked in capitals as STATISTICA) is a statistics and analytics software package developed by StatSoft. Statistica provides data analysis, data management, data mining and data visualization procedures.
- RapidMiner—[formerly YALE (Yet Another Learning Environment)] is an environment for machine learning and data mining experiments. It allows experiments to be made up of a large number of arbitrarily nestable operators, described in XML files which are created with RapidMiner's graphical user interface. RapidMiner is used for both research and real-world data mining tasks. It is distributed under a GNU license. It also integrates learning schemes and attributes evaluators of the WEKA learning environment.
- WordStat—from Provalis Research is a commercial text mining tool integrated with SimStat and QDA Miner.
- Microsoft Analysis Services (part of Microsoft SQL Server, a database management system). Microsoft has included a number of services in SQL Server related to Business Intelligence and Data Warehousing. It substitutes the functions offered by the package. It also features the latest versions of MS Excel, which can easily be applied to a rough analysis of simple data.

The programs discussed are interested in possible ways of analysis and performance additives which have these programs. Also text analysis which will be made in the next paragraphs are good tests of usefulness of mentioned above applications for beginners and advanced data miners.

## 3 Methodology

### *3.1 Text Analysis*

Text mining is a process of extracting meaningful information from unstructured data [4]. This method can be use for data bases texts, web pages, e-books, server logs, emails and other text documents. Text mining gives also chance to compare two or more documents.

Text mining include text categorization, text clustering, relation modeling, sentiment analysis and document summarization and entity relation modeling [5].

Nowadays there are many open source and commercial programs for text mining analysis.

- R-tm extension package,
- Weka,
- Statistica,
- WordStat from Provalis Research,
- Rapid Miner,
- MS SQL Server.

The task of text categorization is to assign document to one or few categories [5]. Categories are based on document contents. Classification can be divided into two methods: supervised and unsupervised document classification. First one is when some external mechanisms exist, for example human feedback. In the second case classification is made without reference of external information. Here we can use neural networks, decision trees, Bayes models, k-nearest neighbours, genetical algorithms, case-based reasoning and fuzzy logic.

Text clustering is closely related to the concept of data classification. The main issue of this method is to find which documents resemble the other. If the documents have the common word they are stored in the same group. Numbers indicate how often each word exist in a document. In the same way clustering could be process inside a document in each paragraphs. The cluster analysis has two main types: hierarchical and partitional clustering.

Correspondence analysis unveil distribution of words among subgroups to the total distribution, or relationship between words [6]. Interpretation of correspondence analysis is easy to be made with 3D or 2D graphs, but interpretation should be process with caution.

In some text mining tools it is possible to perform automated text classification. It is supervised machine-learning task. This method can be used to automatically classify document into proper categories or to find relevant keywords. The same is with correspondence analysis. Data mining programs can find some connection between word and sentences, but the scientist are necessary to judge if the found rule is true.

## *3.2 Text Analysis Process*

Text analysis with text mining process consist of 5 steps:

First of them is text preprocessing. Second is transformation of text, next one is feature selection [7]. The fourth step is pattern discovery with data mining tools. Interpretation and evaluation are the fifth and the last step of analysis. All the programs mentioned above have similar functions, so for analysis we choose the WordStat 6.0.1 with graphical interface. It is a easiest tool for beginning users.

*Analysis with WordStat 6.0.1 from Provalis Research*

Importing data to the program is very easy to do. For the analysis there is a possibility for using documents:

- Microsoft Excel xls and xlsx,
- SPSS sys and sas,
- MS Access mdb,
- Paradox db,
- Lotus/Symphony wk and wr,
- Quattro Pro wq and wb,
- CSV and TAB, MMO, SSS, XML.

There is also document conversion wizard for many different files extensions. Next step is to make a dictionary, specify how the textual information should be processed and which words should be ignored.

Preprocessing step was made in SimStat 2.5.7 [7]. Data had been imported to program where checked and save as *dbf* file (Fig. 1). In this step basic statistics can be made, if data have numerical variables. After changing program for WordStat preprocessing is continued. Common English suffixes can be removed here, and also the decomposition of every word into sequences of 3, 4 or 5 characters can be made on this stage.

In transformation process individual words can be replaced with another word or with sequence of words. Automated spelling correction of common misspellings is also situated in this step of analysis. Words that should not be in analyzed document are added to exclusion list in exclusion process.

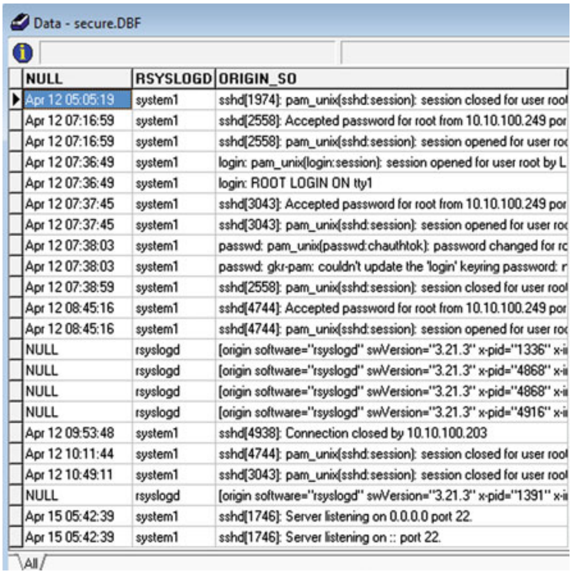
Feature selection is performed to gain better subset, which describes data from an original dataset. The main aim of this step is to choose a relevant data and reduce the amount of data. In logs data all variables are relevant. If many logs files were chosen for the analysis, the feature selection will be an important step.

## 4 Results

Discovery patterns from data were made in WordStat with English dictionary and without added substitution and exclusion dictionaries.

During this process univariate frequency analysis where made [8]. The frequency matrix may contain included, leftover or unknown words, with amount or percentage amount occurred in document. During this analysis it was discovered that the word connected with some threat appear only in 1 % of all logs. The most common word in logs was "accepted"—99 %.

Examining the relationship between included categories was the second step (Fig. 3) of discovery patterns. It was made by using the cross tables (Fig. 2). Here we discover words which come together. Those connected words will help with finding threats. For example "password+ change+ failed" or "login+ failed or unknown".

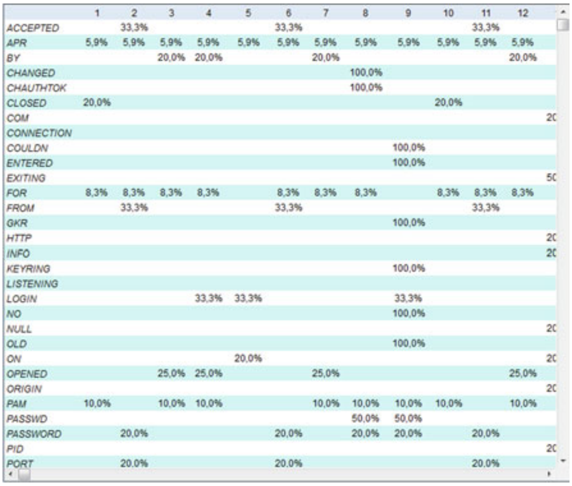


Data - secure.DBF

| NULL | RSYSLOGD | ORIGIN_SO |
|---|---|---|
| Apr 12 05:05:19 | system1 | sshd[1974]: pam_unix(sshd:session): session closed for user root |
| Apr 12 07:16:59 | system1 | sshd[2558]: Accepted password for root from 10.10.100.249 por |
| Apr 12 07:16:59 | system1 | sshd[2558]: pam_unix(sshd:session): session opened for user roo |
| Apr 12 07:36:49 | system1 | login: pam_unix(login:session): session opened for user root by L |
| Apr 12 07:36:49 | system1 | login: ROOT LOGIN ON tty1 |
| Apr 12 07:37:45 | system1 | sshd[3043]: Accepted password for root from 10.10.100.249 por |
| Apr 12 07:37:45 | system1 | sshd[3043]: pam_unix(sshd:session): session opened for user roo |
| Apr 12 07:38:03 | system1 | passwd: pam_unix(passwd:chauthtok): password changed for rc |
| Apr 12 07:38:03 | system1 | passwd: gkr-pam: couldn't update the 'login' keyring password: r |
| Apr 12 07:38:59 | system1 | sshd[2558]: pam_unix(sshd:session): session closed for user root |
| Apr 12 08:45:16 | system1 | sshd[4744]: Accepted password for root from 10.10.100.249 por |
| Apr 12 08:45:16 | system1 | sshd[4744]: pam_unix(sshd:session): session opened for user roo |
| NULL | rsyslogd | [origin software="rsyslogd" swVersion="3.21.3" x-pid="1336" x-i |
| NULL | rsyslogd | [origin software="rsyslogd" swVersion="3.21.3" x-pid="4868" x-i |
| NULL | rsyslogd | [origin software="rsyslogd" swVersion="3.21.3" x-pid="4868" x-i |
| NULL | rsyslogd | [origin software="rsyslogd" swVersion="3.21.3" x-pid="4916" x-i |
| Apr 12 09:53:48 | system1 | sshd[4938]: Connection closed by 10.10.100.203 |
| Apr 12 10:11:44 | system1 | sshd[4744]: pam_unix(sshd:session): session closed for user root |
| Apr 12 10:49:11 | system1 | sshd[3043]: pam_unix(sshd:session): session closed for user root |
| NULL | rsyslogd | [origin software="rsyslogd" swVersion="3.21.3" x-pid="1391" x-i |
| Apr 15 05:42:39 | system1 | sshd[1746]: Server listening on 0.0.0.0 port 22. |
| Apr 15 05:42:39 | system1 | sshd[1746]: Server listening on :: port 22. |

All

**Fig. 1** Input data



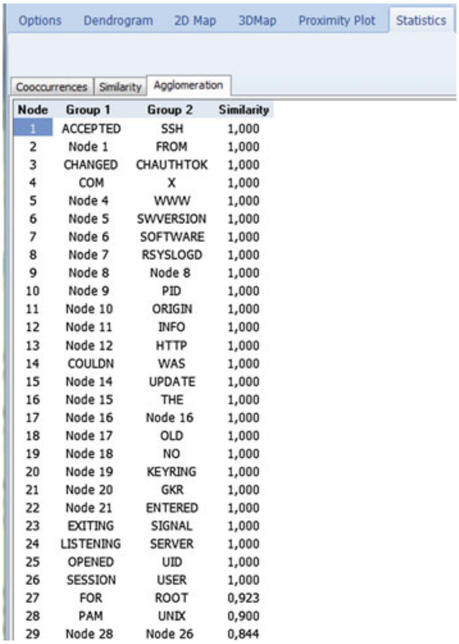
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ACCEPTED | | 33,3% | | | | 33,3% | | | | | 33,3% | | |
| APR | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | 5,9% | |
| BY | | | 20,0% | 20,0% | | | 20,0% | | | | | 20,0% | |
| CHANGED | | | | | | | | 100,0% | | | | | |
| CHAUTHTOK | | | | | | | | 100,0% | | | | | |
| CLOSED | 20,0% | | | | | | | | | 20,0% | | | |
| COM | | | | | | | | | | | | | 20 |
| CONNECTION | | | | | | | | | | | | | |
| COULDN | | | | | | | | | 100,0% | | | | |
| ENTERED | | | | | | | | | 100,0% | | | | |
| EXITING | | | | | | | | | | | | | 50 |
| FOR | 8,3% | 8,3% | 8,3% | 8,3% | | 8,3% | 8,3% | 8,3% | | 8,3% | 8,3% | 8,3% | |
| FROM | | 33,3% | | | | 33,3% | | | | | 33,3% | | |
| GKR | | | | | | | | | 100,0% | | | | |
| HTTP | | | | | | | | | | | | | 20 |
| INFO | | | | | | | | | | | | | 20 |
| KEYRING | | | | | | | | | 100,0% | | | | |
| LISTENING | | | | | | | | | | | | | |
| LOGIN | | | | 33,3% | 33,3% | | | | 33,3% | | | | |
| NO | | | | | | | | | 100,0% | | | | |
| NULL | | | | | | | | | | | | | 20 |
| OLD | | | | | | | | | 100,0% | | | | |
| ON | | | | | 20,0% | | | | | | | | 20 |
| OPENED | | | 25,0% | 25,0% | | | 25,0% | | | | | 25,0% | |
| ORIGIN | | | | | | | | | | | | | 20 |
| PAM | 10,0% | | 10,0% | 10,0% | | | 10,0% | 10,0% | 10,0% | 10,0% | | 10,0% | |
| PASSWD | | | | | | | | 50,0% | 50,0% | | | | |
| PASSWORD | | 20,0% | | | | 20,0% | | 20,0% | 20,0% | | 20,0% | | |
| PID | | | | | | | | | | | | | 20 |
| PORT | | 20,0% | | | | 20,0% | | | | | 20,0% | | |

**Fig. 2** Cross table

Correspondence analysis of data is the next step. The correspondence analysis graph for this case is shown on Fig. 4. Here we can make 2d or 3d graphs, which show the relationship between words [8].

Last one step in a pattern discovery is making dendrogram. Dendrogram is a graphical presentation of hierarchical clustering [8] (Fig. 5).

Fig. 3 Trust data




| Node | Group 1 | Group 2 | Similarity |
|---|---|---|---|
| 1 | ACCEPTED | SSH | 1,000 |
| 2 | Node 1 | FROM | 1,000 |
| 3 | CHANGED | CHAUTHTOK | 1,000 |
| 4 | COM | X | 1,000 |
| 5 | Node 4 | WWW | 1,000 |
| 6 | Node 5 | SWVERSION | 1,000 |
| 7 | Node 6 | SOFTWARE | 1,000 |
| 8 | Node 7 | RSYSLOGD | 1,000 |
| 9 | Node 8 | Node 8 | 1,000 |
| 10 | Node 9 | PID | 1,000 |
| 11 | Node 10 | ORIGIN | 1,000 |
| 12 | Node 11 | INFO | 1,000 |
| 13 | Node 12 | HTTP | 1,000 |
| 14 | COULDN | WAS | 1,000 |
| 15 | Node 14 | UPDATE | 1,000 |
| 16 | Node 15 | THE | 1,000 |
| 17 | Node 16 | Node 16 | 1,000 |
| 18 | Node 17 | OLD | 1,000 |
| 19 | Node 18 | NO | 1,000 |
| 20 | Node 19 | KEYRING | 1,000 |
| 21 | Node 20 | GKR | 1,000 |
| 22 | Node 21 | ENTERED | 1,000 |
| 23 | EXITING | SIGNAL | 1,000 |
| 24 | LISTENING | SERVER | 1,000 |
| 25 | OPENED | UID | 1,000 |
| 26 | SESSION | USER | 1,000 |
| 27 | FOR | ROOT | 0,923 |
| 28 | PAM | UNIX | 0,900 |
| 29 | Node 28 | Node 26 | 0,844 |

# 5 Conclusion

Log analysis using data mining methods can significantly speed up the retrieval of the most important information within the data collected. Search patterns using the automated method allow text searches to prevent human errors resulting from omission of relevant information.

Moreover, the use of mathematical reasoning through a thorough analysis of the relationship between the huge amounts of data (a quick comparison of the results of many observations, even in real time) can often detect threats which would be impossible to identify by a human. In addition, analysis of data at a right angle can prevent likely problems occur in the future forecast on the basis of phenomena that have already been registered. Log analysis using data mining methods is the only growing sector of having a large range of possibilities before us.

# 6 Future Work

The article describes the proposal, only the possibility of using data mining methods for the analysis of system logs. The possibility of effective analysis of system logs recorded by computer programs to prevent attacks, system failures and data loss, therefore, optimizing the process of log analysis is very important. In the current phase of the project it is only in the planning phase of implementation. In

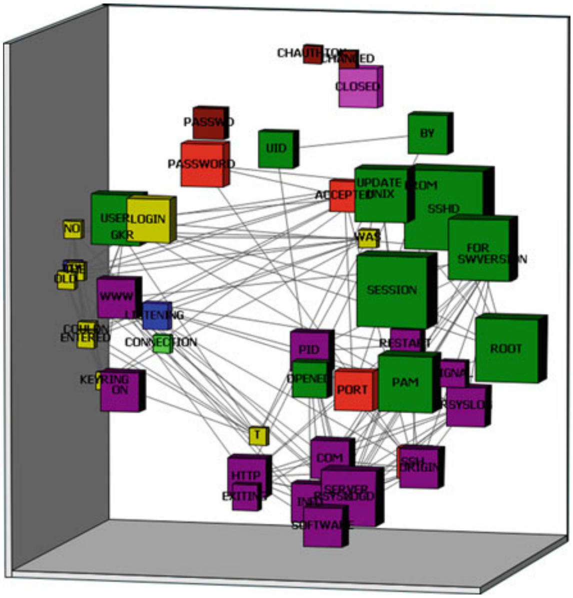



**Fig. 4** Correspondence analysis graph

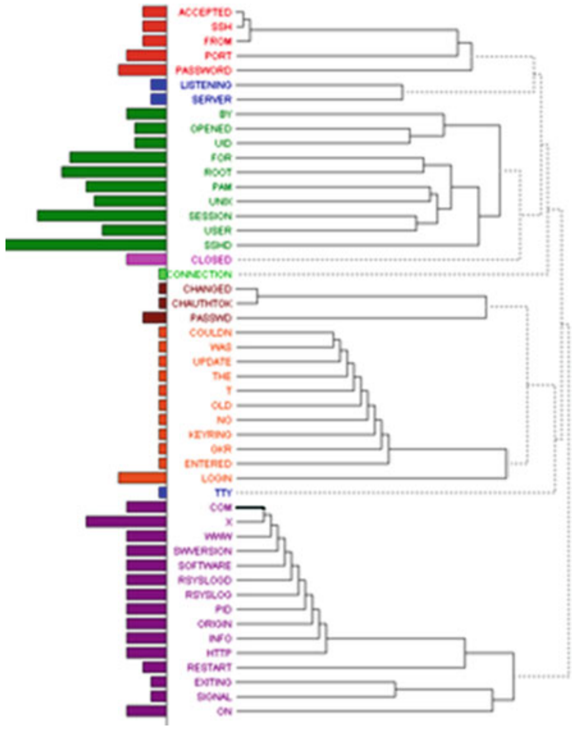



**Fig. 5** Dendrogram

this moment only few method where used. Next step of the project will be connected with full and complex analysis with classification tools using neural networks, fuzzy logic and many more. Also different methods of text mining will be applied, for finding proper and useful tools for log threats.

Ultimately, we want to create a complete system for analysis of aggregate KVM server logs around the machinery using chosen tools. The program would allow for profiling the performance of machines as well as warning of potential threats and intrusions in real time. The project is so useful that will be used to monitor virtual machines on servers in the university where classes are conducted with the students. It can therefore be expected that in the course of system administration classes students will generate a lot of potential risks allowing the creation of rules of inference for our system. Ultimately, we want to create a web application allowing users to monitor system status, management entirely online.

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# C# Based Media Center

**Taner Arsan, Rasim Sen, Barkan Ersoy and Kadir Kadirhan Devri**

**Abstract** In this paper, we design and implement a novel all-in-one Media Center that can be directly connected to a high-definition television (HDTV). C# programming is used for developing modular structured media center for home entertainment. Therefore it is possible and easy to add new limitless number of modules and software components. The most importantly, user interface is designed by considering two important factors; simplicity and tidiness. Proposed media center provides opportunities to users to have an experience on listening to music/radio, watching TV, connecting to Internet, online Internet videos, editing videos, Internet connection to pharmacy on duty, checking weather conditions, song lyrics, CD/DVD burning, connecting to Wikipedia. All the modules and design steps are explained in details for user friendly cost effective all-in-one media center.

## 1 Introduction

It would be difficult to argue that the invention of the television affected more people compared to any other innovation in the last century. Once the usage of the TV expanded and the word is spread, movies quickly followed. When going to the movies was the only alternative to see a recent movie, people figured out that if they could get those movies to show on their screens at home which led to the birth of home theater systems. And this initiative fact triggered different areas of home theater usage. People then demanded to play their favorite music, view the pictures

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DOI: 10.1007/978-1-4614-3558-7_87, 

they took and watch other visual content using their home theater system by simply hooking it up into their television sets. Then they determined that this activity can be expanded widely, after that devices called Home Theater Personal Computers (HTPC) drew the interests which are basically media center boxes but capable of doing everything that a personal computer is able to.

In this study, firstly, HTPC systems are explained. Then modular C# based Media Center is introduced as all-in-one media system. Finally, complete system architecture of media center is given and some differences between implemented media center and media centers that are available in the market are explained.

## 2 History of Media Centers

The birth of HTPC is related to several innovations in technology which started in early 1990s, including the shift from CRT monitor to high definition screens, speedy home computers, the development in digital media and the integration of the TV and personal computers. By the year 2000, consumers were focused on seeking the ways to improve the picture quality. Then the DVD became very popular. But since the use of stand alone DVD players only supported the obvious feature, this fact drove more usage to the personal computers as a DVD player and home media device.

The working principle of a DVD covers progressive scanning and it is used for storing film-based material into a DVD as certain formats [1]. P-scan is used for most CRT computer monitors, all LCD computer monitors, and most of the HDTV because the display ratios and pixel resolutions are progressive by default. Some of the televisions and most of the projectors have one or more progressive scan inputs. Before high definition displays became very common, some high end displays supported 480p. This allowed these displays to be used with a device which outputs p-scan like DVD players and most of the video game consoles.

In 2002, software developments started to get media and content presentation facilitated. Open source software called MythTV led the way and provided a solution using Linux environment [2, 3]. The concept was to integrate PC capabilities, program guides and digital video recording out of a TV broadcast. Then the XBMC came up as another open solution. The purpose was to use the Xbox game console as a HTPC. Then other versions also for Windows and Macintosh have been released under the names of Boxee and Plex. Some of the popular software packages contained Windows XP Media Center Edition which was bundled with Windows Operating System.

As satellite and digital broadcast happened to be standard, HTPC software became in need of receiver boxes, and these had membership costs. In 2009, hardware restrictions were taken away for cable CARD devices and this maintained the possibility of integration to the HTPC.

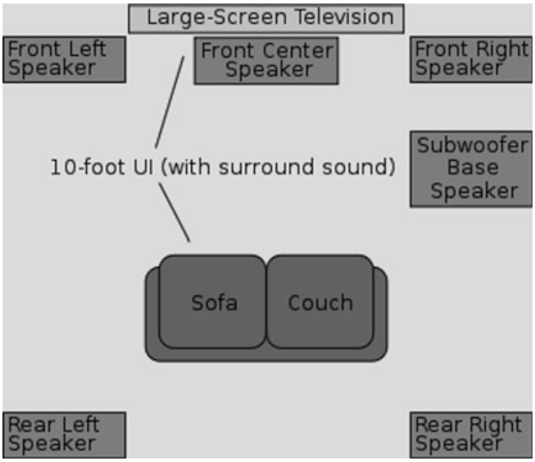


**Fig. 1** 10-foot user interface—a home theater surround sound setup

### 2.1 Home Entertainment Systems

Graphic User Interface (GUI) and the interaction between user and home entertainment systems are two important factors for a home entertainment system. The interaction with home entertainment system is different from interacting with a typical desktop computer. It is expected that the control and the navigation on menus to be founded very easy to control by the user. The remote control also has to be easy to use and the elements have to be clear to be distinguished. It is assumed that the user's eyes when using a desktop computer are approximately 2 feet away from the screen. And the phrase "10 foot User Interface" [4] is used to differentiate the interface style from desktop computers' and it is designed for display on large screen televisions in order the remote control interaction not to be different than using the TV. "10 foot" refers to the condition when the user is sitting 10 feet away from the large screen television so that the GUI elements have to be large enough to easily be read from that distance. The Fig. 1 is an example representation of the 10 foot experience [5].

### 2.2 Home Theater Personal Computer Software

The most important point for a HTPC system is the selection of convenient software. We select Media Portal because it is flexible, open source and intended for developing in Microsoft.NET framework. Media Portal software is also suitable for future development and it gives us the possibility to customize the interface design according to the design guidelines of the 10 foot UI. Following items are a few design guidelines that we considered: *installation*, *user input* by means of Microsoft remote control (alternatively a game input device such as a joystick or a keyboard can be used, when the user wants to play games).

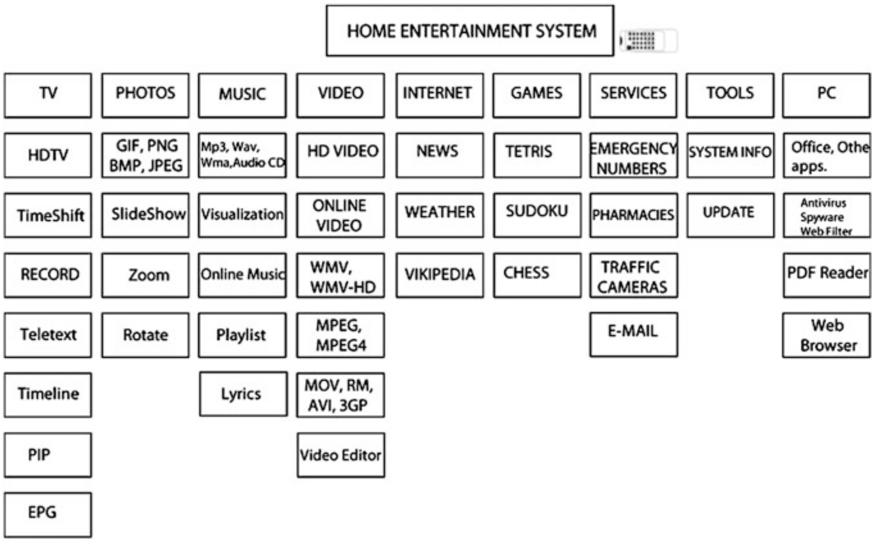


**Fig. 2** Home entertainment system components

## 3 General Specifications of the Implemented Media Center

Specifications of home entertainment system are the most important point for new design of such system [6]. Implemented media center has Turkish language support. Unfortunately, almost none of media center that are available in the market does not have Turkish language support. This is one of the contributions for media center design. The other contributions are the ease of use design, skin design and plugin & extensions. The new media center contains HDTV support, picture viewer, weather forecast, web browser, traffic cameras, song lyrics, play/write CD/DVD, video player, on-line videos, games, emergency numbers, Wikipedia connection, video editor, music player, news feed, radio, pharmacies on duty, e-mail support and alarm clock. Implemented media center components are shown in Fig. 2, Graphic User Interface- GUI of implemented home entertainment system is shown in Fig. 3.

### *3.1 Hardware Specifications*

In this study, lowest power consumption and the performance are two important criterias that we need for the 1080p formatted movie playback. Therefore, hardware components are searched by considering these criterias. Zotac ION seems to meet our requirements [7]. It is a fully functioning Mini-ITX type motherboard which is suitable for the case we are planning to use.


**Fig. 3** Graphic user interface of implemented C# based media center

Zotac ION contains the Intel Atom 330 processor with 1.6 GHz clock rate. It is the best solution around with its low power consumption and excellent performance compared to the other dual core processors. Intel Atom 330 processor delivers enough of power for Internet based applications, e-mail, multimedia applications, office productivity, web browsing and many other applications. The NVIDIA ION graphic processor also supports up to 4 GB RAM. The Mini PCI express slot, SATA/e SATA 3Gbs with RAID supports, onboard Geforce 9,400 M GPU and the 802.11/n Wi-Fi interface card are the other components also embedded to the system. Ports on the back contain D-Sub, DVI, HDMI and two S/PDIF outputs. Zotac ION motherboard is capable enough to play 1080p high definition videos and all of the other media formats. Since the main target of this study is to maintain the HD support at all times, this features comes handy. Also robust support for DirectX 10, OpenGL 2.1, NVIDIA CUDA and PhysX games and applications are other features that the device is capable of handling. The integrated NVIDIA GeForce 9,400 M GPU series graphics card offers ultra-realistic effects and perfect functionality for all types of PC gaming and multimedia environment.

The other hardware components of media center system are summarized below.

### 3.1.1 Satellite Receiver

SkyStar USB 2 external satellite receiver is mounted inside media center's case. Receiver contains DVB-S (digital video broadcasting, satellite) that is basically a modulation standard used in satellite systems. The compact box of the receiver which connects through a USB 2.0 interface supports the reception of unencrypted TV and radio satellite broadcasts such as TurkSat 42°. The prerequisites we take into consideration for the receiver are as follows: At least 20 GB available memory for the DVR function, one available USB connection, 3D graphics card, sound card with a digital connection, DirectX 9.0 or higher [8].

#### 3.1.2 Slim DVD Writer

Media center devices usually use mini-ITX cases with a maximum power output of 300 watts. Since the cases are designed to be as small as possible the room for the DVD drive is also limited. That is why just like on the laptops, the case we use has the slot for the slim type mini-dvd internal drive. We mounted Sony's optiarc AD 7580S model which weighs about 170 grams and 12.7 mm wide. It features high recording and reading speeds for fast and easy operations. Up to 8x recording speed for single-layer DVD-R media and up to 5x recording speed for DVD-RAM is supported.

### 3.2 *Software Specifications*

C# based Media Center is developed in modular manner and under a GNU public licensed MediaPortal media center software [9]. It is possible to develop and implement limitless number of modules, but on the other hand, the user interface has to be simple and tidy ding to the goal of the project. In this chapter, usage, implementation and features of the modules are going to be discussed.

#### 3.2.1 Media Portal General Specifications and UI Architecture

The software MediaPortal only runs under Microsoft Windows operating systems unlike most of the other media center softwares. The software by default features a DirectX GUI, a video renderer to be used in mixing, a renderer for rendering the video content, advanced digital DVB support for DVBEPG and several integrated plugins, however it can be extended with extra plugins. It also has the internal support with custom keymapping that allows the user to map basically every key on a PC keyboard onto remote devices.

MediaPortal is developed in C#.NET framework, and it is possible to write a plugin with any.NET language using one of the following programming environments:

- Visual Studio 2008 (commercial)
- Visual C# 2005 Express Edition (free, closed source)
- SharpDevelop 2.1 (open source)

MediaPortal supports a few sorts of plugins. It is possible to use any of the following types to extend MediaPortal's ability in a different way. The plugin types can be sorted by:

(1) Process plugins: They are plugins that has no UI, and just do its work in the background. Examples of process plugins: Caller id plugin, LCD/VFD plugin and plugins that run remote controls.

(2) Tag Reader Plugins: They are utilized to receive media tags from media files, for example from MP3 and AVI files.
(3) External Player Plugins: They are employed for playing media using 3rd party applications, for example WinAmp, Media Player Classic and iTunes.
(4) GUI Plugins are the most attractive one. They have the UI components such as "Traffic Cams", "Farmacies on Duty" and "Web Browser" that allow the user to interact with them.

MediaPortal is designed to be modified and customized. The user can either choose one of the available community skins which are accessible through the website of the software or design and create his/her own skin. The user reaches the functionality surfaced from the application code through skins which are developed using XML [10–12]. The application will load the appropriate XML skin file upon initialization. For instance, when the software starts off, the initial skin to usually be loaded will be the Home.xml or myHome.xml depending on which setting the user has configured. The utilization of XML basically provides a more precise way to let MediaPortal know the page layout, fonts, positioning of each item on screen such as color of text, graphics transparency etc. By changing the XML file within a skin the entire look and feel can be modified. Although the details are very different, the idea is the same as making a webpage however XML files have a distinct structure and they are case sensitive. The XML files are located in the skins folder under the main MediaPortal application folder.

There are also folders under the relevant skin folder for fonts, media and sounds. The most commonly used "media" folder has all the visuals that the skin file uses (normally in PNG format for best quality and transparency support for better appearance). Software Architecture of the system is shown in Fig. 4.

### 3.2.2 XML File Aspects

Inside the skin directory, there are two special XML files. One is fonts.xml, the other is references.xml.

The fonts provided to the relevant skin are defined in the fonts.xml file. The actual fonts are stored in the font's sub-folder. Each font element defines:

- The name that the font will be referenced as in the skin files
- The filename of the actual font file
- The height of the font which can be bold or italic
- The numeric start character (default 0)
- The numeric end character (default 255)

The references.xml file contains information about the skin version and resolution at minimum. It may also contain other values for any of the controls that exist in the skin so for example, the sizes of buttons do not have to be defined every time you use it in other skin files. It can also define styles that can be applied to any control.

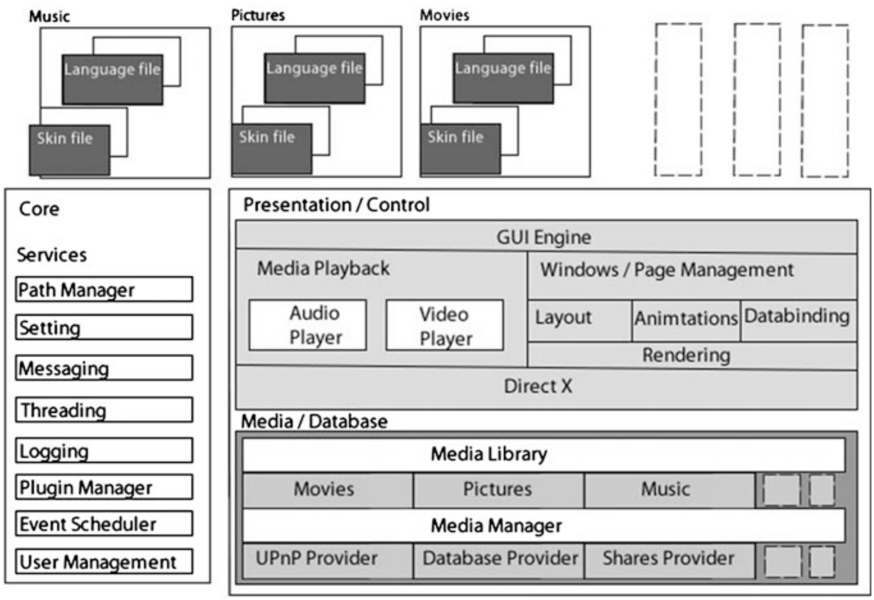


**Fig. 4** Software architecture of media center system

### 3.2.3 Application of Media Center Plugins

This section contains the principal features and brief explanation of the plugins that the software runs. These are mostly GUI plugins that allow users to interact directly which are also possible to adjust via the configuration.exe according to the needs. Every installed plugin adds an entry into the plugin configuration section and they can be customized instantly. Installing plugins is a fairly easy operation. Only process that should be done is that after compiling the prepared C# project, Microsoft's implementation of shared library concept called the DLL files and the XML files are both sent under Media Center's skin and plugin directories with the relevant images and visuals. This operation enables the configuration.exe to view such plugin. The following are the plugins that Media Center contains.

Television

The following is the features listed that are supported by Media Center's integrated TV-Engine. There are two different TV engines; the built-in engine which gets installed with Media Center automatically and the new stand-alone TV Server, which can be used to replace the built-in engine. Analog TV support is also available (both with software and hardware), DVB-C (cable), DVB-T (antenna), DVB-S (satellite). Other supported plugins are:

- HDTV and AC3 audio codec support.
- Support for several tuners.
- Instant or scheduled recording, watching, and time shifting possibility of the live TV.
- Advanced scheduler to record: Record now, once, daily, weekly, on weekdays, every time a program shows up on the certain TV channel, or every time a program appears on any TV channel.
- Advanced recording features: Handles file name conflicts, and sets recording priorities. Converts recordings to any desired file format such as wmv, xvid, or mpeg. Disk Management can be set to automatically remove old recordings. TV supports over 10,000 channels and teletext, automatic channel tuning. Standby control that puts the Media Center to sleep. It awakes when there is a scheduled recording. Comskip feature skips commercials in recordings.

### Movies and DVD Plugins

There are two separate plugins for video files and DVD playback. The DVD plugin instantly detects the DVD media inside the DVD drive and displays the root menu. More features are as follows:

- Any movie format can be played. Every possible codec that video and audio files need in order to play, is installed in the system. .mkv, .avi, .mp4 etc. are example file extensions that the system has no problem playing.
- All the movies are stored in Media Center's video database.
- View and sort your movies by title, actors, genre, release year, rating. The relevant information is retrieved such as pictures, actors and so on from database.
- Stacking/unstacking is possible if the movie consists of multiple files.
- On Screen Display (OSD) for pause, rewind, fast forward, stop, mute, bookmarks, switching audio streams and subtitle languages.
- It asks the user if to resume from previously stopped playback or not on next play.

### Radio

Via radio plugin, FM, DVB and also Internet streams and shoutcasts may be listened. FM radio tunes automatically. The logos can be displayed for each radio station and a nickname for each radio station can be supplied however it is a manual process. It is possible to start listening to the selected radio station on startup automatically.

Music

Plugin features are as follows:

- Viewing the music by artist, album, genre, rating or browse the music files and sorting the music in many ways like track, genre, filesize, artist, album.
- Visualizations from Windows Media Player 10 and higher.
- Load, create & save playlists (.m3u, .pls, .b4u). And Alarm clock plugin is integrated with the playlists we create. The Alarm tone can be set to a playlist.
- Automatically gets pictures such as album cover and info for all of the artists and albums in the directory. And they can be viewed as list, icons or big icons.
- Shuffle, party shuffle mode, repeat, fast-forward, rewind, pause functions.
- Music ratings and favorites can be marked by the user. And all of the favorite songs can be displayed in one screen.
- Winamp, or iTunes plugins for music playback can be utilized.

Photos

Pictures and photos can be displayed optionally with a slideshow that enables nice transitions and pause previous/next picture skip options. While viewing them, zoom in/out and rotate function is available. The rotation can be remembered next time when the file is viewed. Also the thumbnail is automatically generated for each folder. Pictures are stored in a chosen directory like to the movies but it can be accessed and deleted from the UI whenever needed. While slideshow is working a background music can be picked either from the songs from the music plugin or out of the radio.

Weather Forecast and News

The weather forecast plugin shows the latest weather information for previously selected cities from the configuration file. The data is retrieved via the Weather Channel so almost every city in the world is supported. 5-day forecast with the current temperature is displayed in either °C or °F with the visuals. Also the values such as UV index, humidity (%) and wind-speed can also be viewed and live satellite images from the Internet are supported.

The plugin "News" is capable of viewing asked RSS news feeds from a desired source. Periodically followed TV channels and newspapers can be added to the shortcut list and opened whenever needed.

## Online Videos and Movie Editor

The plugin “Online videos” has a database of the websites that periodically posts videos to the Internet. And the content continuously changes and certain statistics about the viewed videos are recorded under particular titles. Online videos plugin goes through the selected source sticking to a regular expression pattern and parses the contents as thumbnails under certain titles. And desired video can instantly be viewed no matter if the content is HD or not. It is actually very functional since the contents are constantly refreshed and kept recent.

The plugin “Video Editor” enables the user to pick a mpeg video and optionally an audio file. After choosing the files it is possible to crop the video into pieces and put music onto the finished product. The operation is simple but functional since it only takes couple of minutes to roughly make customized video files.

## Web Browser

The main goal of the Media Center is to restrict the user in a certain way when user feels relax. Designing a browser into our media center is one of the fun facts that give the user more freedom.

The plugin runs the Mozilla Firefox in full screen mode. And rest of the operation is exactly the same with using the Firefox Browser. Whenever the ESC button is pressed, the application quits and turns back to the root menu of the media center. Even though the browser have limitless abilities it is not very common to attach it into a media center system and it can lead to a trouble if it is used very often since all of the visited website content is stored under temporary files. We found a solution to this by deleting the content which is visited, after turning the browser off. So that way we will not worry about that. And other problem was coming from the memory utilization. If the browser worked in the background that means it would use the memory that is reserved for the media center. And that would lead the media center to operate not fast enough to play HD content. Our solution to such problem happened to be just turning off the browser whenever the plugin is turned off by pressing the ESC button.

## CD/DVD Writer

The plugin “CD/DVD Burner” enables to burn data, audio or video into a CD or a DVD. The plugin makes the operation easier and faster.

Alarm Clock

It is possible to set every setting of the alarm clock such as weekday settings, media center wake up if put on sleep. And the music playlists that we create from the music plugin can be defined as the alarm tone and it will play respectively.

E-mail

From the configuration.exe incoming mail options can be set and the received mails may be selected, viewed and deleted via the plugin. If the content of the e-mail is too long to fit to the screen, it scrolls down automatically and enables the viewer to read the whole thing without touching a button.

Games

An entertainment box could not be without games inside. Media center comes up with the three most popular games; sudoku, tetris and chess. They let users to play just with the remote control.

Pharmacies

Pharmacies that are working nightshift are viewable through the plugin. The istanbulsaglik.gov.tr website publishes the relevant pharmacies every day. So the main idea is to catch the sources sorted by city, parse them and publish it onto the plugin by using a regular expression that we have written considering the links used to navigate inside the website.

Emergency

It is always good to know what number to call when something extraordinary happens. So this plugin just sorts the essential numbers in order and shows to the viewer.

Traffic

Traffic cameras that are positioned in several locations are accessible through a web service inside tkm.ibb.gov.tr website. So the plugin “traffic cameras” just connects to the traffic cameras’ server and grabs the live broadcast in order to publish on the plugin. Users may navigate through the cameras and select the ones they want to view in fullscreen.

**Table 1** Recording time depending on file system

| File system | HDTV (min) | SDTV (min) |
|---|---|---|
| FAT16 | 15 | 30 |
| FAT32 | 30 | 60 |
| NTFS (recommended) | 2.000 | 4.000 |

## Lyrics

The plugin "MyLyrics" enables the user to view the playing song's lyrics instantly. From configuration.exe lyrics of every song inside music folder that the music plugin is looking for can be searched inside a lyrics database. As soon as it is found, while playing music out of the music plugin, myLyrics plugin may be run and lyrics may be followed instantly on the screen in the style of a karaoke

## Software Support

For a proper and smooth operation the Media Center software needs to be setup on top of a certain hardware and software.

(1) Supported OS

- Windows XP 32 bit Edition with at least service pack 3
- Windows Media Center Edition 2005 with service pack 3
- Windows Vista 32 and 64 bit with at least service pack 1
- Windows 7 32-64 bit—which is built under media center.

(2) File System

Depending on the bit rate of the transmission recordings TV can take up lots of hard disk space. By recording for 1 h you get a file size peaking from around 4 GB for SDTV to about 8 GB for HDTV (See Table 1.).

(3) Drivers and Codecs

The most recent drivers for the video and audio card should be used. The open source MPV and MPA codecs are bundled with Media Center for mpeg2 allowing you to watch movies and TV out of the box. If user wants to watch HD content, then user needs to install a 3rd party h.264 codec. Popular codecs are from Cyberlink's Power DVD, Core AVC or ffdshow which are available for free. But we just go ahead and install one of the codec packs that contain popular codecs which are freely available around the Internet.

## 4 Conclusions

In this paper, we developed and implemented a media center by using C# and an HTPC. The hardware is designed by considering the power consumption, noise factor and it is designed to be as practical as possible in a home theater environment. The software on top is a freely available and modifiable media center called Media Portal. The.NET platform also enabled us to develop several plugins.

Ease of use is another important factor in this study. Since the system is designed for a living room environment, complexity is the only thing that we should be avoided. We make it to work like any other plug and play device without any extra configuration. Also the user interface is kept straightforward and simple in both design wise and also application wise. The Media Center skin is designed by considering the 10-foot experience guidelines.

The possibility to upgrade the hardware components is another quality factor that we want to maintain which may come handy when there are new standards in the media technology. Since the aspect of connectivity is concerned with the upgradeability, a modern media center should offer this feature for the user to upgrade his/her device with other components. The possibility to upgrade the hardware components is another quality factor that we want to maintain which may come handy when there are new standards in the media technology. Since the aspect of connectivity is concerned with the upgradeability, a modern media center should offer this feature for the user to upgrade his/her device with other components.

One other important factor with the media center is to support for different media formats and standards. We take compatible with various technologies into consideration. One of the main goals of the product is to give the ability to the device in order to present every high definition video format available without any trouble.

We believe that Media Center is a complete convergence device that is ready to be enjoyed with lots of technological features that respects to the developing technology in its field. We believe that Media Center is a complete convergence device that is ready to be enjoyed with lots of technological features that respects to the developing technology in its field.

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# An Efficient Intrusion Detection System for Mobile Ad Hoc Networks

**B. V. Ram Naresh Yadav, B. Satyanarayana and O. B. V. Ramanaiah**

**Abstract** A Mobile ad hoc network is a collection of nodes that is connected through a wireless medium forming rapidly changing topologies. Mobile ad hoc networks are vulnerable due to its fundamental characteristics such as open medium, dynamic topology, distributed co-operation and constrained capability. Real time Intrusion detection architecture for ad hoc networks has been proposed for detecting the attacks in mobile ad hoc networks. The main problem with this approach is that the detection mechanism process relies on a state based misuse detection system. In this case every node needs to run in the IDS agent. This approach does not make use of a distributed architecture to detect attacks that require more than one hop information. In this paper we propose an Efficient ID, a novel architecture that is used to detect active attacks against AODV protocol in mobile ad hoc networks. Our architecture involves the use of Finite State Machines for specifying AODV routing behavior and distributed network monitors for detecting the attacks. Our methods can detect the attacks that require more than one hop information. We compared the EID Architecture against RID architecture against percentage of detecting the attacks both in static and dynamic case. We have developed a prototype that was evaluated in AODV enabled networks using the network simulator (ns-2).

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## 1 Introduction

Mobile Ad hoc networks are one of the recent active fields and have received spectacular consideration because of their self configuration and self maintenance. Early research assumed a friendly and co-operative environment of wireless network. In order to maintain the connectivity in a mobile ad hoc network all participating nodes have to perform routing of network traffic. Therefore, a network layer protocol designed for such self organized networks must enforce connectivity and the security requirements in order to guarantee the undisrupted operations of higher layer rotocols, unfortunately all the widely used ad hoc routing protocols have no security considerations and trust all the participants to correctly forward routing and data traffic. The routing protocol sets the upper limit to security in any packet network.

If routing can be misdirected or modified the entire network can be paralyzed [1]. Several efforts have been made to the design of a secure routing protocol for ad hoc networks. The main problems with this approach are that it requires changes to the underlying protocol and that manual configuration of the initial security associations cannot be completely avoided.

The Efficiet Intrusion Detection Systems for mobile ad hoc network system is based on previous research proposed to detect active attacks against AODV, a routing protocol that is widely used in wireless networks [2]. We have adopted the successful approach of employing distributed network monitors for detecting attacks in real time and have applied to the domain of ad hoc routing. Efficient Intrusion detection Systems for mobile ad hoc networks can be characterized as an architecture model for Intrusion detection in ad hoc networks, while its implementation targets specifically AODV [3].

We clarify our system as an architecture model since it does not perform any changes to the underlying routing protocol but it merely intercepts traffic and acts upon recognized patterns.

In the remainder of this paper we start by briefly presenting the related work on this area in Sect. 2 In Sect. 3 we describe the AODV routing protocol and the threat model associated with it. In Sect. 4 we describe in detail our proposed architecture and the design of Effective ID for mobile ad hoc network for AODV based networks. In the Sect. 5 we evaluate our prototype that has been implemented using ns-2 simulator, Sect. 6 concludes by describing the strengths and short coming of our proposal identifying the directions for future work.

## 2 Related Work

Specification based intrusion detection system is used to detect attacks on AODV. This approach involves the Finite state machine for specifying correct AODV routing behavior and distributed network monitors for detecting runtime violation of the specifications [4]. Specification based system are particularly attractive as they successfully detect both local and distributed attacks against the AODV routing protocol with a low number of false positives. A real time intrusion detection system for ad hoc networks model for detecting real time attacks has been developed specifically for AODV [1]. The model is composed of four main layers, a traffic interception module, an event generation module, an attack analysis module, and counter measure module. The traffic interception module captures the incoming traffic from the network and selects which of these packets should be further processed. The event generation module is responsible for abstracting the essential information required for the attack analysis module to determine if there is malicious activity in the network. The event generation and attack analysis modules are implemented using TFSM'S. The final component of the architecture is the counter measure module that is responsible for taking appropriate actions to keep the network performance within acceptable limits. The result of this research clearly demonstrates that this approach is used to detect active attacks in real time. In effective intrusion detection system for mobile ad hoc networks, we use this work as a basis and apply the developed concepts in the field of ad hoc networking environment and more specifically to the AODV routing protocol.

The watchdog and path rater scheme has suggested two extensions to the DSR ad hoc routing protocol that attempt to detect and mitigate the effects of nodes that do not forward packets although they have agreed to do so [5].The watchdog extension is responsible for monitoring that the next node in the path forwards data packets by listening in promiscuous mode. The path rater assumes the results of the watchdog and select most reliable path for packet delivery. As the authors of the scheme have identified, the main problem with this approach is its vulnerability to black mail attacks.

The intrusion detection and response model proposes a solution to attacks that are caused from a node internal to the ad hoc networks where the underlying protocol is AODV [6]. The intrusion detection model claims to capture the attacks such as distributed false route requests, Denial of Service, destination is compromised, impersonation, and routing information disclosure. The intrusion response model is a counter that is incremented wherever a malicious activity is encountered. When the value reaches a predefined threshold, the malicious node is isolated. The authors have provided statistics for the accuracy of the model.

A cooperative distributed intrusion detection system (IDS) has been proposed in [7] by Zhang and Lee. This method employs co-operative statistical anomaly detection techniques. Each intrusion detection agent runs independently and detects intrusions from local traces. Only one hop information is maintained at each node for each route. If local evidence is in conclusive, the neighboring IDS agents co-operate to perform global intrusion detection. The author utilizes misuse detection techniques to reduce the number of false positives.

A context aware detection of selfish nodes utilizes hash chains in the route discovery phase of DSR and destination keyed hash chains and promiscuous made of link layer to observe malicious acts of neighboring nodes [8].This approach introduces a fear based awareness in the malicious node that their actions being watched and rated, which helps in reducing mischief in the system. A potential problem of this system could be mobility of the nodes. Since the malicious node can go out of range and again come in the network with a different IP address. It can still take advantage of the network. Since this method uses cryptographic mechanisms to detect malicious attacks, it cannot be classified as pure intrusion detection system.

A specification based intrusion detection system for AODV [4]. It involves the use of Finite State Machines for specifying correct AODV routing behavior and distributed network monitors for detecting runtime violation of the specifications. An additional field in the protocol message is proposed to enable the monitoring.

## 3 AODV Security Problems

In this section we present an overview of AODV ad hoc routing protocol and the threat model associated with it.

### *3.1 AODV Overview*

AODV can be thought as a combination of both DSR and DSDV [3].It borrows the basic on demand mechanism of Route discovery and Route maintenance from DSR and the use of hop by hop routing,Sequence numbers from DSDV.AODV is an on demand routing protocol,which initiates a route discovery process only when desired by Source node. When a Source node S wants to send data packets to a destination node D but can not find a route in its routing table, it broadcasts a Route Request (RREQ) message to its neighbors, including the last known sequence number for that destination.The neighbors of the node then rebroad cast the RREQ message to their neighbors if they do not have a fresh route to the destination node.This process continues until the RREQ Message reaches the destination node or an intermediate node that has a fresh enough route.

AODV uses Sequence numbers to guarantee that all routes are loop free and contain most recent routing information [3]. An Intermediate node that receives a RREQ replies to it using a route reply (RREP) message only if it has a route to the destination, whose corresponding destination Sequence numbers is greater or equal to the one contained in RREQ. Otherwise, the intermediate node broadcasts the RREQ packet to its neighbors until it reaches to the destination. The destination unicasts a RREP Back to the node that initiated route discovery by transmitting it to the neighbor from which it received the RREQ. As RREP, back to the node that initiated the route discovery by transmitting it to the neighbor from which it received the RREQ. As RREP is propagated back to the source, all intermediate nodes set up forward route entries in their tables. The Route maintenance process utilizes link layer notifications, which are intercepted by neighbors are the one that caused the error. These nodes generate and forward route error (RERR) messages to their neighbors that have been using routes that include the broken link. In general a node may update the sequence numbers in its routing tables when ever it receives RREQ, RREP, RERR and RREP-Ack messages from its neighbors.

## *3.2 AODV Threat Model*

In this Section the most important attacks are presented that are easily performed by an internal node against AODV [1, 9].

### 3.2.1 Sequence Number (Black Hole) Attack

It is a type of Routing attack where a malicious node advertise it self as having the shortest path to all the nodes in the environment by sending a fake route reply. By doing this, the malicious node can deprive the traffic from the source node. It can be used as DOS attack, where it can drop the packets later. The set up for black hole attack is similar to routing loop attack in which attacker sends out forged routing packets. It can set up a route to some destination via it self and when the actual data packets get there they are simply dropped forming a black hole where data enters but not leaves.

### 3.2.2 Packet Dropping Attack

It is essential in ad hoc network that all nodes participate in the routing process. How ever a node may act selfishly and process only routing information that are related to it self in order to conserve energy. This behavior or attack can create network instability or even segment the network.

### 3.2.3 Resource Consumption Attack

In this attack, the malicious node attempt to consume both the network and node resources by generating and sending frequent un necessary routing traffic. The goal of this attack is to flood the network with false routing packets to consume all available network bandwidth with irrelevant traffic and to consume energy and processing power from the participating nodes.

There are several other similar attacks presented in the literature [10–12]. They exploit more or less the same routing protocol vulnerabilities to achieve their goals. Sequence number attack is specific to AODV, while the other two can be applied to any routing protocol.

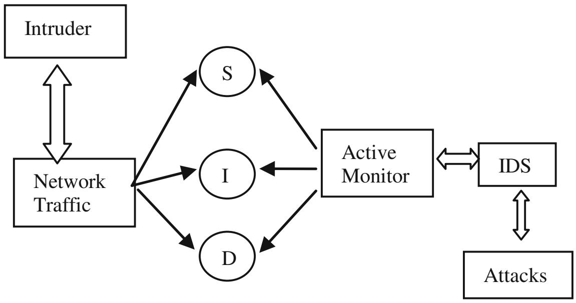


**Fig. 1** Architecture of an efficient intrusion detection systems

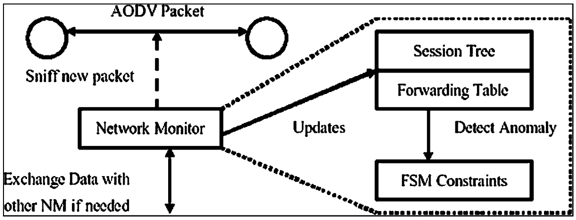


**Fig. 2** Architecture of a network monitor

## 4 Efficient Intrusion Detection System Architecture

The EIDS Architecture utilizes the use of Finite state machines for Specifying AODV routing behavior and distributed Network monitors enable the system to detect attacks in real time rather than using statistical analysis of captured traffic. EIDS detects attacks against the AODV routing protocol in wireless Mobile ad hoc networks. The Architecture of EIDS is as shown in Fig. 1.

The EIDS is used to successfully detect both local and distributed attacks against the AODV routing protocol, with a low number of false positives. It uses Network monitors to trace RREQ and RREP messages in a request reply flow for distributed network. A Network monitor employs a FSM for detecting incorrect RREQ and RREP messages. Figure 2 shows the architecture of a Network monitor.

Networks monitors passively listen to AODV routing message and detect incorrect RREQ and RREP messages. Messages are grouped based on the request-reply flow to which they belong. A request reply flow can be uniquely identified by the RREQ ID, the source and destination IP addresses.

A network monitor employs a finite state machine (FSM) for detecting incorrect RREQ and RREP messages. It maintains a FSM for each branch of a request-reply flow. A request flow starts at the Source state. It transmits to the RREQ Forwarding state when a source node broadcasts the first RREQ message (with a new REQ ID). When a forwarded broadcasting RREQ is detected, it stays in RREQ Forwarding state unless a corresponding RREP is detected. Then if a unicasting RREP is detected, it goes to RREP Forwarding state and stays there until it reaches

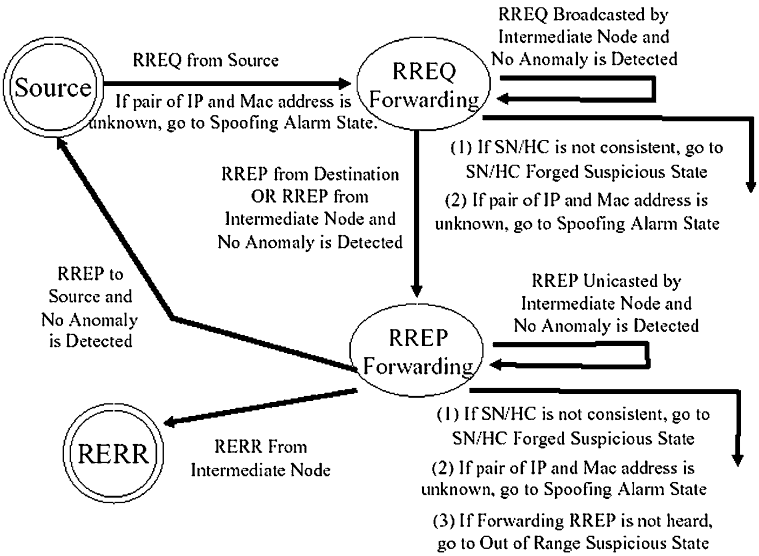


**Fig. 3** Finite state machine diagram

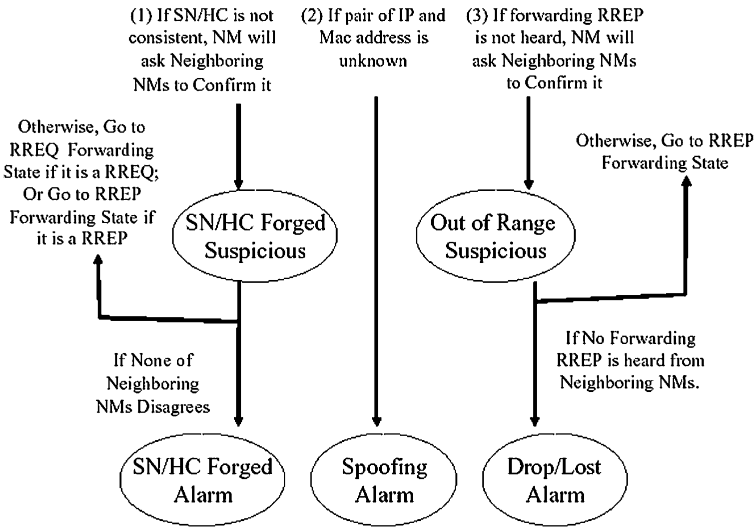


**Fig. 4** Suspicious and alarm state machine diagram

the source node and the route is set up. If any suspicious fact or anomaly is detected, it goes to the suspicious or alarm states (Figs. 3, 4).

When a Network Monitor compares a new packet with the old corresponding packet, the primary goal of the constraints is to make sure that the AODV header of the forwarded control packet is not modified in an undesired manner. If an

**Table 1** Simulation parameters

| Parameter | Value |
|---|---|
| Simulation(Grid) area | 1000*1000 m |
| Simulation duration | 900 s |
| Number of mobile hosts | 30 |
| Type of packet traffic | CBR |
| Maximum speed | 20 m/sec |
| Node mobility | Random way point |
| Transmission range | 250m |
| Routing protocol | AODV |
| MAC layer | 802.11,Peer to Peer |
| Dropped packet time out | 10 s |
| Dropped packet threshold | 10 packets |
| Clear delay | 100 s |
| Host pause time | 15 s |
| Modification threshold | 5 events |
| Neighbor hello period | 30 s |

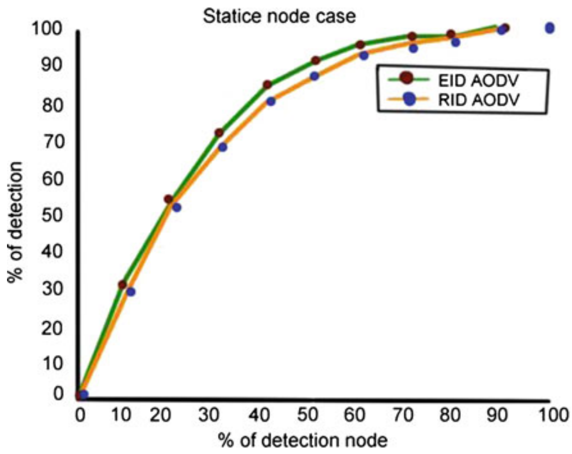


**Fig. 5** Percentage of detection

intermediate node responds to the request, the Network monitor will verify this response from its forwarding table as well as with the constraints in order to make sure that the intermediate node is not lying. In addition, the constraints are used to detect Packet drop and spoofing.

## 5 Evaluation

The experiments for the evaluation of effective Intrusion detection systems for mobile ad hoc networks were carried out using the network simulator (ns-2).we

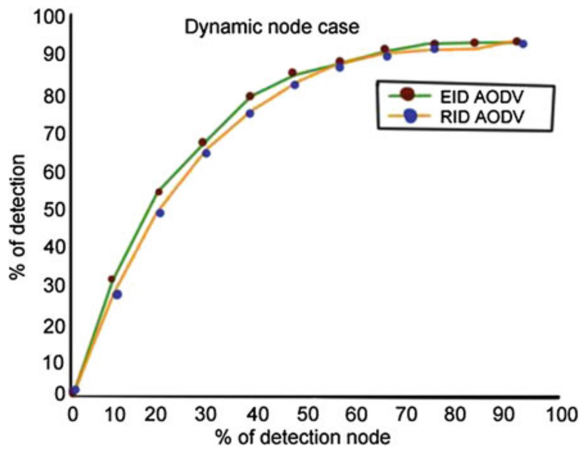


**Fig. 6** Percentage of detection

**Table 2** Comparison for percentage of detection between RID and EID AODV

| Number of nodes | Static case | | Dynamic case | |
|---|---|---|---|---|
| | RID | EID | RID | EID |
| 20 | 52 | 54 | 52 | 57.5 |
| 40 | 80 | 84 | 80.5 | 85.1 |
| 60 | 94 | 96 | 94 | 95 |
| 80 | 98.5 | 99.3 | 99 | 99.8 |

have evaluated AODV with out any modifications, AODV with one malicious node present and AODV with the Effective IDS component enabled having in the network a malicious node. The Scenarios developed to carry these tests use as parameters the mobility of the nodes and the number of active connections in the network. The choices of the simulator parameter that are presented in Table 1 consider both the accuracy and the efficiency of the simulation.

We present results of our experiment by using NS-2 simulator for an Ad Hoc network consisting of 30 nodes. We assume that there is one intruder sending a sequence of consecutive packets constituting an attack to the destination [13]. The intrusion is considered detected if the attack packets pass through any of the nodes that constitute the Intrusion detection system.

We use a randomly selected set of 5 nodes out of 30 nodes and experimented with [2] and consider a sequence of five consecutive packets as constituting the attack signature. We found the accuracy of detection both in static and dynamic condition. It is not clear in [2], how an attack that requires more than one-hop information gets detected but in Efficient Intrusion detection system architecture, multi hop information is considered which overcome the limitation of Real time intrusion detection system.

We have produced percentage of detection of attack using Real time intrusion detection system [2] for both static and dynamic node case, which was not present in the original work. We have given a relative performance of EID and RID systems below.

### 5.1 Static Case

Consider that there is only one node in the intrusion detection system. This node is randomly selected to be one of the nodes out of 30.We consider a system in which nodes that constitute the intrusion detection system (IDS) are chosen randomly.

We show the results for systems with no of nodes 30 in Fig. 1. We see that the performance of EID is better than the RID system [1]. EIDAODV also detects multimode intrusion detection for a static condition (Fig. 5).

### 5.2 Dynamic Case

In Dynamic case, we consider a network using AODV. We assume that the intruder is moving at a speed of 15 m/s. We change the criterion used to determine the nodes that make up the IDS. We use the same criterion as used in case of used in static case. The only difference is that now the intruder is assumed to be mobile. We show the results for such a case in Fig. 2. Here IDAODV also detects multimode intrusion detection for a dynamic condition(Fig. 6, Table 2).

The above table gives a comparison of percentage of detection between Real time Intrusion detection system and proposed method. For all values of number of nodes, the detection rate of proposed method is higher than Real time Intrusion detection system. Where as the complexity of EIDAODV is almost same as RID system.

## 6 Conclusions

An Effective Intrusion Detection System aiming at securing the AODV protocol has been developed using specification-based technique. It is based on a previous work done by Stamouli. The EIDS performance in detecting misuse of the AODV protocol has been discussed. In all the cases, the attack was detected as a violation to one of the AODV protocol specifications. We have compared the results obtained from EIDAODV with RID system. From the results obtained, it can be concluded that our EIDS can effectively detect the attacks both in static and dynamic case. This approach has shown that high detection rate can be achieved with low overhead.

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# The Academic Rating Criteria for Knowledge Web-Based in Thailand

**K. Dowpiset and C. Nuangjamnong**

**Abstract** With rapidly growth of the Information Technology (IT), the original aim of the words "Ranking" was to promote Web publication, not only to rank institutions and organizations. By supporting public open access initiatives, electronic accesses to scientific publications and to other academic materials are primary targets. The result for these reasons, the number of web publication in Thailand has been increasing in each year. The main behavior of most people in cyber world, they prefer to search information before deciding to do something, especially in a part of people in academic areas and business professionals. Searching information and reading information from websites may create a strong and reliable research, academic reports, and making potential documents for business organizations. In order to have some confidences of the contexts in the websites that they can apply and analyze into the business reports, the reliable sources of information may be required a standard ranking. With fully reliable web contents, they can provide the real benefits in terms of money, and reputation for those contexts. However, trustee, reliability and confidence come from several conditions. In academic institutions, most students and instructors refer to specific contexts from the available websites that they can do the reports or create some class materials. Hence, the reliability of websites is very important which it may let others believe in the reports or academic papers. This may assist students and instructors to improve their studies and research. This research mainly studied, analyzed and mapped the rating criteria which related to the trust of information on available websites. The target data was gathered from the lecturers of both private and public universities in Thailand via a survey online. In order to precisely

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understand the weighting of criteria, the rating criteria scale and weighting for each of criteria, the focusing groups in discussion about web publication criteria, and other conditions and factors concerned will be investigated. Giving such opinions of the expertise of the Internet Service Provider (ISP), students, lecturers and the Government Agency may be included as recommendations and further study.

## 1 Introduction

Evaluating web publication quality is a disreputably difficult problem which has no standard solution. In order to publish academic context results should be audited by true experts in the field and given scores for quality and quantity according to established rules. However, in practice, what is called peer review is usually performed by committees with general competence rather than with the specialist's insight that is needed to assess crucial data and technical contents. Committees tend, therefore, to resort to secondary criteria like crude publication counts, journal prestige, the reputation of authors and institutions, and estimated importance and relevance of the research field, making peer review as much of a lottery as of a rational process. From this background, it is hardly surprising that alternative methods for evaluating web publication may be sought, which used the same academic standard such as citation rates and journal impact factors. These standards seem to be quantitative and objective indicators directly related to published academic contents.

## 2 Web Criteria Factors In Acdemic Areas

In order to understand the important criteria of web publication contents, it needs to ask the question "what impact does the web publications have on students, lecturers and academic staff or the academic institution's image if it is well maintained or poorly maintained?" The Webometrics Ranking of World Universities, also known as Ranking Web of World Universities, is the largest taxonomy of websites of higher education institutions, covering more than 20,000 universities worldwide. The aim of the Ranking is to improve the presence of the academic and research institutions on the Web and to promote the open access publication of scientific results [1].

Student web has been addressed extensively in recent learning and research. One area of inquiry involves the role of the web publication in conducting research for class projects. For example, the authors from "An aid to student research or a source of frustration" [2] studied how college students conduct research via the web, and made evaluations on the quality and type of research being conducted. In a similar approach, the authors from "Investigating the practices of student researchers"[3] examined the Internet research habits of students and found that although some did depend exclusively on Internet resources in writing research papers, a mass of the students, lecturers, researchers in the study used a combination of library and online resources. However, this did not imply that students were necessarily choosing the most relevant sources relating to their topics. Instead, as emphasized by the authors [3], students depended upon the availability of web publication giving the most positive ratings to sources that were "easy to understand, easy to find and easy to get access." The most important key points in academic rating factors were ease, convenience, and accessibility. These were being major factors influencing academic Internet use.

In Thailand, another emphasis has been on lecturers and students' ability to evaluate the quality of the sources they face when conducting research, reports and assignments by using the web publication. According to the study on Performance of new college students on an Internet skills proficiency test [4] tested college freshmen's Internet proficiency and found that only 19 % of students received a passing grade (70 % or higher) on questions relating to "evaluation of Web sources, source selection and research strategy, and citing sources". This can be supported an idea of the current emphasis on the evaluation of the quality of the web publication sources in Thailand. Additionally, studies have shown that lecturers, students, researchers use such criteria as the appearance of the ***".ac.th"***, ***".go.th"***, ***".edu"*** and ***".gov"*** top-level domains to establish the reliability of a web publication in academic areas.

For the reasons above, this require of critical thinking skill in regard to web source evaluation is often attributed to academic handbooks focusing for the most part on the mechanics of the search process and the format for electronic sources, rather than offering evaluative criteria for students, lecturers, and researchers to utilize [5]. Even with such handbooks, students scored especially low when answering questions regarding the citation of electronic sources [4]. In this situation, students, lecturers and researchers need more training on how to conduct Internet research in general, with emphasis on critical evaluation of all electronic sources and proper citation of the sources they do use. This can be argued that the use of the web publications for research, making reports, academic assignments and the ways in which quality of information is judged are implicated by the approach in which research on the Web is initiated. For example, target groups in the study of University students' perceptions of the Internet [6] explained that "when approaching research on the Internet, both for their assignments and in general, participants used search engines such as Yahoo!, Google, and Bing" instead of library pages, text books, and high impact academic journals. These popular resources are used even though students express doubt about the accuracy and authority of Internet sources [7].

While this may be disturbing to professional academic members, the students in the study of University students' perceptions of the Internet also illustrated that "they felt the sites of highest quality and reliability were those produced by the government, educational institutions, and reputable businesses and corporations" [6]. Participants in these groups generally agreed that web publication sources found on the Internet alone were never acceptable for research papers. As an alternative study group in the same study found a combination of Internet and library resources was to be most useful. According to a research study on publishers promote e-textbooks, but many students and professors are skeptical [8], half of the college students surveyed said that 20 % of the resources they used were Web-based, while 80 % were traditional library sources. Meanwhile, the article on the Internet "The Internet goes to college: How students are living in the future with today's technology by Jones" [5] reported that over 70 % of college students in USA depended upon the Internet more than the library when conducting research, while only 9 % depended on the library more than the Internet. In only four years, the trend had reversed, suggesting an exponential growth of Internet use in college student life. Similar trends were also observed by Mathew and Varagoor [9], where students expressed an increasing similarity to use the Internet for research.

The use of the web publications for research also emphasizes the increasing affinity for digital information. An example of this increasing acceptance and embracing of the digital can be found in the case of adoption of e-books, e-journals, e-presses and e-magazines. According to a research study on publishers promote e-textbooks, but many students and professors are skeptical [8], in institutions where e-books were being used, "students complained about having to scroll to find sections, about how long it took to scroll, and about the problems of reading from a laptop". Students have also reported that the smaller screen of an e-book reader, designed for just this application, makes the books more difficult to read, as the "tiny screens made the texts seem more fragmented" [10]. Students did find the search feature of an e-textbook to be more convenient than the index of a paper textbook, but these same students still used the traditional textbook more than the e-book [8]. The Chronicle of Higher Education reported that college students are not willing to replace textbooks with e-books. In fact, many of those interviewed expressed the view that e-books "adversely affected the amount of information that they absorbed" [10].

The University of Texas (UT) at Austin, which makes significant usage of e-books, has found an important library position for e-books irrespective of whether students have an equal experience with them and print books: they can't be stolen. UT found that e-books filled significant gaps in their collection caused by theft [11]. However, the same study stated that "we may live in digital times, but it's still an analog world" [11]. Continuing research in this area will be needed as the technology of e-textbooks continues to improve.

These studies, although valuable, are relatively narrow in focus and do not examine the hows and whys of general student Internet use. Other research teams have begun to explore what college students are doing on the Web beyond academics. According to Web-connected generation [12] showed that almost students use the web publication to communicate with friends and family via e-mail. In some institutions where Internet access is relatively reliable and seamless, non-academic purposes represent one of the key Internet usage categories [13]. The article on "The Internet goes to college: How students are living in the future with today's technology" by Jones [5] stated that 72 % of students check their e-mail at least once a day and that e-mail is the most popular online communication method used by students, although instant messaging was another popular choice. Anderson's survey of students' Internet activities [14] indicated that students spent an average of 100 min per day online, thirty-five of which were spent e-mailing. A Harris Poll conducted for Northeastern Mutual Life Insurance found that more than half of the students they surveyed (54 %) reported using the Internet as a career tool to look for jobs after graduation. Finally, O'Hanlon's research study [4], which so negatively revealed students' research proficiency, showed that students are much more skilful at navigating their e-mail accounts. Out of six questions, only one involving e-mail was found to confuse students. On the other five questions, 70 % of students indicated a correct response.

The socio-technological environment of academic institutions that began emerging in the late 1990s has led to increasing dependence on the Internet, which has only grown as many academic members enjoy free access 24 h a day on their campuses. Some have used this access to their educational advantages, as in the case of virtual office hours where Internet-steeped students met with faculty in cyberspace, leading to a more effective use of the "office" hour [15]. Additional studies have documented a state of technological dependence among college Internet users, ranging from eight to thirteen percent of the student population [14, 16, 17]. Dependence, coupled with easy access to technology, points toward students and academic members spending a substantial quantity of time on the Internet [18].

## 3 Methods

A specific question was needed to measure the constructs suggested in this research study. A number of different kinds of measurement instruments are available for assessing the effectiveness of the academic rating criteria for knowledge web-based in Thailand, along with instruments that can be used to measure general attitudes towards web publications among students, lecturers, and researchers. Typically the instruments are either very broad and general or very precise and specific to a particular study and context. Furthermore, many of the instruments that are available are designed primarily to assess attitudes towards computers and computing as generalized constructs without specific reference to the design of Web publications. Some studies have attempted to focus on the specifics of measuring the attractiveness of Web sites based on the psychological parameters of attractiveness and its relation to the Web interface.

Thus, we were decided to develop an instrument for the study by beginning with a set of target group discussions so as to gain an in-depth understanding of the criteria used by students and academic members as they decide on using specific Web sites. Target population groups were conducted with post graduate students at MBA program, professional academic members and researcher at Saint John's

University in Thailand. The students were recruited from different faculties, different departments and majors, which were offered a small incentive for participating in this groups. The protocol for the focus groups included questions about the participants' level of Internet use and types of web publications:

- The categories of Web information sought;
- The participants' feelings about the usefulness of the Web for a variety of functions varying from different academic institutions to academic uses;
- The different criteria that the participants used to make judgments about the quality of Web publications, and
- The participants' general opinions about the use of the Web in their everyday lives.

In all, four groups were conducted over a span of a fortnight, with a total of 12 students.

## 4 Discussion and Results

The respondents replied back to researchers updated on 29 September 2010. These result divided into three parts, there are the content of the website, Time that the website established and the organization who own the website. In part of the content of the website, the result shown that they agreed that the research paper that upload into website was citation and reference in the academic standard such as APA style. The content (referred to any reports, articles, content) of the website so interested for make research especially in Thesis or any kind of research papers. Meanwhile, they did not relied and trust on.

The target population group discussions were followed by the development of a survey instrument to answer the exploratory research questions raised here. The questionnaire included a section with a set of statements that described different attributes of typical Web pages such as "number of links provided by the site," and "textual content of the site;" the respondents were asked to indicate the importance of each of the criteria on an academic rating for knowledge web-based scale ranging from "Very Important" to "Not Important." Another section of the instrument contained questions about the different kinds of sites that students use when they visit the Web. This section (Table 1) included a series of items developed on the basis of the target groups and included items such as "Research Institute," "Well known researcher," etc. to be rated on a five-point scale from "Very Important" to "Very unimportant."

Most results from participants found that the owner of the website was important criteria (67 %), but in terms of the reputation of the owner of the website was neutral (55 %), this may be applied that the participants did not feel this factor will be effect to the sensitive information on web publications that they need. 75 % of participants concerned with the owner of the website should be association or well-known societies both international and national organizations, and slightly

**Table 1** Result from respondents related to the factors of content on the website (percentage)

| Criteria | Very important (%) | Important (%) | Neutral (%) | Unimportant (%) | Very unimportant (%) |
|---|---|---|---|---|---|
| Owner of the website as the Research institute | 33 | 67 | – | – | – |
| Owner of the website is the well known person | 17 | 33 | 50 | – | – |
| Owner of the website is the association or Society such as Thai-American Society | – | 75 | 25 | – | – |
| Owner of the website is the Government Agency or National Institute | 17 | 67 | 8 | – | – |

**Table 2** Criteria factors about the content of the website can be applied (percentage)

| Criteria | Very important (%) | Important (%) | Neutral (%) | Unimportant (%) | Very unimportant |
|---|---|---|---|---|---|
| Citation and reference standard of the contents | 17 | 42 | 33 | 8 | – |
| Content can be applied in business and research | 8 | 33 | 50 | 8 | – |
| Content can be applied for academic research | 8 | 58 | 33 | – | – |
| Content can be applied into the international academic level | 17 | 33 | 33 | 17 | – |

declined in Government Agency and National Institute, this may be applied that the content on the website was developed by local language (Thai language).

The web contents apply for citation and reference on the international research paper. Most of them are duplicated from each others, and translated from English into Thai language only the theoretical information but not application (Table 2).

In terms of the content on the websites can be applied, the results from survey showed that 58 % of participants, web contents for academic research was important, and a little declined in the standard of references and citations (42 %) and international academic level factors (33 %).

For the owner the website is more effect to the level of trust into the content of those websites. However, the academic persons believed in the reputation of the Organization more than reputation of person who owns the website. Despite the individual who want to create the website must be required the well know organization to backup those website as well.

Most of these factors, there are related and influence to the each other factors. For example, when researcher believes in owner of the website they also trust in the content of the website certainly.

**Table 3** Criteria factor about number of year to establishiment (percentage)

| Criteria | Very important (%) | Important (%) | Neutral (%) | Unimportant (%) | Very unimportant (%) |
|---|---|---|---|---|---|
| Number of year that website establishment effect to decision to refer to write the Thesis Research Paper | 17 | 42 | 8 | 33 | – |
| Number of year that website establishment effect to acceptable for academic quality/business context | 8 | 25 | 50 | 17 | – |
| Number of year that website establishment effect to acceptable for Thesis Research paper. | 8 | 42 | 8 | 33 | 8 |

For establishing time of website (Table 3), all respondents said that these factors are not effect to the level of trust which the contents of those websites cannot be applied as criteria to develop the academic impact factors in Thailand. By this result, the researchers will cut this factor off the impact criteria of the website.

## 5 Conclusion

With under the pressure of network economy, a lot of contents on website was developed and distributed to all online users. By this situation, some of researchers and graduate students cited and referred to the content of those websites. Meanwhile, the research papers are required reliable source of information to make their content more valuable and trust to others. Then the research framework for developing the academic rating criteria for knowledge web-base was employed. The rating criteria eliminates by the web contents, a number of years to establish the website and the owner of the website were weighted by testing against main purpose of research and studies. There are many research studies which use private purposes or Thesis papers, the decision on business context and the International research paper. For these reasons, the result of this study found that the owner of the website was the most important criteria; second priority was reliability of citation or reference standards on the website. In terms of the time for establishment of the website cannot count as the criteria for rating the knowledge web-based in Thailand. Figure 1 shows two majors criteria for web publication in Thailand.

In further framework (Fig. 2), the rating criteria will map as the decision mapping for each objective to select the content from knowledge web-based by

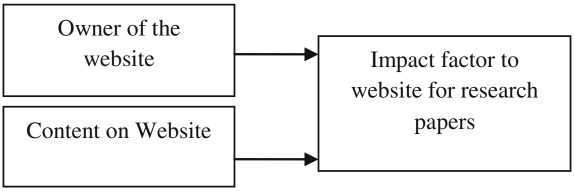


**Fig. 1** The two main criteria the can be counted as the rating criteria for knowledge web-based in Thailand

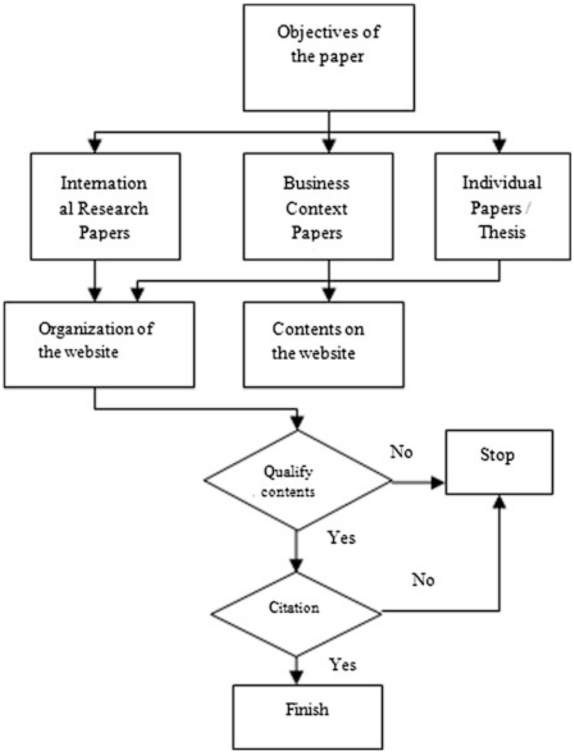


**Fig. 2** The decision mapping for rating criteria for Knowledge web-based belong to two criteria

testing with two criteria. Figure 2 presents the rating criteria to accept the web contents as the reference for research papers and academic materials.

Many Thai Academic Institutions have, for a long time, emphasized the importance of having graduate students, especially those enrolled in master degree programs, lecturers, and educators. An analysis of the Academic Rating Criteria for Knowledge Web-Based in Thailand revealed that many students and educators have concentrated with the quality of web contents in Thailand in many aspects such as standards of citations and references, intellectual content, academic publishing and owner of the website. However, some academic rating criteria need to analyze more in-depth and deal with significant technologies changes as there are no perfect criteria to measure the quality of academic materials.

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# Traditional and Modern MCQ Methods as In-class Formative Assessment

**Cecilia K.Y. Chan, Vincent W.L. Tam and Wilton T.T. Fok**

**Abstract** This study was designed to compare three different Multiple Choice Questions (MCQs) delivery methods namely clickers, pen and paper MCQs and online elearning MCQs on the effectiveness of student engagement used as an in-class formative assessment. The results were also compared without the use of any formative assessment. Overall, the majority of students appreciates and recommends in-class formative assessment particularly clickers and online elearning to be used in other courses. In the presentation, the results of these assessment delivery methods will be discussed as well as issues and concerns found by the observer using these delivery methods.

## 1 Introduction

Traditional Engineering classes in higher education are generally perceived to have minimal student-to-student and teacher-to-student interaction. They are often delivered in a monotonous, one-way conversation, 'rushing to cover a large content' atmosphere where there are little or no activities designed to engage students. In-class formative assessment (graded or non-graded) and student–lecturer discussion and feedback are even less common [2].

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This study was designed to compare three different Multiple Choice Questions (MCQs) delivery methods namely clickers, pen and paper MCQs and online elearning MCQs on the effectiveness of student engagement used as an in-class formative assessment. The results were also compared without the use of any formative assessment [3–5].

## 2 Literature on the Various Types of Multiple-Choice Question Delivery Methods

In engineering education, Multiple Choice Question (MCQ) is often widely used both as a formative assessment and as a summative assessment. MCQs are relatively timely to set, to answer, to correct, to provide feedback and to administer. They have high reliability, validity and manageability. These characteristics together with the changes in the higher education environment such as larger class size, curriculum reform in adopting towards learner-centred approach, and the possibility of administering MCQs using technologies due to dramatic technological improvements have made MCQ a very popular assessment method among all disciplines [6]. However, MCQs do have an inherent drawback. More often than desired, MCQs tend to be design by the assessors to assess only lower-order cognitive levels such as knowledge and comprehension [9], this is often due to common practice and careless assessment design by inexperienced teachers. With proper adjustments, MCQs can be design to assess higher-order cognitive levels. This is evidenced in Nicol [6]'s paper, he analyzed different ways in which MCQs can be administered. He concluded that with well-designed MCQs, positive learning effects can be delivered and the development of learner self-regulation can be supported. Built from Nicol's work, 3 confirmed that it was the pedagogical approach to the design of MCQ that measured more than mere knowledge recall and led to learning gains, that was irrespective of the technology or delivery method used to deliver the questions [7, 8].

Completing MCQs by pen and paper is the most traditional MCQ assessment method for student assessment; it is widely used in tests and exams due to the ease of testing knowledge gained by the students. The logistics for pen and paper MCQ assessment is simple. The assessment can be performed anytime, anywhere as every student has both pen and paper hands-on. However, MCQs by pen and paper as an in-class formative assessment to engage students can be time consuming and may seriously disrupt the lecture flow. Time has to be arranged for students to answer MCQs during lecture. Moreover, this assessment process is often passive; there is minimal/no interaction between student-to-student and student-to-teacher. Though sometimes teachers may ask students to peer assess each other, in a way to encourage student interaction, this kind of immediate assessment and feedback may not always be possible. With the advances in technology, various MCQ styles such as quiz and voting polls can be incorporate with other assessment learning styles electronically to improve student learning experience. MCQs can be electronically administered through different mediums such as online learning management system, mobile devices and offline local network. MCQs administer electronically have the advantages of reducing teachers' workload as the built-in MCQ templates in the electronic system can simplify and automate the process of authoring questions 5; they can also automate the marking of the assessment which reduce the burden of assessing large number of students, and at the same time provide feedback to students with the correct answer and brief explanation [1, 10]. Thus, online delivery of MCQs assist students in gauging their progress in understanding the material [11]. With most learning management systems being able to allow both time-setting for each question and for each assessment, teachers have complete time control over the assessment. This provides the opportunity for the teachers to utilize MCQs administer electronically as an in-class and out of class formative assessment. It can be used as pre-lecture tests to check for misconceptions and allow lecturers to design thorough lectures for difficult concepts [7]; as well as post-lecture tests and after class revisions.

## 3 Methodology

The results were also compared without the use of any formative assessment. Two courses in Year 2 undergraduate classes from Electrical & Electronic Engineering at the university of Hong Kong were selected to introduce to these formative assessment methods. The two courses were: ELEC2601—Human Computer Interaction and ELEC2804—Engineering Economics and Finance, each accounted for six and three credit units respectively. The ELEC2601 Human Computer Interaction course outlines the general features and components of window programming toolkits, information visualization, event handling and layout management, as well as strategies for effective human–computer interaction, managing design process, and evaluation of human–computer interaction. The ELEC2804 course introduces various principles of Economics, Financial Management, Accounting concepts; preparation and analysis of financial statements.

These students were first time users and have not been exposed to clicker technology beforehand. For each assessment delivery methods, ten multiple-choice questions (MCQs) were written to assess students' knowledge and problem solving techniques. Student perceptions on the different assessment methods were surveyed immediately at the end of the class.

# 4 Results

Computer Interaction course outlines the general features and components of window programming toolkits, information visualization, event handling and layout management, as well as strategies for effective human–computer interaction, managing design process, and evaluation of human–computer interaction. The ELEC2804 course introduces various principles of Economics, Financial Management, Accounting concepts; preparation and analysis of financial statements.

These students were first time users and have not been exposed to clicker technology beforehand. For each assessment delivery methods, ten multiple-choice questions (MCQs) were written to assess students' knowledge and problem solving techniques. Student perceptions on the different assessment methods were surveyed immediately at the end of the class.

## *4.1 ELEC2601 CLASS*

In the ELEC2601 class, 69 and 63 % of the students agreed that Clickers (M = 3.81) and WebCT online MCQs (M = 3.63) were effective learning tools for teaching and learning respectively. It was unexpected that 63 % of students agreed that pen and paper was also effective in teaching and learning (M = 3.81). In terms of engagement, 69 % of the students agreed that they were more engaged when Clickers was used (M = 4.00), most students were neutral about the level of engagement that online WebCT MCQs (M = 3.00) and pen/paper (M = 3.25) could bring; 25 % students actually disagreed that online WebCT MCQs could improve student engagement. The majority of students were neutral about either Clickers (M = 3.19), WebCT online MCQs (M = 2.75) or pen/paper (M = 3.06) could motivate them to conduct further research. WebCT online MCQs had the lowest mean scores among the three learning tools.

## *4.2 ELEC2601 CLASS*

At least 75 % of the students agreed that Clickers (M = 3.85) and WebCT online MCQs (M = 3.70) were effective learning tools for teaching and learning respectively. Only 51 % of students agreed that pen & paper was also effective in teaching and learning (M = 3.42). In terms of engagement, 78 % of the students agreed that they were more engaged when Clickers was used (M = 4.15), whereas 62 % of students agreed for WebCT online MCQs (M = 3.44) and a mere 40 % for that of pen & paper (M = 3.25). Slightly over half of the students agreed that Clickers (M = 3.61) and WebCT online MCQs (M = 3.45) would motivate them to further research on the subject, 47 % of students remain neutral about that of pen & paper (M = 3.39). Pen & paper had the lowest mean scores among the three learning tools.

## 5 Conclusions

Overall, the majority of students appreciates and recommends in-class formative assessment particularly clickers and online elearning to be used in other courses. Students generally found Clickers was fun, user-friendly, increased participation in class and feedback useful information to lecturer. The negative comments were related to technical issues like slow response of Clickers and no display from the Clickers device whether their submission was successful. One student commented there wasn't any difference between using and not using any learning tools. When asked why they didn't participate in the activities, students replied due to the slow response of Clickers device.

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# Evaluating the Impact of Various Modulation Schemes on WiMAX Quality of Service

**Justin Morgan and Hetal Jasani**

**Abstract** In order to effectively analyze the QoS performance of WiMAX (Worldwide Interoperability of Microwave Access), it is important to identify different types of modulation techniques that can lead to an increase in performance. Low throughput, high packet loss rate, delayed round trip time (RTT) for packets, increased retransmissions, and increased collisions are the main attributes to look for when analyzing poor network performance. The IEEE 802.16 technology (WiMAX) is a promising technology for prosviding last-mile connectivity by radio link due to its large coverage area, low cost of deployment and high speed data rates. The mobile WiMAX technology was drafted by the International Technological University (ITU) in late 2007. Officially, the IEEE 802.16e revisions promote standards for broadband wireless access systems and currently focus on performance through the PHY and MAC layers of the OSI model. However, the maximum number of channels defined in the current system may cause a potential bottleneck and limit the overall system capacity. We use the OPNET Modeler to simulate IEEE 802.16e WiMAX performance on a network with 35 mobile nodes and seven base stations. We construct a WiMAX deployment with scheduling type ertPS (extended real-time polling service) and different types of digital modulation and coding for both downlink (DL) and Uplink (UL) service flows. We made an assessment of the network performance based on WiMAX throughput and load in bits per second against different modulation schemes. WiMAX delay results are plotted over time (seconds). WiMAX network performance shows no signs of

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queuing with ertPS and QPSK½. The use of improper implementation of digital modulation and coding causes noticeable queuing to occur. WiMAX delay is significantly affected when forward error-correcting methods are enabled.

## 1 Introduction

Today technology plays a more significant role in society than ever before; and the ideas of what technology can do for our day to day lives are expanding and evolving. However, with this increase in demand and market share for high connectivity devices creates a need for better throughput and reliability of wireless services. WiMAX (Worldwide Interoperability of Microwave Access) is an up-and-coming wireless broadband deployment that grants users access to high-speed networks virtually anywhere, even to those who wouldn't typically have network access due to living in difficult to service "last-mile" areas. We found this particular technology deployment to be very interesting; more specifically how to keep the throughput of wireless broadband access at an efficient level. With WiMAX being an OFDM (orthogonal frequency division multiplexing) based technology, we decided it would be best to delve into the different types of digital modulation and coding schemes that allowed for the highest load versus throughput. We also noticed that WiMAX delay could be drastically altered with different configurations so we furthered our research to learn which configurations yielded a decrease in network delay.

WiMAX is currently in revision stages per the IEEE 802.16e committee. They are focusing on higher levels of performance within the MAC and PHY layers. It is stated that, "The well understood goal of these developments was to use OFDM for both downlink (DL) and uplink (UL) to enable relatively simple high-performance receiver structures in the presence of frequency-selective fading channels" [1]. Digital modulation schemes such as QPSK (Quadrature Phase-Shift Keying) and QAM (Quadrature Amplitude Modulation) offer different operational methods for the wireless environment. The basic function of digital modulation is to transfer a message signal encapsulated by another signal which has the ability to be physically transmitted. With this in mind, we knew that QAM and QPSK were both likely candidates for WiMAX to utilize. Figures 1, and 2, convey the two basic forms for QPSK and QAM digital modulation.

Among altering the digital modulation and coding schemes, we also tested methods of improving WiMAX delay. Issues that could cause high delay are triggered by PHY parameter changes. A simple retransmission of a dropped packet can quickly multiply, causing additional latency or interruptions with voice and other data transmissions.

WiMAX supports a number of modulation and forward error correction (FEC) coding schemes and allows the scheme to be changed on a per-user and per-frame

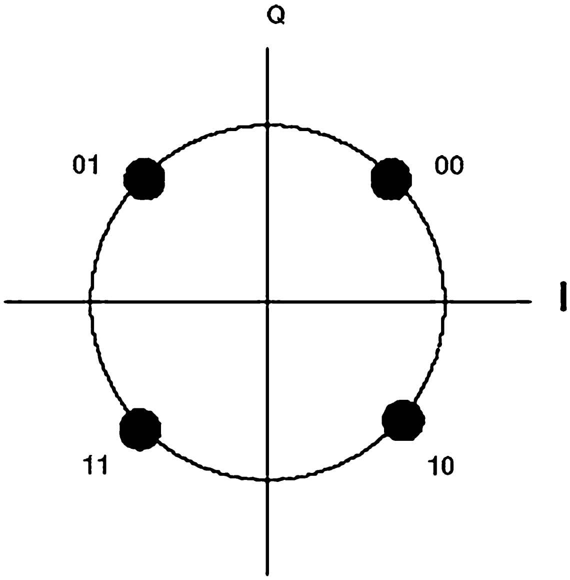


**Fig. 1** QPSK encoding scheme [18]

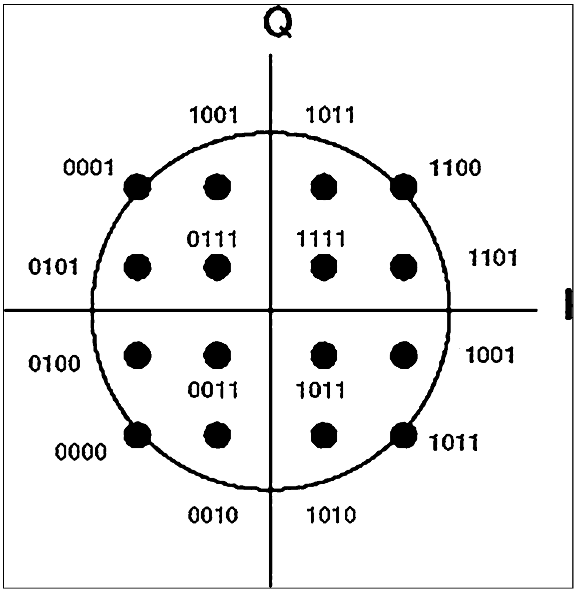


**Fig. 2** QAM encoding scheme [18]

basis, based on channel conditions [2]. Adaptive and Modulation Coding (AMC) is an effective mechanism to maximize throughput in a time varying channel. The adaptation algorithm typically calls for the use of the highest modulation and coding scheme that can be sustained based on the signal-to-noise and interference ratio at the receiver end, the goal being that each user is provided with the highest possible data rate that can be supported by their respective links. Data transmitted through the air are more likely to be corrupted because of channel interferences, background noises, etc. Hybrid Automatic Repeat reQuest (HARQ) can provide a reliable way to ensure that packets are successfully received in sequence. HARQ must play a key role in the system design to reduce system bit error rate (BER). We did research the methodology behind WiMAX forward error-correcting coding and how the differences in the parameters impacted the network as whole. We use a network modeling tool known as OPNET Modeler.

## 2 Related Work

Many authors have performed research and done performance evaluations on the topic of WiMAX [1, 3–10]. There have been some studies examining the performance of WiMAX Networks using AMC and HARQ. Other researchers evaluated the performance of asymmetric Time Division Duplex (TDD) system that employs AMC and HARQ, with consideration of the effect of control delays in TDD [11]. Moh et al. [12] proposed an enhanced HARQ, which would determine the number of multiple copies needed based on the channel feedback. In addition, another group of researchers studied Dynamic HARQ (DHARQ) for WiMAX [13]. They proposed a power control scheme for WiMAX multi-hop relay system. Yousaf et al. [3] look into configurations that don't entail any type of forward-error correction (FEC) methods. Although much work has been done to date [4–10], more studies need to be conducted to ascertain the effects of AMC and HARQ in optimizing network capacity and application delays. A major difference from prior research and our study is that many deployments ran on the scheduling service known as Unsolicited Grant Service (UGS) [14], whereas ours ran on Extended Real-Time Polling Service (ertPS). According to Javvin Technologies, UGS is one of the five Quality of Service (QoS) types defined in the IEEE 802.16 WiMAX, designed to support real-time service flows that generate fixed-size data packets on a periodic basis. ErtPS is designed for real-time traffic with variable data rate (such as VOIP service) over the WiMAX network [3]. According to Mark Wood [15], QoS mechanisms "are all implemented in the PHY layer, and their parameters are based on the QoS requirements handed down by the higher layers". To generate our results, we compared the WiMAX delay present with Automatic Repeat re-Quest (ARQ), Hybrid Automatic Repeat-reQuest (HARQ), Cyclic Redundancy Check (CRC), and no FEC.

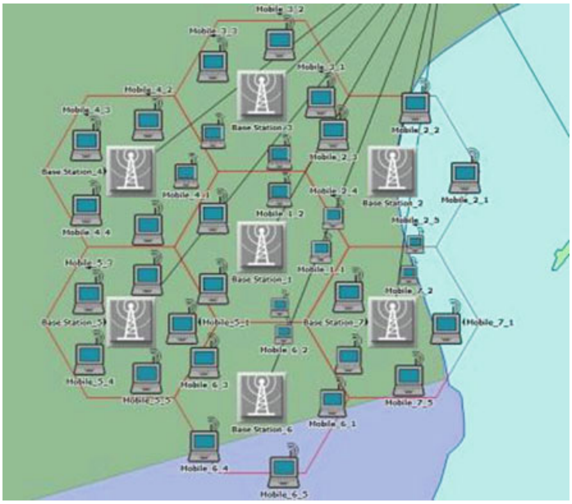

**Fig. 3** WiMAX mesh network

# 3 Performance Evaluation

## *3.1 Simulation Environment*

Through use of OPNET Modeler, we were able to compile our scenarios and generate precise, repeatable results. We generated a WiMAX mesh network containing seven base stations (BS) and 35 mobile stations (MS). We used a voice server to send voice traffic throughout the deployment to interact with and gauge the response of the configuration of the base stations and subscriber stations. We then replicated our scenario of the mesh network involving the 7 BS and 35 MS numerous times with different configurations to compare the results and find the optimum implementation. The default configurations were retained for each base station as per the OPNET standards with alterations on each mobile station's uplink and downlink states. All the parameters were based in the PHY layer per IEEE 802.16. Figures 3, and 4, depict the mesh network that we implemented, as well as the parameter configuration menu.

## *3.2 Simulation Results and Discussions*

The first simulation measured the WiMAX load versus the WiMAX throughput in respect to voice data. We generated three duplicate scenarios, each time only altering the digital modulation and coding schemes. OPNET Modeler was configured to send generated voice data streams of 96 Kbps throughout the scenario once compiled.

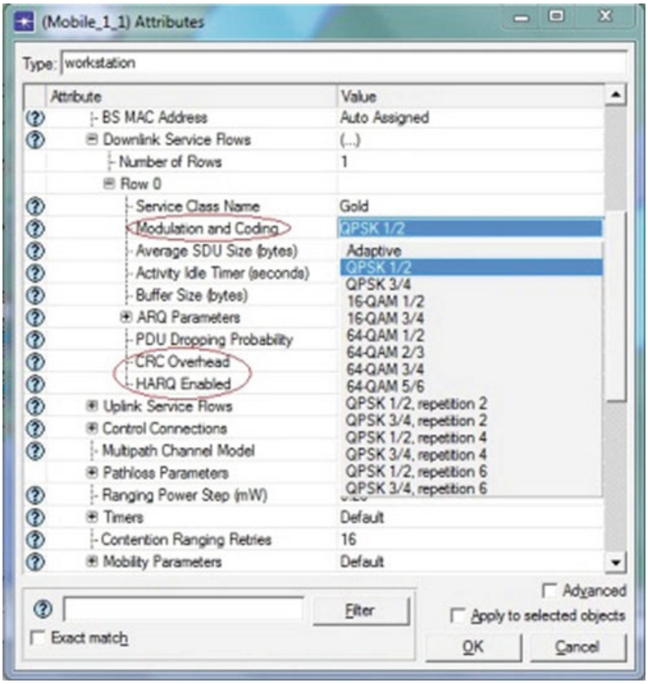


**Fig. 4** OPNET modeler PHY parameters

We will briefly explain the theory behind digital modulation and coding to give insight as to why we chose certain schemes. Each selection utilized an OFDM based digital modulation, while the coding was set to 1/2. As described by OPNET, "Coding refers to channel coding, which is the operation of generating redundancy bits to accompany the information bits transmitted over the channel. The coding rate is defined as the ratio between the uncoded block size and the coded block size. For instance, a coding rate of 1/2 can be achieved in a block code setting, by encoding block of 12 bytes into coded blocks of 24 bytes" [16]. With this in mind, we tested our scenarios in order from highest level of modulation to the lowest. In theory, higher orders of modulation allow for better throughput; however higher orders of modulation also make the signal more susceptible to noise and interference.

The first test utilized 64 QAM 1/2, the highest order of digital modulation and coding available. From the results of this test, it was quite astonishing to see that the magnitude of traffic queuing was so large. As seen in Fig. 5, the greater the gap between the load versus the throughput, the greater the queuing of traffic that occurred. This happens when the size of the payload sent is larger than the base station can handle, therefore traffic is dealt with via a first in, first out methodology.

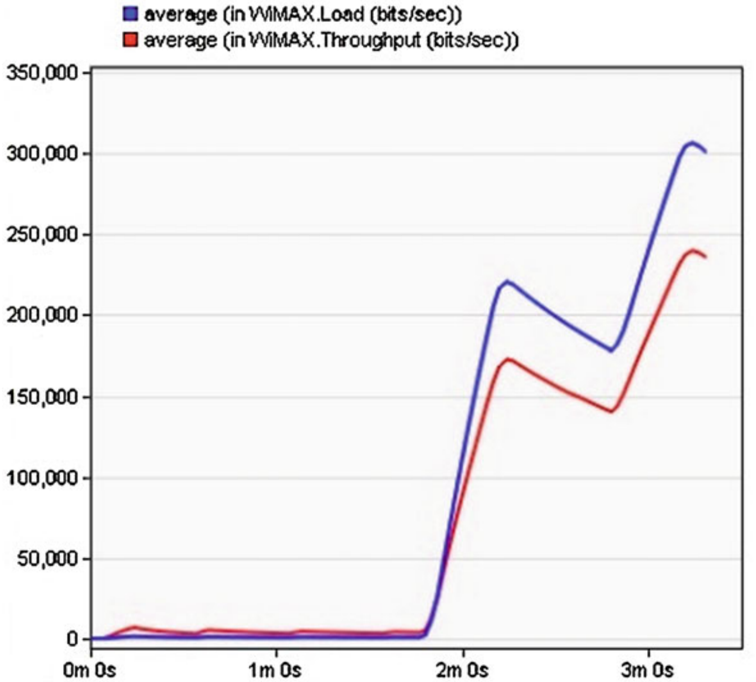


**Fig. 5** 64 QAM 1/2

The second test utilized 16 QAM 1/2, the second highest order of digital modulation and coding. We thought the generated output would show an even larger increase in queuing due to the fact that there are fewer bits per symbol with 16 QAM 1/2. However, the results showed a prominent decrease in the amount of noticeable queuing as seen in Fig. 6.

The third test utilized QPSK 1/2, the lowest order of digital modulation and coding. The results from the simulation displayed an even greater decrease in the amount of queuing. In fact, queuing is almost non-existent under these conditions. The results are shown in Fig. 7.

The test results all point to QPSK 1/2 being the superior selection for the digital modulation and coding scheme for the uplink and downlink states. The most logical reason as to why the QAM modulation had worse throughput, when in theory they should generate far greater throughput, is because of the sheer amount of noise and interference they generate on a large scale. The lower order modulation schemes also allow for the data to reach further distances at the cost of speed. A lower order modulation scheme is definitely the method of choice for granting those in a "last mile" situation WiMAX access.

The Second Simulation measured WiMAX delay in regards to different forward error-correction types. According to Mark Wood, QoS mechanisms "are all implemented in the PHY layer, and their parameters are based on the QoS

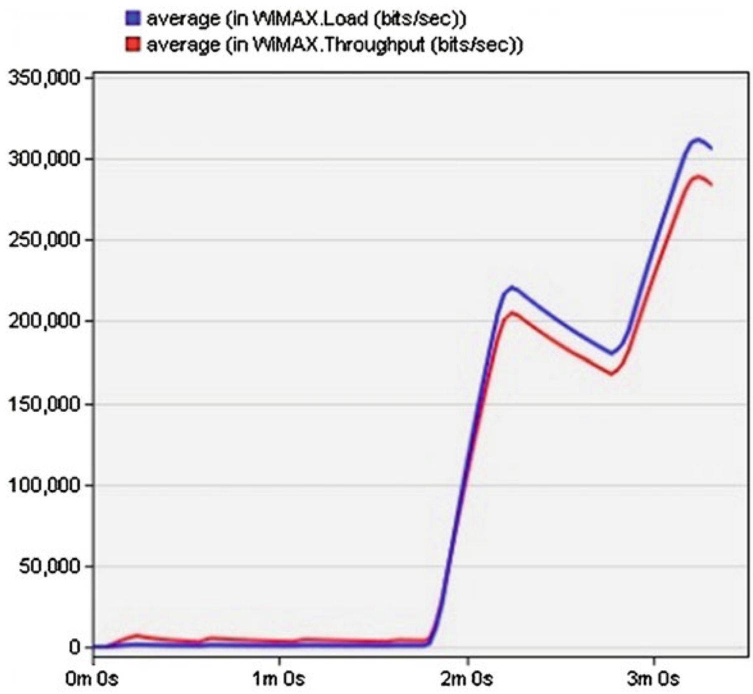


**Fig. 6** 16 QAM 1/2

requirements handed down by the higher layers" [15]. To generate our results we compared the WiMAX delay present with Automatic Repeat re-Quest (ARQ), Hybrid Automatic Repeat-reQuest (HARQ), Cyclic Redundancy Check (CRC), and no FEC. The general methodology for each is as follows: "ARQ uses a simple error-control method in which acknowledgements and timeouts are used to achieve reliable data transmission. In Hybrid ARQ, FEC bits are added to the existing Error Detection (ED) bits to correct a subset of all errors while relying on ARQ to detect uncorrectable errors." [2].

We first ran the simulation under no FEC constraints in order to generate a control graph to use for future comparison. The following simulations were all duplicate scenarios, each with a new form of FEC utilized. Figure 8 shows a comparison between no FEC and a standard implementation of ARQ. As depicted, the level of WiMAX delay slightly decreased through use of ARQ for FEC.

The second and third simulations involved compiling results with one utilizing HARQ only, and the other CRC only. We noticed a radical result once we overlaid the statistics and had the graph represented as an average. HARQ, which performs better than ARQ in poor signal conditions, actually gave the worst WiMAX delay. Standard ARQ turned out to give the greatest throughput while reducing WiMAX delay. Both HARQ and CRC, however, caused a great range of delay. Theoretically, ARQ would cause higher than normal delays as well if the network is

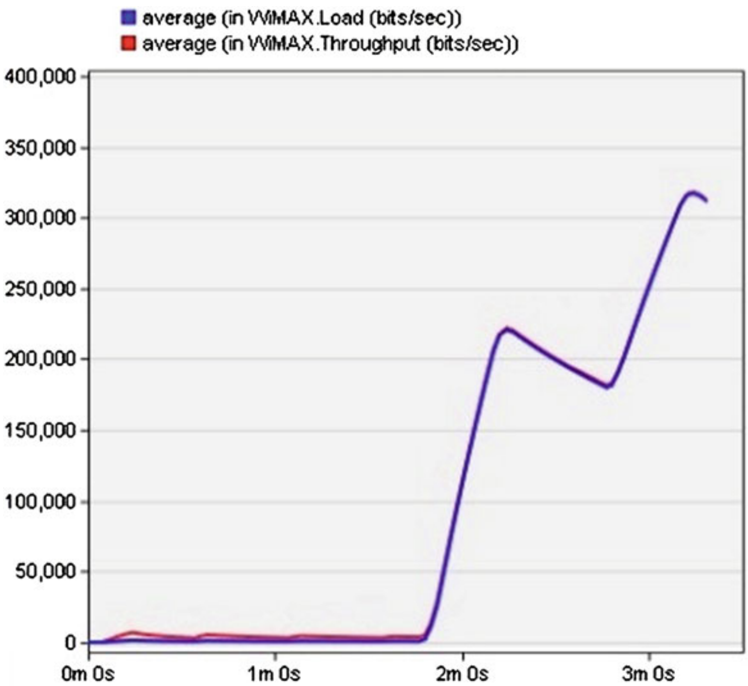


**Fig. 7** QPSK 1/2

performing efficiently. There is a delicate balance when it comes to performance if any sort of FEC is enabled. Latency can be reduced through use of FEC measures by reducing the amount of retransmissions. However, the coding for FEC logically requires more bits causing a decrease in throughput if there are no errors present (Fig. 9).

The figure displays the dramatic difference in WiMAX delay between HARQ, CRC, and no FEC whatsoever.

## 4 Conclusions

The parameters in the PHY layer grant WiMAX technology a great deal of flexibility that can be used to enhance performance and reliability depending on the conditions present. We gathered results that prove network traffic queuing is near non-existent through our research and scenario creation in OPNET Modeler. QPSK 1/2 is the superior selection in our implementation because it allows for the load to match the throughput, allowing for better QoS. The more advanced methods of FEC such as HARQ and CRC apparently consume too many resources

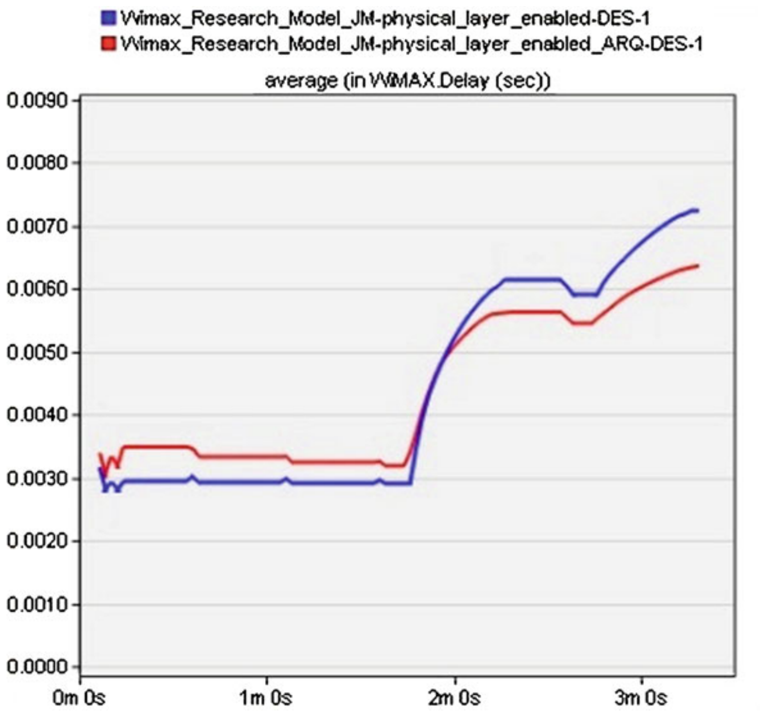


**Fig. 8** No FEC versus ARQ

leading to a high delay in WiMAX performance. WiMAX delay was far less using standard ARQ than using no FEC at all. However, the ARQ protocol will consume more resources than necessary if there are no errors present.

## 5 Future Work

Since WiMAX will be deployed on a location basis, it should be noted that configurations will depend on the terrain and scenario. 3G and 4G networks are more prevalent than ever, and the QoS can be greatly enhanced if the correct configuration is implemented. We also feel that managing WiMAX QoS and security on the PHY and MAC layers is not the most ideal situation. It would be ideal to devise a method for users to remain secure while being able to retain a high Quality of Service. Prior research has also found, “the security mechanism of IEEE 802.16 is mainly focused on security in the MAC layer, which may not be able to provide sufficient security in multi-hop scenarios” [17]. Potential integration of layer three security and authentication may be able to solve the problem, but it is currently a gray area based on performance evaluations.

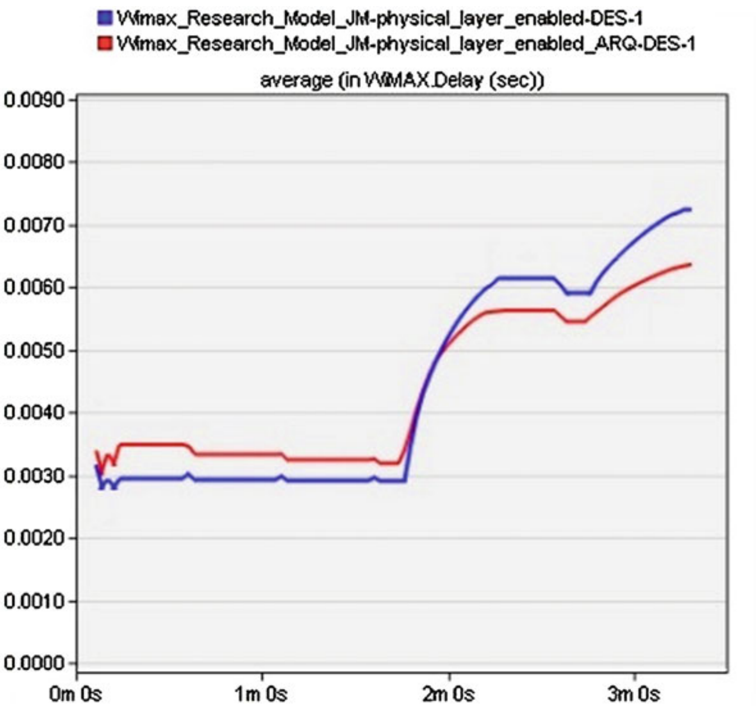


**Fig. 9** HARQ versus CRC versus No FEC

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# Estimation of Depth Map Using Image Focus: A Scale-Space Approach for Shape Recovery

**W. A. Smith, K. P. Lam, D. J. Collins and J. Tarvainen**

**Abstract** Laplacian-based derivatives used as a local focus measure to recover range information from an image stack have the undesirable effect of noise amplification, requiring good signal-to-noise ratios (SNRs) to work well. Such a requirement is challenged in practice by the relatively low SNRs achieved under classical phase contrast microscopy and the typically complex morphological structures of (unstained) live cells. This paper presents the results of our recent work on a new, multiscale approach to accurately estimate the focal depth of a monolayer cell culture populated with a moderately large number of live cells, whose boundaries were highly variable both in terms of size and shape. The algorithm was constructed in classical scale-space formalism which is characterised by an adaptive smoothing capability that offers optimal noise filtration/sensitivity and good localisation accuracy. Moreover, it provides a computationally scalable algorithm which not only obviates the need for additional heuristic procedures of global thresholding and (subsequent) interpolation of focus-measure values, but also generates as an integral part of the algorithm, a final range image/map that is demonstrably more realistic and, perceptually, more accurate.

## 1 Introduction

The visual inspection of cells is a fundamental tool for discovery in biological science and represents the principal approach in the characterisation of bio-structural complexity in histology and image cytometry. Recent advances in digital

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microscopy have facilitated the crucial transition from fixed to living cells and from qualitative to quantitative imaging experiments in modern biological research. Increasingly, the latter is characterised by the unprecedentedly extensive analysis of cell cycle behaviours via tracking and motion analysis of objects in time-lapse microscopy images [1–6]. Phase contrast microscopy, which yields image intensity values by enhancing contrast in optical path length between specimen objects and the surrounding medium, is widely utilised to examine dynamic events in live cells that are (often) optically transparent and colourless.

Analysing the exploding quantity of imaging data produced with contemporary microscopy techniques is non-trivial, typically requiring detailed studies of the dynamic behaviour of single cells or cells in tissue and involving the tracking and quantification of large numbers of cells over extended periods of time that render most manual procedures impractical if not impossible. To date, however, the automation of these tasks has faced several challenges, which include the generally poor image quality (e.g. low SNRs), the varying density of cell populations due to division and cell migration, and the possibility of cells touching each other without showing sufficient image contrast. In particular, one commonly known problem that occurs during long term imaging experiments (say, over several days), is the drift or loss of focus within the image sequences due to evaporation of the substrate, mechanical shift of the microscope, etc. Indeed, maintenance of focus for such experiments, especially in 3/4D, is of paramount importance and must be achieved with dependable autofocus algorithms that automatically adjust the objective and microscope stage [7]. Early work on recovering structures of dynamic scenes offered a computationally efficient solution to rapid and dense range estimation using the *depth from focus* methodology [8]. The algorithm used different focus levels to obtain a sequence of object images, to which a local focus operator, known as the *sum-modified Laplacian* (SML), measuring locally the quality of image focus was then applied. The enabled the determination of a set of focus measures at each image point of the image sequence of the object(s) of interest. Being a second derivative operator, however, the SML has the undesirable effect of amplifying noise. One approach to address this problem is to reduce the high frequency noise component by using a larger filter mask/operator to estimate the required gradients. However, this approach has several practical limitations, and is largely heuristic in nature [9, 10]. More importantly, accurate depth estimation requires theoretical and practical solutions to a variety of problems including recovery of textureless surfaces (particularly applicable to live cell microscopy), precise blur estimation and magnification variations caused by defocusing. As proof of concept, this paper presents our recent work on the application of a multiscale image analytic framework developed for detecting and visualising salient image structures that occur at multiple scales [11, 12]. The approach is compared with the more established *Depth from Focus*/SML algorithm referred to above. Using the scale-space formalism, an image is presented as a parameterised family of smoothed images which are controlled by a (Guassian) smoothing kernel whose support was allowed to grow (shrink) with scale, thus adapting to scale-dependent correlation lengths in images. Such a representation exhibits scale-invariant characteristics in general, and in particular offers optimal localisation properties in the context of depth estimations from focus, as objects project to images at different scales depending on distance from the image plane (or camera). In essence, the principal goal was to capture the scale dependent differences in a sequence of 'noisy' images generated at different and non-overlapped focal distances of the same scene, by complementing our scale-space representation with a simple yet effective procedure for automatic scale selection based on the maximization of normalized derivatives over scales [11, 13–15]. In this way, the proposed algorithm can adapt automatically to the unknown scale variations that may occur due to objects and substructures of varying physical sizes, and as a result of the varying distances from which objects are sampled.

## 2 Technical Background

In classical computer vision, depth from de/focus is the problem of estimating the 3D surface of a scene from a set of two or more images of that scene. The images are obtained by changing the camera parameters, typically the focal setting or the image plane axial position, and taken from the same point of view. The previous work described in [16] offers a method that can produce an all-in-focus image of a cell culture to assist further processing. The method (summarised in Fig. 1) works by first calculating the focus measures for each pixel, and then selecting the pixels with the best (or high) focus measures. The latter was simply achieved by the application of a global threshold that selected pixels that are deemed to be "accurate" (in focus), discarding in effect the estimated range/depth values of those pixels which have relatively low focus measures (and are thus deemed to be inaccurate or out of focus). In most cases, the method rendered many missing values from the range image that correspond to pixels from large(r) and low frequency areas where the spatial gradients between neighbouring pixels are comparatively low. These missing values were obtained by an interpolation procedure which defined the individual range value as the weighted sum of the range values of four nearest in-focus pixels, located in four non-overlapped regions of the image plane, with weightings set to the inverse of their respective Euclidean distances from the pixel in question [16].

The range estimation algorithm described above has two drawbacks. First, the use of a global threshold is, at best, heuristic and as such represents a compromise between noise sensitivity and localisation accuracy. It is also dependent in no smaller part the optical characteristics of the detected objects (in relation to the surrounding medium). In a similar vein, the interpolation model of range map is largely arbitrary and offers few guarantees or evidence that the values computed accurately represent the real map or "ground truth". Further, as one increases the number of stack images (alongside increased computational power), the accuracy of the resulting estimates may not be improved accordingly.

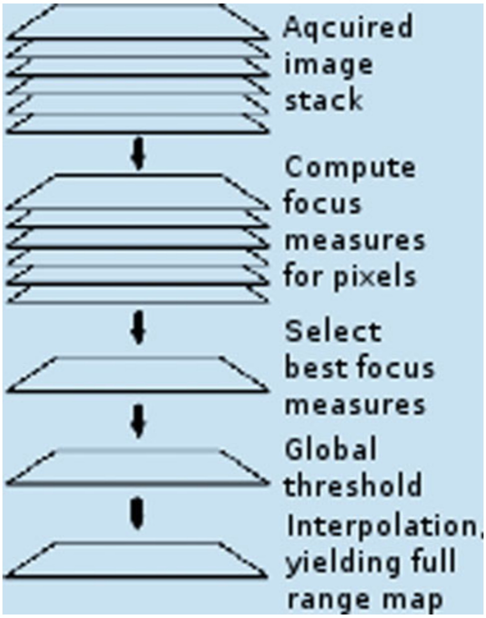


**Fig. 1** Summary block diagrams for the sum-modified-laplacian (SML) algorithm as described in [16]

## 3 Depth Estimates With Shape-Smoothing

Recent work [11] on investigating a multiscale analytic procedure which could aid detection of specific anatomical features in CT (Computed Tomography) images; for example, abnormality, lesions, etc., to support a detailed quantitative analysis of textural features of different anatomical objects, was achieved by encoding at different scales the smoothed image and the residual to facilitate a better understanding of local texture segmentation. To date, the approach has generated promising results in discerning anatomical structures particularly within CT scans [12]. Here, our measure of the texture granularity is based on the local scale whose optimal values are computed using the information theoretic based principle of Minimum Description Length (MDL) $L$ [17, 18], to achieve maximum image smoothness for $I_\sigma$ with a minimal residual $\varepsilon_\sigma$;

$$L(I_0|\sigma) = L(I_\sigma) + L(\varepsilon_\sigma) \tag{1}$$

where $I_\sigma$ is a Gaussian smoothed image at scale $\sigma$ and $I_\sigma$ is the original image. Based on the *Sampling* theorem, $L(I_\sigma) \sim \frac{1}{\sigma}$ and $L(I_\sigma) \backsim \varepsilon^2$ and $L(I_\sigma) = \varepsilon^2$ is modelled with zero-mean Gaussian density. Thus, for each pixel r,

$$L(I_0(r)|\sigma(r)) = \gamma(\frac{\alpha}{\sigma^2(r)} + \varepsilon_\sigma^2(r)) \tag{2}$$

where $\alpha$, $\gamma$ are constants. The probability, $\rho(r) = \frac{1}{\phi_r} e^{-L(I_0(r)|\sigma(r))}$ defines the likelihood of $r$ under MDL to facilitate the computation of the maximum likelihood estimator for $\sigma$(r), where $\Phi$ is a normalising constant [11]. Here, the local scale $\sigma$ gives a quantitative measure of the local texture granularity provided the noise variance (proportional to $\alpha$) is comparatively small. More importantly, the latter estimates the optimal local smoothness $\sigma^*$ for each (x, y), allowing the construction of an adaptive Gaussian kernel whereby each image pixel can be filtered in accord to the estimated parameter of $\sigma^*(x, y)$; in other words, the resulting image is optimally smoothed (in Bayesian sense). Note that the degree of smoothness is controlled locally by $\sigma$ in the scale space, whereby the Gaussian kernel also adjusts its shape adaptively. In essence, if (x, y) is close to discontinuities (*i.e.* edges), the MDL selects $\sigma$ closed to the minimum possible scale; otherwise, $\sigma$ is chosen close to the maximum variance set if the (x, y) is within a uniform structure—see equation (2). Furthermore, the shape of the filter kernel changes as a function of MDL; in the neighbourhood of discontinuities the residual ($\varepsilon^2$) grows much faster with respect to $\sigma$ than in a relatively uniform region. In other words, the local scale selected will be small close to discontinuities, and large (r) over uniform regions. This facilitates as a result effective noise suppression whilst preserving accurately any discontinuities.

The multiscale algorithm adopted in this study can be viewed as a reverse of the standard application of the multiscale techniques described above. Instead of a single, in focus image (the '*ground truth*',) there is instead a stack of images that have been blurred by the defocusing. In optical theory this is equivalent to Gaussian filtering [19], which means that the algorithm must instead be oriented towards calculating the residual between the blurred images in the stack and then select the pixel locations with the lowest residual. This works on the principle that the original image ($I_o$) is a combination of the blurred image ($I_\sigma$) and some degree of residual ($\varepsilon_\sigma$) which can be summarized as:

$$I_\sigma(x, y) + \varepsilon_\sigma(x, y) = I_o(x, y) \tag{3}$$

which illustrates that the residual increases as the image becomes increasingly defocused [20]. The object (cell culture) is moving into and out of focus at fixed distances when the stack of images is collected by the camera, so the degree to which the image is filtered is adapted to the proximity of the object to the focal point of the camera. Using these principles, the algorithm establishes the degree to which a region in an image has been blurred relative to the other images in the stack (and therefore, which possess the most information) and then proceeds to establish which pixels (selected from the z-plane) are suitable to reconstruct the in-focus image. The algorithm essentially solves the z number of equations (corresponding to the z number of images in the stack) and each pixel will have 1 of the 26 values of $\sigma$.[1]

[1] Each image stack consists of a sequence of twenty-six (0–25) co-registered images, corresponding to the individual image/frames sampled at different focal/depth planes.

This means that as the number of images in the stack increases (along with the computational power) the accuracy in relation to the real world appearance is improved (which is in contrast to the approach outlined in [16] as previously mentioned).

The strength of this approach lies in the fact that information within the stack of images is fully utilised, rather than using techniques such as interpolation of pixels in discontinuous regions; i.e. the appropriate local scale can describe and preserve continuity. In addition, features such as large and small scale edges are considered in each image plane, which yields a composite image that is (visually) clearer compared with the Laplacian (and other) techniques. Yet another strength lies in the fact that the initial step of generating Gaussian filtered images in the stack is not necessary due to the inherent defocusing by the camera, which means that the computational time of the approach is significantly reduced compared to the standard utilization of the multiscale algorithm.

## 4 Results And Discussion

As an illustration of the concepts/algorithm discussed so far, regular snapshots were taken from the cell culture during a continuous period when a specific event of interest had been detected in the cell culture monitored under phase contrast illumination.[2] For simplicity, the data input into the algorithm was limited further to a region of interest; i.e. (x,y) locations, which contained a cell undergoing mitosis (highlighted in Fig. 2). The depth map (z-axis) generated by the SML algorithm gives a somewhat clear version of the final image [16]. This is illustrated in Fig. 3, which shows a cell undergoing mitosis. However, the consistency of the depth map over time and the local smoothness (such as a cell surface or boundary) is questionable (Fig. 4). There are also multiple artefacts observed in the sequence of images, such as the double halo seen in Fig. 3. This highlights the fact that the local smoothness of the depth map must be sufficient for a clearer image. It (perhaps more importantly) highlights the limitations of using fixed-scale, thresholding and interpolation in image processing, since large and small scale features are not preserved in the absence of local filtering.

The usage of global thresholding results in a (potential) loss of valuable information within the stack, which yields a depth map that is inconsistent over time and does not realistically reflect the true depths of the cells and the culture in relation to the camera. Furthermore, the usage of interpolation where data is not sufficient is a somewhat heuristic approach to the problem as interpolation inherently causes distortion of the pixel values. The resulting inconsistent edge boundary of the cell will also have consequences when using the constructed

[2] The cells used were HUVECs (human umbilical vein endothelial cells), which were seeded onto a Hydro Gel. Courtesy *of Chip-Man Technologies* Ltd..

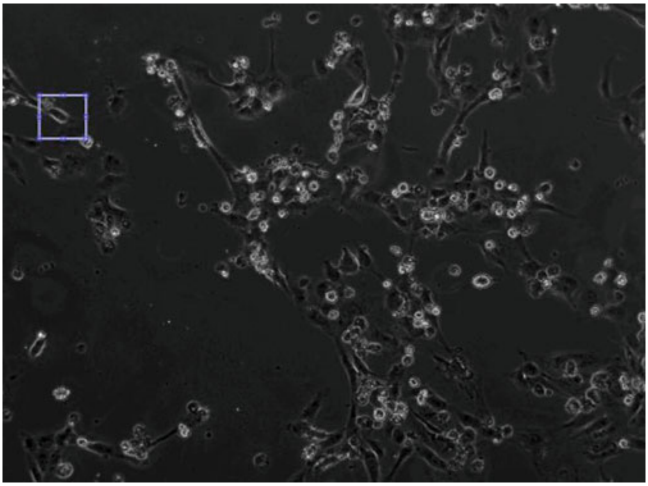

**Fig. 2** The region of interest (ROI) tracked with multiscale characterisation. (ROI dimensions: 100 × 93. Original image dimensions: 1392 × 1040)

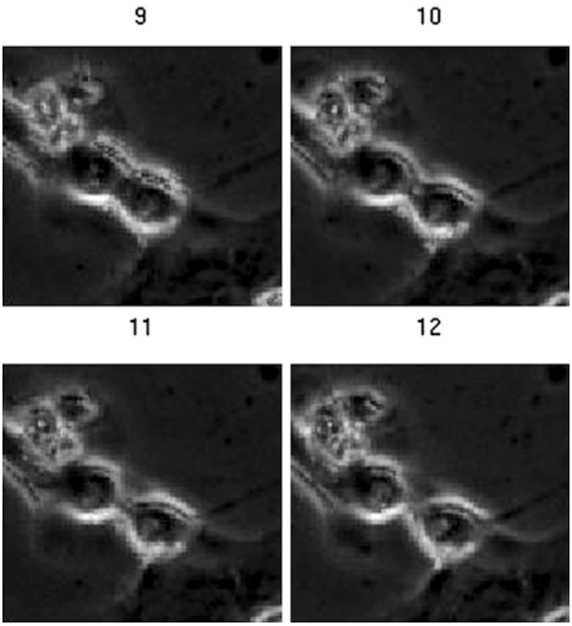


**Fig. 3** A dividing cell at the later stages of mitosis. Note the double halo at the cell boundaries, which would cause complications when attempting segmentation, classification and characterisation

image for further processing, such as cell counting and classification; a concept which has been explored in [21].

The multiscale approach is able to generate a depth map that more accurately reflects the relative depth levels of the observed object. The obtained images demonstrate the strength of this technique (Fig. 5), and the depth levels may be

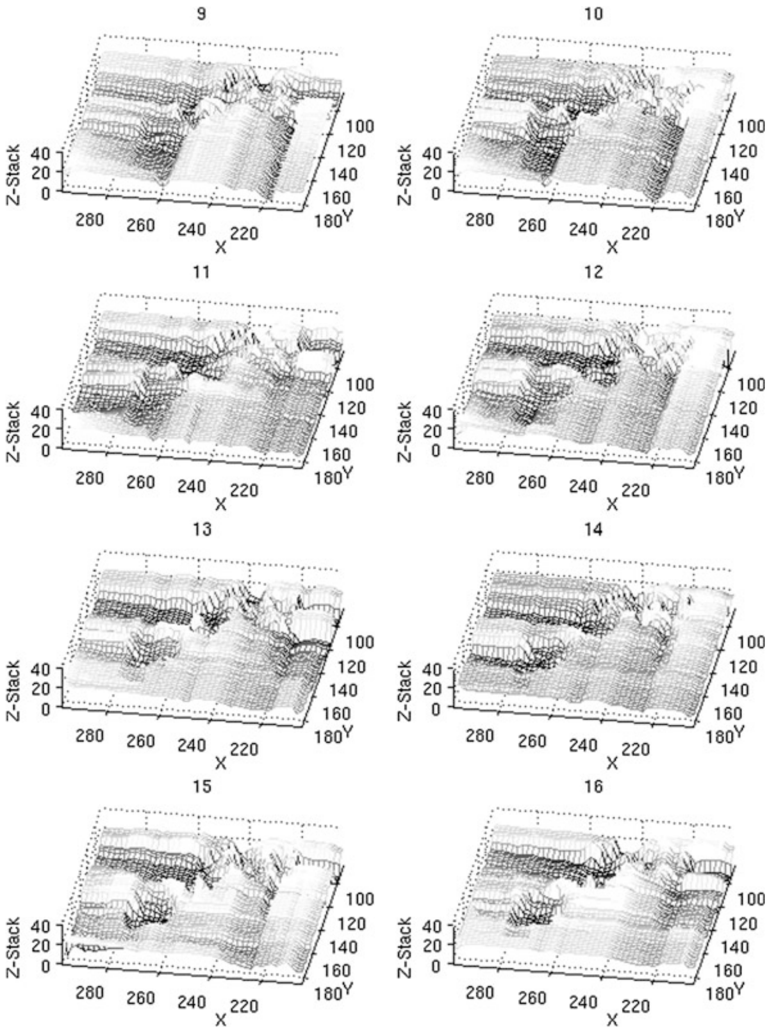


**Fig. 4** The sequence of surface focus maps from the all-in-focus technique

used to produce more accurate results in subsequent calculations ranging from simple cell counting to timing the duration of mitosis and tracking an individual cell in a culture.

The boundary of the cell during anaphase is visible in the 3D surface focus map. This may contribute to the segmentation when dealing with cell clusters, due to knowledge of each cells location in the z-plane. The cleavage furrow created by the contractile ring [22] is also visible in the surface focus map (Fig. 6, Images 9–10), which highlights the value of extracting features within the image stack, rather than just the regions possessing high focal measures. Once mitosis is

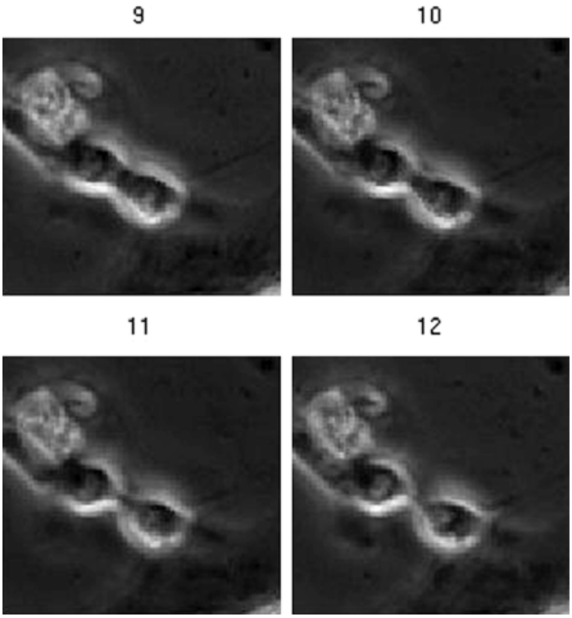


**Fig. 5** The image sequence of a dividing cell seen in Fig. 3 reconstructed using the multiscale approach. Upon visual inspection the boundaries of the cells are much smoother and more well defined using the multiscale approach

finished the gap between the membranes (Fig. 6, Image 13) is seen in the map. Another advantage of this technique that has been demonstrated is the fact that it is less susceptible to local maxima (noise), which allows the features of the cells physical appearance (such as its current stage of mitosis) to be seen more clearly.

The approach discussed has yet another aspect that will require further investigation; the principle that each pixel will be assigned a sigma value (26 in total) means that the problem can be seen as one of data mining. The planes at which a given cell is present will have a distinct region of sigma values, and since the image has been subjected to Gaussian filtering the second-order statistic (i.e. the variance) may be used in the classification and segmentation of the pixel regions. This outlined problem may be solved, for example, by the application of Principal Component Analysis (PCA), which is based on the very same model of using second-order statistics to explore high-dimension data [23]. The image is composed of a linear combination of the various regions which can be separated based on the intrinsic dimensionality of the data set. Once again increasing the size of the data set will (in theory) enhance the accuracy of the approach.

## 5 Conclusions

This novel use of the multiscale algorithm provides a non-heuristic solution to the problem of determining the focal depth of objects in high performance phase-contrast time-lapsed microscopy. The algorithm was constructed in classical

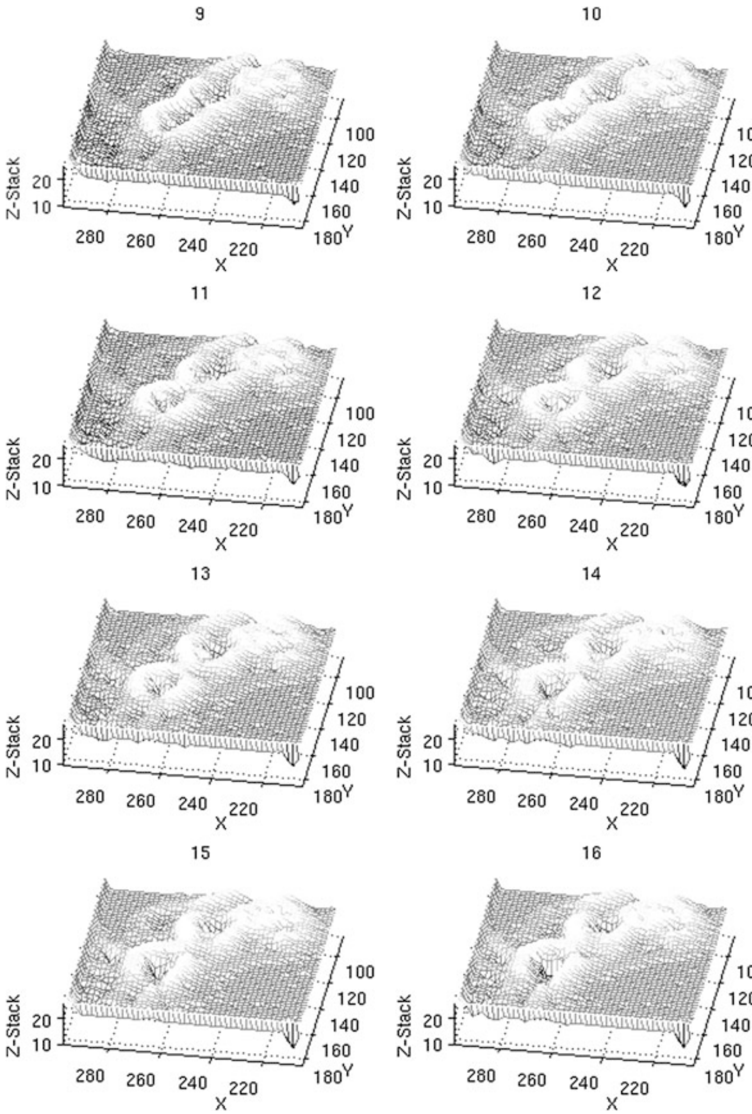


**Fig. 6** The sequence of surface focus maps from the multiscale approach

scale-space formalism which is characterised by an adaptive smoothing capability that offers optimal noise filtration/sensitivity and good localisation accuracy. These properties are crucial to our on-going research in robust and scalable computational procedures that would greatly assist subsequent analytical tasks such as cell type identification and lineage tracking.

**Acknowledgments** We are indebted to Chip-Man Technologies Ltd. for the preparation and loan of the image/video stack used in this study, as part of our research collaboration in improving algorithms for the automated tracking of live-cell cultures.

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# Applying Intelligent Agents in Traffic Control for Traffic Intersection Groups

**Tzong-An Su and Yau-Chiuan Yang**

**Abstract** Improving the efficiency of the transportation systems is essential for our economic and environment. Applying intelligent agents in traffic control for traffic intersection groups has been suggested in the past. The intersection agents use fuzzy control strategy and have coordination ability. By using traffic detectors, agents can get real-time traffic information to calculate optimal signal settings and quickly respond to incidents. In this thesis, we present an application of intelligent agents in traffic control for traffic intersection groups. In our research, an algorithm is proposed to calculate the most impacted route during a traffic incident. A technology called green light bandwidth adjustment is then applied to relieve the traffic jam. We use the software "DynaTAIWAN" to verify the effectiveness of our approach.

## 1 Introduction

Congestion is one of the single largest threats to our economic prosperity and way of life [1]. This issue exists in major cities around the world because of growing number of vehicles. Improving the efficiency of transportation systems is essential for our economic and environment. Intelligent traffic control systems have become a useful approach in addressing traffic congestion. How to use advanced technologies to improve the existing traffic problems is a critical issue in traffic control and management.

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Traffic conditions can be divided into two types, there are under control events and emergencies. The former can be forecasted by mathematical models and algorithms. By analyzing the past of road traffic, traffic engineers can design proper traffic control arrangements. However, for the latter, the unpredictable incidents often cause difficulty. If not readily grasp the unexpected traffic incident, the signal or other traffic management facilities will not be properly set up, traffic congestion will occur. That's why real-time control has to be in place.

Applying intelligent agents in traffic control for traffic intersection groups has been presented for some time. [2] proposed and designed a fuzzy controller to control traffic of a set of intersections. By using detectors [3, 4], agents can get real-time traffic information and control traffic signals [5–8]. The intelligent agents calculated optimal signal settings based on observed flow distribution and can quickly respond to incidents.

With all these technologies at hand, we present an application of intelligent agents in traffic control for traffic intersection groups. Not like [9]. In our research, an algorithm is proposed to calculate the most impacted route during a traffic incident. A technology called green light bandwidth [10–11] adjustment is then applied to relieve the traffic jam.

We use the software "DynaTAIWAN" to verify the effectiveness of our approach through average travel time.

The rest of this paper is organized as follows. Section 2 describes related research. Section 3 explains existing problems. In Sect. 4, we present an "arterial-based area signal-coordination control" method. Simulation results are presented in Sect. 5. Section 6 concludes.

## 2 Related Research

Fuzzy control theory [12] is used by intelligence agents to do signal control. In [2], the authors use fuzzy control technique to control traffic within a group of intersections. The controller of an intersection controls its own traffic and cooperates with its neighbors. It gets information from its traffic detectors and its neighbors. Using this information, the fuzzy rule base system gives the optimal signal arrangement.

In [10], the traffic issues of main artery roads in a city are investigated. The main part of urban transportation networks are the trunks (big roads). They have higher, more stable and better traffic flow characteristics. So, it is easier to handle traffic problems on these types of roads. To solve urban traffic problems traffic engineers often start the design of signal systems from the trunks. The current signal timing optimization software and research have created dynamic signaling systems, most of the trunks are entered with the same system settings as a group, and within the intersection group adjustments are made based on the current traffic condition. The aim is to make the arterial system with sufficient green light bandwidth. The appropriate and adequate green light bandwidth will ensure smooth passage of traffic flows.

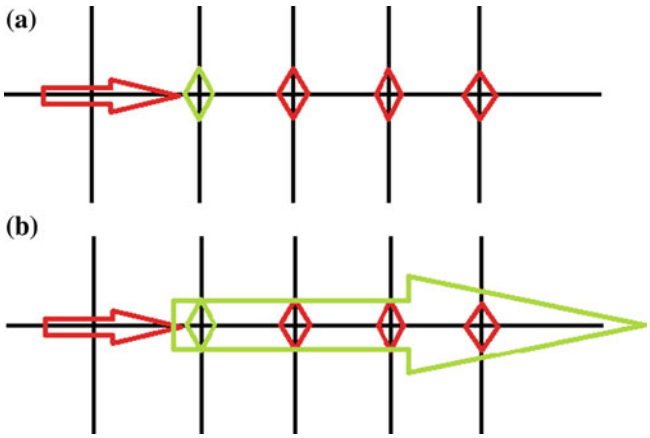



**Fig. 1** Catastrophic congestion problem

## 3 Problem Statement

The gradual and slight congestion problems can be alleviated by fuzzy traffic controller. But the catastrophic congestion problems like traffic accidents or ball games, can not be solved just by fuzzy traffic controllers. One reason is the fuzzy controller approach does not extend green light time in a series of the heavy congested intersections. The other reason is the fuzzy controller would tend to undermine the original design of the road green light bandwidth.

For a single traffic intersection, if the downstream is heavily congested, extending the green light time of this intersection will only lead to more serious congestion as shown in Fig. 1a. Figure 1b is the situation that we allow extending the green light time. In the case of Fig. 1a, the whole congestion situation did not improve, or can be even worse.

To solve the problem described above, we present an algorithm for the development of optimal arterial-based progression schemes. Our algorithm is based on Markov chain model [13–15].

## 4 Arterial-Based Area Signal-Coordination Control

Our goal is to design an algorithm to find out the most impacted route during a traffic incident or a traffic jam. After finding this route, we can extend all the green lights time of all the traffic lights along this route.

Because our algorithm is based on Markov chain model, we need to transform traffic information into Markov chain mode. Collecting traffic information through traffic detectors, we can obtain the straight and left turn traffic flows ratio at each intersection. Figure 2a, b show the transformation from traffic information to Markov chain model. The states of Markov model are traffic intersection nodes, and the probability trails of Markov chain model are traffic flows ratios. Note that for simplicity of demonstration, we have assumed there is no right turn traffic in the example of Fig. 2.

The algorithm for calculating the most impacted route by using the constructed Markov chain model is given in the following:

**Algorithm:** *Impacted Route:*

**Input:** Markov Chain model containing congested area traffic information including $n$ intersections where

$I_i$ is the state (intersection) $i$, $1 \leqq i \leqq n$

$r_{is}$, $r_{ir}$, $r_{il}$ are the straight, right turn and left turn traffic flow ratios respectively leaving the intersection $i$, $1 \leqq i \leqq n$

$T$ is the impact factor threshold.

**Output:** $R$ is the set of all intersections along the most impacted route.

**step1:** select the intersection where the traffic incident occurs (or the most congested intersection) $I_i$. Let $R = \{I_i\}$, $p = 1$

**step2:** if ($r_{is} \geqq r_{ir}$) *AND* ($r_{is} \geqq r_{il}$)

{$p = p * r_{ir}$;
$I_i =$ the first intersection straight ahead;
}
else if ($r_{ir} \geqq r_{il}$)
{$p = p * r_{ir}$;
$I_i =$ the first intersection after right turn;
}
else
{$p = p * r_{il}$;
$I_i =$ the first intersection after left turn;
}

**step3:** $R = R \cup \{I_i\}$;

**step4:** if ($p \geqq T$) go to step 2;
else output $R$;

# 5 Simulation and Results

## *5.1 Simulation Settings*

We use the software "DynaTAIWAN" to verify the effectiveness of our approach. In the simulation, we design 32 traffic intersection nodes, and then use "DynaTAIWAN" to produce traffic flows for 1 h in the roads covered by the 32 intersections. Based on the average traffic flow speed, simulation data were generated and separated into the general flow and the high flow. The general

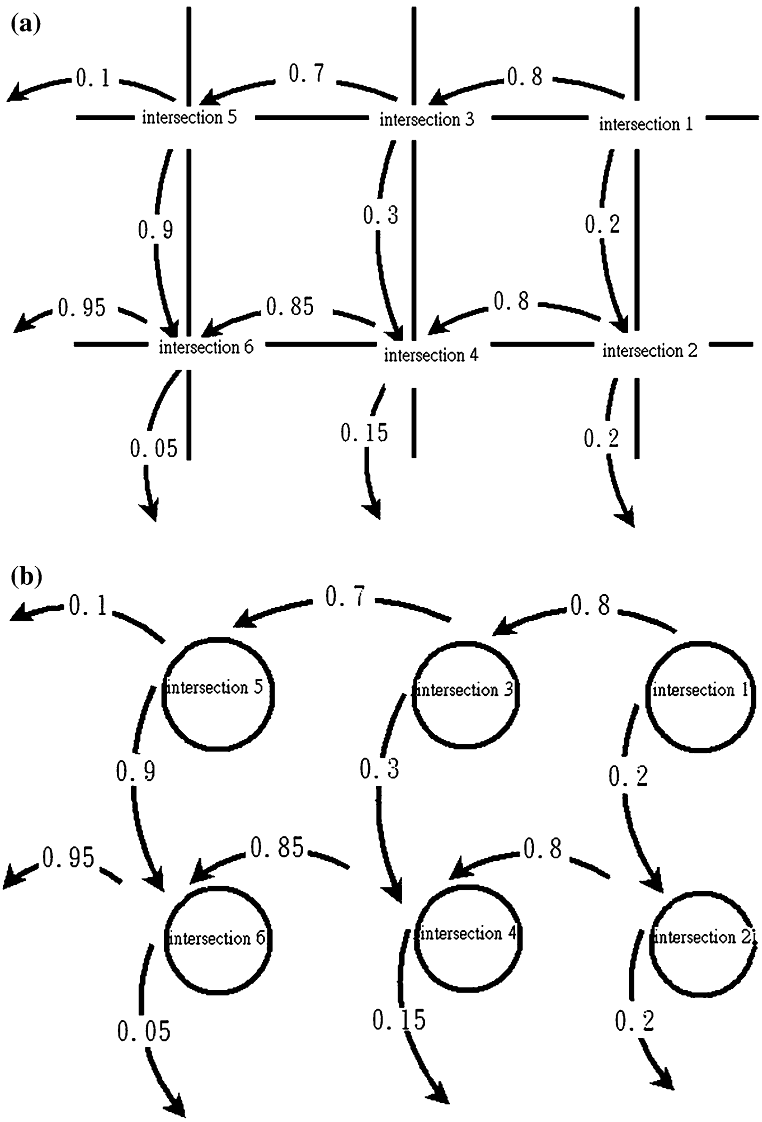
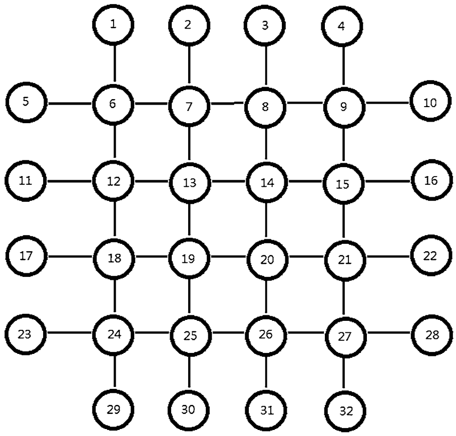



**Fig. 2** Transformation between traffic information and Markov chain model

flow has over 30 km/h average speed, and the high flow has less than 30 km/h average speed (high flow means that some traffic congestions happened).

Figure 3 and Table 1 show the 32 traffic intersection nodes network information. Table 2 shows the general flow and the high flow traffic information.

**Fig. 3** 32 traffic intersection road network




## 5.2 *Finding the Most Impacted Route*

By using algorithm *Impacted Route*, we can find the most impacted route of the traffic network. As we find the route, we extend all the green lights time along the route by ten seconds to relieve traffic congestion. The impact factor $T$ is set to 80 % (Fig. 4).

From the calculation of our algorithm, the most impacted route is $R = \{10, 9, 8, 7, 13, 19, 25\}$. The final $p$ value is calculated as

$r_{10s} * r_{9s} * r_{8s} * r_{7l} * r_{13s} * r_{19s}$

$= 100\,\% * 90\,\% * 95\,\% * 98\,\% * 98\,\% * 98\,\% = 0.80471916$

## 5.3 *Result*

After extending green lights time, we can use "DynaTAIWAN" to run the new traffic simulations again. By Comparing the average travel time and the average waiting time (waiting for the red traffic light), we can verify the effectiveness of our approach. Tables 3, 4 and 5 show the results. The proposed method shows better performance in all cases. In normal traffic flow condition, it shows 4.062 % improvement. In the high traffic flow condition, it shows 20.313 % improvement.

In addition to the average travel time and waiting time, we also observe all the traffic intersections' NumCar (which represents the number of cars waiting at that intersection) along the most impacted route. Table 6a, b show the result. By extending green lights time, it shows 7 cars improvement approximately.

**Table 1** Traffic nework information

| Property | Item | Setting |
|---|---|---|
| Nodes property | Length | 400 m |
| | Lines | 2 |
| | Speed limit | 50 km/h |
| | Road property | Urban road |
| | Motorcycle turn left type | Two-stage |
| | Saturation flow rate | 0.5 veh/s |
| O-D information | Time interval | 5 min (total 50 min) |
| Parameters setting | Simulation time | 60 min |

**Table 2** General traffic flow versus high traffic flow

| Traffic flow | General | High |
|---|---|---|
| Car number | 3,279 | 4,181 |
| Motorcycle number | 4,232 | 4,872 |
| Total travel time(car) | 335,288.964 min | 640,292.214 min |
| Total travel time (motorcycle) | 286,282.510 min | 481,052.750 min |
| Total waiting time(car) | 119,383.172 min | 247,371.136 min |
| Total waiting time (motorcycle) | 59,803.532 min | 82,105.686 min |
| Average travel time (car) | 20.454 min | 30.628 min |
| Average travel time (motorcycle) | 13.528 min | 19.746 min |
| Average waiting time (car) | 7.282 min | 11.832 min |
| Average waiting time(motorcycle) | 2.826 min | 3.370 min |
| Average speed | 36.83 km/h | 25.78 km/h |
| System average travel time | 16.550 min | 24.770 min |
| System average travel length | 489.64 m | 500.998 m |
| System average waiting time | 4.772 min | 7.278 min |

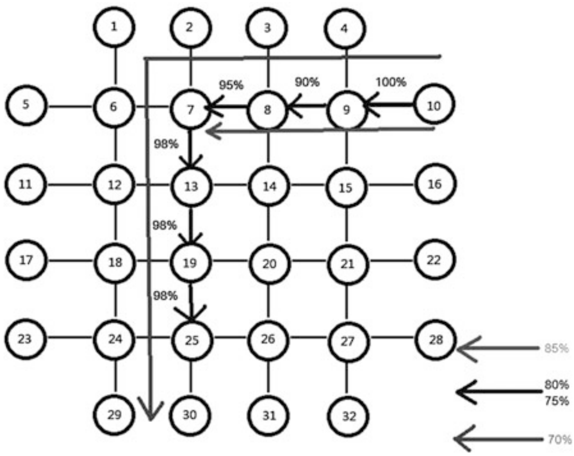



**Fig. 4** The most impacted route in the 32 traffic intersection nodes network (When the impact factor $T$ is 85, 80, 75 and 70 %)

**Table 3** General traffic flow and after extending green lights time

| Traffic flow | General | After extending green lights time |
|---|---|---|
| Car number | 3,279 | 3,045 |
| Motorcycle number | 4,232 | 3,919 |
| Total travel time(car) | 335,288.964 min | 297,859.312 min |
| Total travel time (motorcycle) | 286,282.510 min | 235,832.700 min |
| Total waiting time(car) | 119,383.172 min | 124,336.560 min |
| Total waiting time (motorcycle) | 59,803.532 min | 53,641.680 min |
| Average travel time (car) | 20.454 min | 19.564 min |
| Average travel time (motorcycle) | 13.528 min | 12.052 min |
| Average waiting time (car) | 7.282 min | 8.166 min |
| Average waiting time (motorcycle) | 2.826 min | 2.742 min |
| Average speed | 36.83 km/h | 41.25 km/h |
| System average travel time | 16.550 min | 15.340 min |
| System average travel length | 489.64 m | 490.124 m |
| System average waiting time | 4.772 min | 5.116 min |

**Table 4** High traffic flow and after extending green lights time

| Traffic flow | High | After extending green lights time |
|---|---|---|
| Car number | 4,181 | 4,206 |
| Motorcycle number | 4,872 | 5,083 |
| Total travel time(car) | 640,292.214 min | 640,053.772 min |
| Total travel time (motorcycle) | 481,052.750 min | 501,155.872 min |
| Total waiting time (car) | 247,371.136 min | 212,182.866 min |
| Total waiting time (motorcycle) | 82,105.686 min | 63,188.850 min |
| Average travel time (car) | 30.628 min | 30.426 min |
| Average travel time (motorcycle) | 19.746 min | 19.718 min |
| Average waiting time (car) | 11.832 min | 10.090 min |
| Average waiting time (motorcycle) | 3.370 min | 2.486 min |
| Average speed | 25.78 km/h | 25.85 km/h |
| System average travel time | 24.770 min | 24.570 min |
| System average travel length | 500.998 m | 496.882 m |
| System average waiting time | 7.278 min | 5.928 min |

**Table 5** Compare result and improvement degree

| Average time (min/veh) | General flow | High flow |
|---|---|---|
| Travel time (before extending) | 16.550 | 24.77 |
| Travel time (after extending) | 15.340 | 24.57 |
| Waiting time (before extending) | 4.772 | 7.278 |
| Waiting time (after extending) | 5.116 | 5.928 |
| Saving time | 0.866 | 1.548 |
| Improvement | 4.062 % | 20.313 % |

**Table 6** **a** Traffic intersections' numcar of the most impacted route (*before*) **b** Traffic intersections' numcar of the most impacted route (*After*)

| Intersection ID (min) | 10 | 9 | 8 | 7 | 13 | 19 | 25 |
|---|---|---|---|---|---|---|---|
| 10 | 27 | 24 | 22 | 25 | 31 | 33 | 33 |
| 20 | 26 | 27 | 21 | 22 | 29 | 25 | 25 |
| 30 | 22 | 21 | 21 | 22 | 25 | 27 | 26 |
| 40 | 26 | 23 | 21 | 25 | 28 | 20 | 24 |
| 50 | 27 | 25 | 21 | 21 | 23 | 23 | 27 |
| 60 | 22 | 23 | 23 | 21 | 27 | 22 | 27 |
| Intersection ID (min) | 10 | 9 | 8 | 7 | 13 | 19 | 25 |
| 10 | 20 | 19 | 16 | 18 | 24 | 23 | 23 |
| 20 | 19 | 20 | 13 | 15 | 21 | 18 | 18 |
| 30 | 15 | 14 | 14 | 14 | 17 | 21 | 20 |
| 40 | 18 | 16 | 12 | 17 | 19 | 14 | 19 |
| 50 | 20 | 19 | 13 | 13 | 15 | 15 | 21 |
| 60 | 14 | 16 | 16 | 14 | 17 | 15 | 21 |

## 6 Conclusion

The intersection intelligent agent system cannot effectively handle large-scale road network or high traffic flow network. This research proposes a Markov chain model to find the most impacted route when traffic congestions happen. Use our method, intelligent intersection agent system will have more powerful traffic control ability.

The results obtained from the simulations show the superiority of the proposed method in terms of average travel time, average waiting time and NumCar (waiting quene). In the higher flow traffic condition, it shows about 20 % improvement. Further study is underway to investigate the "multi-impacted route" situation. We believe our approach should also yield better performance in term of traffic control.

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# Energy Saving in Advanced Absorption Heat Pump with Object Oriented Programming

**R. J. Romero, S. Silva-Sotelo, Rodríguez Martínez and J. Cerezo Román**

**Abstract** This paper shows the algorithm for the calculation of energy savings using an advanced absorption heat pump. The main parameters for the heat transformer system is defined as COP, it is the ratio between the useful energy and the waste energy. The modeling is based on thermodynamics data. The heat balance of the Advanced Heat Pump (AHP) is used for determination of total amount of saved energy. The object oriented programming (OOP) is used for calculate the mass flows for each line into a thermodynamic cycle for energy recover. The OOP is made using HPVEE software. The results show values for recover 98 % of waste energy using the Carrol – water mixture into the cycle. Waste energy is added at the system at 70 °C. Water $^{TM}$–Carrol mixture is used in the DSHT. The recover energy is obtained in a second absorber at 128 °C with two scenarios.

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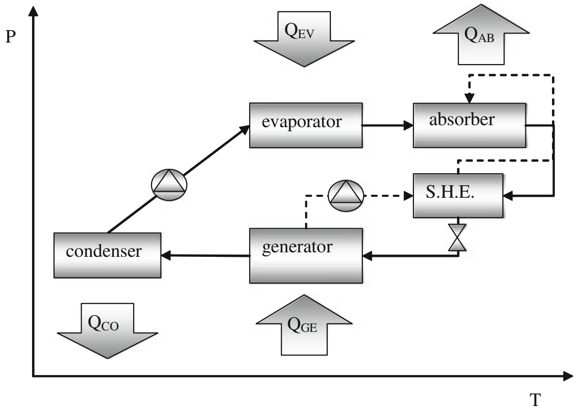
**Fig. 1** Schematic diagram of an AHT




## 1 Introduction

An absorption double stage heat transformer (DSHT) is an advanced thermal machine. The DSHT is a system of 16 devices used in a thermodynamic cycle. The absorption heat transformer (AHT) is a Type of heat pump. The DSHT is a device of two AHP that has the capability of transform waste thermal energy into useful energy. The main advantage of the DSHT is that it uses only 0.2 kW of electric energy for revalorize each thermal kW of waste heat.

## 2 Advanced Heat Transformer

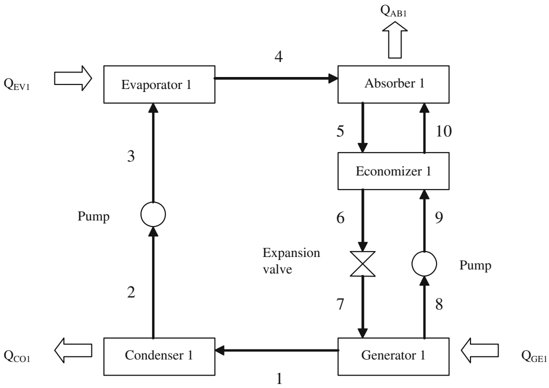
An AHT consists of an evaporator, a condenser, a generator, an economizer and an absorber. Figure 1 shows a schematic diagram of an AHT. A working solution (water—lithium bromide + ethylene glycol) flows between absorber and generator. This solution is called water—Carrol™, it was created by Carrier Co. for air conditioner systems.

A schematically representation for the calculation is shown in Fig. 2. The figure is numbered each line for a logical sequence for algorithm implementation.

## 3 Operating Conditions for Simulation

The AHT was installed with ten plate heat exchanger made of stainless steel 316, of seven plates, thermal capacity by design of 2 kW. Gear pumps are connecting the pressures zones between generators and condensers in the lines 2–3, while the other gear pumps are connected the lines 8–9. Expansion valves control the diluted solution from the absorbers to the generators (see lines 6–7 in Fig. 2).

**Fig. 2** Schematic diagram of the DSHT




The Cycle for the AHT is as follow: Waste heat is added to generator and evaporator. In the generators, the concentrated solution of Carrol–Water is boiling at low pressure (see Fig. 1). The working fluid (WF) for this AHT is water at lower pressure. The vapor in line 1 is condensed with the condenser. The condensers are delivering no useful heat to the surroundings. The WF is pumping from the condensers to evaporator at higher pressure. In the evaporator the WF change phase to vapor and then goes through the absorber. In the absorber the concentrated solution (Water–Carrol) is putting in contact with the vapor from evaporator. The absorption process delivers heat at higher temperature [1].

## 4 Main Parameters

The main parameters in the heat pump studies are the Coefficient of performance (COP), the Flow ratio (FR) and the Gross Temperature Lift (GTL).

These parameters are defined as follow:

$$COP = \frac{Q_{AB}}{Q_{GE1} + Q_{EV1} + W_{P1} + W_{P2}} \quad (1)$$

Where: $Q_{AB}$ is the useful energy deliver in the absorber.

$Q_{GE1}$ and $Q_{EV1}$ are the heat added from waste heat into the generators and the evaporator.

$W_{P1}$ and $W_{P2}$ are the energy for the operating of the pumps in the lines showed in Fig. 1.

Flow Ratio (FR) is the ratio of working fluid and diluted solution (Carrol–water)

$$FR = \frac{X_8}{X_8 - X_7} \quad (2)$$

where $X_i$ is the mass concentration of Carrol ™ in the line i.

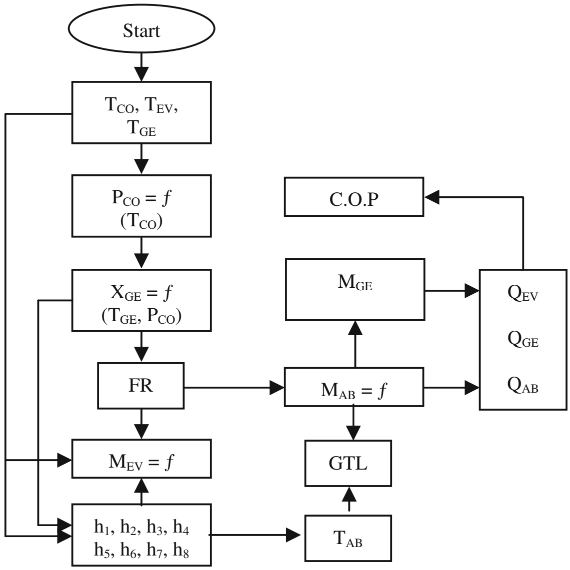



**Fig. 3** Implemented algorithm for energy saving process

$$GTL = T_{AB} - T_{EV} \tag{3}$$

Where $T_{AB}$ is the highest temperature in the system and $T_{EV}$ is the operating temperature in the evaporator after the heat transfer from waste heat.

Type T thermocouples were used, in each heat exchange are placed 8 thermocouples. The thermocouples are connected to a data logger for monitoring the temperature every five seconds. The temperature measures are sending in line to an Excel® file.

The total heat transferred from the AHT is calculated by:

$$Q_{AB} = m_{out} Cp\ (\Delta T) \tag{4}$$

Where $m_{out}$ is the flow that recover the useful energy from second absorber and Cp is the heat capacity of the fluid that is recovering the energy. ΔT is the difference of temperature from the application and the AHT.

## 5 Algorithm for AHT

The algorithm used for the calculation of the mass flow, absorber temperature, GTL, FR and COP are show in Fig. 3.

Where each $Q_i$ is calculated by previous thermodynamic model [2].

The Flow Ratio can be defined by a new and different way:

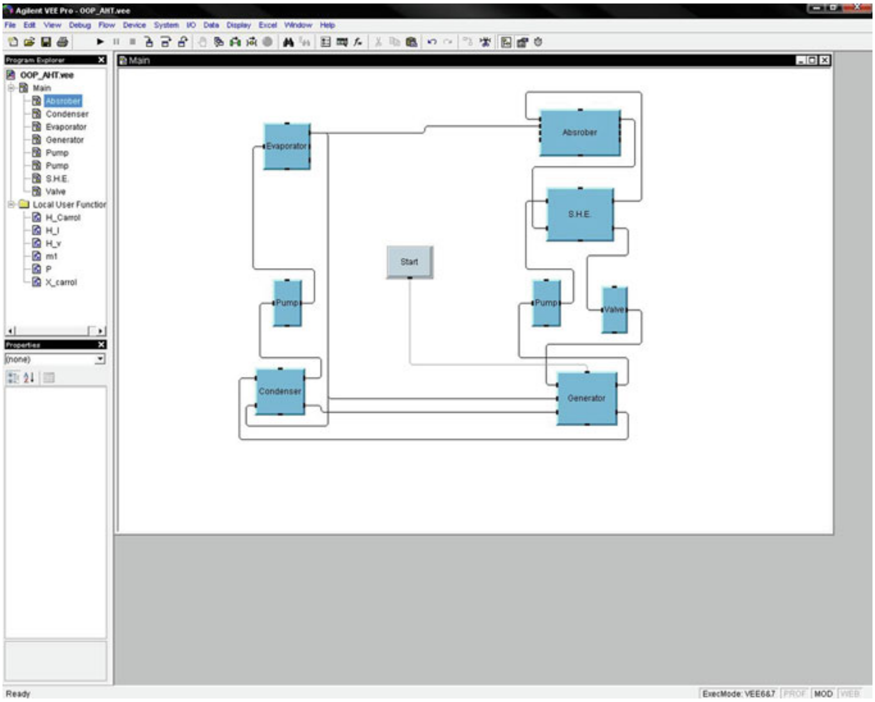



**Fig. 4** OOP for AHT

$$FR = \frac{m_5}{m_4} \tag{5}$$

Where $m_i$ is the flow in the "i" line.

From this new definition at $T_4$ and $T_5$ defined by the GTL exist a constant ratio for calculate the mass flows into the AHT. When the flows mass are calculated, the model for an AHT converges. And the AHT's model is based by mass and energy balances.

All the Qi are calculated with the actual Temperature, concentration and pressure for each component.

$$Q_{GE} = M_{GE,V}H_{GE,V} + M_{GE,S}H_{GE,S} - M_{AB,S}H_{AB,S} \tag{6}$$

$$Q_{CO} = M_{CO}(H_{CO,S} - H_{GE,V}) \tag{7}$$

$$Q_{AB} = M_{CO}H_{EV,V} + M_{GE,S}H_{HX,S} - M_{AB,S}H_{AB,S} \tag{8}$$

Whit the pressure in each component defined by:

$$P_{CO} = P(T_{CO}) \tag{9}$$

$$P_{EV} = P(T_{EV}) \tag{10}$$

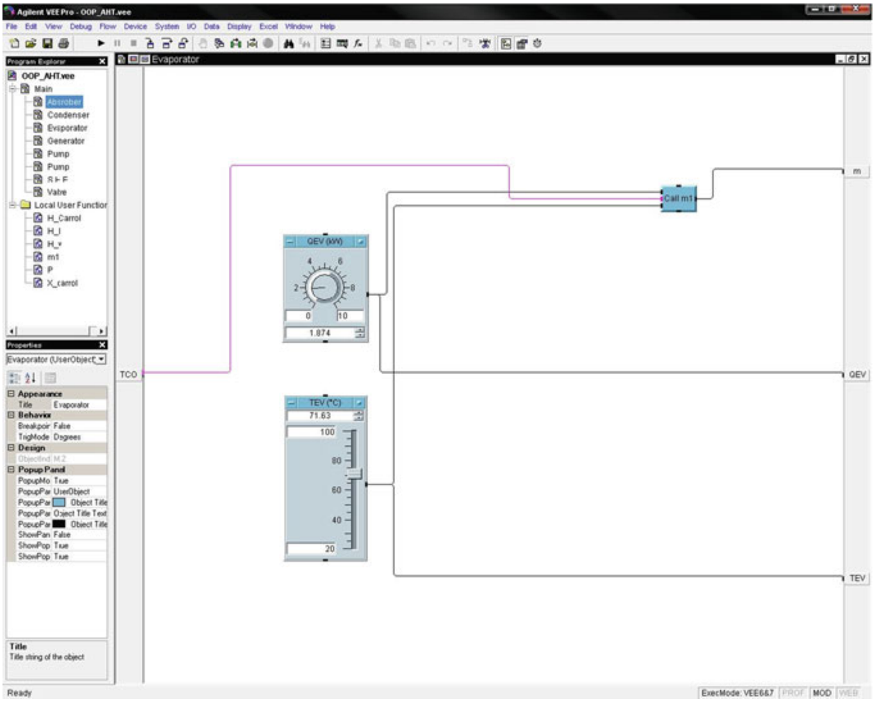



**Fig. 5** Subroutine for evaporator component

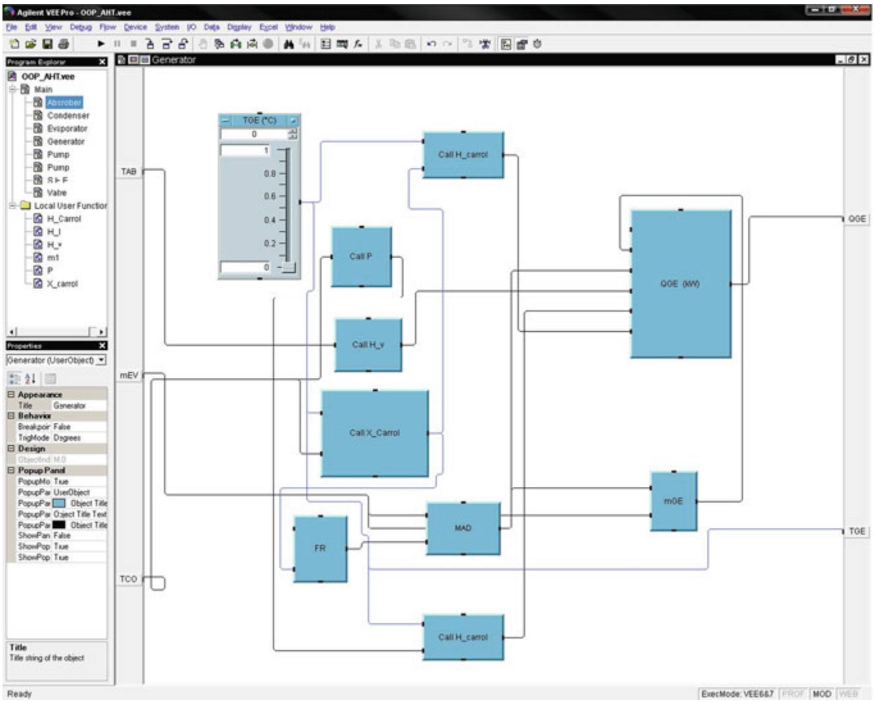



**Fig. 6** Subroutine for generator component

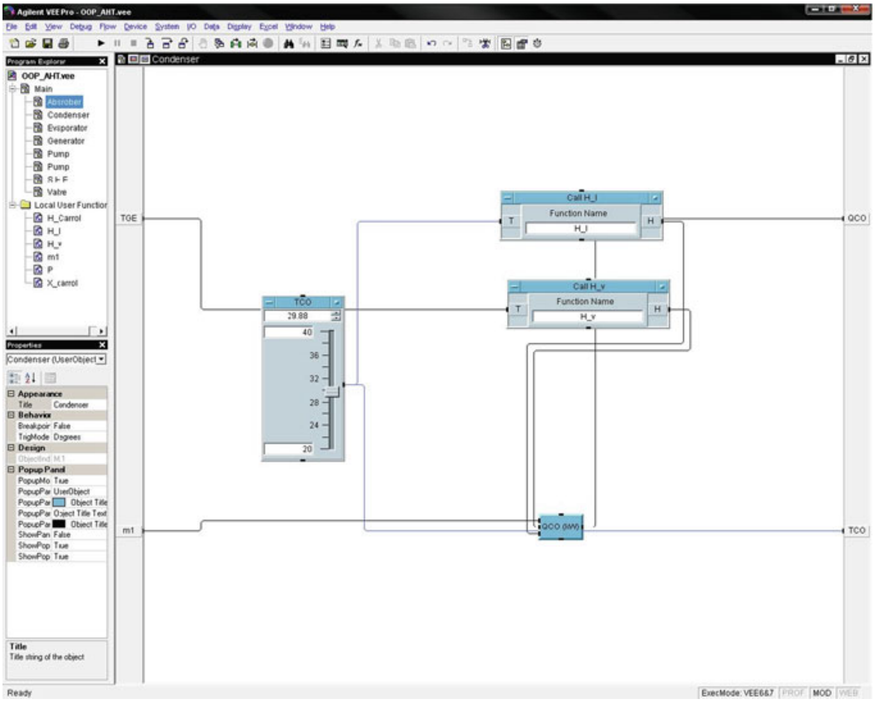



**Fig. 7** Subroutine for condenser component

## 6 Results and discussion

The OOP was implemented as follow:

An OOP for each energy balance was programming on HPVEE.

The subroutines programs are shown in Figs. 4, 5, 6, and 7. The power for each component into the AHT was made with mass balance in a HPVEE sub-module program. This other program is shown in Fig. 8.

The calculated data were obtained, for steady state and that was validated with a Heat pump simulator designed and reported by Romero [2].

The operating conditions show several operating conditions for the AHT. The calculated data confirm that COP is a temperature function.

The temperature of waste heat was simulated as constant value for any process.

The energy simulated has a constant temperature of 70 °C for the adding into the generators and evaporator.

The surroundings have the capability to sink energy at 20 °C for the non useful energy at condensers.

The AHT operates as literature [3], and the energy may be useful for water purification process.

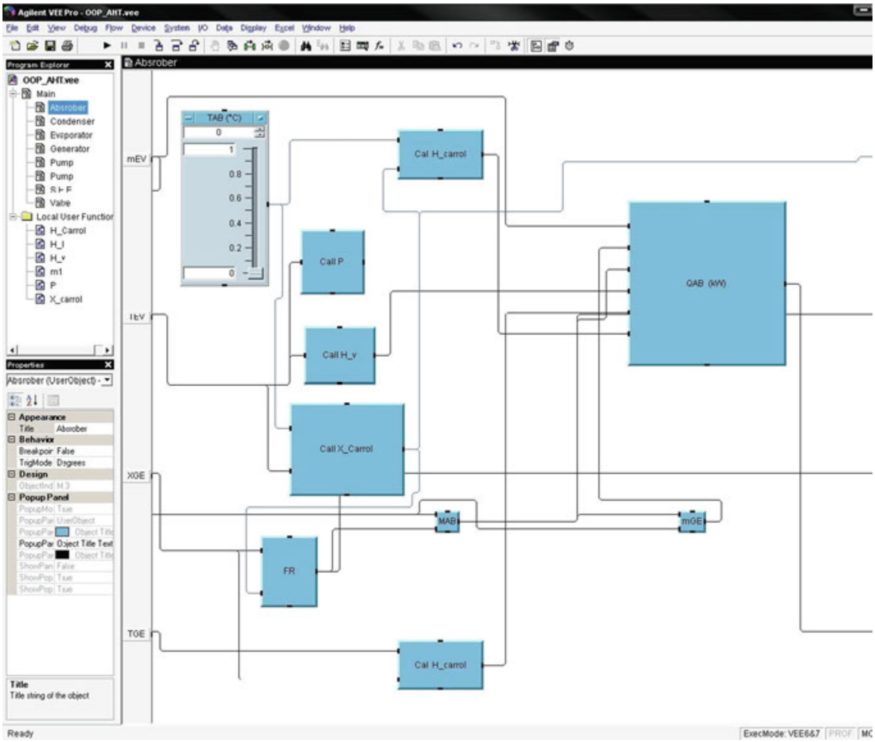



**Fig. 8** Subroutine for absorber component

The Fig. 4 shows the general linking or wiring for the subroutines for an advanced heat transformer. This program shows the local user functions defined for the Carrol – water mixture. For enthalpy (H_carrol), for vapor enthalpy (H_v), for water enthalpy (H_l), for mass flow (m1), for equilibrium pressure (P) and for Carrol concentration (X_carrol), take from literature [4], and using a different configuration by other authors [5] with and different mixture [6].

The Fig. 5 shows the evaporator subroutine, in this sub- program it is constant the power into the evaporator component, the input is only the variable $T_{CO}$, and the output are $m_{EV}$, $Q_{EV}$ and $T_{EV}$.

The Fig. 6 shows the subroutine for generator component, in this part the inputs are $T_{AB}$, $M_{EV}$ and $T_{CO}$, and the output are $Q_{GE}$, and $T_{GE}$.

The Fig. 7 shows the condenser subroutine, the inputs are $T_{GE}$ and m1 and the outputs are $Q_{CO}$ and $T_{CO}$.

The Fig. 8 shows the absorber subroutine, this is a complex program with 4 inputs: $m_{EV}$, $T_{EV}$, $X_{GE}$, $T_{GE}$ and 4 outputs: $X_{AB}$, $m_{AB}$, FR and $Q_{AB}$. There are 5 calls to several user functions. The flow control is very important parameter [6] and is used as reference value for aqueous lithium bromide cycles [7] and COP comparison.

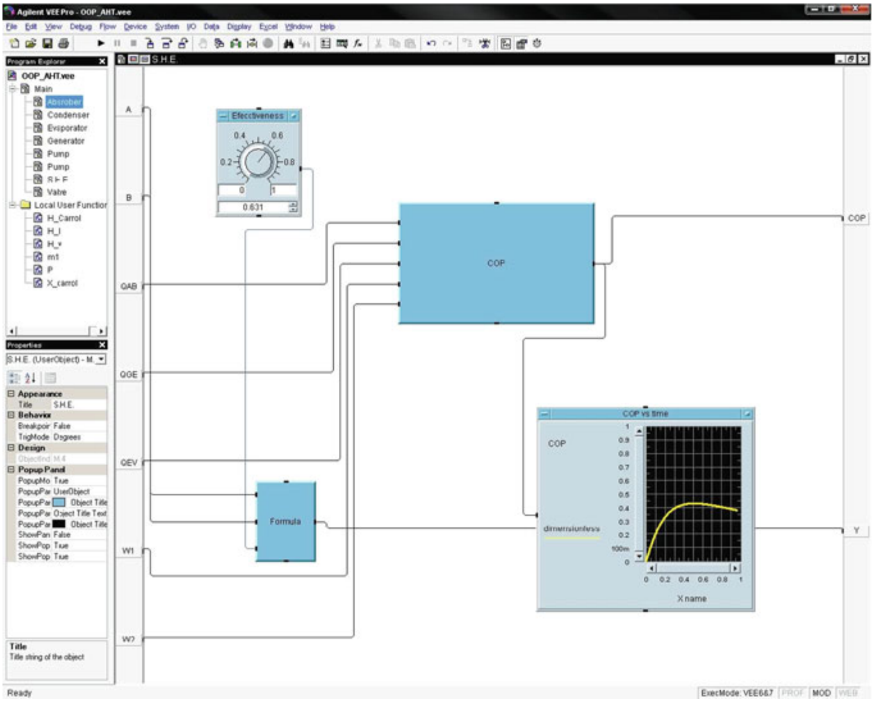



**Fig. 9** Subroutine for solution heat exchanger component

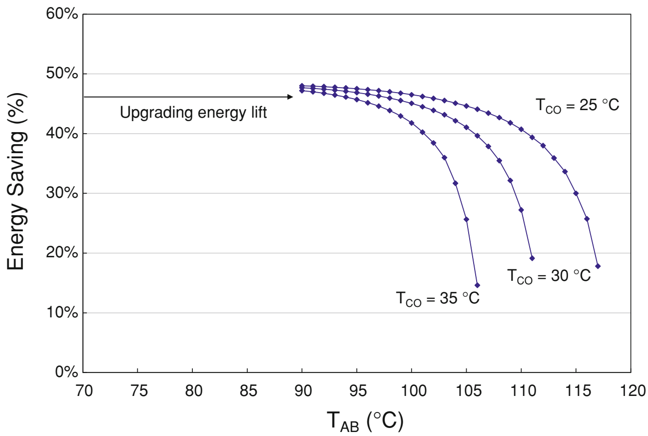



**Fig. 10** Energy saving percentage as function of useful level

Finally, the Fig. 9, shows the COP calculation as function of effectiveness of the heat exchanger, the power into the absorber, the generator and evaporator, as well, the pumping into the cycle.

Figure 10 shows three operating conditions simulated with the software, in this figure it can be observe there is a upgrading energy lift, from 70 to 90 °C or higher. The cycle saves 47 % at 90 °C, without influence of Condenser temperature. The Condenser temperature, which is the surroundings temperature, affects the saving percentage. For condenser temperature of 25 °C the saved energy is 30 % at 115 °C. For condenser temperature at 30 °C the saved energy percentage is 32 % at 109 °C. For sunny days at 35 °C the saved energy percentage is 32 % yet, but useful temperature is 104 °C. The best operating condition is 100 °C at 47, 45 and 42 % for condenser temperatures at 25, 30 and 35 °C, respectively. The range for water—Carrol concentrations was from 50.39 to 68.59 %, that values must be correlated using optical methods as literature suggests [8].

## 7 Conclusions

The object oriented programming (OOP) was used for calculate the mass flows for each line into a thermodynamic cycle for energy recover cycle. All subroutines were made for each component into an advanced heat transformer. Temperatures are assumed and powers are calculated, but evaporator power is constant. Effectiveness was assumed for the AHT. Simulation of AHT for revalorized effect of the waste energy was carried out. The maximum temperature for an AHT was calculated at 115 °C with a Coefficient of performance of 0.30. This means a 30 % of recover and revaluation of waste heat. The best recovered energy is 47 % at 100 °C.

**Acknowledgments** The authors thank to the CONACTY and PROMEP for partial support.

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# Application of Artificial Neural Networks in Chosen Glass Laminates Properties Prediction

**Soňa Rusnáková, Zora Jančíková, Pavol Koštial, David Seidl, Ivan Ružiak and Richard Puchký**

**Abstract** The article deals with applications of the artificial neural networks at the evaluation of chosen material's properties (sample thickness, sample shape) measured by electronic speckle pattern interferometry. We have investigated the dependence of the generated mode frequency as a function of sample thickness as well as the sample shape of glass laminate samples. Obtained experimental results for differently shaped glass laminate samples are compared with those of artificial neural networks and finite element method simulation. The coincidence of both experimental and simulated results is very good.

## 1 Introduction

The glass fabric laminates are widely used when large strength to weight ratios is required. Fibre-reinforced components of various shapes and different boundary conditions (free, clamped, and hinged) commonly occur in practice. Designers need to be able to predict the stiffness parameters and damping values of components for conditions such as aeroelasticity, acoustic fatigue, and so on [1, 2]. The paper [3] reviews the main developments in the field of electronic speckle pattern interferometry that have been published over the past 20–25 years.

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In the work [4] a specimen subjected to uniaxial tensile tests undergoes a thickness reduction that leads to out-of-plane displacements. The combination of the fringe projection technique and the Fourier transform method (FTM) allowed to monitor in real-time the out-of-plane displacement fields, induced on a brass sheet specimen in different regions of the tensile test. These maps enabled us to detect different trends in the deformation process and nonlinear effects linked to the progression of the thickness necking.

The high resolution technique electronic speckle pattern interferometry can be very useful in determining deformation of laboratory specimens and identifying of failure [5].

ANN are suitable for approximating complex mutual relations among different sensor-based data, especially among non-structured data, with a high grade of non-linearity, and with inaccurate and incomplete data. This type of data often occurs in material engineering. A number of applications, which are based on neural network exploitation, occur in material engineering at present. In this field neural networks are applied especially in diagnostics and process modelling and control [6].

Neural networks are capable of simulating behaviour of systems with very complex internal structure and complicated external behaviour, where analytic description is considerably complex; eventually it does not exist at all. They enable to simulate dependences which can be hardly solved by classic methods of statistic data evaluation (e.g. regression analysis) and they are able to express more complex relations than these methods [7, 8]. Neural networks are suitable for modelling of complex systems especially from the reason that their typical property is capability of learning on measured data and capability of generalization. Neural networks are able to appropriately express general properties of data and relations among them and on the contrary to suppress relationships which occur sporadically or they are not sufficiently reliable and strong [9].

The aim of the paper is to outline possibilities of artificial neural networks application for prediction of natural frequencies of glass laminates and to compare obtained experimental results for differently shaped glass laminate samples with those of artificial neural networks and *FEM* simulation.

## 2 Experimental Technique and Methods

*ESPI* records surface displacement of an object in response to the applied force. *ESPI* can be used in arrangements where fringes will represent lines of either in-plane or off-plane displacement.

The Fig. 1 schematically describes the layout of *ESPI* setup for off—plane measurement and real arrangement of the *ESPI.*

In the first step we have tested the mode frequency generation as a function of the sample thickness. Samples were prepared according to the Table 1. Table 2 describes the sample shape and dimensions for experiments with a different

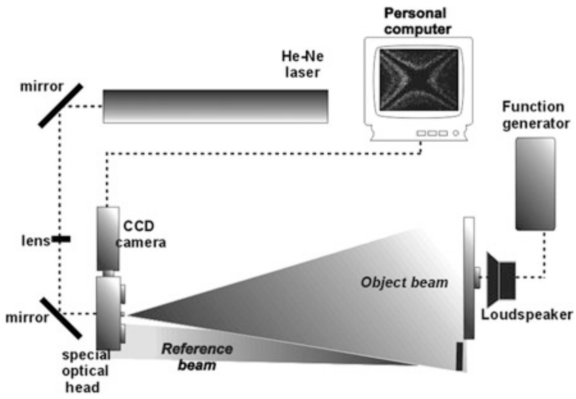
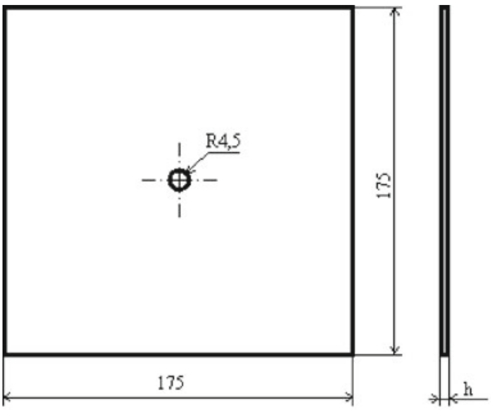



**Fig. 1** Schema of ESPI setup

**Table 1** Sample thickness values and corresponding sketch

| Sample number | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Thickness (mm) | 0.8 | 1.05 | 1.35 | 1.65 |




rounding. Sample with $r = 0$ is tetragonal and sample with $r = 87.5$ mm is a disc. Finally the Table 3 describes the sample shape and dimensions with different canting.

Neural networks were created in software STATISTICA—Neural Networks. This system enables among others a choice of most suitable with the best performance, it contains efficient investigative and analytic techniques and enables to achieve summary descriptive statistics, to execute sensitive analysis and to create response graphs. For particular neural network models a quality of network adaptation to the submitted patterns and generalization scale were observed.

The rate of inaccuracy between predicted and actual output represent a prediction error. In technical applications the error is mainly represented by

**Table 2** Sample rounding values and corresponding sketch

| Sample number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Sample rounding (mm) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 87.5 |

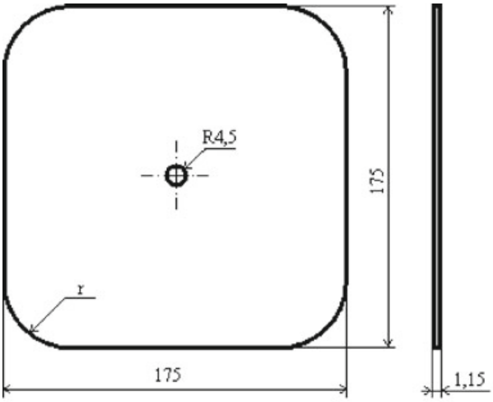
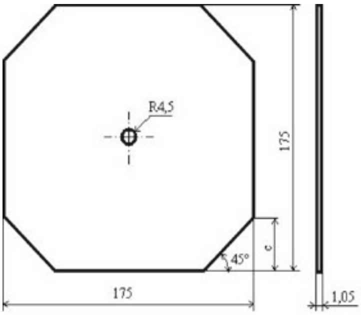



**Table 3** Sample canting values and corresponding sketch

| Sample number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Sample level (mm) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 87.5 |




following functions: relation for RMS error (Root Mean Squared), relation for REL_RMS error, $R^2$—determination index, SSE—Sum of squared error [7].

## 3 Results and Discussion

In the first step of our analysis we focus an attention on the (FEM) application and its comparison with ESPI mode measurements. Results are collected in the Tables 4 (ESPI) and 5 (FEM). Corresponding mode shapes are presented in all cases (Figs. 2, 3).

**Table 4** Resonance frequencies obtained by ESPI

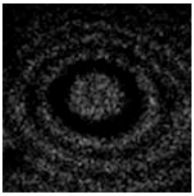
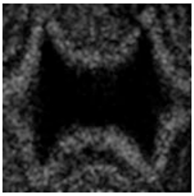
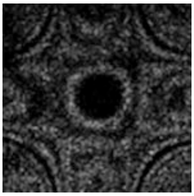
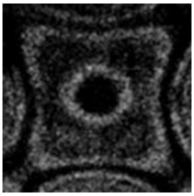
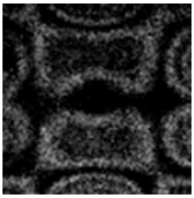
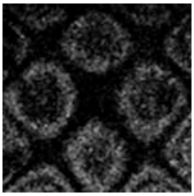
| | Mode | | Sample thickness h (mm) | | | |
|---|---|---|---|---|---|---|
| | | | 0.8 | 1.05 | 1.35 | 1.65 |
| Resonance frequency (Hz) | 1 |  | 61 | 78 | 93 | 112 |
| | 2 |  | 138 | 187 | 228 | 293 |
| | 3 |  | 179 | 248 | 309 | 378 |
| | 4 |  | 374 | 522 | 663 | 800 |
| | 5 |  | 432 | 620 | 758 | 919 |
| | 6 |  | 498 | 694 | 861 | 1058 |

**Table 5** Resonance frequencies obtained by FEM

| | | Sample thickness h (mm) | | | |
|---|---|---|---|---|---|
| | Mode | 0.8 | 1.05 | 1.35 | 1.65 |
| Resonance frequency (Hz) | 1 | 48 | 63 | 81 | 99 |
| | 2 | 167 | 219 | 282 | 345 |
| | 3 | 210 | 276 | 355 | 434 |
| | 4 | 403 | 530 | 681 | 832 |
| | 5 | 512 | 672 | 864 | 1055 |
| | 6 | 515 | 676 | 869 | 1062 |

**Table 6** Percentage deviation between ESPI and FEM results

| | | Sample thickness h (mm) | | | |
|---|---|---|---|---|---|
| | Mode | 0.8 | 1.05 | 1.35 | 1.65 |
| Percentage deviation | 1 | 27.1 | 23.8 | 14.8 | 13.1 |
| | 2 | 17.4 | 14.6 | 19.1 | 15.1 |
| | 3 | 14.8 | 10.1 | 13 | 12.9 |
| | 4 | 7.2 | 1.5 | 2.6 | 3.8 |
| | 5 | 15.6 | 7.7 | 12.3 | 12.9 |
| | 6 | 3.3 | 2.6 | 0.9 | 0.4 |

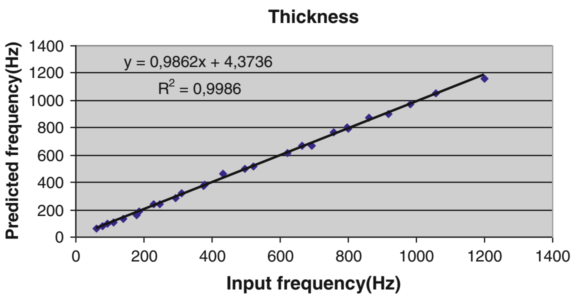



**Fig. 2** ANN prediction of resonance frequencies for different plate thickness

The measured values are higher than computed ones in the first mode only. The percentage difference of both sets decreases from the left to right table corner as well as in vertical direction than means at increasing mode frequency. These observations could be caused by model imperfections as well as material's constants indefinites of a model and real body respectively. A maximum observed percentage difference for the first mode is 27 % (thickness 0.8). All other differences are smaller than this value (Table 6).

For prediction of the resonance frequency in the dependence of the sample thickness data about sample thickness and type of mode (7 types of modes) were used as an input vector (8 neurons in the input layer). Output vector represented the resonance frequency (1 neuron in the output layer). The best results of prediction proved multilayer feedforward neural network with topology 8-3-1. Above

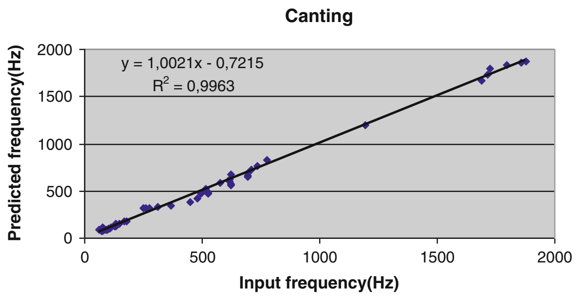



**Fig. 3** ANN prediction of resonance frequencies for different plate canting

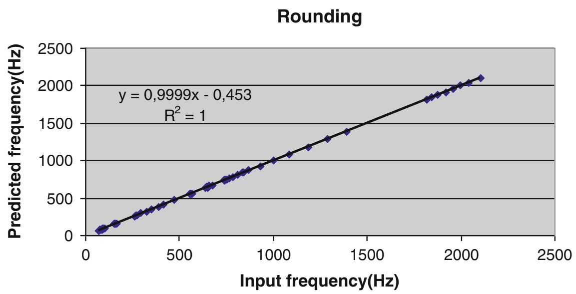



**Fig. 4** ANN prediction of resonance frequencies for different plate rounding

mentioned prediction errors for this neural network are: RMS = 13.668 Hz, REL_RMS = 0.0226, $R^2$ = 0.9983 (Fig. 4).

For prediction of the resonance frequency in dependence of sample rounding data about sample rounding and type of mode (9 types of mode) were used as an input vector (10 neurons in the input layer). Output vector represented the resonance frequency (1 neuron in the output layer). The best results of prediction represented multilayer feedforward neural network with topology 10-7-1. Prediction errors for this neural network are: RMS = 2.743 Hz, REL_RMS = 0.0031, $R^2$ = 0.9999.

For prediction of the resonance frequency in the dependence of the sample canting data about sample canting and type of mode (8 types of mode) were used as an input vector (9 neurons in the input layer). Output vector represented the resonance frequency (1 neuron in the output layer). The best results of prediction proved multilayer feedforward neural network with topology 9-3-1. For this neural network the prediction errors are: RMS = 31.6 Hz, REL_RMS = 0.0438, $R^2$ = 0.9962.

## 4 Conclusion

The models of artificial neural networks for prediction of resonance frequencies of glass laminates were created. These models enable to predict glass laminates resonance frequencies with a sufficiently small error. Obtained experimental results for differently shaped glass laminate samples were compared with those of artificial neural networks and finite element method (FEM) simulation. The coincidence of both experimental and simulated results was very good.

After evaluation of achieved results we can state that exploitation of neural networks is advantageous, if it is necessary to express complex mutual relations among sensor-based data and thus also for prediction of glass laminates properties.

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# Archaeology, Incas, Shape Grammars and Virtual Reconstruction

**W. Iain Mackay and Neander F. Silva**

**Abstract** This paper explores the application of shape grammars to Inca architecture with a view to establishing a system for virtual reconstruction at partially and substantially damaged archaeological sites.

## 1 Introduction

Archaeology as a discipline is well known for drawing on a range of seemingly unrelated topics and disciplines, which are used to expand the knowledge and understanding of the past. Archaeology can be of an almost parasitical nature, feeding off whatever disciplines it finds relevant and to which it can be attached. The "host" disciplines are often "tricked" into participating and collaborating. The Stockholm syndrome establishes itself and in no times at all the "victims" *cum* disciplines find themselves collaborating and even integrating studies from other disciplines. It can also be a symbiotic relationship, as often as not the target discipline also seeks to make use of data obtained archaeologically. A form of interdisciplinary syncretism frequently develops in these circumstances.

For example, an archaeologist may seek to understand the relationship of the skies, particularly the nocturnal skies that were contemporary with the construction of ancient structures or the development of calendars (e.g. the Mayas, Egyptians, Assyrians, Iron Age Britons, etc.). This process of understanding the past may involve consulting astronomers regarding the position of the Sun at

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certain times of the year, establishing the effects of structural positioning and topographic locations particularly in relation to events such as the solstices (e.g. the positions of Stonehenge; the Torreon and Intihuatana or Intiwatana, Machu Picchu, etc.), positions of stars and other heavenly bodies thousands of years ago; or understanding changes in the Earth's magnetism (through variations at the Magnetic North Pole), glacial advances and retreats and the embedded record (Quelccaya Ice Cap and Glacier, Cuzco, Peru), the El Niño phenomenon (linked to the demise of the Moche Culture; and the wider availability of the much cherished warm-water Spondylus shell), plate tectonics, changing environmental and climatic conditions, etc. The last items are more the remit of geologists. The list and range of experts from different fields of study can expand depending on the finds and observations made at the archaeological site being studied. The studies on the Mary Rose shipwreck have drawn in experts from a wide range of fields including those with expertise in the analysis of micro-fibers. Archaeology benefits and so does the discipline applied. The biologist will know from the micro-fibre analysis that such and such breed of sheep existed 600 years ago, or that hemp was cultivated around then, or that oak forests were wiped out in some areas in order to build the warship, etc.

Continuing in this tradition of borrowing extensively from other disciplines and seeking to apply the knowledge generated by these to archaeology and archaeological remains, this paper explores the initial stages of an algorithmic system for classifying groups of related structures and their parts.

The focus here is twofold; one is with regard to the description of structural and architectural remains and the second part or stage of the study has to do with the analysis and generation of rules used to establish basic algorithms for defining these architectural remains and their key parts. This is a useful step in preparation for integration of an interface (computing) which is expected to form part of the overall objective of generating virtual reconstructions of partially and substantially destroyed structures (the procedures should also have the potential to be applied to a range of other items, such as ceramics, etc.).

The principles of the system draw on an element of linguistic theory (initially developed by Noam Chomsky [1] in the 1950–60s and include research originally carried out by the mathematician Emil Post [2]) and its subsequent and modified application to the analysis of arts, architecture and related structures, through what are now commonly referred to as shape grammars [3]. Chomsky developed a generative grammar, where all the validated sequences of words (phrases) in a language could be generated starting from an initial symbol, gradually working through a series of substitutions. An analytical grammar will work in the opposite direction; from a sequence of words, the elements are isolated through Boolean procedures. Analogous to spoken languages, shape grammars follow the same path, but instead of words and phrases, they deal with two and three dimensional geometric shapes [4].

## 2 Shape Grammars

Shape grammars were developed by computer scientists, architects and theoreticians: James Gips and George Stiny [5, 6], William Mitchell [7], and a number of others such as Ulrich Flemming [8] and Terry W. Knight [9] from early 70s to late 80s. These consist of a system, somewhat similar to the earlier ones, but this time based on geometric shapes and Euclidian transformations for modifying and generating forms based on rules (these could include removing, adding shapes, the process of rotation, translation and scaling up or down, mirroring, etc.). In view of these factors, the concept of shape grammars was rapidly linked to computational design. Amongst the seminal studies in the field were those on Palladio's Italian villas [10], Mughal Gardens [11], Ice-ray Chinese Lattice work [12] and house plans, which were largely the work of Mitchell and Stiny.

Interest has grown in the use and application of shape grammars over the past 50 years, gathering greater momentum in the late 1990s. Much has been written on a range of methods used to develop shape grammars, be they analytical, parametric, set grammars, labeled grammars or colour grammars to name a few. Some were set up to deal with the problems of working in three dimensions, others with colours; others were of a predictable deterministic nature. The range of themes and topics where these grammars are developed and applied has also expanded and has, for example, been used for describing the megalithic tombs of Orkney [13]: Wren Churches of London City [14]; Ndebele Palaces [15], Turkish houses [16], Oscar Niemeyer's designs [17], coffee machine designs, and a wide range of other topics. The list continues to expand.

So where does archaeology fit in this case, that is, along with its endearing habit of absorbing any and every relevant topic and discipline? What do shape grammars have to offer the archaeologist?

As the study on Orcadian megalithic tombs and settlements would suggest, practical archaeology and the more theoretical aspects of shape grammar thinking can indeed be integrated. As we will suggest, and expand on at a later stage, it is not merely a fairly straightforward matter of methodically applying shape grammars to structures. What we propose here is more a question of going beyond analysis of structures through the application of shape grammars and seeking to find a practical application for these systems and their procedures. The expectation is—following through from the development of a series of rules generated by architectural-style-specific shape grammar—that it may be possible to set up shape grammars which contain algorithms of a generic nature which can be used to generate virtual reality reconstructions of archaeological structures which have been substantially altered or destroyed.

There are a number of advantages to this type of algorithmic system:

(1) Archaeology has moved considerably from the Layard, Schliemann, Woolley, Evans and Petrie schools of thought and associated methods of excavation, where vast areas of a site could be cleared to focus on the key monumental structures, to the detriment of retaining a chronological key to a site. In other

words a site would be extensively excavated, obliterating much of the archaeological record in the process. To their credit some of the early excavators would maintain a good record of the layers and the general stratigraphy. Nonetheless much of the stratigraphic record was destroyed during these excavations. With time the archaeologists excavating sites of major significance have become more restrained and more reticent in terms of carrying out major all-embracing excavations; with the exception of archaeological sites that are subject to emergency excavations (i.e. before major construction is due to take place or a valley is to be flooded). Today's archaeologists are rather more selective in terms of the areas they subject to an excavation. A good example of this is the restraint exercised by the excavators at the mound sites where the Emperors Warriors were buried in Xian, China. The archaeologists expressed a highly enlightened desire to leave as much of the site undisturbed until certain scanning skills had been developed and improved. This in turn has meant a higher level of preservation at the site. Preservation of archaeological sites and their associated record is now considered to be paramount. This means that other systems for obtaining useful data about a site need to be considered. A basic and more conventional one consists of marking off specific areas of an archaeological site and carrying out an excavation on a test pit or a restricted sample area. Other options include ground scans with resistivity systems, modified x-rays and laser technology.

In many instances there has been sufficient study of architectural examples and styles within a certain cultural group, which give the archaeologist and excavator a priori knowledge of what can be expected to be found, at a later date through an archaeological excavation. Roman state-sponsored and military architecture tends to fall into this category (from amphitheatres, blocks of flats, to *oppida,* bridges, ports and wharfs).

We would propose that where there is a "database" of structural types; shape grammars developed and linked to these groups of buildings can be brought into play in order to suggest and predict structural layouts and distribution, particularly in instances where the archaeological records are not readily available, thereby reducing the need for major excavations. To a limited extent this has already happened, in that a surveyor of a site will attempt to carry out manual reconstructions on paper from the limited structural foundation data he has available. At the same time the archaeological record is preserved, or, at least most of it is left undisturbed.

(2) The speed of virtual reconstruction should increase. A data-base based on pre-existing knowledge of prevalent structure shapes and sizes (of a specific culture or tradition) permits a greater appreciation of the architectural trends of the period being studied. Virtual reconstruction should be able to harness databases with pre-set shapes and types, saving time and reducing the need to have an in-depth knowledge of the system for generating shape grammars. It should almost certainly involve reduced computational input. Substantial progress has been achieved in the last years regarding the automation or the construction of friendlier interfaces for rapidly translating shape grammars into computer applications. It is not necessary any more for the implementer to be a fully trained programmer in

the sense of one who knows structured programming languages. It is possible to work most of the time within a graphical interface using metaphorical entities such as windows, icons, forms and flowcharts in order to produce a functional shape grammar application. The burden of resorting to scripting languages is being significantly reduced and this trend should continue in the coming years. Shaper 2D [18] was one of the earliest examples of such graphical programming environments. Some of the best examples of powerful programming systems are at present ParaCloud [19] and Grasshopper [20], just to name a few of them.

(3) Excavation costs should be vastly reduced as the result of such a system and only selective excavation at an archaeological site may be required to clarify relationships of structures as well as some stratigraphic and chronological problems (including recovery of other materials, which are useful tools, generally used in refining and defining chronologies; these can include ceramic evidence, metallurgy, bones and organic matter, carbon and pollen sampling, etc.).

(4) Virtual reconstruction plays an important part in many excavations and can be successfully integrated into museum displays and interactive opportunities for visitors. Virtual reconstructions in museum displays can be highly useful ways of portraying the past (and stages at a site or building) and ones that incorporate shape grammar derived reconstructions may well have an advantage, in that they can be generated from algorithms specifically formulated for a project and not from a generic and commercially available programme which could eventually be withdrawn from the market. It has to be recognized that some virtual reconstructions do not need computer technology to establish a highly successful representation of the appearance of ancient structures. The Guildhall, City of London representation of the Roman Amphitheatre, which was found below it, is based largely on the existing foundations and a creative display etched into glass and cleverly backlit to give the viewer a general outline of this structure. This however requires a lot of space. When space is at a premium computerized virtual reconstructions would have an advantage. There are a number of similar structures around the world ranging from the Coliseum, Rome, Italy to regional variations in amphitheater designs, for example, at El Jem, Tunisia, and similar structures, to the London one in Chester, England, which can be used for comparative purposes. While they may be built on different scales, there is a pattern to be established and a parametric shape grammar could be developed to describe this range of structures, wherever they might be found in the Roman world.

## 3 A Test Case: Inca Architecture

A test case for the application of parametric shape grammar rules to commonplace examples and one that provides fascinating results is as follows:

Inca architecture (approximately 1200–1450 A.D.) from the Andean region of South America is seen to reflect a high level of organization and in the overall scheme of things, demonstrates a substantial degree of application of modular

**Fig. 1** External view of a *kancha* wall at Ollantaytambo, Cuzco. Note the wall camber, sturdy corner blocks and trapezoidal doorway (Photo: Mackay 2007)

elements, which are repeated and in some instances expanded upon. The structures are, by and large rectangular and seemingly repetitive and unimpressive, adopting a format, which is of a universal nature, which are long low structures with triangular gable ends. What makes Inca architecture so distinctive? What are the traits? A relatively untrained eye will easily recognize Inca architecture anywhere in the Andes, quite often by identifying the fine masonry and the quality of the stone construction; however it must be mentioned that a large proportion of Inca architecture was fairly hastily built in *pirca* (fieldstones in mortar) or even adobe and yet it is still readily recognizable as Inca architecture.

The key to Inca architecture may initially appear to be the fine stonework but more careful analysis will point to the fact that Inca architecture is dominated by an obsessive interest in applying the trapezoid shape to everything in (and often around) a structure. The ground-plans of many a Inca structure will be discreetly trapezoidal. We go on to observe the walls. They have an internal inclination and a slightly greater external inclination or camber. Cut a section through an Inca wall and you will find that the cross-section is trapezoidal in shape (very slightly eccentric in cross-section). Structurally this type of design makes a lot of sense as the region sits on some extremely active tectonic plates (the Nazca Plate in particular) and faults. The corners of Inca structures are the most robust parts of the structure (see Fig. 1), and the joint of two tapering walls helped to produce highly anti-seismic structures capable of withstanding earthquakes in excess of 7–8 on the Richter scale. We like to compare this style of construction with the Greek concept of entasis, although this was most probably designed and applied with aesthetic motives in mind by the latter. The Inca architects took their concept of "trapezoidality" and Inca entasis a stage further by including doors, niches, full-length niches and windows which were invariably trapezoidal in shape. Some doors and niches could be double and in some instances even triple-jambed, yet always faithful to the tenet of trapezoidality. The distribution of these doors, windows and niches is usually carried out with consideration to location and placement factors such as symmetry along with fairly strict ratios and proportions.

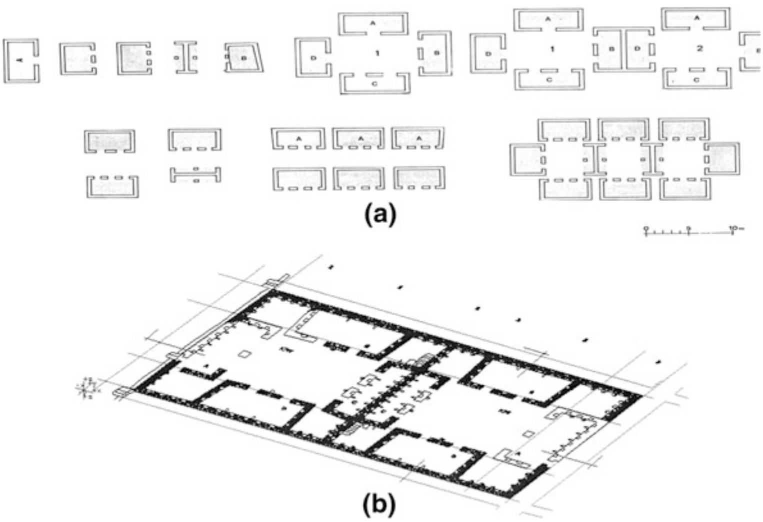



**Fig. 2** **a** Potential components of a *kancha* or multiple *kancha* structure **b** A ground plan of an Ollantaytambo *kancha* (based on Protzen 2005)

We have observed that in Inca architecture there are certain traits which are particularly distinctive, and that these can receive values which can be used to define shape grammars. These values can be based on ground plans but should preferably include elevations, which will refer to and include the Inca concept of entasis and trapezoidality. As it can be appreciated here, a degree of emphasis on the main features, and the need to understand the architecture to be analyzed can be beneficial in terms of what is considered the best method of applying shape grammar theory to it. This procedure should in fact apply to any study of architectural forms and archaeological remains which are going to be subjected to shape grammar theory and practice.

The majority of Inca structures tend to be rectangular in format with fairly set ratios. Quite often a rectangular structure of Inca origins and design can be split into smaller identical parts, or have other similar rectangular or quadrangular units added to them. These groups of related structures can be used to create compounds, which in Quechua are known as *kanchas* [21].

The term *kancha* or *cancha* is a fairly common indicator or toponym in the Cuzco region (the Inca heartlands) [22]. In the ancient Inca capital of Cuzco there are structures and areas known as Coricancha and Amarucancha; outside the capital, Patacancha (also known as Patallaqta) and a range of other sites.

These building groups are usually formed of four rectangular structures placed symmetrically round a central space or patio. Whilst there is an orthogonal rigidity to these compounds they can present a degree of variety within the *kancha* format. For example a rectangular unit may be excluded (possibly because of insufficient space, topographic restrictions, etc.) or a partial, or even a compressed, smaller scale structure may be added; another *kancha* placed adjacent to the original one, etc. Fig. 2.

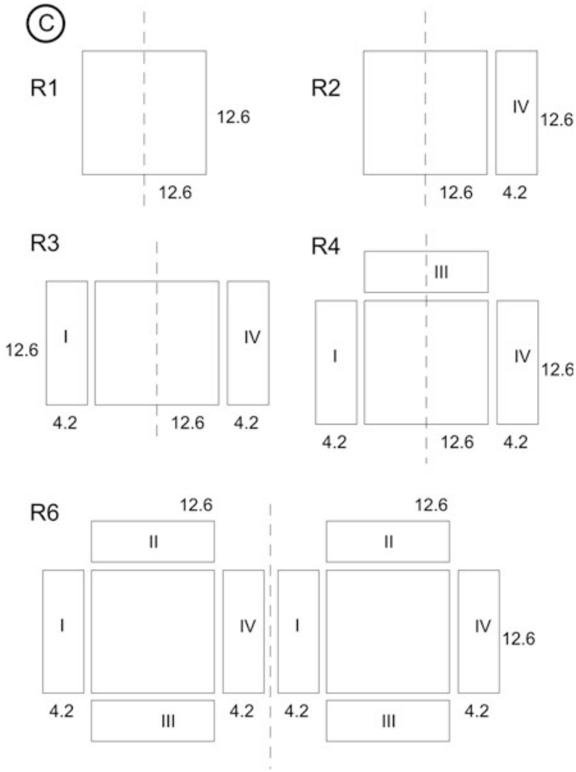
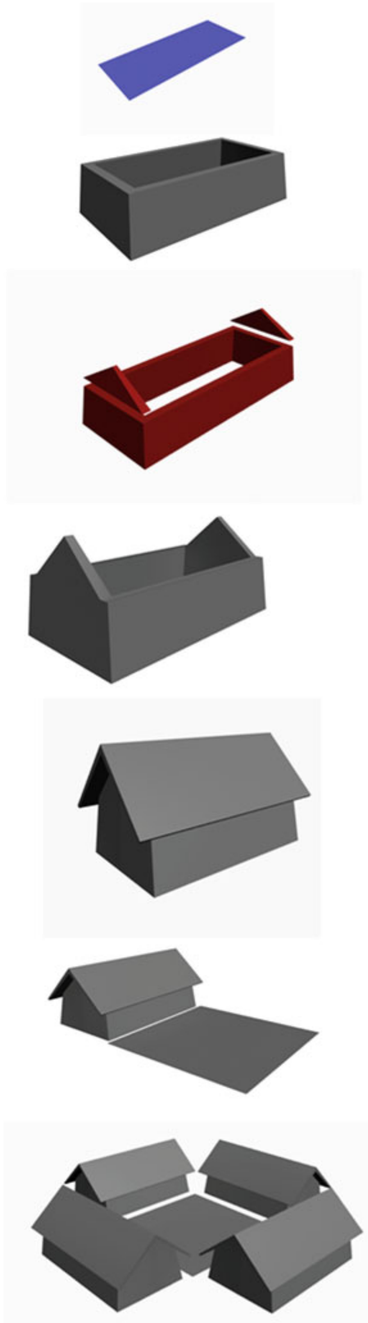



**Fig. 3** Summarized development of a shape grammar for an Inca *kancha* and double-*kancha* in two dimensions (ground plan)

This presents a unique opportunity to develop and test a shape grammar specifically designed for use with Inca architecture (similar projects have been developed by Stiny and Mitchell for Palladian Villas). Once defined, the groups of structural shapes can be added to and a more complete grammar of Inca architectural types can be developed. A full shape grammar is unlikely to be completed as the Incas did create a number of structures, which cannot readily be defined by shape grammars, for example various irregular shaped structures under rock faces at Machu Picchu and a few other similar structures. The area dominated by the Incas was the highly varied Andean region with an extraordinarily complex topography. Much as the Incas would probably have wanted to build orthogonal symmetrical layouts, the varied topography obliged them to adapt their modular structures to fit into confined spaces (e.g. if a rectangular structure was placed on one of a series of curved terraces, at least one wall of the rectangular structure was likely to follow the curvature of final terrace, and so forth).

The first stage in the definition of Inca shape grammars is that of generating a series of generic rules based on specific and more commonplace structures and groups of structures; subsequently applying transformation rules before reaching the final and transformation rule for each key structure. We will demonstrate the stages applied first of all through the illustrations below in two dimensions and then in three dimension (Figs. 3 and 4).

**Fig. 4** Summarized 3D version of development of a shape grammar for an Inca *kancha* (Felix Alves)



We have had to exclude the algorithms linked to the development of these as there is insufficient space, and likewise, those that describe the trapezoidal windows, doors and niches.

## 4 Conclusions

We hope to have shown how the concept of using shape grammars can be applied to ancient and pre-historic architecture, in this case specifically Inca architecture. However, the concepts could equally be applied to certain groups of pre-Inca architecture and similar architectural groupings worldwide, particularly where there is a strong stylistic thread evident in the architecture. As mentioned at the beginning of this paper, archaeology is adept at drawing from other disciplines and here we hope to suggest that the system developed and put forward could be used towards the virtual reconstruction of partially and substantially destroyed Inca sites. The concept has potential for application to virtual reconstruction in other areas such as ceramics, particularly where there is fragmentary evidence of a shape, etc. It should be possible to apply similar shape grammars procedures elsewhere, perhaps even going beyond the original and limited plans; and as Mitchell managed to achieve with his study on Palladio, devise 210 and more ground plans for Palladian Villas—considering design as computation—that is many more than the great architect Andrea de Palladio thought up himself [23].

The applications that have been proposed in connection with shape grammars over the last decades are many. The contribution of most of them is related to applying the theory to different cultures or architectural styles. In this sense our contribution to knowledge is also related to fact of developing a grammar to a style not studied before under this formalism: Inca architecture. However, we believe that our original contribution to knowledge goes further and resides in the potential application of shape grammars in the reconstruction of archeological sites which are highly damaged or where excavation is undesirable or impossible. To the best of our knowledge a study of this nature and detail this has not been proposed before.

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# Strategic Design of a Financial Model

**Simone Santos, Brandon Link, Mauricio Tagliari and Adolfo Alberto Vanti**

**Abstract** The study presents a strategic reconfiguration of a management system financial model involving Business Intelligence in the context of IT governance. Its practical application was tested with the use of a fuzzy design algorithm that was applied in a German plastics company in southern Brazil. It utilized the methodological technique called design research that was applied at all stages of the referred design. The new conceptual proposal was structured through interviews and the analysis of the company's systems. In addition the study quantified the relationships between strategic variables and created relevance matrices to reduce uncertainty. Elements of strategic planning were uncovered through documental analysis and submitted to the model based on the fuzzy algorithm [10], the result was a ranking by degree of importance that served as the design of the new system of Business Intelligence. After the new design was inserted in the context of Information Technology Governance, it identified the need for greater financial disclosure. To meet this need the study used the XBRL language and was validated in the "satisfactory" category by the Controller. In addition image/brand and cost optimization requirements were defined to align IT with organizational

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strategy, controlling the supply of information technology resources and preparing them to be used properly and in opportune moments of the decision-making process.

## 1 Introduction

Current economic pressures force companies to make decisions and respond quickly and flexibly. Decision making is the exercise of the skills and competence of the manager applied to the implementation of activities [11]. To [4, 13], information is an organized set of facts that generate added value and specific value beyond the fact itself. Business Intelligence (BI) is an area of information technology (IT) widely used in organizations because of its dynamism. This helps with formatting and reporting the firm's tactics and strategies.

BI is responsible for gathering information about organizations with the goal of providing useful and relevant information to users. This is of interest to decision makers and allows manipulation of data (sometimes in real time), giving users greater capacity for adequate analysis. Many times the decision requires the use of a multitude of nonstandard information and managers in this scenario raised concerns because of work overload and the limitations of the systems that provided the data manipulation. The manipulation of data (see the latest financial economic crisis triggered in 2008) encourages the need for information transparency for its users and the organization's managers, a fact relevant in the context of IT governance and possible with the use of BI.

Information Technology Governance (ITG), together with the assumed alignment between the strategic guidelines and objectives of the organization and the actions of IT, "does not consist of making specific decisions on IT because the administration already does this, but determines who systematically decides and contributes to them, i.e.," the specification of decision-making rights and responsibilities framework to encourage desirable behavior in the use of IT [19]. IT is also responsible for the interaction between internal and external users of corporate information. This is where the eXtensible Business Report Language (XBRL) language arises. It has the ability to generate files with transparency, reliability, timeliness and availability to all stakeholders, with the aim of improving the image of the company or to enforce legislation. This corporate image has been identified as a priority in this study.

## 2 Controllership

Managers have the responsibility to develop and implement strategies within organizations. The need to bridge the gap between operating and strategic goals leads organizations to redesign their systems, trying to align the information needs of their existing information systems with their strategic objectives. There is also need to disclose the status of company managers and shareholders through management reporting. This consists of agile, cohesive and confident information, necessary for making decisions which include the financial position of the organization.

Financial and property information of the company are available to the controllership or the financial department, which are responsible for the information system and assist managers in their decision making. To [8], the controllership performs the function of conducting and implementing information systems, along with motivating, coordinating, evaluating, planning and monitoring these systems which together serve as a basis for decision making for managers.

The controller is the manager of his area because he has the job of planning, managing, leading and conducting the plans to achieve the objectives outlined by the organization. In other words, the manager develops strategic and operational plans that he thinks are most effective in order to achieve the proposed objectives, along with coordinating and implementing those plans. Reference [15] emphasizes that to perform their functions in the organization the controller requires the application of appropriate principles that cover all activities of the company, from planning to obtaining the final result.

It can be said that the controller is the professional or manager in charge of controllership that familiarizes the managers from other areas about events that are occurring in the past and about new ways the company can draw on to achieve the goals set by management, enabling synergies. Therefore, this type of professional must be equipped with information technology resources and be prepared to use them properly.

## 3 Business Intellignece

For the IT area to be able to contribute to the development of BI, it is necessary that strategic planning is integrated and aligned with the strategic planning of information technology. For Ref. [2], "strategic alignment is the process of ensuring that all business functions operate in balance with each other to support the commercial scope." This consists of the strategic adaption and functional integration between the external (market and politics) and internal (administrative structure and technologic, human and financial resources) environments to develop the skills and maximize organizational performance. A novelty in this model is that the IT strategy can influence business, just as business strategy can influence IT [7].

Reference [9] also analyzes the need to align the area of information technology with the organization's strategy, emphasizing that IT must align itself through the portfolio of strategic services and IT alignment can occur via Business Intelligence systems. It also manages the data and focuses information for the generation of strategic knowledge. According to Ref. [1], one can find many solutions in the BI tools for the process of collecting, analyzing and distributing data and for the improvement of business decisions. These are available for a significant number of users within the organization, using various sources of information to help shape strategies for competitiveness in business affairs.

Reference [1] then characterizes BI "as the utilization of varied sources of information for defining strategies of competitiveness in the business of the company." More broadly, [12] conceptualizes BI as a set of concepts and diverse technologies that help the end user to access and analyze information from various sources, structured or not, but which should be organized to be available to users at any time and place. According to Ref. [16], the BI process is based on transforming data into information, then into decisions and finally into actions. BI also retrieves input usually extracted from various sources such as operating systems (OS), spreadsheets, web services, text files and integrated systems. In addition it is the storage of data (Data Marts and Data Warehouse), the analysis of information (On Line Analytical Processing—OLAP) and data mining, all essential components that make up the Business Intelligence tool.

Within the BI system is also the ETL process (extraction, transformation and load). Extraction consists of reading data from one or more databases, transformation is the conversion of data from its previous form into the form that must be to be inserted into a data warehouse or database and load is entering data into the data warehouse. The goal of the ETL is to load integrated and clean data into the warehouse and, after the ETL process, realize the standardization of these data, a "cleaning" which consists of the construction of filters and even the correction of some data derived from sources.

## 4 Research Method

Research is qualitative with a descriptive and applied nature. It is also characterized by the use of a quantitative and fuzzy algorithm [3, 5, 17]. It uses the Design Research (DR) technique for artifact generation of BI for the management system financial module.

This research was done on a subsidiary of a German multinational. The company was located in Sao Leopoldo—RS, in southern Brazil and operated within the plastics industry and it was focused on Financial Management Systems.

Data collection occurred with the following sources: documents, files, interviews, participant observation and physical artifacts [20]. The survey used the techniques of participant observation to identify the documents and the key people who participated in the survey. The documents used for the research were the following: company's strategic planning for the SWOT analysis (Strengths, Weaknesses, Opportunities and Threats), Manual of Business Intelligence Systems (Sadiq) and the CenariusERP system, in addition to various other documents and systematic interviews.

The respondents who answered questions pertaining to this study were the following: the controller, the industrial manager and the sales supervisor (responsible for the commercial and marketing areas). They provided information involving the relative values of importance of the elements used in the matrix of the strategic alignment model of Ref. [18] and information technology support, providing information on the systems used by the organization. The controller was interviewed during the assessment phase of the proposal and he did the proposal evaluation.

The survey was developed in the design cycle [14]. It consisted of five steps: problem identification, suggestion, development, evaluation and conclusion.

## 5 Data Analysis

**1st Phase of Research**—Identification of the problem—Related with the design of a BI proposal to improve the disclosure of financial information in the context of IT governance.

**2nd Phase of Research**—Suggestion—Aimed to consider the contributions of the theoretical framework reviewed in order to develop a provisional model of the strategic redesign of the financial system. This model was refined during the interim phase of development as recommended by the technical design research.

**3rd Phase of Research**—Development—Studied the reality of the company's ability to report the information utilized in the application of the proposal. There were five steps developed within this phase:

Step 1 Performed the reading of the studied systems and analyzed databases that were the basis for design development. The organization had an ERP called CenariusERP and a Business Intelligence system called Sadig Analysis. This analysis concluded that the ETL process (extraction, transformation and load) was done only for commercial modules (sales) and supply (stock). Data were extracted, processed and consolidated for uploading to a Sadig Analysis management database.

Step 2 With the managers (controller, supervisor and manager of industrial sales) the degree of relevance of the relationship between the elements of environmental analysis and the strategic objectives and actions was identified.

Step 3 Used the strategic alignment model from Ref. [18] to compose the information needed to apply compensatory fuzzy logic and the questionnaire proposed by the authors to guide the round of interviews. It assigned degrees of relevance to the fuzzy relations between the elements analyzed, using a scale of 0 (false) to 1 (true). As a result of the SWOT-OA, the system generated a report with a degree of relevance ranking that served the new design of the financial system.

Step 4 Presented the Cycle of ITG for the proposed new strategic redesign of the financial system that was conducted in the context of ITG [6]. It introduced the factors that provide the alignment of the strategic objectives of the organization. Another issue identified refers to XBRL which examined the financial disclosure with greater transparency, providing better flow of information and flexibility to users.

Step 5 Completion of the Artifact—From the analysis of the CenariusERP system models the level of support to managers and prioritization of strategic variables the elaborated a framework to illustrate the strategic redesign of the financial system model.

As shown in Fig. 1, the departmental data marts presented with the suggested reconfiguration of the new model of BI are: commercial (the current Sadig Analysis system already contemplated revenue), financial supplies (the current Sadig Analysis system already included the inventory position), production and cost, and quality control.

The departmental data marts presented in the suggested redesign of the new model are commercial (in the current Sadig Analysis system already included in sales), finance, suppliers (in the current Sadig Analyses already included in the supply position), cost and production and quality control.

As discussed in the financial disclosure cycle of ITG, it was suggested that reports be made available in XBRL format. The suggestion was made with the aim of redesigning the financial system in the context of ITG. Reports to clients and stakeholders can be informed via the website of the studied company.

**4th Phase of Research**—Presentation and evaluation of the new proposed strategic reconfiguration—The evaluation of the proposed redesign was done by qualitative analysis through interviews with the controller to compare whether or not they had achieved their goals. With this, five questions led to the appraisal interview for the completion of the artifact. The proposal for a strategic redesign of the financial system was presented to the respondent with the appropriate diagramming for better understanding, as well as the context of ITG and also the reports in XBRL. It also presented the results of the prioritization of the three interviewees collected from the application of fuzzy logic. These prioritizations were used to determine which needs the financial system should be met first.

According to the analysis of Subject 1 (controller), the redesign prioritized the information needs of the organization, improving decision-making speed. He also noted that with this new design, finance area (controllership) started to act more effectively in decision support, informing and guiding the areas in relation to the present and the future of the company. They showed interest in disclosing company information provided in XBRL format to consider the integrity and security of corporate information. They affirmed that with gains the new design also included further optimization in the costs models, this being one of the current actions of the financial area.

**5th Phase of Research**—Conclusion—In agreement with the evaluation of the controller, the new strategic design of the ITG financial system met the

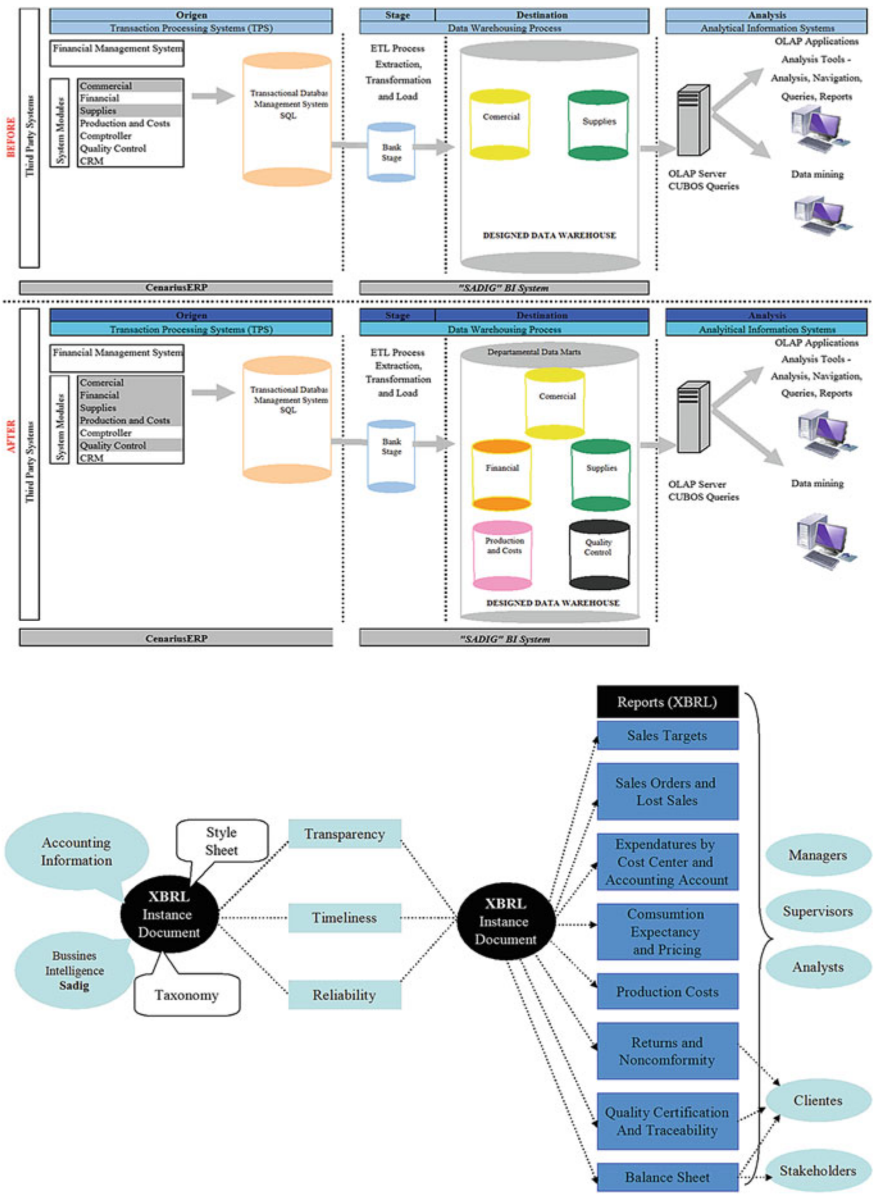


**Fig. 1** Business intelligence system before and after the strategic reconfiguration

expectations of managers. The strategic focus of BI, defined by calculating the priority of objectives and strategic actions has adequately met the needs of the company. This occurred through the use and cycle established in the design research technique.

With this it was possible to align the research objectives and with the assessment it was also possible to show that the “Image/Brand,” were the items that the evaluator affirmed as the greatest interest of the company that the new system should exhibit. It also showed that IT objectives aligned with IT Governance. Thus, the financial area could provide information in a faster and more cohesive manner to support decision making, informing and orienting managers in relation to possible changes to the present and future market demands for this type of company.

## 6 Conclusions

The general objective of this study was to develop a new strategic design of Business Intelligence for the financial module in the context of IT governance.

The decisions made in an organization can be affected by the lack of reliable and timely information. Thus the BI proposal in this research provided strategic information pertinent to the information needs of the decision maker.

Other strategic variables were identified according to the use of system management support and new needs. The proposed new design redefined the financial system in the context of ITG and the use of the Design Research (DR) technique was considered satisfactory, reaching the proposed objectives. It found that “Image/Brand” were the items mentioned with most interest by the company in disclosure with the business partners. The cost reduction was proposed in the modules of the new BI as one of the very specific actions of the area.

The research concluded that development of a new strategic Business Intelligence design requires an answer to IT governance and, consequently, Corporate Governance. One should also align the organization’s strategic objectives with IT in ways calculated to provide an understanding of their own organizational strategy.

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# Numerical Analysis of Electromagnetic Field Coupled with the Thermal Field in Induction Heating Process

**Mihaela Novac, Ovidiu Novac, Ecaterina Vladu, Liliana Indrie and Adriana Grava**

**Abstract** The main goal is to present results of numerical simulations of induction heating process in pieces of cylindrical shape, using an inductor with variable step between the coils. Inducting heating process modelling was made with the Flux2D software and for study we present the temperature charts of the billet at different time steps.

## 1 Introduction

In the process of solving the electromagnetic state of the coupled electromagnetic and thermal field calculation it was used the Flux 2D program. The electromagnetic field can be analyzed using the finite element method (FEM) or the finite element method (FEM) complemented with an impedance boundary condition. The geometry and the skin depth give the selection of the solution method. [1].

For the numerical analysis of electromagnetic field we have used the FEM. Also in the process of solving the electromagnetic field is useful to take in consideration

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the problems of eddy currents and for the thermal field, the Fourier and heat equations [2].

Modern technologies based on heating by eddy currents were developed rapidly in recent years, due to the significant advantages offered by this process compared to other conventional heating methods [3].

In the process of solving the electromagnetic state of the coupled electromagnetic and thermal field calculation we have used the Flux2D program. The electromagnetic field can be analyzed using the FEM or the FEM complemented with an impedance boundary condition [1, 4, 5].

Different calculation methods, computer programs and experimental equipments used for matematical and physical analyses of the complex process in the induction heating, are discussed in the technical literature [2, 6–8].

# 2 Problems of the Electromagnetic Field Coupled with the Thermal Field

## 2.1 Electromagnetic Field

Electromagnetic field is described by Maxwell equations:

$$rotvrot\mathbf{A} + \left(\sigma\frac{\partial \mathbf{A}}{\partial t} + \sigma grad\ V\right) = 0 \quad in\ \Omega \tag{1}$$

$$rotvrot\mathbf{A}{=}J_0 \text{ in } \Omega_0 \tag{2}$$

From Eq. (2), it results:

$$div\left(\sigma\frac{\partial \mathbf{A}}{\partial t} + \sigma grad\ V\right) = 0 \tag{3}$$

We impose V is defined only on Ω. On surface of conductor body Ω, the normal component of current density is zero, so:

$$\left(\sigma\frac{\partial \mathbf{A}}{\partial T} + \sigma grad\ V\right)\mathbf{n} = 0 \quad pe\ \partial\Omega \tag{4}$$

A standardization condition frequently, used is standardization condition Coulomb, a supplementary condition which must be imposed in order to vector potential **A,** this condition is used to ensure oneness of solution (**A**,V) in addition, on border $\partial\Omega_T$we have folowing border conditions ($FR_A$):

$$(\alpha)\mathrm{nx}\nu\mathrm{rotA} = \mathrm{gpe\ S'}$$

$$(\beta)\mathrm{A_n} =\ 0\ \mathrm{peS'}$$

$$(\gamma)\mathbf{A}_\mathrm{t} = \mathbf{f}\mathrm{peS''}$$

($\delta$)if $S''$ is formated from n surafaces $S_k$, then on n-l surfaces flux **A** is zero Standardization condition Coulomb:

$$\mathrm{div}\mathbf{A} = 0 \tag{5}$$

which, for discontinuos surfaces, preserves the normal component. Then **A** is continuous on $\Omega_T$.

## 2.2 Thermal Field Problems

The Fourier equation for stationary regime of thermal field

$$-\mathrm{div}\lambda \text{ grad T} = \text{p} \tag{6}$$

where: $\lambda$ is the thermal conductibility and p is the volume density of the power that is transformed from electromagnetic form to heat.

We have the boundary condition:

$$-\lambda \frac{\partial T}{\partial n} = \alpha(T - T_e) \tag{7}$$

where: $\alpha$ is convective thermal coefficient and $T_e$ represents the temperature outside of the domain $\Omega_\theta$.

Thermal diffusion equation is:

$$-\mathrm{div}\lambda \text{ gradT} + \text{c} \frac{\partial \text{T}}{\partial \text{t}} = \text{p} \tag{8}$$

where: c is the volume of thermal capacity.And the initial condition for the temperature is considerated: $T(0) = T_{in}$ .

# 3 Numerical Modeling

This aim of this paper is to study an induction heating system with axial symmetry in which we have a combined electromagnetic and thermal field calculation for the induction heating system.

The inductor length is $L_i$ = 1240 mm, and a particular property of the inductor is the variable step between the turns of coils. The shape of inductor turns are rectangular.

We have obtained the following results from calculus:

- current density $J_i$= 31 A/mm$^2$;
- frequency f = 2500 Hz;
- inductor length $L_i$ = 1240 mm;

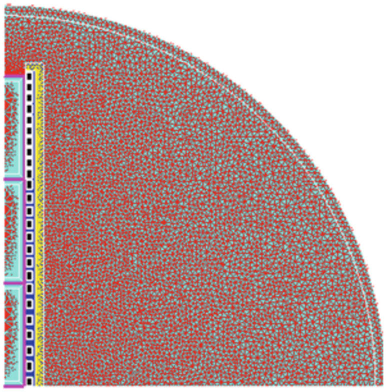


**Fig. 1** Mesh

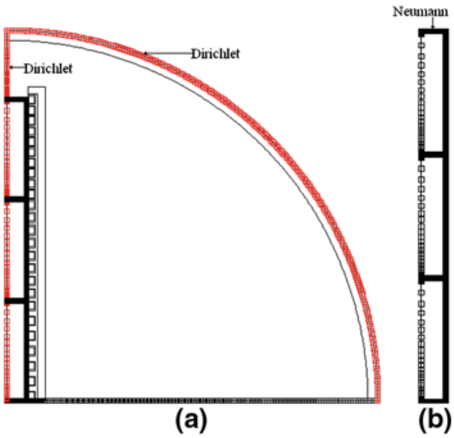



**Fig. 2** **a** The border conditions for electromagnetic field problem, **b** The border conditions for thermal field problem

- piece length $a_2$ = 200 mm;
- piece diameter $d_2$ = 80 mm;
- number of turns $N_{sp}$= 56.

The inductor process pieces of cylindrical shapes and the distance between two consecutive turns is variable, In the middle of inductor the distance between two consecutive turns is 5 mm, and at the end of inductor the distance between two consecutive turns is 1 mm (Figs. 1, 2, 3, and 4)

The structure of Magnetic field lines demonstrate the poor penetration of electromagnetic lines at the start of heating when all the piece is magnetic; and at the end of heating when we reach the maximum temperature (1300 °C) the surface of piece is characterized with temperature above the Curie point, the piece is non-magnetic and the electromagnetic field has a better penetration in the piece.

Temperature map in piece for different times steps: (Figs. 5, 6, 7, and 8)

The distance between two consecutive turns of inductor is variable at the end of inductor and is equal to 1 mm and the distance increase towards the middle of

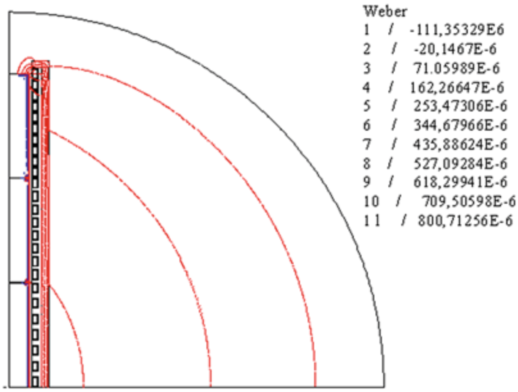



**Fig. 3** Magnetic field lines at the start of heating process

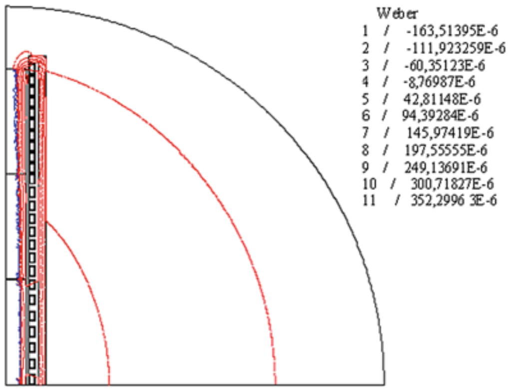



**Fig. 4** Magnetic field lines at the end of heating process

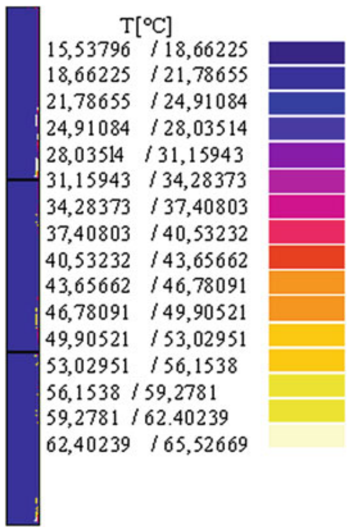



**Fig. 5** Temperature map in piece t = 0,00331 s

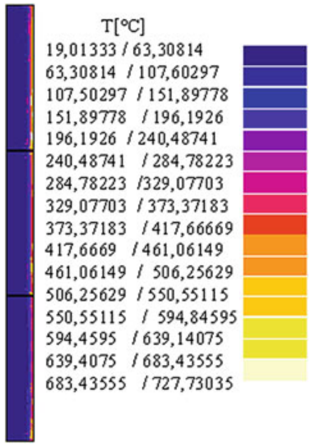



**Fig. 6** Temperature map in piece t = 1,4331 s

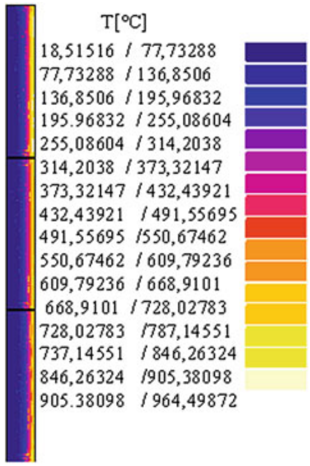



**Fig. 7** Temperature map in piece t = 5,2971 s

inductor until 5 mm between two consecutive turns. From this reason we observe that at the end of heating process (Figs. 9 and 10), the pieces towards the ending of inductor have higher temperatures.

In Fig. 11 we present temperature evolution in points 1-(5,600) and 2-(35,600), in pieces, where we will make the analysis of temperature field.

The point 1 is situated in the middle on the piece and the point 2 is situated at the surface of the piece.

**Fig. 8** Temperature map in piece t = 7,0771 s

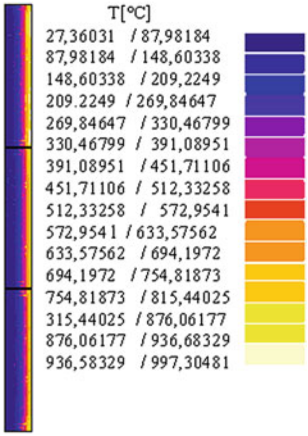



**Fig. 9** Temperature map in piece t = 10 s

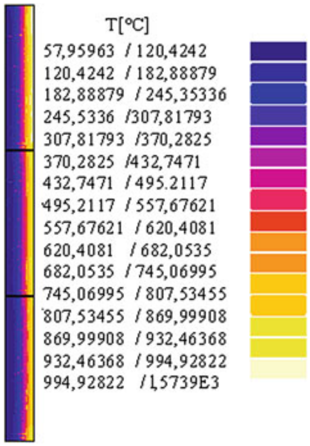
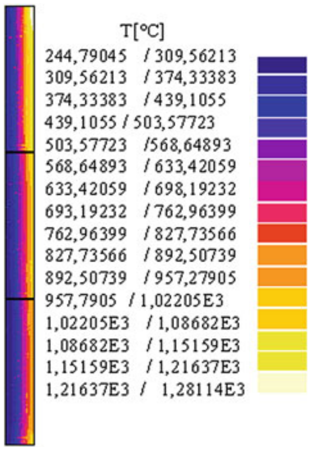



**Fig. 10** Temperature map in piece t = 20 s



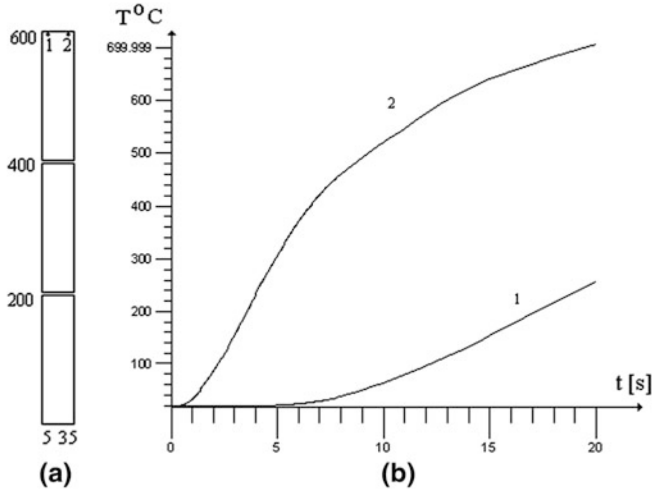



**Fig. 11** **a** Position of points 1 and 2 where we will make the analysis of temperature field **b** Curves that presents the temperature evolution in points 1 and 2

## 4 Conclusions

The paper presents the examination results of induction heating process of cylindrical shapes pieces with variable distance between two consecutive turns. Simulation was carried out on the basis of two-dimensional, axis-symmetrical model. Flux2D was used to solve coupled electromagnetic and temperature problems. On the basis of the obtained results we can com to following conclusions:

At the end of heating process when we reach the maximum temperature (1300 °C), the surface of piece is characterized with temperature above the Curie point, the piece is non-magnetic, and the electromagnetic field has a better penetration in the piece.
At the end of heating process, the pieces towards the ending of inductor has higher temperatures, were the distance between two consecutive turns of inductor is lower (turns are more dense)
Application of magnetic core can improve parameters of the heating device. Additional advantage is considerable limitation of electromagnetic radiation round the inductor.

The disadvantage that belong to all applied methods consists in the fact that electromagnetic design problems are very demanding in terms of computing resources, by requiring the resolution of a complex electromagnetic problem for each evaluation. When the complexity of the adopted model increases, the development time of a new device configuration is high.

Additionally, applying optimization methods in the design of the electromagnetic devices lead to better designs that behave with higher efficiency and a more uniformly distributed temperature.

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# Process Deployment: A Taxonomy of Critical Success Factors

**Luz S. Bayona, Jose A. Calvo-Manzano, Gonzalo Cuevas and Tomás San Feliu**

**Abstract** Various methods, models and standards for software process improvement have been adopted by organizations to improve their software processes. However, despite these efforts they still encounter difficulties in their process deployment throughout the organization. This is because the vast majority of these efforts focus more on the technical aspects, bypassing the human aspects. There is a set of factors that influence the successful deployment of new or modified processes. This paper presents taxonomy of critical success factors in software process deployment to achieve the processes institutionalization. The development of a taxonomy related to these critical success factors is based on a systematic review of existing literature on specialized databases and industrial experiences that have deployed or implemented processes.

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## 1 Introduction

VARIOUS models and standards have been created to improve processes. However the implementation of these models and standards in organizations presents difficulties that include: (1) improvement efforts are not aligned with business goals (2) lack of leadership and visible commitment to improvement efforts (3) the process does not respond to business needs (4) efforts to implement technical aspects ignore strategies based on the social aspects [1].

According to Niazi [2], the problem of process improvement is not the lack of standards or models, but the lack of a strategy to implement these standards or models. Not considering the social aspects of a strategy for process deployment, threatens the institutionalization of the deployed processes.

Deploying processes based on any of the models and/or standards for process improvement requires a strategy to achieve the use and adoption of the new processes. This strategy should be based on change management and focusing primarily on the people to facilitate transition to the changes which involve the deployment of the new processes, and minimize resistance to such changes.

Although the above seems so basic, when putting into practice is neglected.

We have detected that most research are focused on improving the technology, but few mention other important factors such as culture, change management, people, communication, and training during and after the deployment process. Mc. Dermid and Bennet [3] have argued that human factors for software process improvement have been ignored and this has impacted heavily on process improvement.

According to Zahran [4], the inadequacy of proposals on the implementation of process improvement is one of the most common reasons for failure of improvement initiatives.

Identifying the factors that determine the success or failure of the process deployment is fundamental. However, it is necessary to standardize and classify these factors, which are described by different terms by different authors.

It is then necessary to have a method to classify them using common terms. To do this, two sources have been used; systematic review of the literature and the factors identified in software development organizations.

Then, to identify these factors, it is necessary not only to review the scientific evidence resulting from empirical or organizational research, but also check what is really happening in organizations that deploy their processes and identify critical success factors that influence the successful process deployment.

In order to maintain a common language in the organization, it is important to classify the factors that determine the success or failure of the process deployment.

With this objective, this paper presents a method for developing a taxonomy of factors that impact the deployment process and should be considered in the deployment strategy.

The identification of these factors is based on a systematic review of articles and studies contained in bibliographic databases and those factors that have been identified in software development organizations during the deployment process.

This paper is organized as follows: Section 2 describes the research method for identifying the critical success factors of the deployment process, Sect. 3 describes the method to developing taxonomy, Sect. 4 presents the critical success factors taxonomy, Sect. 5 presents benefits of the critical success factors taxonomy, and Sect. 6 presents the conclusions.

## 2 Research Method

The identification of the factors was obtained from two sources:

- Factors identified during the systematic review of articles and publications.
- Factors identified through process deployment in software development organizations.

### 2.1 A. Factors Identified During the Systematic Review of Articles and Publications

The factors were identified during the systematic review of articles, publications, presentations and technical reports contained in specialized databases such as Science @ Direct, IEEE Computer, ACM Digital library, SpringerLink, ISI Web Knowledge, Wiley InterScience; articles and conference presentations as Software Engineering Process Group (SEPG) Conference Series Specialized and European Systems & Software Process and Innovation (EUROSPI).

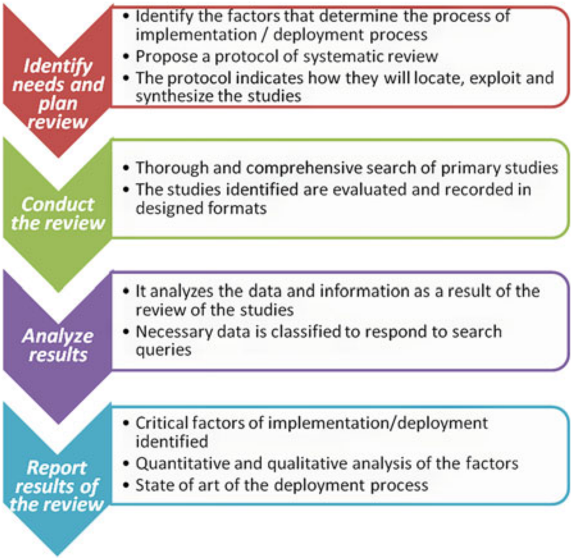
In addition, articles and presentations by Software Engineering Institute (SEI), Crostalk, IT Governance and Google Scholar, were also taken into account.

All of the above are related to process improvement and deployment. To perform a systematic review the method proposed by Kitchenham [5] and Biolchini [6] has been followed. Figure 1 shows the steps and activities of the method used for the systematic review.

### 2.2 B. Factors Identified Through Process Deployment in Software Development Organizations

The factors were identified through process deployment in software development organizations using CMMI [7] as a reference model for the definition of their processes.

Fig. 1 Systematic review phases




To identify the factors affecting the process deployment in organizations, a research was conducted in five organizations distributed in Latin America and Europe.

To achieve this objective, the following activities were carried out:

- Identify issues to investigate and develop the work plan.
- Identify those responsible for the deployment of processes in organizations.
- Identify the processes deployed in the organization.
- Develop a questionnaire with open and closed queries on the critical success factors identified in the deployment process.
- Conduct a survey in organizations.
- Analyze the results of the questionnaires.

## 3 Taxonomy of Critical Factors and Method for ıts Construction

With the results of previous activities, two lists of critical success factors are obtained in order to be considered in the process deployment.

It is necessary to standardize the critical success factors in order to use a common language.

For this, a basic activity that has been performed is the development of a taxonomy to classify the critical success factors based on a systematic review, and on the industrial experience and knowledge of experts.

The purpose of taxonomy is to enable organizations to identify the factors that may affect the deployment process and include an inventory of the items identified.

Identifying critical success factors of process deployment is to classify the factors that can determine the success or failure of the deployment. The critical success factors should be taken into account when developing a deployment strategy. The result of the identification of factors is a list containing the key success factors which have been identified.

The main objectives of establishing the taxonomy are:

- Provide support during the preparation of the process deployment method.
- Facilitate the search and grouping of relevant information.

To set this taxonomy, a method based on a systematic review of methods and models used for the development of taxonomies has been developed [8–16].

In this section, the method for the design of the critical success factors taxonomy for the process deployment is explained.

The method has been developed in order to serve as a guide for building the taxonomy of critical success factors of the deployment process.

The proposed method consists of five phases.

- Phase 1. Planning.
- Phase 2. Identification and extraction of information.
- Phase 3. Design and construction of the taxonomy.
- Phase 4. Testing and validation.
- Phase 5. Deployment of taxonomy.

These phases are described in briefly in the following sections.

## 3.1 Phase 1: Planning

The purpose of this phase is the planning of the project that will result in the design and implementation of the critical success factors taxonomy of the process deployment. The products obtained in this phase are: (1) Work Plan for the development of the taxonomy, and (2) Taskforce for the development of the taxonomy.

## 3.2 Phase 2: Identification and Extraction of Information

The purpose of this phase is to align the work plan with the information needs of the organization. At this stage the sources of information, the terms or variables to use, the definitions that will be part of the taxonomy will be identified.

The extraction of the necessary information for the elaboration of the taxonomy may come from internal and external sources. Internal sources are: (1) revisions which are carried out with the user's taxonomy (2) surveys to identify needs

(3) policies to be followed for the taxonomy to have meaning and to be of usefulness to the organization, and (4) the information from representatives of all involved areas.

External sources include information from other organizations such as (1) scientific literature related to the subject under study (2) existing business cases, similar experiences of other organizations.

The products obtained in this phase are: (1) general inventory for the construction of the taxonomy (2) policies for using the taxonomy (3) characteristics of the technology to use, and (4) list of representatives of all involved areas.

### 3.3 Phase 3: Design and Construction of the Taxonomy

The purpose of this phase is the design and construction of the taxonomy using the inventory of terms. Identify the first level of categorization and other levels to determine the final structure of the taxonomy.

The products obtained in this phase are: (1) categorization of the first level terms (2) general taxonomy and (3) dictionary of categories and subcategories.

### 3.4 Phase 4: Testing and Validation

The purpose of this phase is to ensure that the designed taxonomy would be useful to users. The necessary tests and validation must be performed. The products obtained in this phase are: (1) validated taxonomy (2) dictionary of categories and (3) validated subcategories.

### 3.5 Phase 5: Deployment of the Taxonomy

The purpose of this phase is deploying the taxonomy throughout the organization. The products obtained in this phase are: (1) staff trained in the taxonomy and (2) taxonomy available to users.

Figure 2 shows the main activities for each stage of the method to develop the taxonomy of critical success factors.

## 4 Critical Success Factors Taxonomy

As a result of the implementation of the taxonomy of critical success factors in the deployment process a limited number of categories are identified.

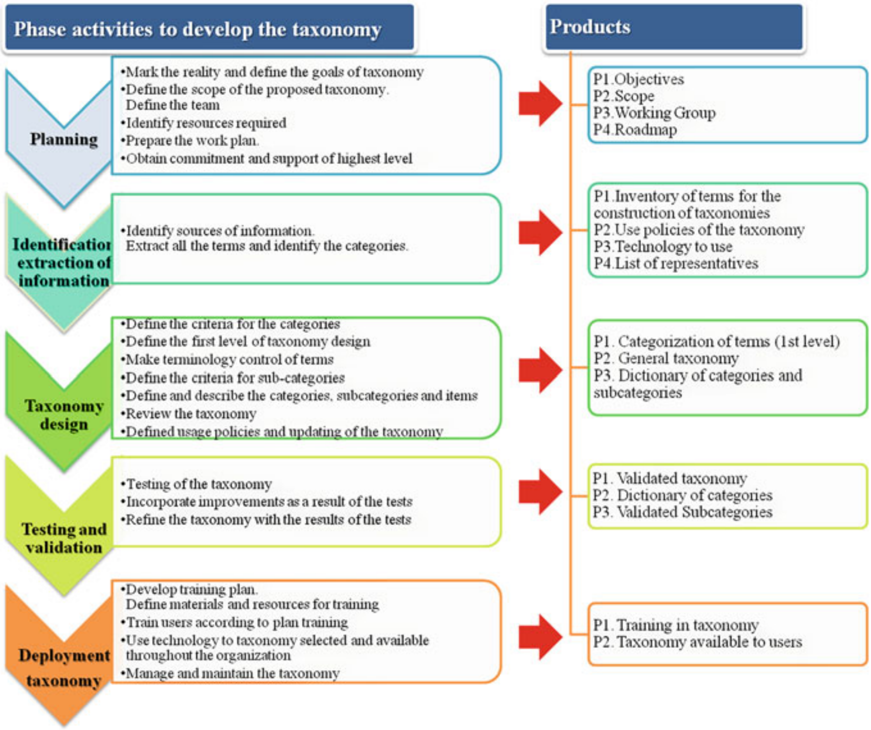



**Fig. 2** Main activities to develop the critical factors taxonomy

These categories were defined after a review of research literature on critical success factors taxonomy in process improvement and process deployment [17–21].

This taxonomy includes five categories related to the object of study. The categories are:

- *Organization*: many factors which are not covered in the deployment process depend on the organization in which to carry out the process deployment.
- *People*: the deployment process is based on people at all levels, groups, teams and organization. etc.
- *Processes:* processes are deployment input and this process may be influenced by several factors.
- *Product:* quality product, delivered on time and on budget and required functionalities.
- *Others:* this includes other factors not found in the above categories.

Having identified the categories, the related elements are identified in the list of factors, grouped into subcategories.

**Table 1** Subcategories of taxonomy

| Category | Subcategory |
|---|---|
| 1. Organization | Top management commitment |
| | Infrastructure |
| | Policies |
| | Corporative vision |
| | Organizational Culture |
| | Standards and procedures |
| | Commitment stakeholders |
| 2. People | Leadership |
| | Skills |
| | Communication |
| | Knowledge |
| | Motivation |
| | Values |
| | Training |
| | Teamwork |
| | Participation |
| | Change Management |
| | Roles and responsibilities |
| 3. Process | Process definition |
| | Process Library |
| | Institutionalization |
| | Deployment of process |
| 4. Product | Quality Audit |
| 5. Other | Globalization of the market |

Table 1 shows the list of factors according to the category and subcategories identified.

## 5 Benefits of Taxonomy

One benefit of the taxonomy is that having identified the critical success factors of the process deployment, it is able to propose a method for the deployment of processes, including these factors and ensure the process deployment.

The critical success factors taxonomy based factors of industrial experience and by systematic review has identified the factors related to the technical and social aspects that should be incorporated into a deployment strategy.

At this point, it is important to clarify that the method will take such factors as preconditions before starting the deployment of processes in the organization, such as:

- Obtain commitment from key stakeholders in the project.
- Have commitment of top management.

- Having the necessary resources to carry out the deployment of processes.
- Strategically aligning processes with business needs.
- Take the lead in carrying out the deployment process.
- Establishing clear reasons for the change, because understand why we need to change helps people to accept and work for the change.
- Establishing clear objectives and the benefits to be achieved for both the organization and the employees.
- Having defined and measured processes adapted to the needs of the organization which will be implemented (including tailoring guidelines).
- Have a library of automated processes that allows online access and use of participants in the deployment.
- Factors that have been considered in the taxonomy of factors obtained.

## 6 Conclusions

Despite the existence of different methods, models and standards for software process improvement, difficulties arise during the implementation process. Because organizations when implement into their processes, most of them are focused on solving the technical aspects and leave out other factors related to social aspects. Specifically, the factors related to people who are running the activities.

Identifying the factors that determine the success or failure of the deployment process of processes is fundamental. However, it is necessary to standardize and classify these factors.

Several authors have classified the critical success factors for improving processes; however, there is no evidence of the classification of factors for the process deployment, which motivate to the interest in having a taxonomy of factors to focus on the process deployment, which incorporates factors such as process definition, deployment of processes, process library and institutionalization.

In this paper, have been presented two techniques: (1) review of the literature on critical success factors in the process improvement and process deployment and (2) the analysis of the presence of the factors contained in the taxonomy at the level of subcategories, in software development organizations.

Having a method for the preparation of taxonomy has allowed us to sort and classify the critical success factors of the deployment process, standardize the concepts and it could be incorporated into a strategy that considers the factors focused on people.

The taxonomy of research-based factors of experience in organizations and in the systematic review has shown the need to take into account not only technical aspects, but to incorporate social aspects in order to achieve the process institutionalization, when a process deployment strategy is developed.

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