Eiman Kanjo
Dirk Trossen (Eds.)

LNICST

143

Sensor Systems and Software

5th International Conference, S-CUBE 2014
Coventry, UK, October 6–7, 2014
Revised Selected Papers

ICST

Springer

Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering 143

More information about this series at http://www.springer.com/series/8197

Eiman Kanjo · Dirk Trossen (Eds.)

Sensor Systems and Software

5th International Conference, S-CUBE 2014
Coventry, UK, October 6–7, 2014
Revised Selected Papers

Springer

Editors
Eiman Kanjo
Nottingham Trent University
Nottingham
UK

Dirk Trossen
InterDigital Europe, Ltd
London
UK

ISSN 1867-8211 ISSN 1867-822X (electronic)
Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering
ISBN 978-3-319-17135-7 ISBN 978-3-319-17136-4 (eBook)
DOI 10.1007/978-3-319-17136-4

Library of Congress Control Number: 2015937530

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Preface

It is a great pleasure to welcome you to S-CUBE 2014, 5th International Conference on Sensor Systems and Software, held in Coventry, UK, October 6–7, 2014. This conference is the fifth in a series of meetings of researchers and practitioners from both academia and industry, established to serve as forum for sensor systems and software.

The Program Chair for S-CUBE 2014, Dr. Dirk Trossen (InterDigital, UK), has put together a very good program. We received 16 submissions for review from Europe, USA, and Asia. We selected 9 regular papers for an acceptance rate of 45%. An excellent Technical Program Committee has contributed to the technical program by providing informative and timely reviews of the submitted papers.

The Local Arrangements Chair, Dr. Weisi Guo (University of Warwick, UK), has done a very good job in setting the venue and overseeing the aspects of meeting social events and student volunteers. We also acknowledge the invaluable efforts and contributions of the Publicity Co-chairs, Dr. Alan Chamberlain (University of Nottingham, UK) and Dr. Alessio Malizia (Brunel University London, UK), who coordinated and implemented publicity for the conference throughout different mailing lists.

We also thank Siyi Wang (University of South Australia, Australia) for updating our website regularly and his effective contributions as Web Chair. A special thank goes to Petra Jansen and Dr. Elisa Mendini (European Alliance for Innovation) for their timely and effective coordination and the EAI Society for the best paper award.

We finally thank the two distinguished speakers, Alan Carlton (InterDigital, UK) and Dr. Nishanth Sastry (King's College London, UK), for delivering the Keynote Talks at S-CUBE 2014.

Eiman Kanjo
Dirk Trossen

Organization

Steering Committee

Imrich Chlamtac	CREATE-NET, Italy
Sabrina Sicari	Università degli Studi dell'Insubria, Italy
Stephen Hailes	University College London, UK

Organizing Committee

General Chair

Eiman Kanjo	Nottingham Trent University, UK

Technical Program Committee Chairs

Emiliano Miluzzo	AT&T Labs Research, USA
Dirk Trossen	InterDigital, UK

Local Chair

Weisi Guo	University of Warwick, UK

Workshop Chairs

Vivek Kumar Singh	MIT, USA
Sarah Gallacher	University College London, UK

Publicity Chairs

Alan Chamberlain	University of Nottingham, UK
Alessio Malizia	Brunel University London, UK

Web Chair

Siyi Wang	University of South Australia, Australia

Technical Program Committee

Hamed Haddadi	Queen Mary University of London, UK
Venet Osmani	CREATE-NET, Italy
Oscar Mayora	CREATE-NET, Italy
Frank Hopfgartner	DAI-Labor, Technische Universität Berlin, Germany
Dana Pavel	TecVis, UK
Christos Efstratiou	University of Kent, UK

Daniele Puccinelli	University of Applied Sciences and Arts of Southern Switzerland, Switzerland
Raghu K. Ganti	IBM Research, USA
Immanuel Schweizer	Technische Universität Darmstadt, Germany
Gang Zhou	College of William and Mary, USA
Moo-Ryong Ra	AT&T Labs Research, USA
Flora Salim	RMIT University, Australia
Hong Lu	Intel Labs, USA
Qingquan Sun	Oakland University, USA
Amin Al-Habaibeh	Nottingham Trent University, UK
Kunal Mankodiya	Carnegie Mellon University, USA

Contents

Design of a Novel Adaptive Indoor Air Quality Control for Co-learning Smart House

Markus Johansson[1(✉)], Keijo Haataja[1], Mikko Kolehmainen[2], and Pekka Toivanen[1]

[1] Department of Computer Science, University of Eastern Finland, Yliopistonranta 1, 70211 Kuopio, Finland
{markus.johansson,keijo.haataja,pekka.toivanen}@uef.fi
[2] Department of Environmental Science, University of Eastern Finland, Yliopistonranta 1, 70211 Kuopio, Finland
mikko.kolehmainen@uef.fi

Abstract. The use of multivariate methods is popular in indoor air quality applications such as prediction of indoor air quality, ventilation control and classify comfort Indoor air quality data used in this study was collected continuously in a family house in Kuopio, Eastern Finland, during ten months long period. Indoor parameters were temperature, relative humidity (RH), the concentrations of carbon dioxide (CO_2), TVOC and carbon monoxide (CO) and differential air pressure and particle counts(0.5 um and 2.5 um). In this study, self-organizing map (SOM) were applied to indoor air quality data for define correlation between of non-linear variables. The SOM was qualified as a suitable method having a property to summarize the multivariable dependencies into easily observable two-dimensional map. In addition, this paper presents the development of adaptive indoor air quality control for co-learning smart house.

Keywords: Indoor air quality · Monitoring system · Data analysis · Smart house

1 Introduction

Nowadays, people are staying indoors most of the time in the work and at home. Low quality indoor air can cause health problems such as allergies and asthma [1]. Indoor air quality also affects to the work efficiency and living comfort. Indoor air is affected by a variety of physical, chemical and biological factors [2]. Factors influencing the indoor air quality of a building include comfort issues and biological or chemical contaminants. The Physical factors temperature and humidity affect to comfort. Too cold or warm indoor can cause the decrease in work efficiency and comfort. For work efficiency and comfort, recommended indoor air temperature is about 21 °C. Air humidity is of great importance to health and comfort. Too low humidity (below 20 %), dry the mucous membranes and can cause health problems. Too high humidity conditions (above 70 %),

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 1–10, 2015.
DOI: 10.1007/978-3-319-17136-4_1

moisture may condense on the structures and thus can speed up the growth of bacteria and fungi [3]. Recommended humidity should be between 20–60 %. Most of the indoor air problems can be remedied by improving ventilation [4]. However, by improving ventilation the building heating energy consumption will increase [5, 6]. Indoor air chemical factors are for example, building materials chemicals, detergents and carbon dioxide from the human metabolism. Chemicals from building materials and detergents are usually volatile organic compounds, which are abbreviated as VOC [7]. Indoor air volatile organic compounds are often described as total number of concentration TVOC (Total Volatile Organic Compounds). Most of the volatile organic compounds do not affect a serious health problem, but they can cause for example headaches. Indoor air of carbon dioxide and TVOC concentration can rise above the recommended value of inadequate ventilation. In this case, high concentration of carbon dioxide can cause fatigue and headaches. Indoor Air carbon dioxide concentration recommended value in Finland is set to of maximum levels as following comfort levels:

- comfort level S1 700 ppm
- comfort level S2 900 ppm
- comfort level S3 1200 ppm

Where S1 is a good level, S2 satisfactory and S3 is a poor level [8].

Data analysis and computational methods have been used widely in prediction and clustering of indoor air quality and energy consumption measurement data. For example, neural networks have been used for prediction of indoor air quality using feedforward backpropagation [9, 10] and model comparison [11]. Also, studies have been done concerning with forecasting outdoor air quality parameters [12, 13] and air pollution episodes [14] using computational methods. This paper presents preliminary results of design adaptive co-learning smart house. Paper describes the methodology used in the analysis of indoor air quality data, including data pre-processing and computational methods for design adaptive control in smart house. Computational methods used to optimize the building automation systems, such as indoor air quality would be on good level and reduce energy consumption. The optimising building automation systems is multi-objective problem since in situations, where the outdoor temperature is lower than indoor air temperature can causing condensation to building structures and at the same time indoor humidity reduced. Also, too high indoor air temperature affects the construction materials in such way that materials evaporate of TVOC compounds to indoor air. The problem is therefore to optimize heating and ventilation in order to keep humidity on healthy level, but at the same time to prevent humidity condensation in the structures. The temperature should be appropriate, taking into account the previous problem, and in addition to heating should not consume too much energy. Optimization of ventilation in such way that heat loss would be minimal and keep indoor air quality in acceptable level.

2 Materials and Methods

Indoor air quality data for data analysis was collected during the period from 11st of October 2011 to 13th of July 2012 in a family house with area of 120 m^2 + garage 20 m^2. The measurements were collected from five rooms' living room, bathroom, and vestibule and from three bedrooms. Measured variables, units and sensor locations are shown in Table 1. The collected indoor air quality data consisted of continuous measurements on temperature, relative humidity, carbon dioxide, carbon monoxide, particle counts 0.5 µm and 2.5 µm particle size and TVOC concentration and differential air pressure between indoors and outdoors in the study house in Eastern Finland, in city of Kuopio. Temperature sensor measurement range was 0-50°C, humidity sensor measurement range was 0-100 %RH, carbon dioxide sensor measurement range was 0-2000 ppm and TVOC sensor measurement range was 0-30 ppm. TVOC sensor measure of total of volatile organic compounds concentration of toluene ($C_6H_5CH_3$/C_7H_8), ammonia (NH_3) and hydrogen sulphide (H_2S). Data was collected using a monitoring system developed by the research group of Environmental Informatics, university of Eastern Finland [15, 16]. Sampling rate of measurement devices was 10 s.

Table 1. Measured parameters and the location of measurements

Parameter	Unit	Vesti-bule	Bath room	Bedroom 1	Bedroom 2	Bedroom 3	Living room	Outdoor
Temperature	°C	x	x	x	x	x	x	x
Humidity	%RH	x	x	x	x	x	x	
CO_2	ppm	x	x	x	x	x	x	
TVOC	ppm					x		
CO	ppm						x	
Diff Pressure	Pa	x						
Particle Counter (0.5 µm)	count/ft^3	x						
Particle Counter (2.5 µm)	count/ft^3	x						

Indoor air quality data pre-processed in such a way, that the abnormal values were removed and calculated hourly averaged values. The pre-processed data size was 6623 rows. Pre-processed data parameters and their statistical information are shown in Table 2.

Table 2. Pre-processed data parameters and their statistical information.

Parameter	Unit	Min	Max	Mean	Median	STD
Fireplace Temperature	°C	27,7	81,9	34,0	29,4	9,3
Diff Pressure	Pa	-1,0	0,5	-0,3	-0,4	0,2
Vestibule Temperature	°C	21,6	25,6	23,3	23,2	0,5
Vestibule Humidity	%RH	11,3	57,2	27,3	26,5	7,8
Vestibule CO_2	ppm	404,2	1117,4	521,8	513,8	73,3
Bathroom Temperature	°C	17,4	29,1	22,3	22,4	1,2
Bathroom Humidity	%RH	13,4	67,9	30,9	28,8	9,5
Bathroom CO_2	ppm	324,0	936,5	407,4	397,6	55,3
Bedroom1 Temperature	°C	21,8	27,4	23,5	23,2	0,9
Bedroom1 Humidity	%RH	14,6	48,7	28,7	27,6	6,3
Bedroom1 CO_2	ppm	436,9	1980,5	765,9	674,6	287,5
Bedroom2 Temperature	°C	19,5	26,3	22,8	22,7	1,1
Bedroom2 humidity	%RH	11,4	50,1	27,4	27,1	6,6
Bedroom2 CO_2	ppm	365,9	1971,1	663,7	559,2	316,5
Bedroom3 Temperature	°C	20,7	25,8	23,6	23,6	0,5
Bedroom3 Humidity	%RH	13,1	53,9	26,6	25,5	7,0
Bedroom3 CO_2	ppm	319,3	1229,2	513,6	506,7	116,6
Bedroom3 TVOC	ppm	1,7	27,3	14,3	14,3	2,5
Living room CO	ppm	0,0	0,4	0,0	0,0	0,0
Living room Temperature	°C	20,0	37,7	23,1	22,9	1,0
Living room Humidity	%RH	10,9	63,8	25,5	23,9	8,1
Living room CO_2	ppm	460,1	1423,0	629,5	623,3	105,2
Outdoor Temperature	°C	-29,7	24,6	1,8	1,3	9,6
Particle Counter (0.5 μm)	count/ft^3	0,0	6677,0	447,9	333,3	418,1
Particle Counter (2.5 μm)	count/ft^3	0,0	1097,0	34,3	22,5	45,3

Indoor air quality pre-processed data was used in the data analysis where calculated values of carbon dioxide concentration comfort levels, autocorrelation of temperature, humidity and carbon dioxide concentration. In addition, we analysis data by a self-organizing map (SOM). The Carbon dioxide concentration comfort levels used for estimate adequacy of ventilation. The autocorrelation used for to detect similarity between observations as a function of the time lag between them. The self-organizing map is a neural network algorithm developed by Teuvo Kohonen in the early 1980s, and its common purpose is to facilitate data analysis by mapping n-dimensional input vectors to the neurons, for example in a two dimensional lattice [17]. In this lattice, the input vectors with common features result in the same or neighbouring neurons, preserving the topological order of the original data. The SOM learning process is unsupervised: no a priori classifications for the input vectors are needed. A large variety of SOM-based applications have been developed. The common application fields of SOM have been, for example machine vision, signal processing, exploratory data analysis and pattern recognition [17].

The training of SOM results in a topological arrangement of output neurons, each of which has a special reference vector describing its hits, or input vectors. Each neuron of the SOM is defined on one hand by this reference vector, which has the same dimensionality as the input vectors, and on the other hand by its location. The reference vector can be defined as follows:

$$\mathrm{r_m} = \left(\mathrm{r_m}, \mathrm{r_{m2}}, \ldots, \mathrm{r_{mn}}\right), \ (\mathrm{m} = 1, \ldots, \mathrm{M}). \tag{1}$$

Where n is the number of variables, and M refers to the number of neurons in the map.

In the beginning of the training, the SOM must be initialized. In linear initialization, the SOM is initialized along the map dimensions, according to the greatest eigenvectors of the training data. In random initialization, the map is initialized by using arbitrary values for the reference vector. The use of linear initialization results in an ordered initial state for reference vectors instead of arbitrary values generated by random initialization [17]. The Best Matching Unit (BMU) is the neuron being at the smallest Euclidean distance from the input vector:

$$\beta(\mathrm{x_i}, \mathrm{R}) = \arg\min_{\mathrm{j}} \left\| x_i - r_j \right\|. \tag{2}$$

Where β is the index of the BMU, denotes the input vector, and R includes the reference vectors of the SOM.

The BMU and the group of its neighbouring neurons can be trained using the following update rule: [17] (Eq. 3):

$$\mathrm{r_m}(\mathrm{k}+1) = \mathrm{r_m}(\mathrm{k}) + \mathrm{h}_{\beta\mathrm{m}}(\mathrm{k})\left[\mathrm{x_i} - \mathrm{r_m}(\mathrm{k})\right]. \tag{3}$$

where k is a number of iteration rounds and m implies the index of the neuron updated. The reference vectors gradually become weighted averages of the original data samples assimilated to each of them. The neighbourhood function is usually assumed to be Gaussian [17] (Eq. 4):

$$\mathrm{h}_{\beta\mathrm{m}}(\mathrm{k}) = \alpha(\mathrm{k}) \exp\left(-\frac{\mathrm{v}_\beta - \mathrm{v}_\mathrm{m}^2}{2\sigma^2(\mathrm{k})}\right). \tag{4}$$

where v_β and v_m are the location vectors of the corresponding nodes, α refers to the factor of the learning rate, and $\sigma(k)$ defines the width of the kernel.

In summary, the training of SOM proceeds as follows: (1) finding the BMU for one input vector according to the minimum Euclidean distance, (2) moving the reference vector (using the update rule) of the BMU towards this input vector, (3) moving the reference vectors (using the update rule) of neighbouring neurons towards this input vector, (4) repeating steps 1-3 for the next input vector until all input vectors have been used, (5) repeating steps 1-4 until the algorithm converges, (6) finding the final BMU for each input vector according to the Euclidean distance.

3 Results

The Carbon dioxide comfort levels of the pre-processed data are shown in Fig. 1. Results of carbon dioxide comfort levels are calculated of pre-processed data rows where the CO_2 concentration was more than 450 ppm. In this way, we will assess CO_2 concentration when the house is occupied. Otherwise, the results contains all the data rows, i.e. also those data rows where the residents would not be in the house and thus the interpretation of the results would give a false impression to assess carbon dioxide comfort levels. Figure 1 show results that, carbon dioxide comfort levels are most of the time in good level when house is occupied. However, in living room and bedrooms carbon dioxide comfort levels are satisfactory about 30 % of time and bedrooms 1 and 2 carbon dioxide comfort levels are poor about 20 % of time.

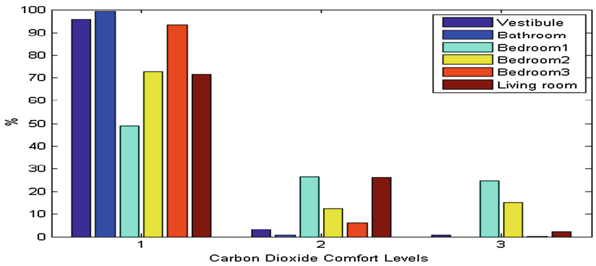


Fig. 1. Percentage of carbon dioxide comfort levels 1, 2 and 3 in different rooms when house is occupied

The Autocorrelation of the pre-processed data is shown in Fig. 2, which show that from parameters carbon dioxide and temperature can be found repeating patterns. This repeating pattern occurs on 24 h period. The autocorrelation of humidity does not seem to be repeating patterns.

The results of the SOM analysis is shown in Fig. 3. The Fig. 3 shows the SOM component plane of variables. Component plane show every variables in their own plane. Correlation between the variables can examine by finding same lattice of component plane. For example, correlation between of fireplace temperature, differential pressure and outdoor temperature is shown clearly in the component plane, when

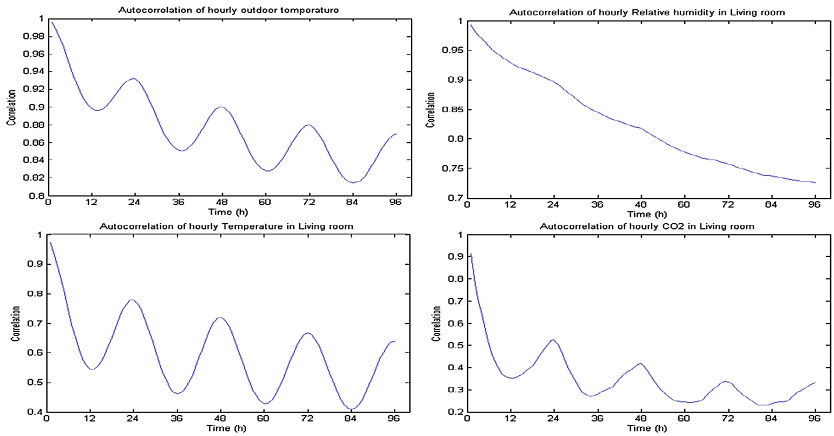


Fig. 2. Autocorrelation of outdoor temperature (top left), and living room humidity (top right), temperature (bottom left) and carbon dioxide concentration (bottom right) of the 96-hour period.

temperature of fireplace is raised, the differential pressure is positive i.e. air pressure is higher than in outdoor. Other correlation is shown clearly in the component plane, when outdoor temperature is cold, which indicate the winter season, then rooms temperatures are lower than average and in another way, when outdoor temperature is higher than average, rooms temperatures are higher than average. In winter season, rooms humidity is lower than average. Correlation between concentration of carbon dioxide and other variables do not shown clearly in component plane.

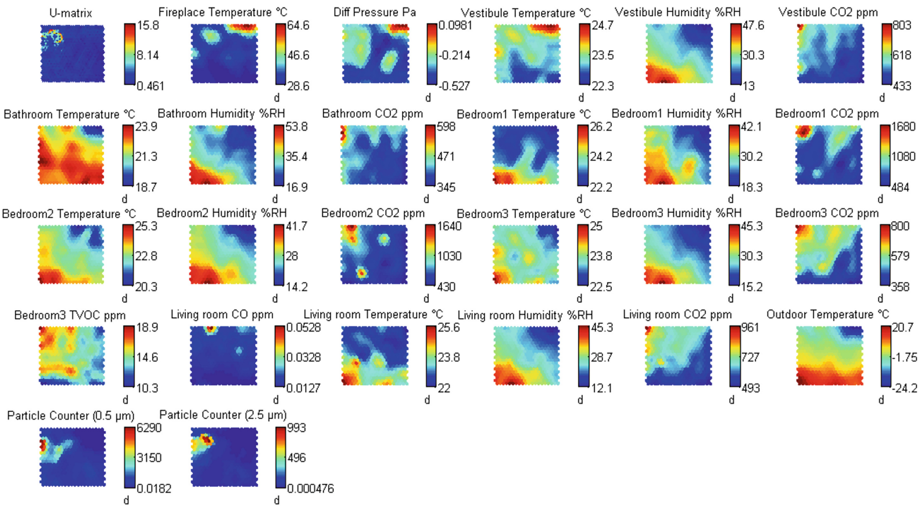


Fig. 3. SOM component plane of pre-processed data

On the basis of data analysis we design adaptive indoor air quality control for co-learning smart house. The block diagram of the design is shown in Fig. 4. User of the co-learning smart house give input of comfort of temperature, humidity and a sense of air quality i.e. predefined category value for example fresh or stale. User behavioural used for indicate when user is on home and which room user use for example most of time. Smart home system measure the indoor air quality and energy consumption to give feedback for adaptive control system. These measurements are combined in adaptive control, which is shown in block diagram as a “computational intelligence” processing unit. The computational intelligence processing unit process data for control heating system and ventilation control. It also gives information to user of indoor air quality and consumed heating energy.

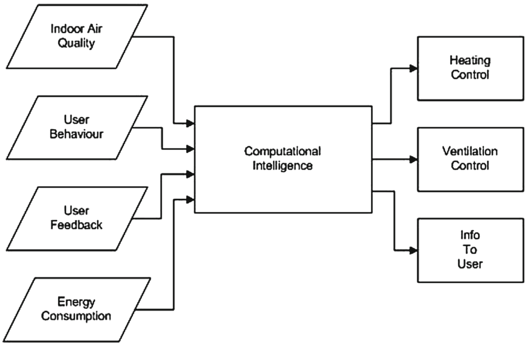


Fig. 4. Block diagram of data sources and control outputs of adaptive control for co-learning smart house

The co-learning smart house is based on supervised learning. The training data consist of a set of typical indoor air quality features. Also, training data include features of user behaviour, user feedback and heat energy consumption. The supervised learning model is inside of block “computational intelligence”, which was presented in Fig. 4. Model is trained to detect anomalies of indoor air quality, user’s behavioural and heat energy consumption. Co-learning smart house system measure and analyse continuously indoor air quality and heat energy consumption. When system detect anomalies of indoor air quality and heat energy consumption, system aims to control the ventilation and heating control systems to reduce heat energy consumption and preserve the indoor air quality good as possible. User behaviour and feedback is used for to reduce heat energy consumption. When the resident is not at home, the system can decrease indoor temperature and that way reduce heating energy consumption. This, however, requires that the behaviour of residents can be predicted. The system adaptively is, therefore, monitoring indoor air quality and energy consumption and detection and prediction of resident’s behaviour. These data is used for control ventilation and heating control systems in such way that it does not harm the building and preserve indoor air quality good enough for healthy living (See Fig. 5).

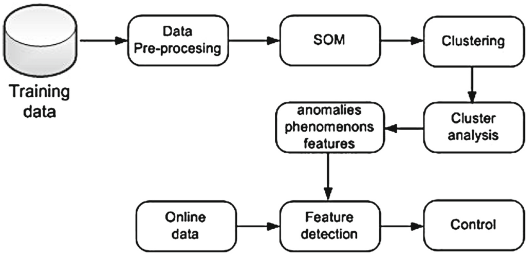


Fig. 5. Data processing in adaptive control

4 Discussion

As mentioned before, this paper presents preliminary results of data analysis on indoor air quality and design of the adaptive control system. The Carbon dioxide comfort levels in case study house was in good level of most of the time but carbon dioxide comfort levels was also satisfactory and poor levels especially in bedrooms. In particular, SOM analysis showed different phenomena can be characterizing indoor air quality in the case study house. Based on analysis, it can be concluded, that using SOM for examine of correlation between non-linear data variables in an efficient way. In addition, using SOM to detect different anomalies, phenomena and features can use this information to design adaptive control for smart house. Based on analysis, that using autocorrelation for detects carbon dioxide and temperature periodic variations can be used for to give feedback for design adaptive control.

5 Conclusion

SOM-based method can reveal dependencies between data variables relatively quickly and easily, than for example using principal component analysis to reveal the dependencies of multi-dimensional data. The results presented in this paper show that the applied SOM-based neural network is an efficient way to analyse indoor air quality data. Nowadays, buildings are more energy efficient and airtight. This can cause problems with indoor air quality. In this study, the ventilation rate of the study house was sufficient concerning indoor parameters, when the study house was occupied. Finally, we will extend our research work to design adaptive indoor air quality control for co-learning smart house, and we are also developing data analysis methods for detecting abnormal situations in indoor air quality also, we are developing methods for user feedback system to receive feedback given by the user and methods for detecting user behavioral. In addition, we will research the application possibilities of neural network modelling further in the field of energy efficiency and healthy housing. In this study, preliminary results are interesting. Particularly, further research on variable distribution of clusters and seasonal variation of indoor air quality and its effect on energy consumption, is needed.

Acknowledgments. This research work was funded by the European Union (EU) Artemis projects Adaptive Cooperative Control in Urban (Sub)Systems (ACCUS) and Design, Monitoring, and Operation of Adaptive Networked Embedded Systems (DEMANES). For financial support, the authors would like to thank the European Commission, as well as, authors would like to thank research group of Environmental Informatics, University of Eastern Finland, for providing the indoor air quality data for this research.

References

1. Salo, P.M., Sever, M.L., Zeldin, D.C.: Indoor allergens in school and day care environments. J. Allergy Clin. Immunol. **124**(2), 185–192 (2009)
2. Asumisterveysohje. Sosiaali- ja terveysministeriön oppaita. 2003:1, Sosiaali- ja terveysministeriö, Oy Edita Ab, Helsinki (in Finnish)
3. Daisey, J.M., Angell, W.J., Apte, M.G.: Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air **13**(1), 53–64 (2003)
4. Clements-Croome, D.J., et al.: Ventilation rates in schools. Build. Environ. **43**(3), 362–367 (2008)
5. Becker, R., Goldberger, I., Paciuk, M.: Improving energy performance of school buildings while ensuring indoor air quality ventilation. Build. Environ. **42**(9), 3261–3276 (2007)
6. Dascalaki, E.G., Sermpetzoglou, V.G.: Energy performance and indoor environmental quality in Hellenic schools. Energy Build. **43**(2), 718–727 (2011)
7. European Commission. Report 19: Total volatile organic compounds (TVOC) in indoor air quality investigations. Office for Official Publications of the European Communities (1997). ISBN 92-828-1078-X
8. Sisäilmastoluokitus, 2008 Sisäilmayhdistysry, Rakennustietosäätiö RTS, Asunto-, toimitila- ja rakennuttajaliitto RAKLI, Suomen Arkkitehtiliitto SAFA, Suunnittelu- ja konsulttitoimistojen liitto SKOL (2008). (in Finnish)
9. Sofuoglu, S.C.: Application of artificial neural networks to predict prevalence of building-related symptoms in office buildings. Build. Environ. **43**(6), 1121–1126 (2008)
10. Xie, H., Ma, F., Bai, Q.: Prediction of indoor air quality using artificial neural networks. In: Fifth International Conference on Natural Computation, ICNC 2009, vol. 2 IEEE (2009)
11. Lu, T., Viljanen, M.: Prediction of indoor temperature and relative humidity using neural network models: model comparison. Neural Comput. Appl. **18**(4), 345–357 (2009)
12. Kolehmainen, M., et al.: Forecasting air quality parameters using hybrid neural network modelling. In: Urban Air Quality: Measurement, Modelling and Management. Springer, Netherlands, pp. 277–286 (2000)
13. Kolehmainen, M., Martikainen, H., Ruuskanen, J.: Neural networks and periodic components used in air quality forecasting. Atmos. Environ. **35**(5), 815–825 (2001)
14. Niska, H., et al.: Hybrid models for forecasting air pollution episodes. In: Artificial Neural Nets and Genetic Algorithms. Springer, Vienna (2003)
15. Skon, J., Kauhanen, O., Kolehmainen, M.: Energy consumption and air quality monitoring system. In: 2011 Seventh International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), IEEE (2011)
16. Skön, J.P., et al.: Wireless building monitoring and control system. World Acad. Sci. Eng. Tech. **65**, 706–711 (2012)
17. Kohonen, T.: Self-organizing maps, vol. 30. Springer, Heidelberg (2001)

A Design-Led, Materials Based Approach to Human Centered Applications Using Modified Dielectric Electroactive Polymer Sensors

Anne Toomey(✉), Raymond Oliver,
Niamh O'Connor, and Patrick Stevenson-Keating

Faculty of Arts, Design and Social Sciences, Northumbria University,
1-15 Bradley Close, White Lion Street, London, N1 9PN, UK
anne.toomey@northumbria.ac.uk

Abstract. This paper describes a design-led exploratory scoping study into the potential use of an industry standard dielectric electroactive polymer (DEAP) sensor for applications in assistive healthcare. The focus of this activity was to explore the physical format and integration of soft materials and sensor combinations with properties that afford an opportunity for accurate and unobtrusive real time body mapping and monitoring. The work involved a series of practical investigations into the capacitance changes in the sensor brought on by deformation through different ways of stretching. The dielectric sensors were selected as a direct mapping tool against the body based on the similarity of the stretch qualities of both the sensor and human skin and muscle resulting in a prototype vest for real time breathing monitoring through sensing thoracic movement. This involved modification of the standard sensors and handcrafting bespoke sensors to map critically relevant areas of the thorax.

Keywords: Dielectric electroactive polymers · Breathing monitoring · Handcrafted sensors · Stretchable electronics

1 Introduction

This paper describes a 10-week exploratory study carried out by our design-led interdisciplinary research group that explores future ways of living through materials and technology interrogation to determine and demonstrate innovative interventions that resonate with the way we experience our material world [1]. We recognise that the products of tomorrow have to 'do more with less' in order to attempt to meet the societal challenges of the 21st century. A significant domain for smarter products is within assistive healthcare [2–4]. Products that incorporate sensors and sensing are increasing and have a pivotal role in assistive healthcare and personalized monitoring [5]. However, sensors, actuators and other electronic components are frequently made of rigid and stiff materials that limit their incorporation into products and the type of product that they can be used for. Much work has been done in the area of smart textiles, integrated sensors and wearable computing [6–10]. In recent years however, two major

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 11–19, 2015.
DOI: 10.1007/978-3-319-17136-4_2

developments are changing the form and function of sensors and their incorporation into wearable or on-body solutions. These are conductive polymers (high electron mobility) that can be solution processed and hence form the basis for printable sensor fabrication via ink jet and screen printing technology [11, 12]. The other is stretchable electronics which are light, flexible and can withstand robust handling [13–15]. Of particular interest is the class of stretchable electronics based on electro-active or electro-responsive polymers (EAP's). These form a family of useful sensor materials as follows:

EAP's

Ionic	Electronic	Piezo	Other stimuli
° Ionic polymer metal composites ° Carbon nanotubes ° Ionic polymer gels	° Piezo electric polymers ° Electro- strictive polymers ° Liquid Xtal elastomers ° Ferroelectric polymers ° Dielectric electro active polymers (DEAP)	° Piezoelectric ceramics ° Piezoelectric inorganic composites ° Electro rheological fluids	° Shape memory alloys ° Shape memory polymers ° Magneto- strictive Xtals

Of these, we have chosen to examine dielectric electro active polymers (DEAP) in some detail because they offer a large degree of freedom in terms of their strain behaviour under an applied electric field [4–8].

The DEAP basic structure is made up of a film of a dielectric elastomer material that is coated on both sides by another expandable film of a conducting electrode. When voltage is applied to the two electrodes a Maxwell pressure is created upon the dielectric layer. The elastic dielectric polymer acts as an incompressible fluid which means that the electrode pressure comes the dielectric film to become thinner in the 2 directions and expansive in the planar directions (x,y). When this occurs, the electric force field is converted to mechanical actuation and motion.

We explored the DEAP sensors developed by the Danfoss company in Denmark which have the added benefit of specific electrode shape and topology which gives use to an accentuated movement in either the x or y direction with the other constrained to the mechanical structure of the assembly [5].

DEAP are intrinsically position or strain sensors. DEAP sensors have certain advantages even when an actuation function is not included. The large strain characteristics and environmental tolerance of DEAP materials allow for sensors that are simple and robust. In sensor mode, it is often not important to maximise energy density since relatively small amounts of energy are converted. Thus the selection of DEAP materials can be based on criteria such as biocompatibility, maximum strain, environmental robustness and cost.

Sensor Form Factors: Thin tubes, filaments, flat strips and ribbons, arrays of diaphragms or large area sheets are all possible. In filament or ribbon formats, DEAP sensors can be woven and integrated into textiles and provide positive feedback for human movement. The softness and compliance of DEAP sensors is ideal for interaction with the human body therefore [6]. DEAP sensors can also be integrated into flexible structures and surfaces to provide position and eventually volumetric information for multifunctional 'smart' products. It is these particular properties that make DEAP systems ideal for real time analysis of physical functions that are discrete and generally unobtrusive. In addition, the sensor could be flexed or stretched many times with no loss of reproducibility. Under these conditions the DEAP sensors could be used to measure sensitive movements of the human body. In our case, monitoring breathing through measuring thoracic activity allowed lung capacity to be described under different physical states of exertion.

As will be demonstrated later, the response of the particular DEAP materials used were highly linear and so allowed us to work at strain behaviour (in the form of a capacitance output signal that allowed us to infer a linear displacement) for the range $L(x) + 0.1L(x)$ to $L(x) + 0.9\,L(x)$.

Below, how we used the sensors and the outputs are described in more detail.

2 Materials and Methods

Our scoping activity involved a series of practical investigations into the capacitance changes in the sensor brought on by deformation through different ways of stretching. An understanding of the construction of the sensor was gained through a site visit to the industrial partner's lab and also by the deconstruction of the industrial sensors and handcrafting our own versions in our studio-lab. Sensor readings were taken under a range of temperatures in order to determine if external parameters such as ambient temperature would affect performance. None was found. The stretch capability of the sensor is up to 100 % and enables a sliding scale between 'on' and 'off' and scope for nuanced effects. The sensor has good stretch compatibility and affinity with human movement. From this start point of ideas generation one embryonic demonstrator was selected. The purpose of the demonstrator was to create a probe for further investigation and development rather than demonstrate a resolved design prototype.

2.1 Demonstrator: Thoracic Motion and Volume Sensor for Respiratory Monitoring

The aim of the demonstrator was to align the DEAP sensors to the outside of the body to tell us what is going on inside the body. Both Lycra and the stretch sensors have ideal softness and compliance for interaction with the human body [8]. The sensors behave as variable capacitors and to measure their capacitance at any given time, and under any given load, a number of methods were used. To get usable readings from the sensors, custom circuitry and software was produced to measure and interpret the data. The range of the sensors is typically between 100e-12 F to 100e-9 F; therefore a capacitance meter able to measure down to 90pF was required. Firstly we tested a UNI-T desktop multimeter, secondly a self-solder capacitance measuring printed circuit board from Sparkfun Electronics and thirdly an ATMega328pu microprocessor in the form of an arduino uno board. This board was used, with the addition of an external resistor and capacitor of known values, to create a basic RC circuit with a low pass filter. Using this circuit, and the following equation;

$$c = \frac{1}{\sqrt{2\pi f}} \cdot \frac{1}{\left(\sqrt{\left[\left(\frac{V_i}{V_o}\right) - 1\right]}\right)^{0.5}}.$$

C = capacitance (Farads), f = frequency (Hz), Vi = voltage in, Vo = voltage out (Volts)

it was possible to derive the capacitance of the sensor accurately. It is important to note here that the capacitance of the sensor was being inferred rather than directly measured. The values actually being received from the sensor into the arduino were changes in voltage. These voltage changes were then used to calculate the capacitance. As a result, there maybe minor inaccuracies due to measurement error in terms of the minimum values able to be detected, but these were shown to be small enough as to be negligible in relation to the calculated readings. For each of the tests performed, it was shown that the DEAP sensor had a linear response. The third method for data collection proved to be most successful for gathering real time results in large numbers, and had the additional benefit of the information being able to be instantly plotted on a line graph.

2.2 Integrating the Sensors with the Vest

The areas of the thorax where the biggest movement occurs during respiration were mapped out together with essential anchor points of least or no movement by drawing directly onto a model wearing a pre-made white Lycra vest. The positioning of the sensor ribbons was chosen to correlate with specific areas of movement during respiration. Shorter sensors are used to read the smaller movements of the inspiratory and expiratory muscles while the longer sensor ribbons are used to measure the overall movement of the thorax. To enable individual readings from each sensor ribbon an anchoring system was developed to stabilise the end points and isolate the deformation. The specific length required for each sensor necessitated a bespoke, made to fit sensor for each measuring area, the design of which enabled the sensor ribbons to be slightly under strain when placed on the vest, allowing the sensor to work at maximum efficiency (see Fig. 1). The positioning of the sensor ribbons for the initial testing are Shoulder Sensor, 1, Upper Chest Sensor, 2, Lower Chest Sensor, 3 and Lower Rib Sensor 4 (see Fig. 2).

2.3 Construction of the Vest

We used a medium weight 2 way stretch Lycra, allowing a skintight cover of the body while enabling the integration of the sensor ribbon without hindering or altering the movement of the thorax and the sensor. Lycra also has good stretch and recovery

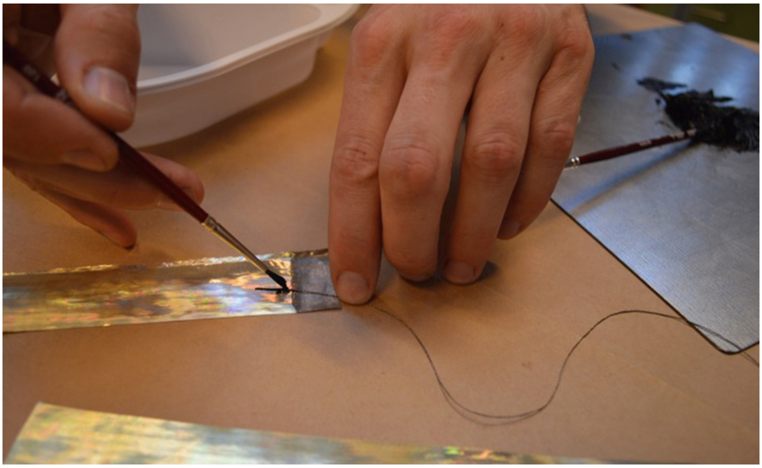


Fig. 1. Handcrafting bespoke sensors

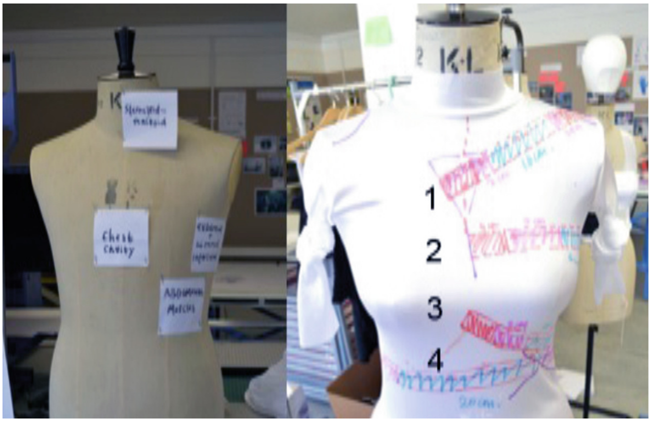


Fig. 2. Positioning the sensors

properties [7]. Velcro was used to attach the sensors to the vest. The loop side of the Velcro is sewn with a zig-zag stitch onto the anchor areas and retains a slight movement in the Lycra without the thread breaking. The hook side of the Velcro is embedded into the sensor ribbon by firstly sewing Zeelon, a heavy weight nonwoven, onto the base of the hook side of the Velcro with a zig-zag stitch. The new base is then thinly coated with T13 silicone. When dried the nonwoven Velcro base and the nonwoven silicone encased sensor ribbon base are thinly coated with Wacker E 43 silicone. The two are then sandwiched together to create a secure joining. Due to the nature of the sensor, using Lycra for the vest and using Velcro for integration there is room for flexibility in placement. This allows the vest to be worn by different users of varying sizes.

2.4 Data Collection

The vest is worn by the wearer. One at a time each sensor ribbon is placed on its set anchor points, secured and connected to the laptop. Once the wearer is connected a live reading is taken (see Fig. 3). The wearer is asked to undertake a number of tasks, such as shallow breathing, deep breathing, normal breathing, inhale and hold, exhale and hold, swallowing and chewing to stimulate different breathing patterns.The wearer is asked to perform each task twice, resting for 1 minute between each task to regulate breathing. Every task is video recorded and the live graph readings are video recorded with sound. The sensor ribbon is removed. The same sequence of tasks is then repeated for each sensor ribbon on its set position and recordings taken (see Figs. 4 and 5). An arduino pro mini was used due to its reduced size, however the ATMega processor and external components remained the same as the third method for data collection.

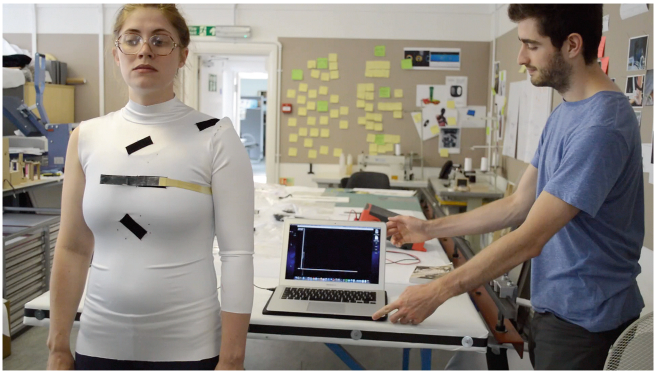


Fig. 3. Taking live readings

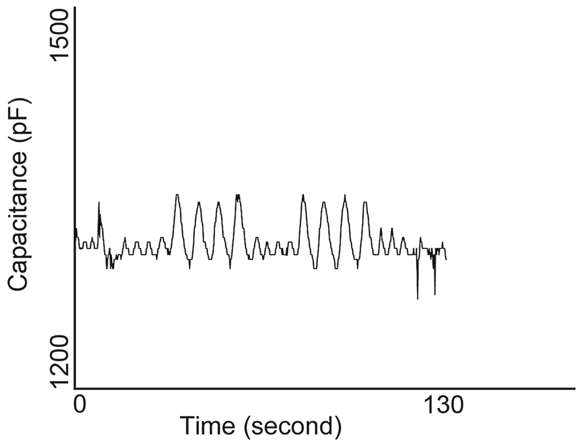


Fig. 4. Deep breathing using lower rib sensor

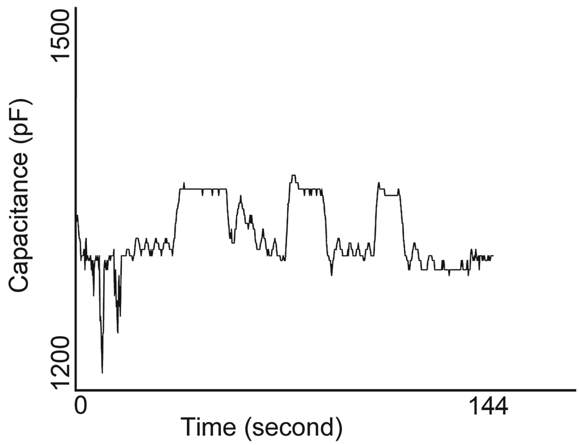


Fig. 5. Inhale and hold using lower rib sensor

3 Findings

The embryonic prototype demonstrates that there is significant scope for DEAP technology in human centered design applications for assistive healthcare and could support a sensing platform. Materiality and physical forms require careful consideration when designing products for on-body and real time monitoring. Devices and systems need to be as unobtrusive as possible. Materials that are soft, stretchable and conformable such as elastomers offer promising opportunities for accurate and unobtrusive body mapping in real time. We demonstrate the use of elastomeric sensors as a valuable tool for dynamically mapping the physical self. The thoracic sensor vest is an example of an intuitive, unconsciously interactive mapping tool aligned to the outside of the body to tell us what is going on inside the body. For expediency and deadline constraints we used a physical connection between the sensor and the computer, but envisage a wireless connection. We recorded markedly different patterns for each of the different breathing movements, two of which are shown, (see Figs. 4 and 5) and suggests that with further work, particularly on the cross correlating the breathing movements data with volume change data, the stretch sensors could potentially be used for sensitive measuring of volume changes within the lung and that would allow an understanding of both the breathing rate and the capacity simultaneously and unobtrusively in real time.

4 Conclusion

We consider the sensor vest to have potential for a sensitive and accurate breathing monitor, subject to further tests, data collection and correlation. The development of wearable or on-body assistive healthcare devices necessitates the convergence of both digital and physical platforms. However, materials are invested with social and cultural values that supersede their functional physical properties and we must explore and understand these relationships in order to design assistive healthcare devices and systems successfully and meaningfully [8]. Physical materials are being re-imagined as substrates invested with computational properties [9]. So-called transitive materials have been identified as revoking the gap between artefact and gadget [10]. It is essential that these functional and transitive materials that can span digital and physical platforms be exposed to practical design interrogation in order to develop their cultural currency [11]. Among these is the relationship of analogue values on a digital platform that can go beyond the now conventional motor parameters of the digit to larger scale interactive devices activated by limbs and/or whole bodies. Through this short scoping study we would envisage developing a range of product ideas for educational and rehabilitation uses, possibly for multi sensory environments and people with learning difficulties or neuro-disabilities, that could exploit the idea of using different parts of the body and different motor skills to activate and control responses through a stretchable electronics platform.

The scope to alter both the sensor's physical dimensions and encapsulant are important opportunities for design intervention and offer possibilities for large scale ambient sensing [12], bi-directional stretch sensing and alternative encapsulants for engineered responses such as embedded materials for controlled release, modification of the encapsulant to swell in the presence of specific stimuli, e.g., changes in pH and embedding chromics within the encapsulant for real time visual indicators.

References

1. Oliver, R., Toomey, A.: A physical basis for ambient intelligence. In: Gabrielli, S., Elias, D., Kahol, K. (eds.) AmBI-SYS 2011. LNICST, vol. 70, pp. 1–11. Springer, Heidelberg (2011)
2. Malins, J.P., et al.: Future Textile Visions: Smart Textiles for Health and Wellness. Robert Gordon University, Aberdeen (2012)
3. Ochoa, M., Rahim, R., Babak, Z.: Flexible Sensors for Chronic Wound Management. 1–1 (2013)
4. Rakibet, O.O., et al.: Epidermal passive strain gauge technologies for assisted technologies. IEEE Antennas Wirel. Propag. Lett. **13**(1), 814–817 (2014)
5. Kumar, P.S., et al.: Nanocomposite electrodes for smartphone enabled healthcare garments: e-bra and smart vest. In: International Society for Optics and Photonics SPIE Nanosystems in Engineering + Medicine (2012)
6. Mattman, C., Amft, O., Harms, H., Troster, G.: Recognizing upper body postures using textile strain sensors. In: 11th IEEE International Symposium Wearable Computers (2007)
7. Huang, K., et al.: A technology probe of wearable in-home computer-assisted physical therapy. In: Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems. ACM (2014)
8. Lanata, A., Scilingo, E.P.: Smart textiles: technology and wireless system network applications. In: Autonomous Sensor Networks. Springer, Heidelberg, pp. 127–158 (2013)
9. Mazilu, S., et al.: GaitAssist: a wearable assistant for gait training and rehabilitation in Parkinson's disease. In: 2014 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops). IEEE (2014)
10. Stoppa, M., Chiolerio, A.: Wearable electronics and smart textiles: a critical review. Sensors **14**(7), 11957–11992 (2014)

11. Komuro, N., et al.: Inkjet printed (bio) chemical sensing devices. Anal. Bioanal. Chem. **405**(17), 5785–5805 (2013)
12. Tongrod, N., et al.: Design and development of data glove based on printed polymeric sensors and zigbee networks for human-computer interface. Disabil. Rehabil. Assistive Technol. **8**(2), 115–120 (2013)
13. Rogers, J.A., et al.: Mater. and mechanics for stretchable electronics. Science **327**, 1603 (2010). AAAS
14. Lai, Y.-C., et al.: Stretchable organic memory: toward learnable and digitized stretchable electronic applications. NPG Asia Materials **6**(2), e87 (2014)
15. Yu, Y., Yan, C., Zheng, Z.: Polymer assisted metal deposition (PAMD): a full solution strategy for flexible, stretchable, compressible, and wearable metal conductors. Adv. Mater. **26**, 5508–5516 (2014)
16. Bar-Cohen, Y., Zhang, Q.: Electroactive polymer actuators and sensors. MRS Bull. **33**(03), 173–181 (2008)
17. Ozsecen, M.Y., Mavroidis, C.: Nonlinear force control of dielectric electroactive polymer actuators. In: SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring. International Society for Optics and Photonics (2010)
18. Carpi, F., De Rossi, D.: Dielectric elastomer cylindrical actuators: electromechanical modelling and experimental evaluation. Mater. Sci. Eng., C **24**(4), 555–562 (2004)
19. De Rossi, D., et al.: Electroactive fabrics and wearable biomonitoring devices. AUTEX Res. J. **3**(4), 180–185 (2003)
20. Pelrine, R.E., Kornbluh, R.D., Joseph, J.P.: Electrostriction of polymer dielectrics with compliant electrodes as a means of actuation. Sens. Actuators A: Phys. **64**(1), 77–85 (1998)
21. Danfoss Polypower DEAP Material. http://www.polypower.com
22. Moessinger, H.: Demonstrating the Application of Dielectric Polymer Actuators for Tactile Feedback in a Mobile Consumer Device. Philips Research, Eindhoven (2010)
23. O'Connor, K.: Lycra: How A Fiber Shaped America. Routledge, New York (2011)
24. Kuchler, S.: Technological materiality: beyond the dualist paradigm. Theory Cult. Soc. **25**, 101–120 (2008)
25. Wiberg, M., Robles, E.: Computational compositions: aesthetics materials and interaction design. Int. J. Des. **4**(2), 67 (2010)
26. Coelho, M., et al.: Programming reality: from transitive materials to organic user interaces. In: CHI Extended Abstracts on Human Factors in Computing Systems, pp. 4759–4762. ACM press (2009)
27. Toomey, A., Oliver, R., Tillotson, J.: Bioengineered textiles and nonwovens-the convergence of bio-miniturisation and electroactive conductive polymers for assistive healthcare, portable power and design-led wearable technology. In: WACBE-TBIS Special Symposium (2010)
28. Sekitani, T., Someya, T.: Stretchable large-area organic electronics. Adv. Mater. **22**, 2228–2246 (2010). Wiley

How to Ruin Sensor Network Performance Using Duplicate Suppression

Reinhardt Karnapke(✉), Stefan Lohs, and Jörg Nolte

Brandenburg University of Technology Senftenberg, Cottbus, Germany
{karnapke,slohs,jon}@informatik.tu-cottbus.de

Abstract. Duplicate suppression is an essential part of most of today's routing protocols for wireless sensor networks as well as for other wireless networks. It is necessary to reduce network load and to refrain from falsifying data on the application layer. However, most routing protocol descriptions do not include a description of the duplicate suppression that should be used. In many cases, duplicate suppression is not even mentioned anymore.

In this paper we describe common mistakes during implementation and usage of duplicate suppression. We also show an example where seemingly correct use of duplicate suppression lead to a decline in delivery ratio of more than 13 percent.

Keywords: Wireless sensor networks · Routing · Duplicate suppression · Performance reduction

1 Introduction

Most papers describing routing protocols do not specify the way duplicate detection should be implemented. Often, it is only stated that a duplicate suppression mechanism should be used. If a way of suppressing duplicates is specified, it is frequently proposed to use the identity of the originator and a sequence number to uniquely identify a message.

When a node receives a message, the first thing it should do in order to avoid unnecessary work is to consult its duplicate suppression. If the message has been received and handled before, there is no need to process it any further and it is silently discarded. Otherwise, the tuple (sender ID, sequence number) is entered into the duplicate list and the message is processed.

While this may seem straightforward, we found that there are a number of possible problems that can occur with duplicate suppression. Their origins can vary from simple error during implementation of the duplicate detection via wrong usage up to the constraints imposed on the duplicate suppression by the sensor node hardware and changes in network connectivity.

In this paper we take a look at different types of mistakes we identified in the hope that they can be avoided by students in the future.

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 20–29, 2015.
DOI: 10.1007/978-3-319-17136-4_3

This paper is structured as follows: Sect. 2 takes a brief look at a few routing protocols and the information they supply about the necessary duplicate suppression algorithms. Section 3 describes some of the problems students often encounter when implementing and using duplicate suppression algorithms and some ideas on how to evade these problems in the future. We finish with concluding remarks in Sect. 4.

2 Duplicate Suppression Specification in Routing Protocols

Most papers about routing protocols for wireless sensor networks do not state what kind of duplicate suppression algorithm should be used, if any.

GEAR. In Geographical and Energy Aware Routing (GEAR) [8], the authors use geographic routing to reach a certain region R.

"Once the packet is inside the target region, a simple flooding with duplicate suppression scheme can be used to flood the packet inside region R." [8].

No further information about the type of duplicate suppression is given.

CTP. The Collection Tree Protocol (CTP) [1] is the state of the art TinyOS protocol for data gathering scenarios. A collection tree is built by minimizing the value delivered by ETX (maximize link quality) on the route to the sink node. To establish routes, an adaptive beaconing algorithm is used. Due to the use of retransmissions and acknowledgments CTP needs a link-layer duplicate suppression mechanism called transmit cache. To detect a duplicate, three values are observed: origin id, origin sequence number, and THL. The THL value is necessary to recognize looping packets. When CTP receives a data packet at first the send queue is scanned for duplicates. Afterwards, the transmit cache containing the 3-tuples of the recently forwarded packets is also examined. The scanning of the send queue enables the detection of messages that have already finished processing and are about to be transmitted while the transmit cache is used to compare the current message with messages that have already been transmitted.

Trickle. In trickle, nothing is said directly about the way duplicates are suppressed, only a reference to SRM is included.

"Taking advantage of the broadcast nature of the medium, a sensor network can use SRM-like duplicate suppression to conserve precious transmission energy and scale to dense networks." [3].

3 Interaction Between Routing Protocols and Duplicate Suppression

In this section the problems with duplicate suppression we identified are presented. They can be roughly categorized in problems of the implementation of duplicate suppression (Sects. 3.1 and 3.2), erroneous usage of duplicate suppression (Sect. 3.3) and external reasons (Sects. 3.4 and 3.5).

These descriptions of the problems are followed by example values from sensor network simulations in Sect. 3.6 and some advice on strategies which can be used to avoid those problems in Sect. 3.7.

3.1 Sequence Number Data Type

One of the simplest yet most annoying mistakes that can occur when implementing a duplicate detection is the choice of a wrong data type. Basically, the sequence number only needs to be incremented by a node with every generated message. The most common data type that is used for numbers is an int.

Platform. Before a sensor network is deployed, it is usually simulated with a discrete event simulator like OMNeT++ [7]. In OMNeT++, the communication between nodes can be evaluated. When no events are active, the simulation time in OMNeT can progress directly to the next event, in some cases enabling a simulation of the whole network runtime.

However, OMNeT usually uses 32-bit Integers whereas sensor nodes are often built on a 16-bit micro controllers which use 16-bit integers. Therefore, the number of messages that can be transmitted before a sequence number rollover takes place is 65536 instead of 4 billion. For long running deployments this can be a problem, depending on the way sequence numbers are stored and compared for duplicate detection.

Sequence Number Rollover. While sequence numbers as a concept are never ending, data types have a maximum value. When this value is reached and the number further increased, an overflow arises. Depending on the data type, this results either in the value zero (for unsigned data types) or in the lowest possible negative number (for signed data types).

When the duplicate detection uses an array in which the received messages are marked and the sequence number is used as index, an unsigned data type that reaches zero means that all following message will be discarded. While this is annoying, the reason can usually be found and fixed fast. However, when an unsigned data type is used the overflow results in a negative offset into the data structure. This, in turn, means that the duplicate suppression manipulated the wrong data, which may even belong to any arbitrary entity in memory. As the micro controllers used in senor nodes do not have memory protection, this manipulation will at first go unrecognized. Only later, when the damaged data structure (or even code) is used, errors will occur. These errors are nearly impossible to find.

3.2 Number of Sequence Numbers Stored

On desktop computers and in simulations the available memory seems unlimited compared to what is available on sensor nodes. This enables the storing of all received tuples (originator, sequence number). In sensor networks, this is usually not possible. Instead, the assumption is often made, that only a single sequence number needs to be stored for each originator. All messages with a lower or the same sequence number are discarded.

This approach might work in small networks with large sequence numbers and seldom communicating applications. There are, however, multiple cases where this approach will fail:

If the nodes communicate often, one message might overtake another one. There are many possible reasons for this, e.g., different routes taken (route timeout, route breaks, local route repair), retransmissions (message loss due to interference) or MAC-layer issues. Whatever the reasons my be, the message with the lower sequence number will be discarded.

If the network is large, the number of bytes required to store one sequence number for each node might already be too much. A network with 500 nodes and 16-bit sequence numbers already needs 1 KB of RAM for sequence numbers. As current sensor nodes feature around 4 KB of RAM, one fourth of that memory would be taken, which is usually not acceptable.

To circumvent this problem, a single, combined list in which tuples (originator, sequence number) are stored can be used. But this gives rise to the problem of comparison. When the list is full and the sequence number of the received message is not found, but a higher one (from the same originator) is found, does this mean that the message with the lower sequence number was already forwarded and the sequence number replaced with one from another node? Or did the message with the higher sequence number overtake the one with the lower sequence number?

3.3 Usage of Duplicate Suppression

Initialization. When sequence numbers are stored in the duplicate list, primitive data types are usually used to represent them. Depending on the used programming language, the initial value is either undefined (anything that the memory represented before) or zero.

If the values are undefined, all messages might be discarded until the values contained in the list is reached an surpassed, leading to a large message loss, which is often not reproducible and hard to find.

Programmers usually initialize their data types with zero. If the list is initialized with zeros, the problem described above can not occur. However, if all nodes start the transmission of their messages with the (so initialized) sequence number zero, all of these first messages are lost.

Type Mismatch. If the sequence number is read from the message as one type, e.g., int, and stored in the duplicate list as, e.g., unsigned char, a type conversion must take place. For some types this conversion can be done implicitly, for others problems might arise. Luckily, this kind of type mismatch will normally be detected by the compiler and a warning generated.

Wrong Values. In wireless sensor networks, the code is usually minimalistic, due to the limited amount of available memory. Therefore, plausibility checks are often omitted. A wrong value can result for example from the usage of a wrong index, from alignment problems (e.g., word, byte, word pushed onto a stack and padding ignored) or from undetected bit errors during transmission/reception.

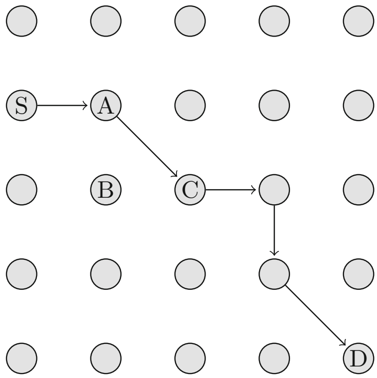
Without plausibility check, these wrong values can lead to false positives, false negatives and even corruption of foreign data structures or code.

Code Reuse. In sensor networks, every byte counts. Sensor nodes have very limited memory, therefore the smallest possible data type is usually used. This may enable the usage of a single byte for the sequence number in a small or short term deployment. When the same code (which is known to have worked in the previous deployment) is reused for a larger/longer running deployment, sequence number rollover once again occurs.

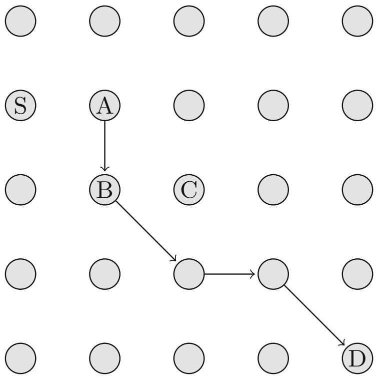
3.4 Route Changes in Intermediate Nodes

One of the major problems in wireless sensor networks is the instability of communication links. The logical topology of the network changes constantly, as links between nodes break and new ones appear. These changes can lead to the following problem, which can only arise for distance vector protocols:

Figure 1(a) shows a path from node S to node D that node S has built with a route discovery. It leads through nodes A and C. During the lifetime of that path, node A has learned a different path that leads to node D (Fig. 1(b)). This could be due to timeouts or simply related to the fact that caching of overheard routes is enabled. As the new path from Node A to node D is not longer but more current than the one stored in node A's routing table, most protocols would use this new path in the future.

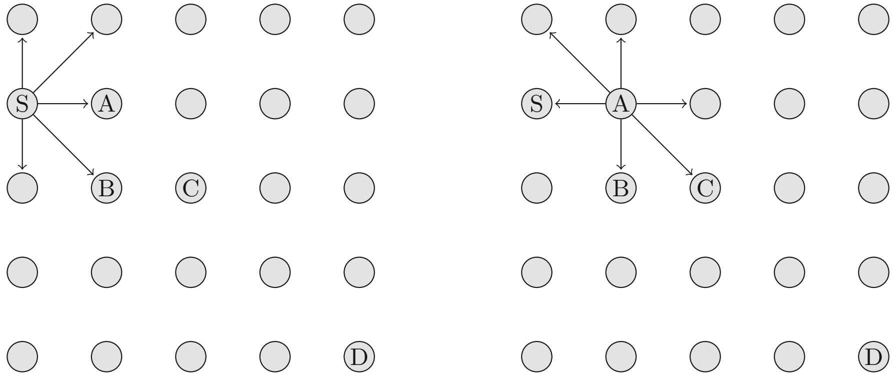


(a) Path from S to D via A



(b) Path from A to D

Fig. 1. Paths from S to D and from A to D



(a) Path from A to D Step One (b) Path from A to D Step Two

Fig. 2. Hop wise transmission

The problem arises the next time node S wants to send a message to node D. It looks up the next hop in its routing table and transmits the message to node A. Due to the broadcast characteristics of the wireless medium, not only node A but all nodes within communication range of node S receive this message (Fig. 2(a)). As the first thing they do upon reception of a message is checking for duplicates, each of the receiving nodes, including node B, decide that the message is no duplicate and enter it into their duplicate suppression. During the processing that follows, each node discards the message except for node A, which is listed as next hop.

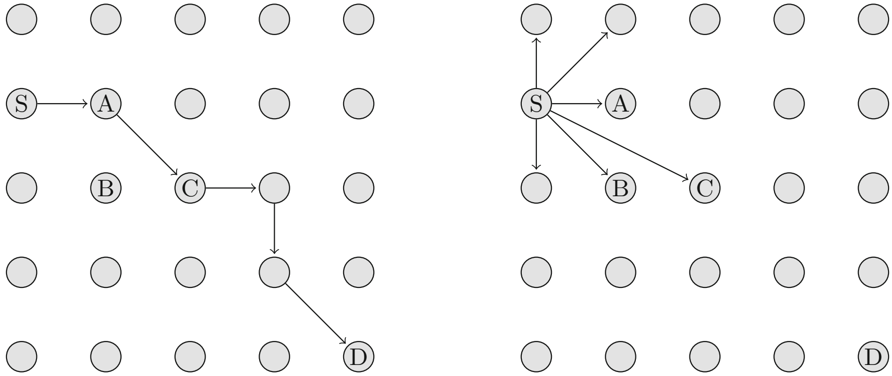
In the next step, node A looks up the next hop on the path to node D in its routing table and inserts node B as next hop in the message before retransmitting. Figure 2(b) shows which nodes receive the message, among them the intended next hop, node B. Upon reception, node B checks if the received message is a duplicate. As it still has the same originator and sequence number, it is identified as a duplicate and discarded even though node B was the intended forwarder.

In source routing protocols this problem should not arise, because intermediate nodes do not change the route.

3.5 Unidirectional Links and Changing Logical Topologies

This problem is experienced by both distance vector and source routing protocols. It is similar to the problem described above, as a node on the path overhears a message before it is addressed as next hop. However, the origin is a different one:

Most routing protocols use only bidirectional links in their route search, unidirectional links are ignored or blacklisted (e.g. in AODV [5,6]). However, the physical properties of the medium remain the same. Hence, a DATA message is also received by those nodes that are connected by unidirectional links. As we



(a) Path from S to D via A (b) Path from S to D Step One

Fig. 3. Paths from S to D and first transmission

have previously shown [4], unidirectional links are far more in number and often span greater distances than bidirectional ones.

Figure 3(a) shows once again the path from node S to node D, leading from node S over node A and node C. Due to a unidirectional link from S to C, the message that node S transmits is also received directly by node C (Fig. 3(b)) in step one. All nodes enter the message into their duplicate suppression, but only node A, being the intended forwarder, retransmits the message. When node C receives the message in step two, it identifies it as a duplicate and discards the message, even though node C is the intended forwarder. Please note that it does not matter if the link between nodes S and C is unidirectional or a bidirectional link which has appeared due to changes in the logical topology, as the error will occur in either situation. Still, as has been shown in [4], unidirectional links often have a far greater reach than bidirectional ones, therefore such longer links might more often be unidirectional.

3.6 Example Results of BuckshotDV

To quantify the influence of the duplicate suppression on the performance of the routing protocols, we evaluated one of our own routing protocols, BuckshotDV in two different versions. In BuckshotDV there are three criteria which are checked to see if a DATA message that has been received by an intermediate node has to be discarded or processed:

- Duplicates are discarded
- If the enlisted next but one hop is not a neighbor, the message is discarded
- If no route to the destination is known, the message is discarded

Only if a message has passed these three checks it is handled and forwarded.

The difference between the two evaluated versions lies only in this handling of a received DATA message. In the first version (A), duplicate suppression is

Table 1. Delivered messages for BuckshotDV, duplicate suppression first vs. last

Number of nodes	Version A	Version B	Difference	Percent lost
100	7691.244	8586.817	895.5733	∼ 10.5
400	32222.42	37224.84	5002.417	∼ 13.5
900	79524.57	88284.47	8759.903	∼ 10
1600	148562.3	160569.4	12007.10	∼ 7.5

used first. In the second version (B), the duplicate detection is moved to the end of these checks and only used on messages that pass the previous two checks. We used the simulation approach described in [2] to simulate a network with unidirectional links and frequent link changes.

Both protocol versions were evaluated with the same settings and the same number of simulations (4950 each).

Table 1 shows the results for the four different network sizes. Using the duplicate suppression first delivers fewer DATA messages for all network sizes, as expected. However, the amount of messages lost is also much higher than expected. Between 7.5 % and 13.5 % of DATA messages less were delivered because they were detected as duplicates (which is correct) and not forwarded (which is not correct in this case).

3.7 Solutions

There are multiple ways to solve these problems, depending on the protocol for which the problems should be solved:

- The implementation issues can only be solved by careful looking at all details of the implementation.
- Disabling new routes. The problem described in Sect. 3.4 can be solved by disabling the learning of new routes in the intermediate nodes for distance vector routing protocols. This is not recommended as it would obviously lead to stale routes.
- Using a Proactive Approach. If intermediate nodes know which other nodes use them as next hop they could notify those of the route changes. However, this would increase network load, with the known follow-up effects.
- Route shortening. Route shortening enables intermediate nodes (node C in the example in Sect. 3.5) to detect that they should forward the message in the future. Thus, they transmit it upon first reception. This is only possible for source routing protocols.
- Splitting duplicate detection into two phases. Instead of entering a received message into the duplicate list at the beginning of processing, only a check whether a message is a duplicate is made in the beginning. If it is not, all processing of the message is performed. Only as last step, directly before the message is forwarded or handed to the upper layers, the sequence number and

originator ID are entered into the duplicate list. This means that duplicates of a message might get processed and discarded at different stages, leading to more computational overhead. But "false positives" are avoided.

For all protocols which include the next hop in their message, it seems to be the easiest way to check upon reception of a message if the current node is the intended next hop and discard the message otherwise. Only after that, duplicate suppression takes place. But even that might not be enough if the forwarding of messages should be used as acknowledgment by the next but one hop. Then, the received message can surely be found in the list of duplicates, because it has been transmitted by this node before. Therefore, the processing order should be similar to the following:

1. Check if the message is a passive acknowledgment
2. Establish whether this node is the next hop
3. Use duplicate suppression.

4 Conclusion

In this paper we have shown common mistakes that can arise when duplicate suppression algorithms are implemented or used. We have also shown the impact of route changes in intermediate nodes and changes in the logical topology due to greater lengths of unidirectional links or appearing links with greater reach. For the latter, we presented simulation results, showing a decrease in delivery ratio of up to 13.5 percent.

In the future we hope that students that are implementing communication protocols and/or duplicate suppression mechanisms can avoid the mistakes presented in this paper.

References

1. Gnawali, O., Fonseca, R., Jamieson, K., Moss, D., Levis, P.: Collection tree protocol. In: Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems, SenSys 2009, pp. 1–14. ACM, New York (2009)
2. Karnapke, R., Lohs, S., Lagemann, A., Nolte, J.: Simulation of unidirectional links in wireless sensor networks. In: 7th International ICST Conference on Simulation Tools and Techniques, Lisbon, Portugal, pp. 118–125 (2014)
3. Levis, P.A., Patel, N., Culler, D., Shenker, S.: Trickle: A self regulating algorithm for code propagation and maintenance in wireless sensor networks. Computer Science Division, University of California (2003)
4. Lohs, S., Karnapke, R., Nolte, J.: Link stability in a wireless sensor network – an experimental study. In: Martins, F., Lopes, L., Paulino, H. (eds.) S-CUBE 2012. LNICST, vol. 102, pp. 146–161. Springer, Heidelberg (2012)
5. Perkins, C., Belding-Royer, E., Das, S.: Ad hoc on-demand distance vector (aodv) routing (2003). http://www.ietf.org/rfc/rfc3561.txt
6. Perkins, C.E., Royer, E.M.: Ad hoc on-demand distance vector routing. In: Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, New Orleans, LA, pp. 90–100, Feb 1999

7. Varga, A.: The omnet++ discrete event simulation system. In: Proceedings of the European Simulation Multiconference (ESM 2001), Prague, Czech Republic, p. 185, June 2001
8. Yu, Y., Govindan, R., Estrin, D.: Geographical and energy aware routing: A recursive data dissemination protocol for wireless sensor networks. Technical report (2001)

A Open Hardware Wireless Sensor Monitoring System for Human Wellbeing Research in Ambient Assisted Living

Sebastian D. Bersch(✉), Djamel Azzi, Rinat Khusainov, and Ifeyinwa E. Achumba

School of Engineering, University of Portsmouth, Anglesea Building, Portsmouth PO1 3DJ, UK
{sebastian.bersch,djamel.azzi,inat.khusainov, ifeyinwa.achumba}@port.ac.uk

Abstract. This paper introduces a simple and easy to use data collection platform specially designed for research in Ambient Assisted Living (AAL). A brief review of existing hardware platforms in AAL and their system limitations is presented. The authors propose an improved hardware platform based on Arduino Nano microcontroller and a set of commonly selected sensors to allow the data collection from 10 Degrees of Freedom. The authors describe the hardware design and make all required files freely available to enable new research teams in the field of AAL to build or modify their own systems based on the proposed hardware platform to facilitate their data collection. Examples of possible data sets and their use are presented with an outlook of future work and improvements.

Keywords: AAL · Accelerometer · Ambient assisted living · Arduino · Barometer · Data collection · Health care · Open hardware · Wellbeing

1 Introduction

Over the past decades, advances in healthcare and technology steadily increased the prospect of a longer healthy life for Western citizens. This demographic change has not only had an impact on humans themselves but also on the society and the economics of the countries they live in. In 2009, the EU commission estimated that in 2060 half of the population would be above the age of 48, including 151 million people above the age of 65 (from 85 million in 2008) and 61 million above the age of 80 (from 22 million in 2008). The increase in elderly combined with a decline in fertility and available labour supply will result in higher spending required from the government to support public healthcare [1]. Moreover, a follow up report highlighted that public spending on long-term care will most like double by 2060 [2]. It is therefore a necessity to find alternative options for the eldercare, which has the aim to supplement the traditional care, allowing for longer independent living at-home and reducing governmental costs for the increased aging population. Several commissions and consortia have been established and funded to investigate key areas under the Ambient Assisted Living (AAL) umbrella. These include fall prevention, promotion of independence, and monitoring of Activities of Daily Living (ADL) for fall detection and activity

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 30–40, 2015.
DOI: 10.1007/978-3-319-17136-4_4

recognition and classification. Consequently, automated monitoring of subjects living independently in their homes, using wearable and environmental Data Acquisition Devices (DADs), has been the subject of numerous research studies, resulting in a vast amount of literature. A review of these studies highlights significant details on event classification and monitoring techniques, but also a shortage of information on the used hardware for other research groups to follow. The Digital Wellbeing research group at the University of Portsmouth sees the necessity for a sophisticated, affordable yet simple to use DAD platform for the area of AAL to simplify the uptake for new research teams in this field.

This paper presents the development of hardware and software for an affordable Open Hardware Data Acquisition Device (OHDAD) for the recording of Activities of the Daily Living (ADL). The rest of the paper is organised as follows: Sect. 2 presents the previous work related to sensor hardware; Sect. 3 details the design and component selection of the OHDAD; Sect. 4 presents the possible measurements of the platform; and the conclusion with a view of further improvements is given in Sect. 5.

2 Previous Work

An understanding of possible and available sensor data is required for the design and evaluation of any monitoring system. A survey of the literature revealed different approaches to get to this vital information. Data acquisition is normally carried out under laboratory conditions or in house-like environments equipped with sensors (Ambient Intelligent Environments). The literature further revealed that due to the lack of mathematical models [3], no good alternative exists for the collection of sensor data using humans. The data sets available in the open domain [4, 5] found by the authors only contain normal ADLs. This is a limiting factor when abnormality, such as a fall, is of interest. For the collection of new data sets that contain abnormalities, some of the more general-purpose DADs for AAL should be highlighted.

The DAD presented in [6] uses two bi-axial accelerometers to emulate a tri-axial accelerometer. The authors only provide a block diagram of the system indicating a wireless network module, but no schematics regarding the microcontroller or any information about the software running on the microcontroller. Another system based on a bi-axial accelerometer, is presented in [7]. Their work uses an on-body DAD for the activity and location recognition. The system includes a Personal Digital Assistant (PDA) as an interface and a microcontroller (PIC 16F873) for the data collection. Additional sensor data is collected from a digital compass sensor and gyroscope. The authors only provide a picture of their complete setup without any further information on the wiring, block diagram, or software workflow.

In [8], the authors stated that a vast amount of literature relies on accelerometer data in the area of AAL. They continued to criticise that most of reviewed research papers use data that is collected under laboratory conditions, which might not correspond to real life scenarios. They point out that a possible solution is the design of a simple DAD that is easy to use and wear, in order to allow for a simplified and more realistic data collection. Therefore, the authors designed their own wearable system based on a

Beagleboard [9]. The system collects pictures from a USB camera and communicates with a Bluetooth (BT) accelerometer. The authors do not explain if the BT connection can be used for additional data transfer or if it is only for the communication with the accelerometer. The system can be used for up to 4 hours with a lithium battery. It is worn by the user on the torso and requires no further interaction after turning the device on. The authors failed to present a block diagram or any other information regarding the circuitry on the Beagleboard or the software running on it.

In [10] the authors highlighted that Wireless Sensor Networks (WSNs) will allow for point-of-care diagnostics that will boost the use of wearable medical devices aimed to advance the general wellbeing and fitness of every person. Therefore, the authors developed a hardware system based on the Tyndall25 platform [11] to remotely monitor the ECG, blood pressure, and pulse rate values of an individual. Wireless communication is provided by an ISM band 2.4 GHz transceivers. The main processing is executed on an unspecified low power 8-bit microcontroller with 128 kB of program memory. The authors do not provide any further information about the hardware platform besides some diagrams of the peripheral amplification circuit. In addition to this, their selection of ISM transceivers requires special hardware or another base station to let it communicate with modern laptops or smartphones.

One of the earlier mentioned data sets [5] was collected using Hoarder boards. These boards were designed at MIT for sensing and manipulating environments with extremity-computing devices [12]. The board collects bi-axial accelerometer data to monitor users whilst they carry out different ADLs. On the project website [13], the author provided all necessary files to reproduce a Hoarder board but stated himself, that the board is out-dated by today's standards. It relies on CompactFlash cards, which have since been superseded by smaller SD and Micro SD Cards and the serial port for the data communication is not available on modern PCs anymore.

The authors of [14] presented a wearable wireless accelerometer device for fall detection. The hardware is based on a Field-Programmable Gate Array (FPGA) Spartan 3, a tri-axial MicroElectroMechanical Systems (MEMS) accelerometer, and a ZigBee transceiver for wireless data transmission. The FPGA is programmed using a USB connection. The sensor is sampled at 10 Hz and has a range of ± 2 g. Each axis acceleration value is transmitted over the wireless communication as an ASCII string. A base station time-stamps received data and controls the data fusion from additional sensors.

3 The Open Hardware Data Acquisition Device

3.1 Design Requirements

The requirements for the developed OHDAD, with respect to the DADs highlighted in literature, are as follows:

- Small and unobtrusive
- Wearable for long-term (at least one day)
- Sensor diversity (for future research and other research groups needs)

- Integrated Development Environment (IDE) should run on as many OS platforms as possible (at least Windows, Linux, and MacOS)
- Programmable through USB connection
- Wireless connectivity
- Affordable

Figure 1 illustrates a block diagram of the OHDAD's hardware architecture derived from the literature [7, 8, 12, 14]. The microcontroller is able to collect sensor information from analogue as well as digital sensors, using either the in-build Analogue-to-Digital Converter (ADC) or Digital Input/Output (DIO) pins. Local storage allows saving extensive amount of sensor information that is collected over long periods of time. The microcontroller can be programmed from a host PC using the USB connection that doubles as a data communication channel. In addition, a wireless module enables the communication with a nearby base station.

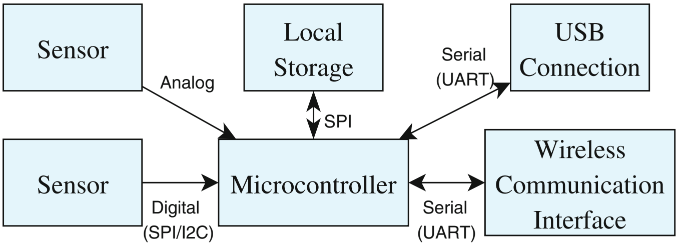


Fig. 1. Block diagram of the Open Hardware Data Acquisition Device

3.2 Component Selection

The OHDAD is designed around the Arduino platform [15] that comes in various sizes and is based on different Atmel microcontrollers like the ATmega168, ATmega328, and ATmega2560. The authors settled for the Ardunio Nano V3 using the ATmega 328. The footprint could have been further reduced using the Arduino Mini (based on the same microcontroller), with the disadvantage of no USB connectivity on board. In addition, the Arduino IDE is written in Java and available for Windows, MacOS, and Linux. Platforms, such as MBed [16] or TelosB [17], are also possible alternatives, but they have a higher cost and an increased physical size.

The sensor selection is influenced by the past work described above [7, 8, 12, 14], which mainly focused on MEMS sensors. In addition, most modern smartphones include at least an accelerometer, with more vendors also including gyroscopes, magnetometers, and even barometers, allowing the collection of up to 10 Degrees of Freedom (DoF). These smartphones not only allow for a resourceful data collection, but also on-board data classification [18, 19]. The problem though is the short battery lifetime when used for such tasks. As the platform described here should offer sensor diversity and provide researchers with various sensors information, it was decided to include at least sensors that could be found in a modern smartphone for a fraction of the price and prolonged battery lifetime. The total cost for the hardware presented here is below £100, which, for now, is cheaper than a smartphone with similar sensors, e.g. iPhone 4 s (£349) or Motorola Moto G (£129). In addition, algorithms developed using the available sensor information could be later implemented on smartphones with similar or better hardware specifications.

MEMS sensors are only available as very small Surface Mounted Device (SMD) components. This hinders their use in non-commercial environments. Therefore, several companies started producing breakout boards to convert these sensors to Throughput Hole Technology (THT) components, which can be easily used by the open source community or in commercial environments for rapid prototyping projects. Another aspect of using breakout boards is their wide availability, the large support community for software libraries, low cost and distribution of schematics under the open hardware license. Breakout boards also allow researchers with limited soldering skills to reproduce the designed OHDAD, hence widening the audience for the presented work. The three main breakout boards used for the OHDAD combine several MEMS sensors and enable the collection of 10 DoF (9 DoF Sensor Board + Barometer). Table 1 presents the respective specifications.

Table 1. Specifications for the sensor boards used in the OHDAD

	9 DoF Sensor Board (SEN-10724) from Sparkfun			SEN-11282 from Sparkfun	ChronoDot from Macetech
	Accelerometer (ADXL345)	Gyroscope (ITG-3200)	Magnetometer (HMC5883L)	Barometer (BMP085)	Real time clock (DS3231SN)
Power supply	2.0 V–3.6 V	2.1 V–3.6 V	2.16 V–3.6 V	1.62 V–3.6 V	3.3 V
Power consumption (measuring)	40 μA	6.5 mA	100 μA	5 μA at 1 sample/sec	200 μA
Sensor I/O interface	SPI /I2C	I2C		I2C	I2C
Number of axes/ measurement	3				Seconds, Minutes, Hours, Day, Data, Month and Year
Sensor resolution	10 Bit	16 Bit	12 Bit	16 to 19 Bit	
Available range	±2/±4/±8/±16 g	±2000°/sec	±8 Oe	−500 m to 9000 m	
Sensitivity	4 mg/LSB	14.375 LSBs per °/sec	2 milli-gauss	0.25 m	±3.5 ppm

The first breakout board combines an accelerometer (Analog Devices ADXL345), gyroscope (Invensense ITG-3200) and magnetometer (Honeywell HMC5883L). The other two boards include a Bosch BMP085 and a Maxim DS3231SN for the on-board barometer and Real-Time Clock (RTC), respectively. The barometer provides the atmospheric pressure and the temperature of the sensor itself. From the former it is possible to gain altitude information that has been used for the fall detection in [20]. In [14], the authors highlight the time stamping of received data at a base station to improve the contextual information of the data itself. The OHDAD is equipped with a Real Time Clock to reliably time stamp collected sensor data over a long period of time. This enables the use of the system outside a controlled laboratory environment within range of a base station. When data should be stored independently of a base station, the internal EEPROM storage of the ATmega328 is insufficient with only 1Kbyte. Therefore, a flash storage implemented using a micro SD card increases the storage and enables the easy transfer of sensor data at the end of an experiment from the hardware platform to a PC for post-processing.

During the post-processing, the collected data needs to be correlated to ADL labels. A time stamped activity execution log allows fast data labelling during this stage, when it is ensured that the on-board RTC and the clock used for the activity log are synchronised. Therefore a wireless communication interface is included in the OHDAD to allow for the inspection of correct operation of the platform, observation of the time stamp of the current sensor reading, as well as the transmission of the sensor reading for direct processing at a base station. In the white paper [21] the different technologies WiFi, Bluetooth (BT) and Zigbee are compared and their advantages based on the application field pointed out (see Table 2). All three technologies provide enough bandwidth for the transmission of the collated sensor data. Therefore, the two important criteria for the selection of communication technology used for OHDAD are battery life and connection ability. In terms of battery life, the ZigBee technology is the most favourable, while BT is the most convenient choice, as it allows for a simple connectivity to PCs and smartphones. The initial design bases the communication on the latter for the convenience to connect to a smartphone. In case of an increased importance of the lower power consumption at a later design stage, a BT module sharing the same ZigBee footprint is used for the OHDAD platform. In addition, the wireless communication allows test subjects to have a certain degree of freedom (movement wise), when performing tasks under laboratory conditions, while another person can wirelessly monitor start and end times of an activity.

Table 2. Comparison of ZigBee, WiFi, and Bluetooth (Source: [21])

	ZigBee	WiFi	Bluetooth
Battery life	Years	1 Week	1 Week
Bandwidth	250 Kbps	Up to 108 Mbps	720 Kbps
Advantages	Low Power	Ubiquity	Convenience

The fully assembled OHDAD is illustrated in Fig. 2 and measures 60 mm × 29 mm × 41 mm with a weight of 38.9 g. The designed circuit schematic, board layout and Arduino program code is too extensive to adequately cover in this paper, but all necessarily files can be freely accessed from [22]. The OHDAD's dimensions are small enough to be usable at different body locations without being too intrusive for the test subject, such as the hip as suggested by [23]. A smaller version of OHDAD could be even sewn into a belt. The authors hope that sharing the OHDAD design will enable new research teams to reproduce the system and modify it to their needs resulting in a speedier data collection that is essential for good research.

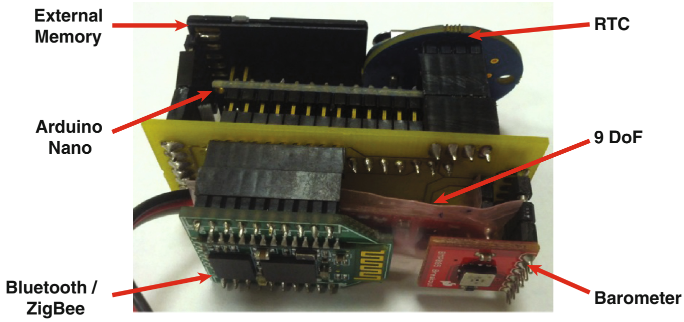


Fig. 2. Fully assembled Open Hardware Data Acquisition Device

4 Hardware Validation and Data Collection Evaluation

After the hardware design, production, and assembly, the correct function of the OHDAD and its accompanying software running on the Arduino has to be verified. The data storage on the OHDAD follows the Request For Comment (RFC) standard 4180 [24], which is designed for the exchange of tabular data between spreadsheet programs. Each data recoding is appended to the end of the file and can be viewed with Matlab or a spreadsheet program for further processing. Each recording consists of 18 sensor data in the following order: year, month, date, hour, minute, second, scaled accelerometer X-Axis, scaled accelerometer Y-Axis, scaled accelerometer Z-Axis, scaled magnetometer X-Axis, scaled magnetometer Y-Axis, scaled magnetometer Z-Axis, gyroscope X-Axis, gyroscope Y-Axis, gyroscope Z-Axis, temperature, air pressure, altitude above mean sea level (AMSL).

An initial test trial was performed to validate the correct working order of the OHDAD and to determine the achievable sampling frequency. The test entailed the test subject using a set of stairs in a University building to descend two levels, passing a corridor and using another set of stairs at the end of the corridor to get back to the second level, walk back to the office and sit down in an office chair. The visual analysis is limited to the accelerometer and barometer as they give the best visual representation of the trial. The accelerometer output is illustrated in Fig. 3. The graph shows the constant movement of the test subject with a stationary phase at the end when the subject reached the chair and stopped producing any significant movement.

Figure 4 illustrates the same experiment for the altitude information from the barometer sensor. The data clearly shows the decent and ascend with constant levels of corridor walking. Close inspection of the decent and ascent shows three landings of the staircase in the sensor data, which corresponds to four single flights of stairs used to connect the different levels of the University building.

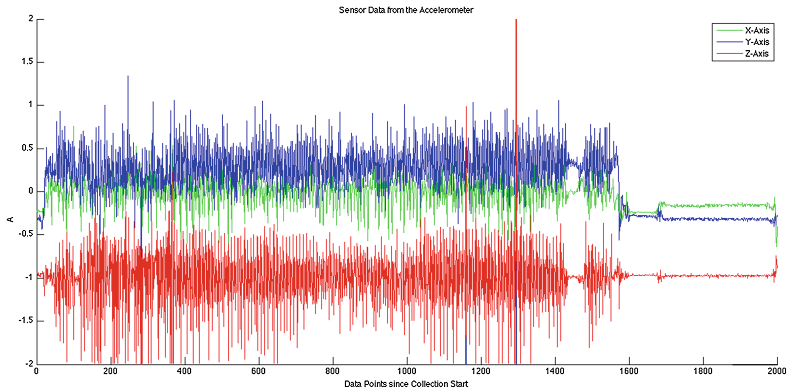


Fig. 3. Accelerometer sensor output

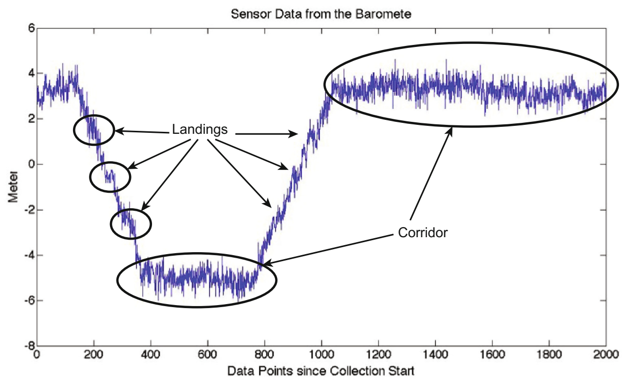


Fig. 4. Altitude output from the barometer sensor

The visualization of the different sensor data shows that an individual sensor type can be used for specific activity classification and sensor combinations enable the localization or improved movement analysis of a test subject. The latter is already used for quad-copters, with recent MEMS sensor developments combining 10 DoF on a single sensor chip [25]. This enables the indoor navigation, where the use of GPS is limited, such as shopping malls and elderly care homes. As the OHDAD is intended for the use indoors, GPS was not included in the design presented here.

The initial trial also allowed identifying the achievable sampling frequency and operational time. For the former, the authors measured a sampling rate of 10 Hz. While this is a comparable low rate, the authors showed in [26] that the sampling frequency is the least important factor for the ADL event classification accuracy. Moreover, it was highlighted that sampling frequencies above 10 Hz only achieve minor improvements. For the operational time, the OHDAD achieved over 24 hour with a fresh set of 4xAA, 2000 mAh batteries.

5 Conclusion

This paper has presented an Open Hardware Data Acquisition Device (OHDAD), mainly aimed at the long-term data collection for Ambient Assisted Living (AAL) research. A review of the literature has discussed the hardware platforms used by other research teams and showed that none of the platforms could be programmed on all three main operating systems Windows, Linux, and Mac, therefore limiting new research teams in the equipment used. Furthermore, the only freely available hardware platform offering all necessary files to reproduce the hardware is over six years old and relies on outdated RS232 serial interface for programming, which is hardly available on modern PCs.

The Data Acquisition Device proposed by the authors is based on the popular and affordable Arduino Nano microcontroller platform and has several benefits. Firstly, the system is reprogrammable under Windows, Linux, and Mac OSX. Secondly, the inclusion of Bluetooth and a Real Time Clock (RTC) enables the recording of activity times using a smartphone for an easier data labelling when post-processing the sensor information. Thirdly, with the hardware schematics and the software freely available from [22], the authors encourage the reproduction and modification of the hardware and software for a speedier and improved data collection that is necessary and essential for good research in Ambient Assisted Living. The authors also show two possible usage scenarios for the on-board sensors and point out the applications of sensor data fusion. Future hardware optimizations will look into a wireless charging method for the hardware platform to improve the long-term data monitoring capabilities of the system, as it will avoid the need for a test participant to open the sensor box to replace the included battery pack. Charging could take place during the night on a nightstand of the user without loosing useful data during the day. On the software side, three aspects need to be further investigated. The first aspect is the use of low power modes of the ATMega328 microcontroller in the Arduino platform. The possibility of energy savings and longer runtime needs to be explored in the context of improving the sampling frequency to about 20 to 30 Hz. The second aspect is the software optimisation to free up resources to enable on-board processing of sensor data inside OHDAD. The third aspect is the interaction with a base station to read the internal memory during inactivity, such as charging. A similar aspect is a smartphone application to improve the collection and labelling of ADL data during supervised collection scenarios.

References

1. The 2009 Ageing Report: economic and budgetary projections for the EU-27 Member States (2008–2060). European Commission (DG ECFIN) and The Economic Policy Committee (AWG) (2009)
2. The 2012 Ageing Report Economic and budgetary projections for the 27 EU Member States (2010–2060). European Commission Economic and financial affairs the Economic Policy Committee (2012)

3. Virone, G., Lefebvre, B., Noury, N., Demongeot, J.: Modeling and computer simulation of physiological rhythms and behaviors at home for data fusion programs in a telecare system. In: Presented at the Proceedings of the 5th International Workshop on Enterprise Networking and Computing in Healthcare Industry, 2003, Healthcom 2003 (2003)
4. Roggen, D., Tröster, G., Lukowicz, P., Ferscha, A., del Millán, J.R.: Activity and Context Recognition with Opportunistic Sensor Configurations (2010)
5. Bao, L., Intille, S.S.: Activity recognition from user-annotated acceleration data. In: Ferscha, A., Mattern, F. (eds.) PERVASIVE 2004. LNCS, vol. 3001, pp. 1–17. Springer, Heidelberg (2004)
6. Pan, J.-I., Yung, C.-J., Liang, C.-C., Lai, L.-F.: An intelligent homecare emergency service system for elder falling. In: Magjarevic, R., Nagel, J.H. (eds.) World Congress on Medical Physics and Biomedical Engineering. IFMBE Proceedings, vol. 14, pp. 424–428. Springer, Heidelberg (2007)
7. Lee, S.-W., Mase, K.: Activity and location recognition using wearable sensors. IEEE Pervasive Comput. **1**, 24–32 (2002)
8. Casale, P., Pujol, O., Radeva, P.: Human activity recognition from accelerometer data using a wearable device. In: Vitrià, J., Sanches, J.M., Hernández, M. (eds.) IbPRIA 2011. LNCS, vol. 6669, pp. 289–296. Springer, Heidelberg (2011)
9. BeagleBoard.org - community supported open hardware computers for making. http://beagleboard.org/
10. O'Flynn, B., Angove, P., Barton, J., Gonzalez, A., O'Donoghue, J., Herbert, J.: Wireless biomonitor for ambient assisted living. In: Presented at the Oral Presentation at Conference on Signals & Electronic Systems (ICSES) (2006)
11. Wireless Sensor Networks Prototyping Platform_25mm | Tyndall. http://www.tyndall.ie/content/wireless-sensor-networks-prototyping-platform25mm
12. Gerasimov, V., Selker, T., Bender, W.: Sensing and effecting environment with extremity computing devices. Motorola Offspring **1**, 30–41 (2002)
13. Gerasimov, V.: Hoarder aka Swiss Army Knife (SAK) board. http://vadim.oversigma.com/Hoarder/Hoarder.htm
14. Lombardi, A., Ferri, M., Rescio, G., Grassi, M.: Wearable wireless accelerometer with embedded fall-detection logic for multi-sensor ambient assisted living applications. In: Sensors (2009)
15. Arduino – HomePage. http://arduino.cc/
16. Development Platform for Devices | mbed. https://mbed.org/
17. TelosB Datasheet http://www.memsic.com/userfiles/files/Datasheets/WSN/telosb_datasheet.pdf
18. Dai, J., Bai, X., Yang, Z., Shen, Z., Xuan, D.: PerFallD: a pervasive fall detection system using mobile phones. In: Presented at the 2010 8th IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops) (2010)
19. Fang, S.-H., Liang, Y.-C., Chiu, K.-M.: Developing a mobile phone-based fall detection system on android platform. In: Presented at the Computing, Communications and Applications Conference (ComComAp) (2012)
20. Bianchi, F., Redmond, S., Narayanan, M., Cerutti, S., Celler, B., Lovell, N.: Falls event detection using triaxial accelerometry and barometric pressure measurement. In: Engineering in Medicine and Biology Society, 2009, EMBC 2009, Annual International Conference of the IEEE, pp. 6111–6114 (2009)
21. International, D.: Demystifying 802.15.4 and ZigBee. http://www.digi.com/pdf/wp_zigbee.pdf

22. Bersch, S.D., Azzi, D., Khusainov, R.: OHDAD — Bitbucket. https://bitbucket.org/Sebastian_B/ohdad
23. Khusainov, R., Azzi, D., Achumba, I., Bersch, S.D.: Real-time human ambulation, activity, and physiological monitoring: taxonomy of issues, techniques, applications, Challenges and Limitations. Sensors **13**, 12852–12902 (2013)
24. Shafranovich, Y.: RFC 4180 - Common Format and MIME Type for Comma-Separated Values (CSV) Files. http://tools.ietf.org/html/rfc4180
25. ADIS16488 datasheet and product info | Tactical Grade Ten Degrees of Freedom Inertial Sensor | MEMS Inertial Measurement Units | Analog Devices. http://www.analog.com/en/mems-sensors/mems-inertial-measurement-units/adis16488/products/product.html
26. Bersch, S.D., Azzi, D., Khusainov, R., Achumba, I., Ries, J.: Sensor data acquisition and processing parameters for human activity classification. Sensors **14**, 4239–4270 (2014)

Artificial Immune System - A New Approach for the Long-Term Data Monitoring in Ambient Assisted Living

Sebastian D. Bersch(✉), Djamel Azzi, and Rinat Khusainov

School of Engineering, University of Portsmouth,
Anglesea Building, Portsmouth PO1 3DJ, UK
{sebastian.bersch,djamel.azzi,rinat.khusainov}@port.ac.uk

Abstract. This paper makes a case for the use of Artificial Immune Systems (AIS) in the area of Ambient Assisted Living (AAL) for anomaly detection and long-term data monitoring. The literature review of relevant solutions developed for AAL and the use of AIS in other fields is presented. It is further highlighted that so far AIS have not been used in the area of AAL. To advocate the use of AIS in this area, the authors compare the accuracy rate of detecting abnormal activity between a simple Signal Vector Magnitude (SVM)-based threshold algorithm, two Artificial Immune System (AIS)-based monitoring algorithms, and four supervised classification algorithms (KNN, J48, Naïve Bayes, and SMO). The results of the comparison, using precision, recall, and f-measure, showed good results for the two different AIS-based monitoring algorithms, warranting current and future work.

Keywords: Artificial Immune System · AIS · Fall detection · Abnormality detection · Supervised classifier · Unsupervised classifier

1 Introduction

Over the past decades, the advances in healthcare and technology steadily increased the prospect of a longer healthy life for Western citizens. This demographic change has not only had an impact on humans themselves, but also on the society and the economics of the countries they live in. In 2009, the EU commission estimated that in 2060 half of the European population would be above the age of 48, including 151 million people above the age of 65 (from 85 million in 2008) and 61 million above the age of 80 (from 22 million in 2008). The increase in elderly combined with a decline in fertility and available labour supply will require higher spending from the government to support public healthcare [1]. Moreover, a follow up report highlighted that public spending on long-term care will most like double by 2060 [2]. It is therefore a necessity to find alternative options for the eldercare, which has the aim to supplement the traditional care, allowing for longer independent living at-home, and reducing governmental costs for the increased aging population. Several commissions and consortia have been established and funded to investigate key areas under the Ambient Assisted Living (AAL)

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 41–50, 2015.
DOI: 10.1007/978-3-319-17136-4_5

umbrella. These include promotion of independence, monitoring of Activities of Daily Living (ADL) for fall detection, and activity recognition and classification. A new research trend is interested in the detection of abnormality in long-term behaviour data. A review of the emerging literature shows already good results. However, Artificial Immune Systems (AIS) have not been used in the area of AAL so far. The authors have previously proposed the use of AIS for an adaptive long-term monitoring system to detect abnormal data points in a stream of data without storing past information. The authors' initial research relied on computer-generated data and achieved promising results. The AIS algorithm is now tested with real tri-axial accelerometer data collected using a test subject and compared with the classification accuracy of four supervised classification algorithms and a simple Signal Vector Magnitude (SVM)-based threshold algorithm.

2 Related Work

When looking at the long-term health development of an elderly person, many studies show that a deviation from a person's normal behaviour increases the probability of a current, impending, or future health problem. It is suggested that each person follows a personal circadian activity rhythm (CAR) [3]. While the behavioural activity of younger people is influenced by a social and a biological rhythm, most elderly fall into a reoccurring routine that is mostly dominated by the biological rhythm as the social interaction is greatly reduced, as stated in [4].

In [5], it is stated that there exist two different methods (profiling and discriminating) for the abnormal behaviour detection. The former requires only normal training data and detects a deviation, while the latter also requires abnormal training data to establish two independent behaviour models. Each method can be further separated into a uniform and an individual approach. The uniform approach tries to generalize, e.g. all monitoring subjects behave equally, while the individual approach aims to establish a separate model for each subject.

In [6] a behavioural pattern monitoring system is described based on basic motion sensors. The work builds on earlier research that uses probability estimates to detect deviations from time spend in a room and extends it to a multi-room environment. Another improvement to past work is the removal of discrete timeslots throughout the day to detect behavioural patterns that may differ with time. The authors do not state if their approach needs a special training phase for each tested subject, which would result in additional work for care personnel.

In [7], the aim is to develop a naïve Bayes system that uses a supervised learning method and facilitates online learning. With the help of the latter, the learned model should adjust to changes in a person's behaviour. The authors continue to state that supervised learning is required, as there exist a wide variety of home layouts and unique ways to perform an ADL. Part of their test data is collected in a laboratory environment and easily labelled, while the same task in a home environment is time-consuming and invasive. Additionally, the authors pointed out that there was a significant variation in labelling identical activities, which raises the question of how efficient and necessary is the labelling of ADLs for abnormality detection.

In [8], the authors also criticize the dull task of acquiring a-priori knowledge for AAL research. The authors continue to point out several typical static classification methods that are used in AAL such as, naïve Bayes, decision trees, and k-nearest neighbour and add that activity recognition becomes more a field of data mining techniques. Furthermore, they emphasize that rule based AI methods will have problems with the complex models in AAL, as the area shows to have an immense number of rules. These rules can interfere with each other as ADLs are not mutual exclusive and can happen in parallel.

Most of the AAL literature presented here is trying to locate shifts in recurring data patterns that represent abnormal behaviour patterns. Parallels can be drawn to Intrusion Detection Systems (IDS) or fault detection systems as stated in [5]. One of the AI methods used for IDS and fault detection, but to the authors' best knowledge, not in AAL, is the Artificial Immune System (AIS).

AIS is a simplified model of the human immune system, with the aim to divide a data set into a self and non-self set. Hereby, frequent events define the former while infrequent events define the latter. The main advantages of AIS are its constant learning and evolving to adjust to changes in the self-set.

In [9] it is stated that AIS works best in applications that require pattern classification and response, a distributed architecture, the detection of novel anomalous patterns, change system behaviour slowly over time and have only limited storage available that does not allow to store the full normal system pattern. The section above highlights exactly these requirements for AAL.

In [10], the authors compare several classic AI methods to Artificial Immune Recognition System (AIRS) in the area of electric fault detection. The five tested methods are: Artificial Neural Networks (ANN), Logistic Regression (LR), Support Vector Machines (SVM) and K-Nearest Neighbour (KNN). The dataset contained real power distribution faults from three regions in North Carolina. In the direct comparison AIRS outperformed ANN 5 out of 6 scenarios for the false alarm ratio.

The combination of the research work described above and the authors' initial work presented in [11] based on computer generated data, give the authors the confidence that AIS is perfectly suited for abnormality detection in an AAL environment and might have been overlooked by other research groups in AAL.

3 Investigation Procedure

The experiment presented in this work is designed to analyse the capabilities of detecting abnormal activity in a long-term data stream using the three different classification approaches:

Simple Signal Vector Magnitude (SVM)-based threshold.

Unsupervised classifier.

- Represented by two AIS-based monitoring systems based on the authors work presented in [11, 12].

Supervised classifier.

- Represented by four different classifier methods and good parameter combinations as identified in [13].

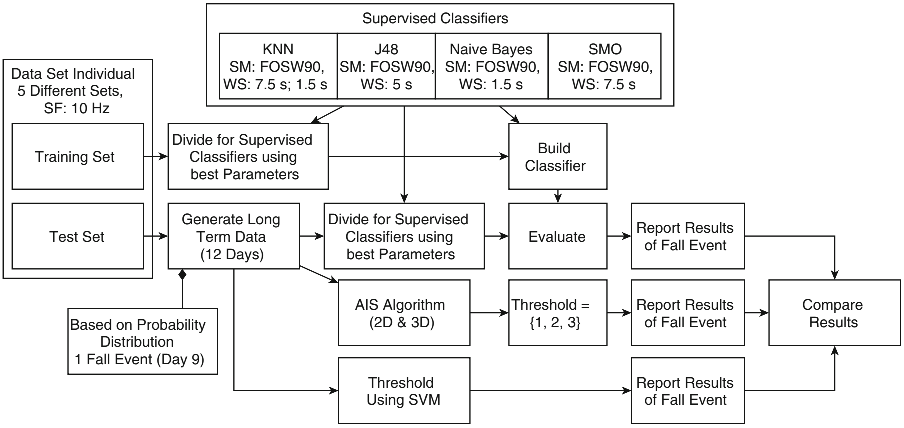
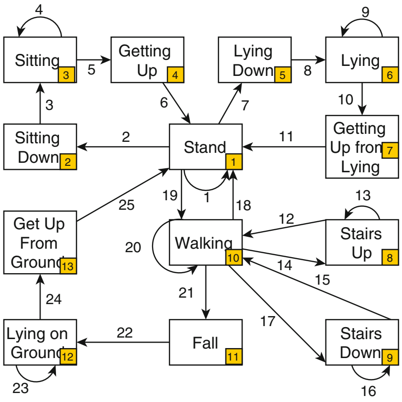


Fig. 1. Flow diagram of the experiment carried out for the comparison of the detection rate

The decision of using a novel approach, such as AIS, for the detection of abnormal activity in the AAL field results in uncertainty of the possible achievable detection rates in comparison with other already established classification methods, due to the non-existent comparison in the key areas of detection rate and false alarm rate. For the comparison of the detection rate of abnormal activity, the authors followed the in Fig. 1 illustrated experimental design. Tri-axial accelerometer sensor data was collected from a test subject using a developed Open Hardware Data Acquisition Device (OHDAD) [14].

The activities recorded for this experiment include standing, walking, sitting, lying, stairs up and down, and a fall. Each activity and transitions from activity to activity were recorded five times to allow for the generation of training and test sets for the four supervised classification algorithms (KNN, Decision Tree (J48), Naïve Bayes, and SMO). While the training set is used to generate the supervised models, the activities in the test set are used for the long-term data generation. For the experiment 12 days of ADLs with one fall during day 9 were required. Instead of recording and labelling data from a test subject for 12 consecutive days, the Markov chain illustrated in Fig. 2.a in combination with the transition probabilities in Fig. 2.b was used to concatenate the pre-recorded ADLs to the required length of 12 days. This approach has the advantage that the data is correctly labelled, activities are not randomly connected, but instead follow defined rules, and data is generated in minutes and not days.

For the supervised classification methods, the generated data is labelled in two different ways. The first approach keeps individual data labels and the second approach divides the data set into abnormal (fall) and normal (the remaining) activities. In [13] the authors presented a method to select well performing parameter combinations for Segmentation Method (SM) and Window Size (WS) for the used supervised classification methods to achieve good ADL event classification accuracy. Therefore, this paper does not detail further, how parameters were selected or which feature attributes were calculated.



Transition		Transition	Simulation Day		
			Day 1 - 8	Day 9	Day 10 - 12
			Timeslot	Timeslot	Timeslot
From	To	Number	0 - 24	0 - 24	0 - 24
Stand		1	0.1	0.1	0.1
Stand	Sitting Down	2	0.3	0.3	0.3
Sitting Down	Sitting	3	1	1	1
Sitting		4	0.7	0.7	0.7
Sitting	Getting Up	5	0.3	0.3	0.3
Getting Up	Stand	6	1	1	1
Stand	Lying Down	7	0.2	0.2	0.2
Lying Down	Lying	8	1	1	1
Lying		9	0.85	0.85	0.85
Lying	Getting Up from Lying	10	0.15	0.15	0.15
Getting Up from Lying	Stand	11	1	1	1
Stairs Up	Walking	12	0.2	0.2	0.2
Stairs Up		13	0.8	0.8	0.8
Walking	Stairs Up	14	0.1	0.1	0.1
Walking	Stairs Down	15	0.1	0.1	0.1
Stairs Down		16	0.8	0.8	0.8
Stairs Down	Walking	17	0.2	0.2	0.2
Walking	Stand	18	0.3	0.3	0.3
Stand	Walking	19	0.4	0.4	0.4
Walking		20	0.5	0.499	0.5
Walking	Fall	21	0	0.001	0
Fall	Lying on Ground	22	1	1	1
Lying on Ground		23	0.65	0.65	0.65
Lying on Ground	Get Up from Ground	24	0.35	0.35	0.35
Get Up from Ground	Stand	25	1	1	1

b

Fig. 2. (a) Markov chain layout for the long-term data simulation environment, (b) Transition probabilities for the Markov chain layout, with one fall during day 9

$$SVM_{FallActivity_j} = \max(\sum_{i=1}^{n} \sqrt{x_i^2 + y_i^2 + z_i^2}) \quad (1)$$

The Signal Vector Magnitude (SVM)-based threshold algorithm relies on a-priori knowledge of the collected ADL sets. For each fall event the SVM value was calculated using Eq. 1. Based on the lowest calculated value, the threshold was set to alarm when SVM is above 2.04 g.

As AIS is a novel approach for the detection of abnormal activity (in particular falls), it is unknown, which combination of accelerometer axes is best for the monitoring process. Therefore, two different monitoring systems for the 2D- and 3D-data representation were designed and developed. Both systems are illustrated in Fig. 3.a and b, respectively. Part of the design approach is influenced by the Hierarchical Temporal Memory (HTM) introduced in [15]. HTM and AIS are both used to generalise the underlying data and only relay out of the ordinary data to higher levels of the monitoring system. In the 2D representation, the combination of the XY, YZ, and ZX axes are monitored in parallel, while the 3D representation uses the X, Y, and Z axes simultaneously. Both abnormal activity-monitoring systems are based on a combination of AIS and a rule-based system. The AIS algorithm, as the Immune Intelligence, identifies abnormal data patterns through the activation of detectors, and the rule-based system defines an alarm condition based on the AIS detector activation level.

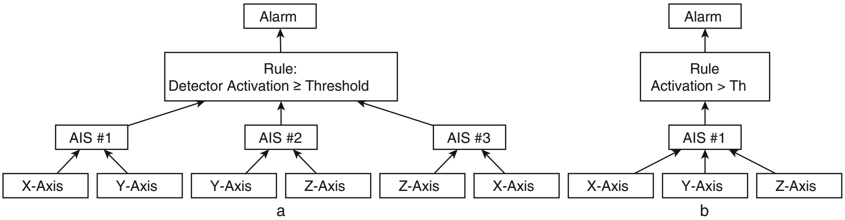


Fig. 3. Rule-based AIS monitoring systems (a) 2D-data representation, (b) 3D-data representation

For the performance measure the authors selected precision, recall, and f-measure as only a small percentage (minority) of the generated long-term data set is of interest. This imbalance in the data set prevents the use of classification accuracy. For example if the data set has a class distribution of 98 % and 2 %, continuously guessing the majority class will result in the 98 % classification accuracy [16]. However, for this experiment the 2 % minority (representing abnormality) is of interest. The classifier prediction can belong to four possible outcomes: True Positive (TP - identifying a true data point as true), False Positive (FP - identifying a false data point as true), False Negative (FN - identifying a true data point as false), True Negative (TN - identifying a false data point as false). Based on these four cases, the new performance measures can be calculated using Eq. 2 (precision), Eq. 3 (recall), and Eq. 4 (f-measure). In terms of detection of abnormality, precision characterises how many of the predicted abnormal data segments were actually labelled in the data set as abnormal. Recall determines how many of the data segments labelled as abnormal were missed. A value below 1 indicates that the classifier missed at least one data segment. In the worst-case scenario, a missed abnormality (e.g. fall) could have severe health consequences. The f-measure parameter calculates the harmonic mean between precision and recall.

$$Precision = \frac{TruePositive}{TruePositive + FalsePositve} \tag{2}$$

$$Recall = \frac{TruePositive}{TruePositive + FalseNegative} \tag{3}$$

$$F - Measure = 2 * \frac{Precision * Recall}{Precision + Recall} = \frac{2 * TP}{2 * TP + FP + FN} \tag{4}$$

4 Evaluation

This section reports on the performance of the threshold algorithm, supervised classifiers with optimal parameter selection, and the two different AIS-based monitoring systems with regards to their ability to detect abnormal activity. Table 1 presents the three performance measures from all methods tested. Each approach is individually assessed, followed by a graphical comparison of the best performing algorithms.

Table 1. Performance results for the detection of abnormal activity in long-term data

Method		Activity	Precision	Recall	F-measure
Threshold	SVM	Abnormal	1	0.5	0.66667
Traditional classifier activities labelled 1 - 13	KNN 7.5s	Fall	0.042614	0.55556	0.079156
	J48 5s	Fall	0.00048436	0.45946	0.0009677
	NB 1.5s	Fall	0.00075803	0.076923	0.0015013
	KNN 1.5s	Fall	0.0024124	0.43407	0.0047981
	SMO 7.5s	Fall	1	0.40741	0.57895
Traditional classifier Activities labelled normal/ abnormal	KNN 7.5s	Abnormal	0.042614	0.55556	0.079156
	J48 5s	Abnormal	0.88235	0.40541	0.55556
	NB 1.5s	Abnormal	0.016931	0.44505	0.032622
	KNN 1.5s	Abnormal	0.0024124	0.43407	0.0047981
	SMO 7.5s	Abnormal	1	0.11111	0.2
Method		Threshold	Precision	Recall	F-measure
AIS	2D with XY YZ ZX	1	0.33333	1	0.5
		2	0.25	0.5	0.33333
		3	0.33333	0.5	0.4
	3D with XYZ	1	0.00038073	1	0.00076118
		2	0.4	1	0.57143
		3	0.33333	0.5	0.4

The precision value of the SVM threshold algorithm indicates the classification of 100 % TP (no false alarms). The 50 % for the recall parameter indicates that only half of the abnormal activity was identified. Further investigation revealed that the selected segmentation method divided the fall event in two data windows. The high SVM value is only present in the second window, resulting in the first window not exceeding the threshold value. This highlights a general problem with the data labelling of abnormal events: how to define an abnormal or normal activity. This is similar to [7], who stated that even the classification of the same activity showed variation when labelled by a test subject and confirmed in [17], stating that abnormalities are ill-defined. For this experiment, any recall value above 0 % highlights the correct fall detection, as the long-term data only includes one fall.

For better readability, Table 1 contains only the fall activity (for the set of thirteen activities) and abnormality (for the two-class problem). The first observation is that the change to a two-class problem improves the performance of the J48 and Naïve Bayes classifiers. The KNN classifier does not improve with different labels, while the recall performance of the SMO algorithm actually decreases. The second observation is that all classifier methods correctly classify the fall for both activity labels. However, the third observation shows a varying success rate for the precision parameter. In particular, KNN and Naïve Bayes show a high FP rate with a precision below 5 %. The next best classifier is J48, which achieves the precision of 88 % for the two-class problem. The achieved recall performance of around 50 % can be attributed to the longer duration of abnormality and not just the short duration of the actual fall. This is followed by SMO with a 100 % precision rate (0 % FP) for both data representations.

For the two AIS-based algorithms (2D and 3D representations) only the detection of abnormality is reported. Each of the two algorithms is further divided with three thresholds. The threshold has the aim of reducing FP alarms. The range under test is limited to $\mathit{Threshold} = \{1, 2, 3\}$ as a higher value will have a negative effect on the precision and recall parameter. The AIS achieves recall values of 100 % to 50 %, similar to the SVM threshold algorithm. The precision parameter on the other hand, indicates a much lower performance. Therefore, the FP segments were further analysed. The segments that are classified as FP by the AIS system with the $\mathit{Threshold} = \{2, 3\}$ are data segments, which directly follow a fall event. This means that the falsely classified activities are 'lying on the ground' and 'getting up from the ground'. The problem is that similar looking activities are not included as a frequent activity. Thus, based on the system limitation that normality is defined to be frequent events, they are considered as abnormalities.

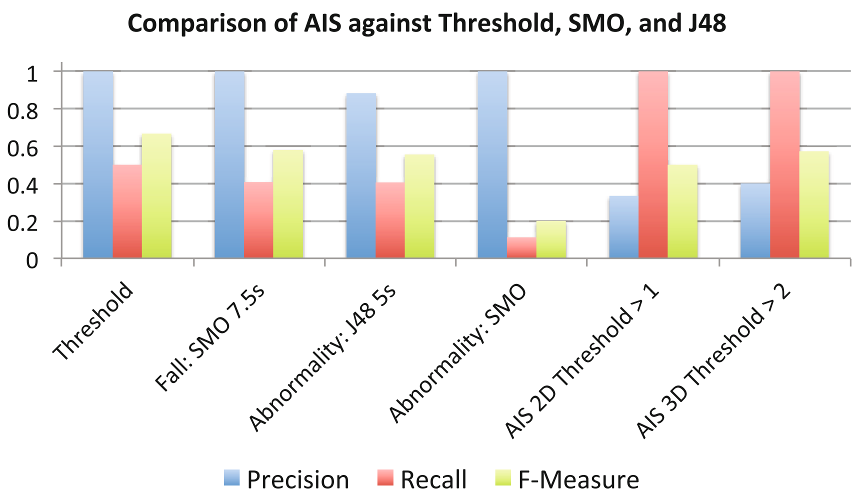


Fig. 4. Graphical presentation of the classification performance results of the experiment

Figure 4 illustrates only the best performing classification methods from Table 1 for a graphical comparison. The evaluation includes the SVM threshold algorithm, the SMO classifier identifying fall and abnormality, the J48 classifier for abnormality, and the two AIS-based algorithms. The AIS-based systems include the 2D representation with

Threshold = {1} and the 3D representation with *Threshold* = {2}. The first observation is that all methods correctly identify the fall. Due to identifying activities directly following a fall, AIS seams to achieve the lowest precision performance (33.3 %). The recall parameter shows mostly values of around 50 % for all methods, besides SMO for the two-class problem, which misses significant more abnormal data segments. For the F-measure, the AIS system for the 3D representation is the third best algorithm. It is only slightly outperformed by SMO (trained with all thirteen activities) and the threshold algorithm. In addition, all AIS algorithms surpass the SMO classifier that is trained to distinguish between normal and abnormal data.

5 Conclusion

This paper has presented a comparison for the accuracy rates of detecting abnormal activities between a simple Signal Vector Magnitude (SVM)-based threshold algorithm, two Artificial Immune System (AIS)-based monitoring algorithms, and four supervised classification algorithms (KNN, J48, Naïve Bayes, and SMO). The review of the relevant literature, while highlighting good results for different approaches, also uncovered that Artificial Immune Systems have not yet been used for the detection of abnormal activity in the Ambient Assisted Living (AAL) field. The authors could not find a particular reason why AIS is omitted in AAL and expect that other research groups might have overlooked it as a possible classification method. As there is no prior comparison of the classification performance between AIS and other classification method for the detection of abnormal activity in AAL, the authors collected four commonly used activities and their transition activities using a Open Hardware Data Acquisition Device (OHDAD) [14] to generate long-term data based on a Markov chain and transition probabilities.

The performance comparison showed that the AIS-based monitoring systems are outperformed by a SVM-based threshold algorithm and SMO classifier. However, the threshold algorithm does only work when an abnormality (fall) has the highest SVM value from the tested activities. The SMO classifier requires a-priori knowledge of the abnormality. In comparison, AIS requires expert knowledge only during the design stage. Moreover, the false positives segments directly follow the fall event (abnormality). The FP segments (lying) can be considered as abnormal when carried out on the floor, but are normal on the bed or couch. The used sensor (accelerometer) does not allow for the differentiation. The results are still encouraging and future work of the authors will expand on the simulation environment to test further ADL scenarios. Planned experiments will also increase the tested simulation runtime from 12 days to over three month. Another aspect the authors are keen to investigate is the required computational load of the AIS-based monitoring systems for the real-time data classification on an embedded system.

References

1. The 2009 Ageing Report: economic and budgetary projections for the EU-27 Member States (2008-2060). European Commission (DG ECFIN) and the Economic Policy Committee (AWG) (2009)

2. The 2012 Ageing Report Economic and budgetary projections for the 27 EU Member States 2010 2060. European Commission Economic and financial affairs the Economic Policy Committee (2012)
3. Virone, G., Alwan, M., Dalal, S., Kell, S., Turner, B., Stankovic, J., Felder, R.: Behavioral patterns of older adults in assisted living. IEEE Trans. Inf. Technol. Biomed. **12**, 387–398 (2008)
4. Franco, C., Demongeot, J., Fouquet, Y., Villemazet, C., Vuillerme, N.: Perspectives in home TeleHealthCare system: daily routine nycthemeral rhythm monitoring from location data. Presented at the International Conference on Complex, Intelligent and Software Intensive Systems (CISIS) (2010)
5. Elbert, D., Storf, H., Eisenbarth, M., Unalan, O., Schmitt, M.: An approach for detecting deviations in daily routine for long-term behavior analysis. Presented at the 2011 5th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) (2011)
6. Barger, T.S., Brown, D.E., Alwan, M.: Health-status monitoring through analysis of behavioral patterns. IEEE Trans. Syst. Man Cybern. Part A Syst. Hum. **35**, 22–27 (2005)
7. Tapia, E.M., Intille, S.S., Larson, K.: Activity recognition in the home using simple and ubiquitous sensors. In: Ferscha, A., Mattern, F. (eds.) PERVASIVE 2004. LNCS, vol. 3001, pp. 158–175. Springer, Heidelberg (2004)
8. Zhou, F., Jiao, J., Chen, S., Zhang, D.: A case-driven ambient intelligence system for elderly in-home assistance applications. IEEE Trans. Syst. Man Cybern. Part C Appl. Rev. **41**, 179–189 (2011)
9. Hofmeyr, S., Forrest, S.: Architecture for an artificial immune system. Evol. Comput. **8**, 443–473 (2000)
10. Cai, Y., Chow, M.-Y., Lu, W., Li, L.: Evaluation of distribution fault diagnosis algorithms using ROC curves. In: 2010 IEEE Power and Energy Society General Meeting, pp. 1–6 (2010)
11. Bersch, S.D., Azzi, D., Khusainov, R.: Artificial immune systems for anomaly detection in ambient assisted living applications. Int. J. Ambient Comput. Intell. **5**, 1–15 (2013)
12. Bersch, S.D., Azzi, D., Khusainov, R.: Fall detection using biologially inspired monitoring - artificial immune system in the area of assisted living. Presented at the ECTA-FCTA - Proceedings of the International Conference on Evolutionary Computation Theory and Applications and the Proceedings of the International Conference on Fuzzy Computation Theory and Applications [parts of the International Joint Conference on Computational Intelligence IJCCI 2011] (2011)
13. Bersch, S.D., Azzi, D., Khusainov, R., Achumba, I., Ries, J.: Sensor data acquisition and processing parameters for human activity classification. Sensors **14**, 4239–4270 (2014)
14. Bersch, S.D., Azzi, D., Khusainov, R.: OHDAD — Bitbucket. https://bitbucket.org/Sebastian_B/ohdad
15. Hawkins, J., George, D.: Hierarchical temporal memory. Technical report, Numenta, Inc. (2006)
16. Chawla, N.V.: Data mining for imbalanced datasets: an overview. In: Maimon, O., Rokach, L. (eds.) Data Mining and Knowledge Discovery Handbook, pp. 875–886. Springer, US, Boston (2010)
17. Acampora, G., Cook, D.J., Rashidi, P., Vasilakos, A.V.: A survey on ambient intelligence in healthcare. Proc. IEEE **101**, 2470–2494 (2013)

A Secure Authentication and Key Management Scheme for Wireless Sensor Networks

Sarmadullah Khan[1(✉)] and Rafiullah Khan[2]

[1] Electrical Department, CECOS University, Peshawar, Pakistan
sarmad@cecos.edu.pk
[2] Communication and Networks Lab, University of Genova, Genoa, Italy
Rafiuk7@gmail.com

Abstract. In recent years, the adaptation of Wireless Sensor Networks (WSNs) to application areas requiring mobility increased the security threats against confidentiality, integrity and privacy of the information as well as against their connectivity. Since, key management plays an important role in securing both information and connectivity, a proper authentication and key management scheme is required in mobility enabled applications where the authentication of a node with the network is a critical issue. In this paper, we present an authentication and key management scheme supporting node mobility in a heterogeneous WSN that consists of several low capabilities sensor nodes and few high capabilities sensor nodes. We analyze our proposed solution by using MATLAB (analytically) and by simulation (OMNET++ simulator) to show that it has less memory requirement and has good network connectivity and resilience against attacks compared to some existing schemes. We also propose two levels of secure authentication methods for the mobile sensor nodes for secure authentication and key establishment.

Keywords: Wireless sensor networks · Cryptography · Key management

1 Introduction

The Wireless Sensor Network (WSN) are usually deployed in possibly remote and unattended locations they are definitely prone to security attacks. Hence to secure the network operation and securely gather and forward the information, security threats and its counter measures should be considered at design time in terms of both requirements and implementation techniques. The design of security algorithms considering the homogeneous sensor networks was the first step to secure sensor networks. However, some research work [1,2] have shown that homogeneous sensor networks have high communication and computation overheads, high storage requirements and suffer from severe performance bottlenecks. Hence, recent research work [4,14] introduced heterogeneous sensor networks, which consists of High-end sensors nodes (H-sensors) and Low-end

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 51–60, 2015.
DOI: 10.1007/978-3-319-17136-4_6

sensors nodes (L-sensors). To achieve better performance and scalability, H-sensors have more resources compared to L-sensors. However, both H-Sensors and L-sensors are still highly vulnerable in nature and are exposed to several security threats and particularly prone to physical attacks. Thus, proper security mechanisms should be applied to protect these nodes against attacks. Hence, a novel key management scheme for heterogeneous sensor networks suitable for scenarios with partial mobility is presented. The proposed solution relies on two types of keys: authentication keys and secret communication codes used to generate secret keys whenever needed. The remaining of the paper is organized as follows. Section 2 presents existing work. Section 3 describes the proposed key management scheme, while in Sect. 4 describe the security analysis of the proposed scheme, and finally conclusions are provided in Sect. 5.

2 Related Work

To secure wireless sensor networks, Perrig [5] proposed SPINS, in which there a secure central entity called server which is responsible for establishing a key among the sensor nodes. Since it is based on centralized base station approach, the failure of base station severely affects the performance of network. To overcome the above mentioned issue, a randomly key distributed approach is proposed by Eschenauer and Gligor [3]. In this scheme, there is no centralized entity like a base station for key distribution and management. Each node in the network is assigned a set of randomly selected keys from a large key set. Since the keys are distributed randomly, the two communicating nodes need to have at least one common key in their sets for secure communication. To further improve the network security, sharing of at least q-keys concept for establishing a secret key is introduced by Chan [6]. The prior knowledge of node's deployment in the network helps in increasing the network connectivity and reduce the memory requirements [7] combined with the Rabin's scheme [15]. To achieve better security and network connectivity with less memory requirements with low computational cost, NPKPS scheme is proposed by Zhang [8] for wireless sensor networks. To reduce the memory cost, Kim [9] introduced a level-based key management scheme while a two-layered dynamic key management for clustered based wireless sensor networks is presented by Chuang [10].

The management of secret keys (MASY) protocol is presented by Maerien in [11] which is based on the trust assumption among the networks managers/base stations. To further improve the network connectivity and reduce the memory requirements of the symmetric key distribution approaches, Du [4] presents an asymmetric key pre-distribution (AP) approach. Du sensor network model consists of two different types of nodes making it a Heterogeneous Sensor Networks (HSNs). This assumption significantly increases the network connectivity and reduces memory requirements compared to the existing symmetric key management approaches. Lu [12] proposes a framework for key management schemes in distributed peer-to-peer wireless sensor networks with heterogeneous sensor nodes and shows by simulation that heterogeneity results in higher connectivity

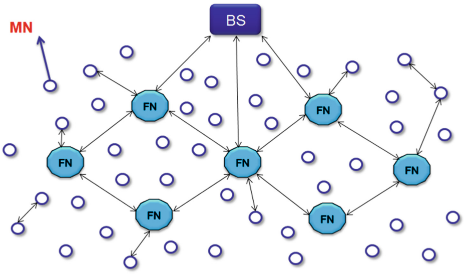


Fig. 1. Virtual network architecture

and higher resilience. Du [13] proposes a routing-driven key management scheme for heterogeneous wireless sensor networks, based on Elliptic Curve Cryptography (ECC), which provides better security with significant reduction of memory overhead.

The considered network model is a Heterogeneous Sensor Network (HSN) composed base station and H-sensors (fixed) while L-sensors are Mobile Nodes (MNs). The virtual network organization is shown in Fig. 1.

CH:	Cluster Head	MN:	Mobile Node
FN:	Fixed Node	KP_{main}:	Main large key pool
KP_{FN}:	Sub key pool for Fixed Nodes	KP_{MN}:	Sub key pool for Mobile Nodes
K_{plc}:	Public key	K_{prt}:	Private key
prand():	Prime number generator	$AUTH$:	Authentication code
PRM:	Generated prime number	SP_{MN}:	Scalar product of a Mobile Node
SP_{FN}:	Scalar product of a Fixed Node	SCC:	Secret communication code

3 Proposed Scheme

First we describe a list of abbreviations used in the proposed solution. Since the proposed key management scheme is built on top of the above network model to provide effective authentication and dynamic key establishment. The key material is generated at the BS. More specifically, a large key pool KP_{mail} is created and then divided into two sub key pools KP_{FN} and KP_{MN} such that $KP_{FN} \cap KP_{FN} = \emptyset$.

The key pool KP_{FN} is used by the FNs of the network while the key pool KP_{MN} is used by the MNs of the network for the secret key establishment. For authentication purposes, Elliptic Curve Cryptography (ECC) is used during the initialization phase for key generation. Three different phases have been taken into account

1. Key pre-distribution to the different sensor nodes i.e. FNs and MNs

2. Node authentication
3. Communication key establishment among the nodes within the network.

Further details will be provided in the following subsections.

3.1 Key Pre-distribution

As already mentioned, in our proposed scheme, the key material is organized at the BS in a large key pool KP_{main} which is then randomly divided into key pool KP_{FN} and into key pool KP_{MN} such that $KP_{FN} \cap KP_{MN} = \emptyset$. Now each FN i is assigned a randomly selected key pool KP_{FN_i} from the key pool KP_{FN} where $KP_{FN_i} << KP_{FN}$ and contains $|KP_{FN_i}|$ keys while each MN j is assigned a randomly selected key pool KP_{MN_j} from the key pool KP_{MN} where $KP_{MN_j} << KP_{MN}$ and contains $|KP_{MN_j}|$ keys. Since these two key pools are disjoint, $KP_{FN_i} \cap KP_{MN_j} = \emptyset$. These assigned key pools will be used by the FNs and by the MNs for the establishment of a secret communication key using the assigned key generation algorithm.

Concerning the authentication key material, each FN and each MN is assigned an elliptic curve $E(a, b)$ over a finite Galois field $F(G)$ and a base point G along with a unique authentication code $AUTH$. Each FN and each MN is also assigned an ECC-based public/private key pair (K_{plc}, K_{prt}) and a prime number generator $(prand())$.

As previously described, FNs and the BS compose the fixed infrastructure of the overall heterogeneous sensor network; they are powerful devices and play an important role in authentication and key management. In order to maintain the availability of these services and to avoid the full network being compromised by attackers, a higher level of security is thus required for FNs and the BS. As a consequence, the authentication of FNs to the network and the communication between the FNs and between a FN and the BS will be based on a standard ECC-based private/public key mechanism. Accordingly, each FN has its own private key and the public key of the BS and of all the other FNs of the network. At the same time, the BS has the public keys of all the FNs.

All the previously introduced key material is transferred to each node of the network by means of secure side channels. Then, after this pre-distribution phase, the specific key material assigned to each type of node of the network is as follows:

- the BS owns all the key material that needs to be pre-distributed (plus, as already described, the public key of each FN),
- each FN i has been given $E(a, b)$, G and $AUTH_i$ for authentication purposes and key pool KP_{FN_i} for communication key establishment,
- each MN j has been given $E(a, b)$, G and $AUTH_j$ for authentication purposes and KP_{MN_j} for communication key establishment.

3.2 Node Authentication

After the deployment and key pre-distribution phase, each FN of the network broadcasts periodic Hello messages. This mechanism enables each FN to fill a table with all neighboring MNs. The FN ID is included in the Hello message along with a random nonce signed by the FN's private key. Upon the reception of those Hello messages, each MN selects a FN as its Cluster Head (CH), e.g. the one with the highest signal strength, after the verification of Hello message by using the FN public key. Since Hello message verification is a part of the authentication phase, at this point the authentication phase among the FNs and the MNs can start. To this aim, each MN_j authenticates the Hello message of the selected FN_i as a CH as follow: First MN_j uses the FN_i ID and generates a prime number PRM_{FN_i} using the prime number generator prand()

$$PRM_{FN_j} = prand(ID_{FN_i}) \tag{1}$$

After the generation of PRM_{FN_i}, the MN_j generates the public key of the FN_i using the scalar multiplication as

$$K_{plc} = (PRM_{FN_i} + ID_{FN_i}) \bullet G \tag{2}$$

Then the MN_j can verify the Hello message signature. Successful verification of the Hello message signature authenticates the CH i.e. FN_i to the MN_j. The MN then calculates the scalar product of the assigned authentication code $AUTH_j$ and its private key as

$$SP_{MN_j} = \left(AUTH_j + ID_{MN_j}\right) \bullet Kprt \tag{3}$$

Then the MN_j sends a joining request including its ID, SP_{MN_j}, and the nonce it had received from the CH back to its selected CH, all signed by its private key. After receiving the MN_j's joining request message, the FN_i first authenticates MN_j before registering it as a trusted cluster member. The FN_i follows the same procedure as the MN_j did to check the authenticity of the received messages. First the FN_i use the MN_j ID and generate a prime number PRM_{MN_j} using the prime number generator prand()

$$PRM_{MN_j} = prand(ID_{MN_j}) \tag{4}$$

After the generation of PRM_{MN_j}, the FN_i generates the public key of the MN_j using scalar multiplication as

$$K_{plc} = \left(PRM_{MN_j} + ID_{MN_j}\right) \bullet G \tag{5}$$

After the generation of the MN_j public key, the FN_i verifies the joining message signature. Successful verification and reception of the correct nonce ensure that the MN_j is an authentic mobile node belonging to the network. The CH registers this MN_j into its authentic MN member list and calculates the scalar product of $AUTH_i$ and its private key as

$$SP_{FN_i} = (AUTH_i + ID_{FN_i}) \ \bullet K_{prt} \tag{6}$$

Finally the CH generates an authentication certificate for this MN using SP_{MN_j} and SP_{FN_i} as

$$Authentication\ Certificate = SP_{MN_j} \bullet SP_{FN_i} \ \ mod \ \ G \tag{7}$$

The CH sends SP_{FN_i} to the MN_j which uses in the secret key generation and for the authentication certificate generation.

3.3 Communication Key Establishment

Once the MN and CH/FN authenticate each other successfully, the key establishment phase starts. During this phase, the MN sends one of its secret communication codes SCC_1, randomly selected from KP_{MN} and encrypted by the CH public key to its CH as described above. The CH also selects randomly another secret communication code SCC_2 from its pool KP_{FN} and sends it to the corresponding MN. After the reception of this secret code by the MN, the MN and the FN both have the same SCC_1 and SCC_2 and are able to generate a secret key using these two codes, SP_{MN_j} and SP_{FN_i} using [15] as

$$Secret\ Key = SCC_1 \bullet SCC_2 \ \ mod \ \ (SP_{MN_j} \bullet SP_{FN_i}) \tag{8}$$

Once a secret key is established between the CH and each MN, the CH has assigned a Shared Secret Code (SSC) to its all member MNs. This shared secret code is updated both periodically and when a MN compromission is detected. Since the MNs move in the network to perform their duties, they may need to establish a secure communication link also with neighboring MNs, possibly very frequently due to their movement within the network. In order to keep track of their neighboring MNs, each MN broadcasts a short range Hello message to know about its neighboring MNs. To establish a secret key with a neighboring MN, both MNs will share their secret communication code IDs assigned to them as KP_{MN}. Now both the MNs will find the maximum number of shared codes with one another and will generate a secret key using all of them as

$$Secret\ Key = \prod_{l=1}^{f} SCC_{1l} \ \ mod \ \ SSC \tag{9}$$

where 'f' represents the total number of common secret communication codes. Since the distributions of the SCC_1 codes to the MNs is random and probabilistic, two neighboring MNs might not have any secret communication code in common. In this case, to avoid any discontinuity, the MNs will use the assigned Shared Secret Code (SSC) from their common CH and their IDs to establishment a secret key with its neighboring MNs. For example, if MN_m wants to establish a secret key with MN_n but these two nodes do not have any common secret communication code (SCC), then they establish a secret key by first calculating and sharing L and K with each other as

$$L = prand(ID_{MN_n}) \bullet SP_{MN_m} \bullet AUTH_m \bullet SSC \ \ mod \ \ G \tag{10}$$

$$K = prand(ID_{MN_m}) \bullet SP_{MN_n} \bullet AUTH_n \bullet SSC \ \ mod \ \ G \tag{11}$$

$$Secret\ key = L \bullet K \ \ mod \ \ SSC \tag{12}$$

4 Security Evaluation

4.1 Denial of Service Attack

In this section we describe some kind of Denial of Service attacks (DoS attacks) that can be brought against our proposed scheme, as well as possible counter measures. The main objective of DoS attacks is to make the resources unavailable to an intended user of the network.

1. *FN Hello messages*: The first possible DOS attack against the proposed scheme is to broadcast Hello messages pretending to be a FN of the network to exhaust the resources of the MNs. Since each Hello message is signed by the private key of the FN, MNs will verify it using the public key of that FN. Since the adversary FN is not an authentic node, the MN would not be able to verify that Hello message and once a MN detects this attack, it will inform its other neighboring authentic FNs. The authentic FNs would then inform the BS and neighboring MNs about this fake FN ID so that they can avoid the messages from that node.
2. *MN Hello messages*: When a MN finds its current CH signal strength value below a threshold value, it starts broadcasting the MN Hello messages to know about its new neighboring FNs. The attacker can launch such MN Hello message broadcast attack by introducing a fake MN. Since the MN Hello broadcast message is also signed by the MN private key, the new FNs first verify it by using the MN public key. This would not be possible for a fake MN. Thus the FNs inform the BS and other neighboring FNs about this malicious MN.

4.2 Sybil Attack

Sybil attacks are those in which a malicious node illegitimately taking on multiple identities. We call the nodes performing these attacks as sybil nodes. Sybil attacks can be of different forms e.g. using direct or indirect communication and fabricated or stolen identities. In the direct communication sybil attacks, a Sybil node communicates directly with a legitimate node. But since, in the proposed scheme, the sybil node is first authenticated by sending a message signed with its private key, the FN would not be able to authenticate it. In the indirect communication sybil attacks, malicious node (who deploy sybil nodes in the network) becomes a router for forwarding the communication to the Sybil node from the FN which is not possible in the proposed scheme because each MN is the end user of the network. In the fabricated sybil attacks, the attacker assigns an unuse identity to the sybil node. In this case, this sybil node needs to authenticate itself to the FNs which would again not be possible in the proposed scheme as described above. Stolen identity based sybil attacks are very dangerous in such resource constrained networks. But this type of sybil attack does not affect the proposed scheme because each communication is encrypted with the key agreed already with the original node having this ID, and the sybil node does not have these keys.

In the key pre-distribution approach, if every MN is assigned KP_{MN} keys and every FN is assigned KP_{FN} keys from a key pool of size KP_{main} and an attacker compromises 'c' nodes to create a compromised key pool of size 'n', then the probability of a sybil node to be successful created is

$$Pr_{sybil\ node} = \sum_{t=1}^{KP_{MN}} \frac{\binom{n}{t}\binom{KP_{main}-n}{KP_{MN}-t}}{\binom{KP_{main}}{KP_{MN}}} \frac{\binom{KP_{main}-KP_{MN}+t}{KP_{MN}}}{\binom{KP_{main}}{KP_{MN}}} \tag{13}$$

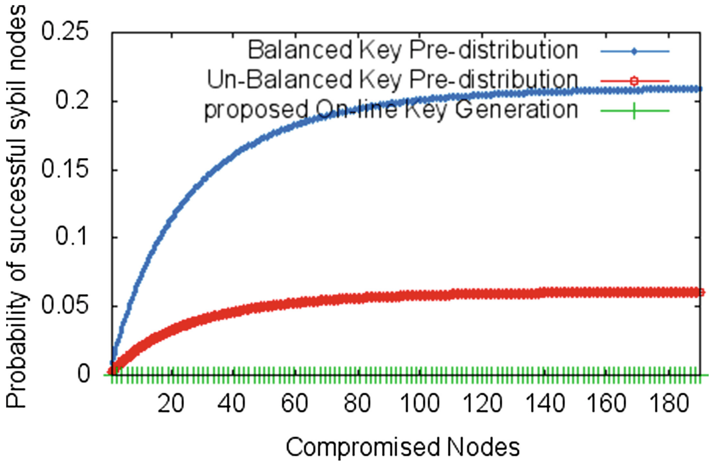


Fig. 2. Probability of generation sybil nodes

Figure 2 shows the probability of successfully generated sybil nodes in the proposed scheme compared with scheme [7,9].

4.3 Node Compromission

Each node is secured by hardware means against access to its keys. However, no such scheme is ever perfect; hence here we analyze the effects of such attacks on our key management scheme.

In existing key pre-distribution schemes for both homogeneous and heterogeneous sensor networks, each node is assigned a key pool, and for secure communication the two nodes must have a shared common key. In that case, once the node is compromised by an adversary, it can compromise all the secure links with neighbors with whom this node has a shared key. Thus the total number of communication links compromised by capturing c MNs are given by

$$P[Compromised] = 1 - (1 - \frac{KP_{MN_j}}{KP_{MN}})^c \tag{14}$$

where $|KP_{MN_j}|$ is the number of keys stored in the MN and $|KP_{MN}|$ is the size of the authentication key pool from which KP_{MN_j} is randomly selected for each MN. Figure 3 shows both the analytical and OMNET++ simulation results of the effect of this kind of attack on our proposed scheme compared with the key pre-distribution scheme in [3,4,8,16]. The graph shows that our scheme provides almost, 100 % resilience against this kind of attack.

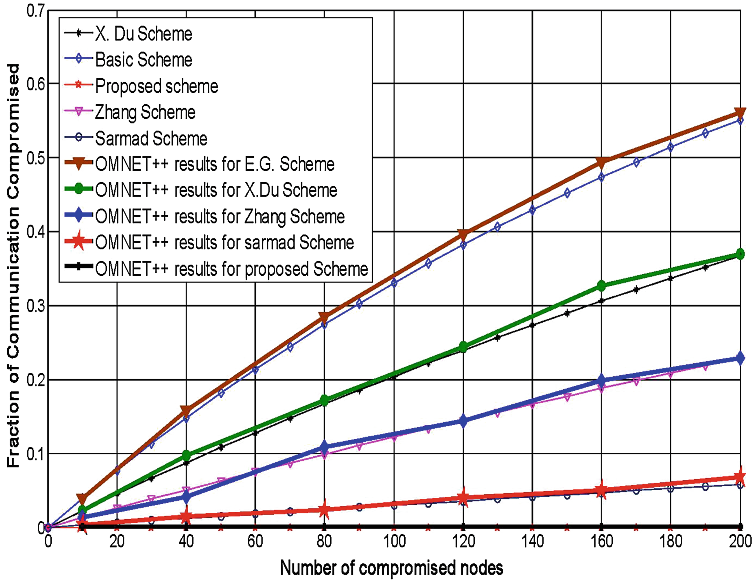


Fig. 3. Network resilience against compromised mobile nodes

5 Conclusion

In this paper, we proposed a new authentication and key management scheme for Heterogeneous Sensor Networks including mobile nodes. The proposed key management scheme is based on two different types of the key pools i.e. an authentication key pool and a communication key pool. Based on these pools, a key pre-distribution mechanism has been defined. The results showed that the two considered key pools provide better security. Furthermore, the proposed solution provides better network resilience against attacks compared to the other reference protocols considered.

References

1. Xiao, Y., Rayi, V., Sun, B., Du, X., Hu, F., Galloway, M.: A survey of key management schemes in wireless sensor networks. Comput. Commun. J. Spec. Issue Wirel. Ad Hoc Sens. Netw. **30**(11–12), 2314–2341 (2007)
2. Xu, K., Hong, X., Gerla, M.: An ad hoc network with mobile backbones. In: 2002 IEEE International Conference on Communications, ICC 2002, vol. 5, pp. 3138–3143 (2002). doi:10.1109/ICC.2002.997415
3. Eschenauer, L., Gligor, V.D.: A key management scheme for distributed sensor networks. In: Proceedings of the 9th ACM Conference on Computer and Communication Security, pp. 41–47, November 2002
4. Du, X., Xiao, Y., Guizani, M., Chen, H.H.: An effective key management scheme for heterogeneous sensor networks. Ad Hoc Netw. **5**(1), 24–34 (2007)

5. Perrig, A., Szewczyk, R., Tygar, J., Wen, V., Culler, D.E.: Spins: security protocols for sensor networks. ACM Wirel. Netw. **8**(5), 521–534 (2002)
6. Chan, H., Perrig, A., Song, D.: Random key predistribution schemes for sensor networks. In: Proceedings of the 2003 Symposium on Security and Privacy, 11–14 May 2003, pp. 197–213 (2003). doi:10.1109/SECPRI.2003.1199337
7. Liu, F., Rivera, M.J.M., Cheng, X.: Location-aware key establishment in wireless sensor networks. In: IWCMC 2006 (2006)
8. Zhang, J., Sun, Y., Liu, L.: NPKPS: a novel pairwise key pre-distribution scheme for wireless sensor networks. In: 2007 IET Conference on Wireless, Mobile and Sensor Networks (CCWMSN 2007), pp. 446–449, 12–14 December 2007
9. Kim, K.T., Ramakrishna, R.S.: A level-based key management for both in-network processing and mobility in WSNs. In: 2007 IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems, MASS 2007, pp. 1–8, 8–11 October 2007. doi:10.1109/MOBHOC.2007.4428761
10. Chuang, I.-H., Su, W.-T., Wu, C.-Y., Hsu, J.-P., Kuo, Y.-H.: Two-layered dynamic key management in mobile and long-lived cluster-based wireless sensor networks. In: 2007 Wireless Communications and Networking Conference, WCNC 2007. IEEE, pp. 4145–4150, 11–15 March 2007. doi:10.1109/WCNC.2007.757
11. Maerien, J., Michiels, S., Huygens, C., Joosen, W.: MASY: MAnagement of Secret keYs for federated mobile wireless sensor networks. In: 2010 IEEE 6th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 121–128, 11–13 October 2010. doi:10.1109/WIMOB.2010.5644977
12. Lu, K., Qian, Y., Hu, J.: A framework for distributed key management schemes in heterogeneous wireless sensor networks. In: 2006 25th IEEE International Performance, Computing, and Communications Conference, IPCCC 2006, pp. 7–520, 10–12 April 2006. doi:10.1109/.2006.1629447
13. Du, X., Xiao, Y., Ci, S., Guizani, M., Chen, H.-H.: A routing-driven key management scheme for heterogeneous sensor networks. In: 2007 IEEE International Conference on Communications, ICC 2007, pp. 3407–3412, 24–28 June 2007. doi:10.1109/ICC.2007.564
14. Yang, Q., Li, Q., Li, S.: An efficient key management scheme for heterogeneous sensor networks. In: 2008 4th International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2008, pp. 1–4, 12–14 October 2008. doi:10.1109/WiCom.2008.896
15. Rabin, M.O.: Digitalized signatures and public-key functions as intractable as factorization. Technical report MIT/LCS/TR-212, Laboratory for Computer Science, MIT (1979)
16. Sarmad, U.K., Lavagno, L., Pastrone, C.: A key management scheme supporting node mobility in heterogeneous sensor networks. In: 2010 6th International Conference on Emerging Technologies (ICET), pp. 364–369, 18–19 October 2010. doi:10.1109/ICET.2010.5638458

HUMsim: A Privacy-Oriented Human Mobility Simulator

Francesco Giurlanda(✉), Pericle Perazzo, and Gianluca Dini

University of Pisa, Pisa, Italy
{giurlanda.francesco,perazzo.pericle,dini.gianluca}@iet.unipi.it

Abstract. Location-based services rise high privacy concerns because they make it possible to collect and infer sensitive information from a person's positions and mobility traces. Many solutions have been proposed to safeguard the users' privacy, at least to a certain extent. However, they generally lacking convincing experimental validation with real human mobility traces. Large databases of real mobility traces are extremely expensive to build or buy. In this paper, we present *HUMsim* (*Human Urban Mobility Simulator*), a generator of synthetic but realistic human traces oriented to the experimental validation of privacy solutions. HUMsim generates trajectories that reflect possibly privacy-sensitive habits of people and that, at the same time, account for constraints deriving from a real map. We also validate the soundness of the produced traces by statistically comparing them to real human traces.

Keywords: Privacy · Human mobility · Simulation

1 Introduction

The number of GPS-equipped smartphones has recently experienced an exponential growth. 850 millions of devices in 2011 became 1.2 billions in 2012 and are expected to get 4 billion in 2018 [9]. This caused an equally considerable proliferation of *location-based* services and applications. The problem with these services is that they are invasive from a privacy point of view. Not only they make it possible to track users, but also to collect traces, analyze them, and discover sensitive information about users' habits.

The scientific community has developed many solutions that strive to provide a viable trade-off between privacy and performance in location-based services. Among them [2,8,11]. The problem with most of these solutions is that they generally lack of a convincing experimental validation on *real* human mobility traces. Large databases of real human mobility traces do exist. Unfortunately they do not come for free. Companies and organizations owning such databases sell them at high prices. On the other hand, running in-home experimental campaigns to take real traces is often impractical.

A possible solution is to use synthetic trajectories. The existing mobility models generate trajectories that are similar to the real ones in terms of, for

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 61–70, 2015.
DOI: 10.1007/978-3-319-17136-4_7

example, speed, direction changes, presence of obstacles and so on. In these models, waypoints are typically chosen at random. This implies that the resulting synthetic trajectories display good statistics that are useful for mobile network analysis (cellular networks, MANETs, etc.). However, this also implies that they do not reflect the habits of a person and therefore they are hardly useful for the validation of privacy solutions.

We propose *HUMsim* (*Human Urban Mobility Simulator*), a human mobility simulator aimed at the validation of location privacy solutions. HUMsim generates *semantic trajectories* which are sequences of *semantic waypoints*, i.e., locations labelled with semantic tags [1,4]. Semantic trajectories are generated according to a *behavioral model* of a person, which describes his daily behavior in terms of visited semantic waypoints (which ones and for how long). For instance, the behavioral model describing a smoker contains semantic waypoints describing stops at a smoke shop. In short, semantic waypoints can reveal information about the person's habits that can put at risk his privacy. Furthermore, HUMsim translates semantic trajectories into *raw trajectories*, which take into account real maps. It follows that the resulting trajectories not only represent "realistic" movements of a person but they also convey privacy-relevant information. As such, differently from existing mobility models which generate trajectories without a semantic value, the semantic trajectories produced by HUMsim allow us to validate location-privacy solutions. We evaluate the soundness of our approach by statistically comparing the trajectories generated by HUMsim to real human traces along two dimensions: the radius of gyration and the displacement between consecutive waypoints. In particular, we compare our results with the results in [10], where the trajectories generated by 100,000 individuals in the European territory are examined. We found some affinity with the results in [10], which corroborates the validity of our synthetic semantic trajectories.

The rest of the paper is organized as follows. Section 2 presents relevant related works. Section 3 describes the HUMsim simulator in detail. Section 4 experimentally evaluates the soundness of HUMsim traces. Finally, the paper is concluded in Sect. 5.

2 Related Works

The analysis and the modeling of human mobility have always been a challenge for scientists of different disciplines. It allows us to optimize many processes which are related to the daily life of many people. At the same time, understanding the human mobility model allows us to reproduce human behavior in new scenarios. Many models have been proposed to approximate the movements of a person. In this section we survey some of them.

Random Walk (RW) model [6] aims at simulating the unpredictable movement of entities in nature. In RW, each node chooses a random speed inside a predefined range $[V_{min}, V_{max}]$, and a random direction.

In Random Waypoint (RWP) model [3], a mobile node begins by staying in one location for a certain period of time. The node then travels towards a new random destination at a random speed in a predefined range $[V_{min}, V_{max}]$. Upon arrival, the node pauses for a specified time period before starting the process again. The problem of this approach is the clustering of nodes that occurs at the center of the simulation area. This happens because the mobile nodes tend to pass through it to reach other destinations.

Random Direction (RD) model [15] is designed to overcome the clustering behavior of RWP. The RD mobility model lets the nodes choose a random direction, rather than random position, in which to travel similarly to RW.

Markovian Random Path (MRP) model [6] reduces the sudden changes of speed and direction that afflict the previous models. Improvements to this approach have been introduced with Gauss-Markov (GM) [14] and Markovian Waypoint (MWP) [12]. These models are slight variants of previous random models as they implement Markovian transition probabilities among waypoints or prohibit unrealistic abrupt velocity changes.

All these mobility models are useful to describe the movements of particles or other physical entities which follow random paths, but they badly fit the mobility of human entities which are affected by many variables like personal interests, habits, etc.

Self-similar Least Action Walk model (SLAW) [13] is more accurate and realistic than the previous mobility models. SLAW represents inherent social contexts among walkers manifested as common gathering places and walk patterns therein. SLAW can also express the trip patterns present in the daily mobility of humans. People typically keep a routine of visiting the same places every day, such as an office, but at the same time make irregular trips. SLAW uses Least Action Trip Planning (LATP) to calculate the trip sequence among all the selected waypoints. SLAW effectively expresses mobility patterns arising from people with some common interests or within a single community. Relevant examples are students in the same university campus or people in theme parks where they tend to share common gathering places. But on a larger scale, such as the urban environment, the choice of the waypoints is driven by the habits of a person, or the nearest destination to accomplish a task, or the best path to pass through all the planned waypoints. These are choices taken automatically by an actual driver around the city. Thus, the traces generated by SLAW do not reflect a behavioral model of a person and are not suitable for validating privacy solutions.

In realistic situations, the travel pattern of a node is restricted by the city section that is a urban area with a street network. The mobile nodes have to take into account the traffic limitations and avoid obstacles. City Section Mobility model [6] considers these aspects. The simulation takes place in a realistic city section with different kinds of roads. But, even if the generated trajectories are more similar to those of an actual driver, the destination points are still chosen randomly and they do not have any semantic validity.

All these "artificial" mobility models have to be compared with real human traces in order to prove their validity. Recently, the scientific literature approached the analysis of human mobility from real traces, and supposed that humans follow a *Lévy-flight model* [5,7,10]. This model foresees many short movements around a spot, mixed to few long movements. The length of the movements follows a *power-law* probability distribution. Such a distribution is long-tailed, thus it gives a non-negligible probability of long movements. This model has shown to be consistent with large databases of real human traces, measured by means of banknote spending [5], mobile phone calls [10], or location-sharing check-in's [7]. We used the Lévy-flight model in order to validate the soundness of the paths generated by HUMsim.

3 Human Urban Mobility Simulator

HUMsim (Human Urban Mobility simulator) is a generator of synthetic human traces, aimed at the validation of location privacy solutions. HUMsim has the following characteristics:

- During the day, a person follows a *semantic trajectory* that touches some *semantic waypoints* (home, work, shops, etc.). Some of these waypoints can be privacy-sensitive, i.e. they can reveal private habits or other sensitive information about the person. For example, where the person lives, or whether the person visits a hospital specialized on some particular disease, etc. The definition of what is privacy-sensitive and what is not depends on the particular application, and does not fall in the scope of the simulator.
- The waypoints can be *usual* (e.g. home, work, etc.), which are chosen once and never changed for a person, or *opportunistic* (e.g. markets, shops, etc.), which are chosen time-by-time depending on the current position of the person.
- The daily path and the pause times on the various waypoints can change day-by-day in a probabilistic manner, following a *behavioral model*.
- Once the semantic trajectories have been generated, they are translated into *raw trajectories*, which take into account the mobility constraints, the streets, and the travel times.

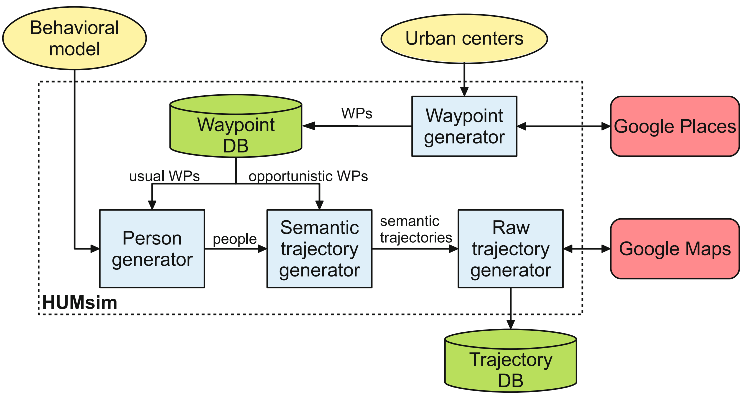


Fig. 1. HUMsim block diagram

HUMsim is composed of four main components, as shown in Fig. 1. The *waypoint generator* generates a database of usual and opportunistic waypoints. Depending on their semantic, the waypoints are generated by means of two techniques: *Google Places query* or *random generation*. Some waypoints (typically shops, restaurants, etc.) are generated by means of Google Places query. In this case, the waypoint generator queries the Google Places API by means of a keyword (e.g. "restaurant"). All the other waypoints (typically houses, workplaces, etc.) are generated randomly. The randomly generated waypoints follow a Gaussian distribution centered on a urban center specified by the user. The user can specify more than one urban center, each of which is identified by a circle. The radius of each circle is proportional to the size of the urban center. The generation process first chooses a particular urban center with a probability proportional to its radius, then generates the waypoint according to the Gaussian distribution. Randomly generated waypoints may end up in inaccessible areas such as rural fields or lakes. We use the Google Maps service to move them to the nearest valid locations. The resulting waypoints are stored in a waypoint database.

The *person generator* generates a set of people. A person is represented by (i) a set of usual waypoints, and (ii) a behavioral model. In practice, the person generator randomly selects a set of usual waypoints from the waypoint database, and associates a behavioral model to them. The "home" waypoint is selected first. The other waypoints are chosen in such a way their distance from "home" follows a power-law distribution. Therefore, a person prefers usual waypoints which are close to home but he does not exclude the possibility of longer distances. We notice that this way of choosing the usual waypoints makes the final raw trajectories more realistic (i.e. closer to a Lévy-flight model, see Sect. 4).

The *semantic trajectory generator* generates a given number of daily semantic trajectories for each person. A daily semantic trajectory is a sequence of semantic waypoints (W_i) that the person visits in a day, together with a pause time (Π_i) for each semantic waypoint.

$$\text{semantic trajectory} ::= (W_1, \Pi_1) \ldots (W_n, \Pi_n)$$

The *raw trajectory generator* translates the semantic trajectory into a raw trajectory, that is an ordered sequence of tuples on the form:

$$\text{raw trajectory} ::= (lat_1, lng_1, t_1) \ldots (lat_m, lng_m, t_m)$$

similar to a GPS trace, where lat_i and lng_i are respectively latitude and longitude and t_i is the timestamp associated to the position. While the semantic trajectory considers the movement between two waypoints to be instantaneous, the raw trajectory takes into account also the travel time and path among them.

3.1 Behavioral Model

The behavioral model specifies the daily mobility of a person in probabilistic terms. It is described by a *transition scheme* and *pause scheme*. The transition

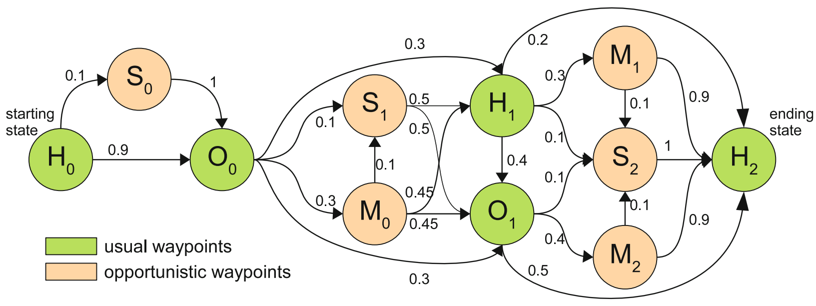


Fig. 2. Example of behavioral model (transition scheme)

Table 1. Example of behavioral model (pause scheme)

State	T_c	T_v	State	T_c	T_v	State	T_c	T_v
H_0	0 min	30 min	O_0	270 min	30 min	M_0	5 min	25 min
H_1	120 min	60 min	O_1	180 min	60 min	M_1	15 min	45 min
H_2	-	-	$S_{0,1,2}$	5 min	5 min	M_2	10 min	30 min

scheme is a discrete-time Markov chain, whose states represent distinct visits of semantic waypoints. Figure 2 shows an example of transition scheme.

In this scheme, we modeled a person which moves between four semantic waypoints, "home"(H), "office" (O), "markets"(M) and "smoke shops" (S). Each semantic waypoint can be visited several times during a day. For example, O_0 and O_1 represent same waypoint O that is visited twice in a day.

The pause scheme (Table 1) is a table used to compute the pause time Π_i for each state, that is how long the person waits in that state. This parameter is fundamental for algorithms that analyze the trajectories in order to profile a person, because it gives a quantitative indication of how important the place is for the person. The pause time is composed by two values: a constant value T_c added to a variable value T_v. The T_c is the minimum pause time for that position. The T_v indicates the variation of the pause time.

$$\Pi_i = [T_{c_i}, T_{c_i} + T_{v_i}] \tag{1}$$

The table keeps the values of T_c and T_v for each state. Table 1 shows an example of pause scheme. The example behavioral model of Fig. 2 and Table 1 represents a smoker that works and returns home at the end of the day. During the day, the person makes some stops at markets or smoke shops. For each simulated day, the simulator starts in state H_0 and computes a sequence of states that ends in state H_2. In the morning, the person goes to work, possibly visiting a smoke shop (states H_0, S_0, O_0). In the afternoon, he possibly visits a market, or a smoke shop, or both (S_1, M_0), and then he returns to work or goes home (H_1, O_1). In the late afternoon, he possibly visits again a market, or a smoke shop, or both (S_2, M_1, M_2), and he finally returns to home (H_2). An example of semantic trajectory is:

$$(H_0, 10), (O_0, 275), (S_1, 6), (O_1, 192), (M_2, 15), (H_2, -)$$

where the pause times are expressed in minutes. The semantic waypoint H_2 does not have a pause time because it is the end of the semantic trajectory. This simple behavioral model serves only as a proof of concept, and does not aim to be fully realistic and representative of all people's habits. HUMsim allows the user to define more complex and realistic behavioral models. The user can also specify several behavioral models, describing the daily behavior of different people. When the person generator creates a person with his usual waypoints, it assigns a behavioral model to him for the entire simulation.

3.2 Semantic Trajectory and Raw Trajectory Generators

The semantic trajectory generator receives a behavioral model as input and generates a semantic trajectory for each simulated day and for each person. This is done by realizing the Markov chain stochastic process for each day. Then, it assigns a position to each semantic waypoint. As we said before, the positions of the usual waypoints of a person are fixed, decided *a priori* by the person generator. On the contrary, the positions of the opportunistic waypoints are chosen on-the-fly by the semantic trajectory generator, depending on the current position of the person and an *opportunistic choice rule*. HUMsim supports several opportunistic choice rules. For example the "nearest" rule, e.g. choosing the nearest market to the current position, or the "nearest-with-score" rule, e.g. choosing the nearest market having a certain score, etc.

The raw trajectory generator translates the semantic trajectory into a raw trajectory. This component uses the positions of the semantic waypoints to calculate the raw trajectory. It leverages on the Direction Service (DS) provided by Google Maps API. The query to the DS needs the list of the visited positions and the mode of transport used. By now, HUMsim implements a single mode of transport for all simulated people (*car*). Future improvements of the

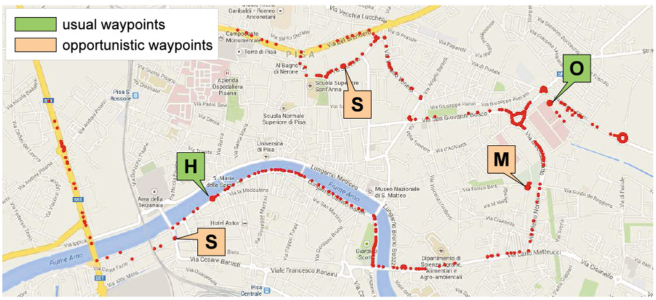
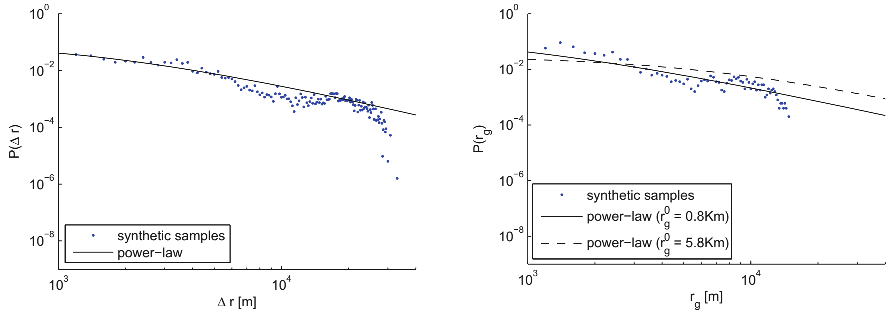


Fig. 3. Example of daily trajectory



(a) Displacements (b) Radius of gyration

Fig. 4. Statistical comparison between HUMsim and real human traces

simulator will include transport preferences as part of the behavioral model of the person. The DS responds with one or more possible paths and a travel time for each of them. The raw trajectory generator chooses a path and extracts the sequence of points (latitude and longitude) which identify the raw trajectory between two semantic waypoints. Moreover, for each point the raw trajectory generator computes a timestamp abiding by the trip time of the path. During a pause in a waypoint, the trajectory generator continues to produce position samples around the position of the semantic waypoint.

Figure 3 shows an example of daily trajectory of a person which lives in Pisa, Italy. The positions of the semantic waypoints are displayed. Note that the person opportunistically chooses two positions for the smoke shop (semantic waypoint S), depending on his current position.

4 Experimental Validation

We run HUMsim using the example behavioral model of Fig. 2 and Table 1, which represents a smoker that works and returns home at the end of the day. Our simulation is focused on the area around Pisa, Italy. We have simulated 5000 users which generate daily trajectories for a period of 30 days. We used the "nearest" opportunistic choice rule for choosing the opportunistic waypoints. We evaluated the soundness of the synthetic traces generated by HUMsim, by statistically comparing them with real human traces. We focused our analysis on two parameters which are at the basis of many studies on human mobility patterns [5,7,10]: the *displacement* (Δr) and the *radius of gyration* (r_g). By Δr we indicate the movement of a person from a waypoint to another. In [10], the authors found that the distribution of displacements, recorded over a six-month period for 100,000 individuals in the European territory, follows a truncated power-law with the following shape:

$$\mathrm{P}\left(\Delta r\right) \propto \left(\Delta r - \Delta r_0\right)^{-\beta} e^{-\Delta r/\kappa} \tag{2}$$

where $\Delta r_0 = 1.5\,\text{km}$, $\beta = 1.75$, and $\kappa = 400\,\text{km}$. Figure 4a shows the probability distribution of the displacements generated by HUMsim compared to the distribution found by [10]. It can be seen that the synthetic traces well fit the truncated power-law distribution.

We also studied the distribution of the radius of gyration according to the scale of our simulation. The radius of gyration is an estimation of the general mobility of a person. It is computed in the following way:

$$r_g = \sqrt{\frac{1}{N}\sum_i \|X_i - X_{cm}\|^2} \tag{3}$$

where X_{cm} indicates the *center of mass* of the person's movements. Even in this case, the authors in [10] found that the radius of gyration can be approximated with a truncated power-law:

$$\mathrm{P}(r_g) \propto (r_g - r_g^0)^{-\beta_r} e^{-r_g/\kappa_r} \tag{4}$$

where $r_g^0 = 5.8\,\text{km}$, $\beta_r = 1.65$, and $\kappa_r = 350\,\text{km}$.

Figure 4b shows the probability distribution of the radius of gyration over all people generated by HUMsim, compared to the distribution theoretically supposed by [10]. We noticed a discrepancy due to the difference in the scale of the scenario. In fact, in the case of [10] the people move in the whole European continent, whereas our simulations are limited to few urban centers. We found that the theoretic distribution better fits the synthetic data by reducing the parameter r_g^0 to 0.8 km, as shown in Fig. 4b. Such a parameter correction lowers the probability of large radii of gyration (cfr. Fig. 4b), and thus makes the power-law more suitable to the scale of our simulation scenario.

From these statistical comparisons, we can claim that our synthetic traces well approximate real traces.

5 Conclusion and Future Works

In this paper we presented a human mobility simulator called HUMsim that generates daily trajectories reflecting the habits of a person. The simulator allows us to define a user's behavioral model in terms of semantically annotated waypoints and then generates trajectories passing through those waypoints and accounting for map constraints. The resulting trajectories are realistic as the statistical evaluation showed. Furthermore, given their semantic value, trajectories can also be used to validate the privacy countermeasures aimed at protecting privacy in location-based services.

We leave for future works the comparative analysis with real human traces, for example from public datasets like CROWDAD or the Nokia Mobile Data Challenge.

Acknowledgment. This work has been partially supported by the Tuscany region in the framework of the POR CRO FSE 2007–2013 Asse IV Capitale Umano - project

SOcial Sensing (SOS); by the Italian Research Project TENACE (pr. no. 20103P34XC); and by Project PITAGORA, cofinanced by the Regional Government of Tuscany (POR CReO Bando Unico R&S 2012) and the European Regional Development Fund (ERDF).

References

1. Alvares, L.O., Bogorny, V., Kuijpers, B., de Macelo, J., Moelans, B., Palma, A.T.: Towards semantic trajectory knowledge discovery. In: Data Mining and Knowledge Discovery (2007)
2. Beresford, A.R., Stajano, F.: Mix zones: User privacy in location-aware services. In: PerCom Workshops, pp. 127–131 (2004)
3. Bettstetter, C., Hartenstein, H., Pérez-Costa, X.: Stochastic properties of the random waypoint mobility model. Wirel. Netw. **10**(5), 555–567 (2004)
4. Bogorny, V., Kuijpers, B., Alvares, L.O.: ST-DMQL: A semantic trajectory data mining query language. Int. J. Geogr. Inf. Sci. **23**(10), 1245–1276 (2009)
5. Brockmann, D., Hufnagel, L., Geisel, T.: The scaling laws of human travel. Nature **439**(7075), 462–465 (2006)
6. Camp, T., Boleng, J., Davies, V.: A survey of mobility models for ad hoc network research. Wirel. Commun. Mob. Comput. **2**(5), 483–502 (2002)
7. Cheng, Z., Caverlee, J., Lee, K., Sui, D.Z.: Exploring millions of footprints in location sharing services. ICWSM **2011**, 81–88 (2011)
8. Dini, G., Perazzo, P.: Uniform Obfuscation for Location Privacy. In: Cuppens-Boulahia, N., Cuppens, F., Garcia-Alfaro, J. (eds.) DBSec 2012. LNCS, vol. 7371, pp. 90–105. Springer, Heidelberg (2012)
9. Ericsson mobility report: On the pulse of the networked society. Technical report, Ericsson, Jun 2013
10. Gonzalez, M.C., Hidalgo, C.A., Barabasi, A.L.: Understanding individual human mobility patterns. Nature **453**(7196), 779–782 (2008)
11. Gruteser, M., Grunwald, D.: Anonymous usage of location-based services through spatial and temporal cloaking. In: Proceedings of the 1st International Conference on Mobile Systems, Applications and Services, pp. 31–42. ACM (2003)
12. Hyytia, E., Lassila, P., Virtamo, J.: A markovian waypoint mobility model with application to hotspot modeling. In: IEEE International Conference on Communications, ICC 2006, vol. 3, pp. 979–986. IEEE (2006)
13. Lee, K., Hong, S., Kim, S.J., Rhee, I., Chong, S.: SLAW: A new mobility model for human walks. In: IEEE INFOCOM 2009, pp. 855–863. IEEE (2009)
14. May, P., Ehrlich, H.-C., Steinke, T.: ZIB structure prediction pipeline: composing a complex biological workflow through web services. In: Nagel, W.E., Walter, W.V., Lehner, W. (eds.) Euro-Par 2006. LNCS, vol. 4128, pp. 1148–1158. Springer, Heidelberg (2006)
15. Royer, E.M., Melliar-Smith, P.M., Moser, L.E.: An analysis of the optimum node density for ad hoc mobile networks. In: IEEE International Conference on Communications, ICC 2001, vol. 3, pp. 857–861. IEEE (2001)

Mobile Health Applications: A Comparative Analysis and a Novel Mobile Health Platform

Antti Väänänen(✉), Keijo Haataja, Mikko Asikainen, Iiro Jantunen, and Pekka Toivanen

School of Computing, University of Eastern Finland, Kuopio Campus, P.O. Box 1627, 70211 Kuopio, Finland
{antti.vaananen, keijo.haataja, mikko.p.asikainen, iiro.jantunen, pekka.toivanen}@uef.fi

Abstract. Modern smartphones and tablet PCs provide connections to the Internet via cellular networks or Wireless Local Area Networks (WLAN). The same devices also provide several wireless interfaces, such as Bluetooth for Wireless Personal Area Networks (WPANs). These interfaces create many novel possibilities for Mobile Health or Telehealth application developers to create systems providing versatile and adaptive environment for health monitoring and assisted living. In this paper, we provide a literature review based comparative analysis of current state-of-the-art mobile health applications and services. In addition, we propose and implement a mobile health platform, Smart Environment for Assisted Living (SEAL), in which smart home and mobile health functionalities are integrated into an open and adaptive Platform. The main attributes of our novel SEAL Platform are adaptivity, user-centered design, accessibility, transparency, safety, security, and privacy. Moreover, we will present some new ideas that will be used in our future research work.

Keywords: eHealth · Mobile health · Remote healthcare · SEAL · Smart home · Smartphone · Telehealth · WPAN · WSN

1 Introduction

Wireless Sensor Networks for Mobile Health purposes have been on the market for three decades. POLAR introduced first wireless heart beat monitor for fitness applications in 1983. The idea involved a heart pulse detector electrode belt around the chest of the user, a wrist-top computer as a display, a User Interface (UI) unit, and an analog 5 kHz inductive wireless link connecting the devices [1].

Wireless medical sensors have been used for a long time in hospital environments. Due to the rapid development of consumer wireless connectivity technologies, such as WLAN, Bluetooth, and ZigBee, the technologies, which are based on the parts of the wireless spectrum dedicated only to medical use, are lagging behind in throughput, reliability, and availability [2]. On the other hand, the special requirements of devices certified for medical use are becoming an obstacle in mobile health development, since mobile phones and other general purpose devices/networks as such are difficult to be

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 71–81, 2015.
DOI: 10.1007/978-3-319-17136-4_8

certified for medical use. If Mobile Health must be arranged through specially developed certified medical devices, the price will be high and development/adaptation of these applications will be slow [3].

Mobile phones have become a device carried along by most of the population providing a Graphical User Interface (GUI), various network connections for forming local networks, connectivity to the Internet, capability to store data, and possibility to run both own and commercial applications [4]. By evolution of the mobile phones and wireless networks, the power usage and the price of digital wireless networking solutions have decreased while the versatility has increased. These developments would enable a wide range of mobile health applications if the regulatory and techno-economic problems can be solved [5].

Due to increasing need for standardized cross-compatible solutions, many business driven initiatives, such as Continua Health Alliance [6] and European Connected Health Alliance [7] have been founded. These initiatives do not define new wireless technologies, but instead adopt the existing ones, such as Bluetooth and ZigBee, and define application layer communication protocols and data formats to ensure interoperability.

Our Results: In this paper, we provide a literature review based comparative analysis of current state-of-the-art mobile health applications and services. In addition, we propose and implement a novel sensor network Platform, Smart Environment for Assisted Living (SEAL), in which smart home, mobile health, and well-being functionalities are integrated into an open and adaptive Platform. Moreover, we will present some new ideas that will be implemented into SEAL and used in our future research work.

The rest of the paper is organized as follows. Section 2 provides a literature review based comparative analysis of the current state-of-the-art mobile health applications and services. Our novel SEAL system is presented in Sect. 3. Finally, Sect. 4 concludes the paper and sketches future work.

2 Comparative Analysis of Mobile Health Applications and Services

The commonly used technologies for mobile health are introduced and a comparison table (see Table 1 on the main characteristics of wireless technologies are provided in Sect. 2.1. Section 2.2 provides use cases that are used in mobile health systems. Section 2.3 describes the main mobile health application types and provides some examples of the main mobile health application use-cases.

2.1 Wireless Technologies for Mobile Health

A WSN contains from two to hundreds or even thousands of spatially distributed autonomous sensor nodes where each sensor node is connected to at least one other node. Sensor nodes monitor physical or environmental conditions, such as the temperature, sound, vibration, pressure, humidity, motion, location, or pollutants. Each sensor node contains a microcontroller for interfacing with sensors, an energy source (usually a battery), and a wireless transceiver [8].

A WPAN is a WSN in which the basic functionality is similar, but the network of devices is centered in individual personal proximity (≈10 m). The terms Body Area Network (BAN) and Wireless Body Area Network (WBAN) are also used to describe sensor networks transferring data from body surface or from inside the body, and each sensor node and a gateway is near the user body (≈2 m). The first worldwide standard for WPAN networking emerged when the Bluetooth standard was released in 1998. Currently, the most common short-range wireless technologies that are utilized in mobile phones are WLAN and Bluetooth. Also new wireless technologies, such as Bluetooth Smart and Near Field Communication (NFC) are available in modern mobile phones. Another standardized wireless technology that can be utilized in WPAN is ZigBee. All these technologies have been standardized within IEEE 802.15 (Bluetooth and ZigBee) or within IEEE 802.11 (WLAN). Also proprietary solutions exist, such as the ANT radio [9].

Table 1. Comparison of mobile device centric wireless technologies.

Wireless Technologies	*WLAN*	*Bluetooth*	*Bluetooth Smart*	*ZigBee*	*ANT*	*NFC*
Nominal range [m]:	≈100	10–100	10–100	10–100	1–30	≈0.20
Bandwidth [Mb/s]:	600	24	1	0.250	1	0.424
Maximum amount of active nodes in a network:	2048	8	2^{32}	65536	65536	2
Applications for mobile operating systems						
- Android	Yes	Yes	Yes	Yes	Yes	Yes
- iOS[b]	Yes	Yes	Yes	No	Yes[a]	Yes
- Symbian	Yes	Yes	No	No	No	Yes
- WP[c]	Yes	Yes	No	No	No	Yes

[a]With 3rd party dongle [9]
[b]iPhone/iPad operating system
[c]Windows Phone operating system

2.2 Mobile Health Use Cases

In this paper, we are focusing our attention on mobile health applications based on the most common mobile device centric wireless short-range technologies, such as WLAN, Bluetooth, ZigBee, ANT, and NFC. These technologies provide use-cases for personalized health monitoring and assisted living.

In an example case, measurement devices can collect health or well-being information from smart home environment (e.g., medication use, daily activities, and health data) and send the collected information to a mobile gateway (smartphone or Mini PC) where the data is analyzed and an application can give a proposal to a person according her health status [10].

In case of an emergency, the health information and measurements can be sent directly via a mobile network to the healthcare professionals. Combining the features of body area networking with the features of personal area networking within one network could – in a healthcare environment – make it possible to monitor and track the health status and whereabouts of a patient wirelessly at any given time.

Measurement devices can monitor the patient and transmit readings continuously, thus gathering a greater volume of data, for example, on the patient's heart rate, than would be possible without wireless networking. The process is also comfortable and convenient for the patient.

Aside from harvesting data, a Mobile Health system can also detect dangerous developments in the patient's biological signals, thus alerting healthcare professionals in case the patient has, for example, a heart attack or the patient falls down. With wireless positioning combined in the system, the position of the patient in danger is also known, thus making emergency responses faster and more reliable. This naturally increases the safety and security of the patient.

With elderly and disabled people, a system like this will enable an autonomous lifestyle without constant attention and makes it possible to remain living at home longer, thus increasing their quality of life [11]. Furthermore, this will put great demands for the Quality-of-the-Service (QoS), since human lives might depend on the rapid and reliable transmission of information within the network.

2.3 Mobile Health Application Types

In this paper, the mobile health applications that utilize wireless networks are categorized into four application types: Data Gathering and Analysis, Wireless Positioning, Context Awareness, and Patient Assistance and Assisted Living. In Mobile Health, applications usually provide functionalities that correlate to one or more of these abovementioned application types.

Data gathering and analysis can be considered as work process in WSNs in which sensor data is collected from sensor network and analyzed for specific purposes, such as medical diagnoses. Analysis is presented to the end-user in a proper format. Data gathering is done by sensors in the WSN and the sensors can collect environmental information, for example, from home/office environment or collect data from user (e.g., heart rate). Data Analysis can be performed either on central node of the network, which can be, for example, a smartphone or a server that collects data from all WSN network levels and create analysis from collected data to be shown to the end-users. Data analysis can be shared with healthcare professionals for the early detection of person's health status [12].

Wireless positioning is a method of determining the position of a radio node and tracking it. This is most often achieved by combining the signals between several static landmark nodes and the mobile node, and forming a position estimate by analyzing the signal strength, travel time, or angle of arrival on these signals. There are various approaches to wireless positioning, but in the scope of this paper, we limit ourselves to using wireless radio devices in indoor environments and leave out, for example, positioning approaches using satellite based Global Positioning System (GPS) or machine vision. With wireless positioning, it is not only possible to know where something or someone is, but also to track movement over time and draw analysis on behavior based on it. In the context of mobile health, wireless positioning has many applications. When we track the movements of a person, we not only know their position, but also information on when, where, how, and how much the person moves. This information can be used to analyze the mobility of the subject and whether the amount of movement indicates an active or passive lifestyle. It can be used to detect if a person is falling ill, becoming passive, or starting to develop behavioral patterns connected with, for example, dementia [13].

Context awareness refers to knowledge and understanding about the surrounding environment where the decision support system has to operate [14]. Context awareness is a concept that has been described for a long time ago, but technologies are now available to support the development of context aware applications. One example of context awareness in mobile health applications or services is a scenario in assisted living where a smartphone centric WSN reads in-house sensors, for example, oven status and water consumption stores. The same time, a WBAN could collect and analyze data from body sensors, for example, fall detection, heart rate, electrocardiogram (ECG), blood glucose level, and the location of individual [15, 16]. A smartphone could analyze sensor data to extract context information and forward the appropriate data for servers in the Internet to be analyzed by healthcare professionals.

Patient assistance and assisted living are key attributes when developing services for seniors, impaired, or patients who need post-operative care. For the people whose normal mobility and capabilities are impaired, WSN technologies can be used to improve the quality of life with home automation.

For example, lighting can be automated or manipulated wirelessly so that a wheelchair bound person need not reach out to the switches. Doors and windows can be locked and unlocked by a single push of a button. From a monitoring point of view, alarms can be automated so that when a fire alarm goes off, the alarm is relayed to the fire department automatically, thus saving valuable time. The health status of at-home patients or elderly can be monitored as well as status developments tracked with sensors and information on health and emergencies can be transmitted to healthcare professionals. This means a reduced need for around-the-clock nursing and a possibility for the elderly to remain autonomous at home, since without these technologies they might need to move to a nursing home.

Table 2 present the comparison of the services and features that are included in studied commercial remote health and mobile health systems. These systems are selected by the criteria that individual system should provide multiple services for remote healthcare or assisted living and these services can be utilized either by mobile devices or by using PC or TV. By analyzing and evaluating services, SEAL will implement the features that provide improvement in quality of life and can offer caregivers the needed information about care and reduce healthcare professional's workload. Last column shows the features which are already implemented into SEAL system or will be implement soon during our research work.

Table 2. Mobile health platforms feature comparison

Remote Health Systems	Smart Visio [20]	Health sense [21]	Mega koto [22]	Zephyr [23]	iQare [24]	CJPS VitalPoint [25]	iTriage [26]	Live scape [27]	Health Vault [28]	SEAL
Biosignals and activity tracking										
Electrocardiography (ECG)			X	X		X				X
Electromyography (EMG)			X							
Heart Rate (HR)			X	X		X				X
Respiration Rate (RR)				X		X				X
Blood Oxygen Saturation (SpO2)		X	X			X				X
Heart Rate Variation (HRV)			X	X						X
Body Temperature						X				X
Position Detection		X		X						X
Activity Tracking		X		X						X
Spirometer			X							X
Blood Sugar		X								X
Body weight		X	X					X	X	X
Blood Pressure (BP)		X	X	X		X		X	X	X
Alert for Healthcare Personnel										X
Services for healthcare staff										
Configuration of clients / patients										X
Timetable planning										X
Video consultation										X
Patient care plan planning										X
Monitoring client measurement history										X
Alarm functionality		X	X	X	X	X				X
Video call	X									X
Fall recognition		X								
Movement surveillance	X	X			X					X
Medication control	X	X			X	X			X	X
Voice notifications		X			X					X
Alarms for healthcare staff	X	X	X							X
Recording response times		X								
Other services										
Showing driving route instructions			X							X
Self-care			X						X	
Calendar	X				X	X				X
Symptoms information for healthcare staff						X				
Recognition of own symptoms							X			
Find hospitals or health facilities							X			
Information about medications							X			X
Medical procedures information							X			
Health related articles							X			
Calorie calculation								X		X
Weight control planning								X	X	

(*Continued*)

Table 2. (*Continued*)

Remote Health Systems	Smart Visio [20]	Health sense [21]	Mega koto [22]	Zephyr [23]	iQare [24]	CJPS VitalPoint [25]	iTriage [26]	Live scape [27]	Health Vault [28]	SEAL
Pedometer								X	X	
Fat percentage measurement								X		
Body mass index calculation								X		X
Stopwatch								X		X
Health Data recording									X	X
Instructions to stop smoking									X	

3 Novel Mobile Health Platform, SEAL

SEAL (Smart Environment for Assisted Living) is a comprehensive combination of smart home and mobile health subsystems. The subsystems provide functionalities for home residents to help them to achieve secure, healthy, and easy living and working environment even if they are suffering from chronic conditions or just want to automate equipment functionalities in their home or to be more aware about their health condition. SEAL system will be used in the Finnish Living Lab in which ambitious and challenging interdisciplinary research work can be conducted. To achieve SEAL Environment Pilot's ambitious goals, SEAL subsystems will be realized as separate entities, which work seamlessly together. Seamless cooperation between subsystems requires open and common communication interfaces. High level of adaptivity will be one of the key requirements in SEAL and it can be achieved by modular planning in which subsystems can operate independently or in cooperation with other subsystems seamlessly.

SEAL Application is a core of SEAL system. It can operate either in mobile device, such as smartphone or tablet or in home gateway device, such as Mini PC. SEAL Application collects the data from sensors or devices, which perform continuous or intermittent vital sign measurements and provide access to personal healthcare information. Measurements can be scaled from chronic condition monitoring (with several concurrent vital signs monitoring) of a patient to active health information monitoring (e.g., weight and blood pressure) for fitness and well-being purposes. SEAL Application also includes functionalities to improve the quality of live, for example, by enabling video conversation with healthcare professionals, family members, or friends. Figure 1 shows the interfaces of our novel SEAL Application. SEAL Application can operate independently conducting measurements and functions. Application can also send information about the current situation and measurements to each other. SEAL Application provides an open Application Programming Interface (API) for message transactions between application and measurement devices and open API to forward data to health information systems.

In Smart Home subsystem, the wireless network collects the environmental data from ambient sensors, which are located in the resident's home. The SEAL system analyzes the collected data and changes the house automation functionality accordingly. Security functionalities are also included, such as door control and fire/smoke

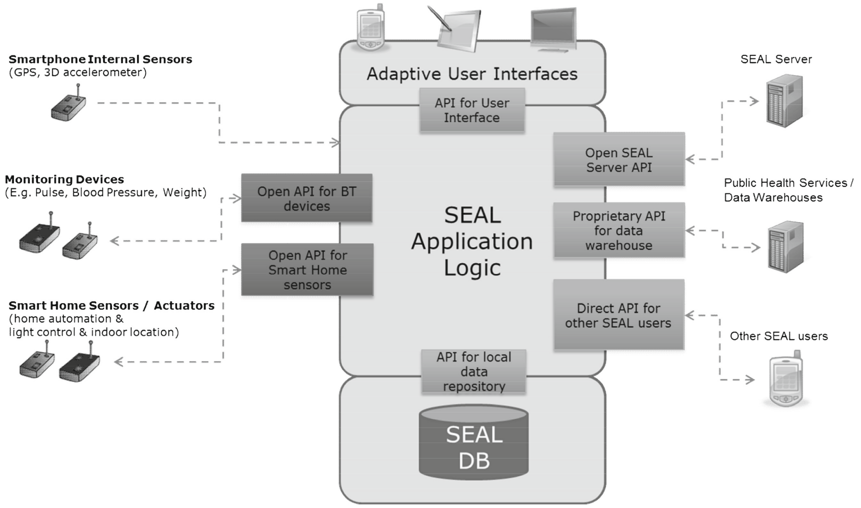


Fig. 1. SEAL application programming interfaces

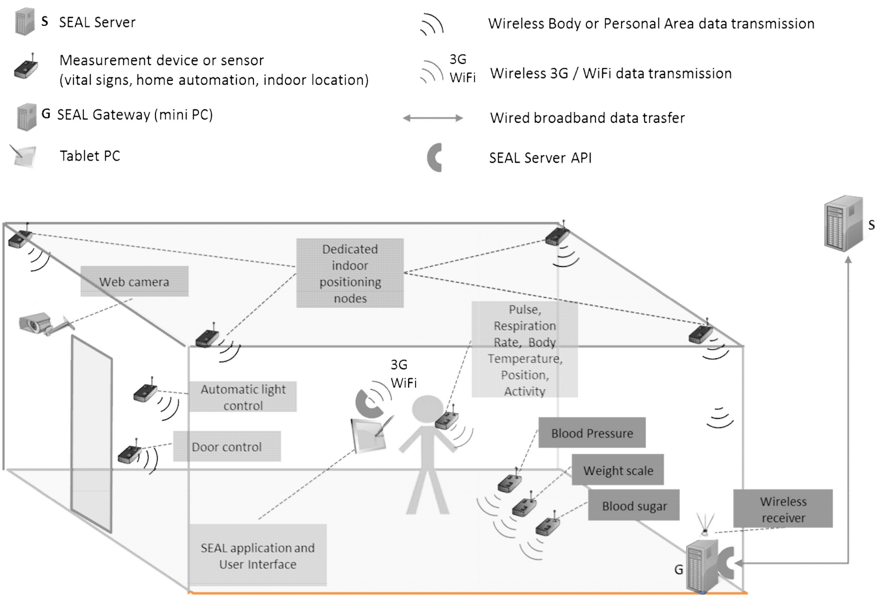


Fig. 2. SEAL smart home scenario

detection. Figure 2 shows SEAL system scenario in which measurement devices are transmitting health and environmental data from measurement devices and sensors to a SEAL Server by using SEAL Application located on a mobile device or on a mini PC.

Within the SEAL system, we have also introduced a novel approach for mobile health application communications in which SEAL Applications share information using Point-to-Point logic with each other in a SEAL network without application server interaction. This functionality is implemented for remote users (e.g., nurses) by using the internal SQLite database in SEAL Application and Google Cloud Messaging service for data routing directly from one mobile terminal to another mobile terminal. In an example case, a healthcare professional can select the customer from the customer list and can check the medicines, health status, and vital signs directly from the customer's SEAL Application wirelessly through 3G network without needing to relay the information through a server.

Another novel approach to the measurement device connectivity or application programming interface (API) development for the hospital information system connectivity is that SEAL will be developed to be able to adapt new interface libraries without the need of interface developer's previous knowledge about the source code or basic functionalities of SEAL core application. SEAL Application provides a GUI with novel adaptive functionality, which is modified automatically depending on the use-case and end user's technological skills. Figure 3 show a screenshot of SEAL GUI. SEAL Application GUI contains functionalities for healthcare professionals and for the customers or patients. SEAL Application GUI has been developed according to Nielsen's heuristics as a design guideline [17].

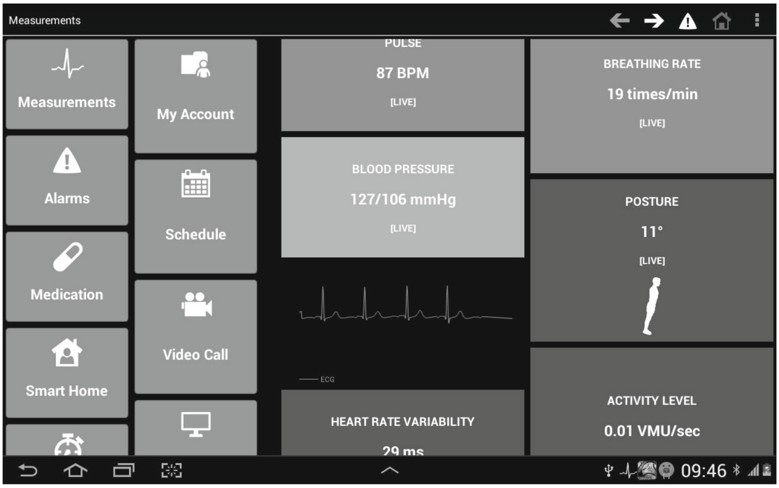


Fig. 3. SEAL application user interface in tablet PC

4 Conclusion and Future Work

A literature review based comparative analysis of the current state-of-the-art mobile health applications and services utilizing WSNs was provided. Moreover, a novel sensor network platform, SEAL, in which smart home, mobile health, and well-being functionalities are integrated into an open and adaptive Platform with special focus on adaptivity, user-centered design, accessibility, transparency, safety, security, and privacy, was proposed and implemented in practice. Currently, we have a first prototype of the SEAL system ready and it will be commercialized first in Finland and after that worldwide as soon as we have completed our extensive testing, validation, and evaluation phases. The validation and evaluation of the SEAL system will be performed in autumn 2014 in co-operation with a local home healthcare organization. Validation findings and end user recommendations will be implemented into SEAL release version after testing. During the validation, we will analyze the performance, adaptivity, user-centered design including usability (ease-of-use), accessibility, transparency, and safety, security, and privacy issues of our SEAL system as a part of our future research work. In addition, the latest data transmission protocols from current mobile health service providers will be studied in order to implement them into SEAL system.

Moreover, the SEAL must also provide comprehensive security measures for wireless authentication, data transmission, and data storage in mobile devices. Thus, we have already performed some wireless security research work related to Bluetooth and ZigBee technologies [18, 19] in order to create easier and more secure access to SEAL system for people with reduced physiological capabilities. We will also carry on this wireless security research path in our future research work for achieving the above-mentioned ambitious security goals of our SEAL system.

Furthermore, the SEAL system provide open APIs for other mobile devices, applications, and data repositories: SEAL Application will be designed to operate in multiple mobile platforms and offer functionalities to several end-user groups, such as healthcare professionals, healthy users who want to monitor their health status, or people who want assistance when using intelligent house technology. One novel aspect when comparing SEAL to other mobile health systems is the adaptivity. In SEAL system the adaptivity lies in the utilization of data from smart home sensors and health measurement devices to create an adaptive system. The SEAL uses a care plan as a plan of action for adaptation. The SEAL system monitors the changes in environment, sensors and measurement devices, human behavior and measurement history and modifies the care plan and devices in smart home adaptively. This continuous process will provide preventive care solution for SEAL end users.

Acknowledgements. This research work was funded by the European Union (EU) Artemis projects Design, Monitoring, and Operation of Adaptive Networked Embedded Systems (DEMANES) and Adaptive Cooperative Control in Urban (Sub)Systems (ACCUS).

References

1. Laukkanen, R.M., Virtanen, P.K.: Heart rate monitors: State of the art. J. Sports Sci. **16**(1), 3–7 (1998)
2. Medical Connectivity. http://medicalconnectivity.com/2009/03/24/can-we-fix-wireless-in-health-care

3. mHealth Regulatory Coalition. http://mhealthregulatorycoalition.org/wp-content/uploads/2010/12/mrcwhitefinal122210.pdf
4. Jantunen, I., Laine, H., Huuskonen, P., Trossen, D., Ermolov, V.: Smart sensor architecture for mobile-terminal-centric ambient intelligence. Sens. Actuators A **1**(142), 352–360 (2008)
5. Patrick, K., Griswold, W., Raab, F., Intille, S.S.: Health and the mobile phone. Am. J. Prev. Med. **35**(2), 177–181 (2008)
6. Continua Health Alliance. http://www.continuaalliance.org/
7. European Connected Health Alliance. http://www.echalliance.com/
8. Dargie, W., Poellabauer, C.: Fundamentals of Wireless Sensor Networks: Theory and Practice, pp. 13–14, 21–22, 168–183, 191–192. Wiley, New York (2010)
9. Dynastream Innovations Inc. http://www.thisisant.com/consumer/ant-101/what-is-ant/
10. Oliver, N., Flores-Mangas, F.: Health Gear: a real-time wearable system for monitoring and analyzing physiological signal. In: Wearable and Implantable Body Sensor Networks, pp. 4–64 (2006)
11. Merilahti, J., Pärkkä, J., Antila, K., Paavilainen, P., Mattila, E., Malm, E.-J., Saarinen, A., Korhonen, I.: Compliance and technical feasibility of long-term health monitoring with wearable and ambient technologies. J. Telemed. Telecare **15**(6), 302–309 (2009)
12. JeongGil, K., Chenyang, L., Srivastava, M., Stankovic, J., Terzis, A., Welsh, M.: Wireless sensor networks for healthcare. Proc. IEEE **98**(11), 1947–1960 (2010)
13. Ready, R., Ott, B., Grace, J.: Amnestic behavior in dementia: symptoms to assist in early detection and diagnosis. J. Am. Geriatr. Soc. **51**(1), 32–37 (2003)
14. Burstein, F., Zaslavsky, A., Arora, N.: Context-aware mobile agents for decision-making support in healthcare emergency applications, In: Proceedings of the 1st Workshop on Context Modeling and Decision Support Context, pp. 1–16.(2005)
15. Niemelä, M., Gonzalez Fuentetaja, R., Kaasinen, E., Lorenzo Gallardo, J.: Supporting independent living of the elderly with mobile-centric ambient intelligence: user evaluation of three scenarios. In: Schiele, B., Dey, A.K., Gellersen, H., de Ruyter, B., Tscheligi, M., Wichert, R., Aarts, E., Buchmann, A.P. (eds.) AmI 2007. LNCS, vol. 4794, pp. 91–107. Springer, Heidelberg (2007)
16. Kröse, B., van Kasteren, T., Gibson, C., van den Dool, T.: CARE: context awareness in residences for elderly. In: ISG 2008 - The 6th International Conference of the International Society for Gerontechnology, pp. 101–105 (2008)
17. Nielsen, J.: Usability Engineering. Academic Press, San Francisco (1993)
18. Haataja, K.: Security Threats and Countermeasures in Bluetooth-Enabled Systems. Ph.D. Diss., University of Kuopio, Department of Computer Science (2009)
19. Vidgren, N., Haataja, K., Patiño-Andres, J. L., Ramírez-Sanchis, J. J., Toivanen, P.: Security threats in ZigBee-enabled systems: vulnerability evaluation, practical experiments, countermeasures, and lessons learned. In: Proceedings of the IEEE 46th Hawaii, pp. 5132–5138 (2013)
20. SmartVisio. http://www.smartvisio.fi/fi
21. Healthsense. http://healthsense.com/
22. Megakoto. http://www.megakoto.fi/
23. Zephyr Technologies. http://www.zephyr-technology.com/
24. Omnicare iQare. http://www.omniqare.com/
25. CJPS VitalPoint. http://www.cjps.com/medicalsystems/vitalpointhome/
26. iTriage. https://www.itriagehealth.com/
27. LiveScape. http://livescape.mobi/
28. Microsoft HealthVault. https://www.healthvault.com/

Overview of Mobile Sensing for Special Needs: Lessons Learned from I Can Workshop

Eiman Kanjo(✉)

Nottingham Trent University, Nottingham, UK
eiman.kanjo@ntu.ac.uk

Abstract. There is nothing more frustrating than being unable to react, hear various noises, see the sunlight, effectively communicate with other humans, or mobilize. Our ability to do so is one of the keystones of what it means to be human, and the very base of our civilization and knowledge. At King Saud University, we have run a workshop to explore and classify the main portable and mobile technologies used for Special Needs and to highlight some of the underexplored sensors or devices which might be help special needs, ranging from motion detection for visually impaired to GPS tracking in the shoes of Dementia sufferers. In this paper we sum up some of our ideas and basic findings during the workshop. Beside some of the future research opportunities and challenges in this area are discussed.

Keywords: Assistive technology · Mobile computing · Location tracking · Mobile sensing

1 Introduction

The use of machines to assist in communications is not a novel idea. For more than 50 years, people with disabilities have been using technology to communicate. Early devices were neither portable nor affordable. An original light-spot operated typewriter, which used a head-mounted light to type, cost upwards of $40,000 and required a typewriter and a board of light sensors. Most of the initial technology was repurposed from the military, developed to aid in navigation or bombing.

Over the years, dedicated devices have become smaller, more portable and somewhat cheaper, although they remain costly. Economically, the audience for such devices is limited, meaning a small consumer base must share the costs for research and development. Even today, specially designed devices can cost somewhere between $2,000 to $10,000 and weigh upwards of 5 pounds. Mobile phones and portable tablets, by comparison, cost around or less $500 and weighs about a pound. Similarly sensing technology has become cheaper, smaller and more accurate. This advancement in technology has led the development in many projects aimed at people with special needs. For example, Real-GPS Shoes by GTX Corp and Aetrex help track people suffering with dementia and Alzheimer's disease (AD) [1]. Using affective and emotion sensors for autistic children is another example, so does noise sensing technology for people

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 82–92, 2015.
DOI: 10.1007/978-3-319-17136-4_9

with hearing difficulties and light sensor for visually impaired people. Eye tracking and gaze interaction by Tobii Technology has also revolutionized computer interaction and research by helping people with special needs to communicate [2].

At King Saud University, we have organized an interactive workshop "I CAN" which aimed at identifying various mobile and sensor technologies used to help people with special needs to achieve complete "social inclusion" ensuring education, employment, independence, communication and entertainment. Thirty workshop participants gathered around 4 design tables. Four provocateurs were employed to manage the tables. Each table has discussed a theme related to special needs. Users were given tens of research papers from related and unrelated conferences along with various stationary and tools to design a poster focused on one special needs categories. Our aim was to review current technologies and recommend new novel ways to adopt other technologies from different disciplines Also we looked at some barriers and difficulties that might be encountered while designing a mobile technology for the special needs. This paper is direct outcome of the workshop; it gives an overview on mobile technology for special needs. Also, it documents various projects that we have explored in our quest to find and develop new portable and assistive technologies to empower people with special needs by utilizing mobile and sensor technology.

2 Classification of Special Needs

2.1 Memory Loss

Today, the number of people who are suffering from memory loss is rising. Memory loss occurs when the person is unable to remember events and information they would normally be able to recall [3]. It has a wide range of causes such as dementia, Alzheimer's disease, Parkinson's disease, stroke, or head injuries [4, 5]. Studies have shown that more than 35 million people worldwide are affected by dementia [6]; therefore there is an urgent need to utilize the current technologies to assist people with memory loss.

2.2 Visually Impairment

Visually impairments could be classified to blurry vision or total blindness. Braille, Seeing Eye dogs, canes, and adaptive computer technology are used to aid people with visual impairments. However, there are recent technologies designed for other disabilities which can be utilized to assist blind people. There are mobile applications that utilize GPS and mapping to aid the visually impaired to navigate their way outdoor. For example, Ariadne GPS Talking Maps allows users to explore the world around them by simply moving their fingers around the map. The territory behind the user is represented on the bottom of the screen and the top portion represents what is ahead [7]. Another mobile application developed is set to help in purchasing and dealing with paper dollar currencies is LookTelMoneyReader. It utilizes the camera on the phone to flawlessly announce the denomination of paper money [8].

2.3 Hearing Impairment

Hearing impairments could be classified as mild, severe or profound hearing loss. Great advancements in the field of assistive hearing technologies have been accomplished in recent years [10]. Cochlear Implants, hearing cell regeneration, Computers, and Text Telephone (TTYs) are new technologies that are developed to help people with hearing impairments. One of the cutting edge technologies is NoiseSpy [9] which is a sensor mobile application used by many users to collect and log noise levels in specific areas using phone's microphones and GPS technology. With little modification, this application can benefit the deaf persons to know if there are sounds around them. Figure 1, shows the sound visualization capability of NoiseSpy.

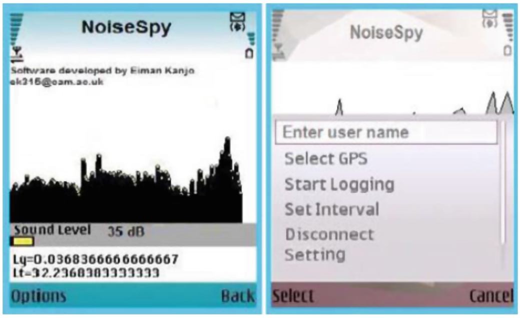


Fig. 1. NoiseSpy sound visualization according to date/time

2.4 Learning Disability and Behavoural Problems

Children with brain impairments may face difficulties in learning or communicating. Some of these conditions are dyslexia, attention-deficit/hyperactivity disorder (ADHD) or autism. Dyslexia is caused by impairment in the brain's ability to translate images received from the eyes or ears into an understandable language [11]. This causes a difficulty in reading, spelling and writing. However, it is not the result from lack of intelligence or sensory damage. In fact, children with this problem may have excellent vision and hearing senses. ADHD patients are different in which their learning and behavioral actions are affected [12]. They may understand what is expected of them, but due to their inability to sit still and pay attention, they will fail to accomplish the required tasks. Autism is a developmental disability that emerges during the first three years of a child's life [13], it affects normal brain function as a result of a neurological disorder which influences the development of the person's communication and socializing skills.

Chronic Diseases: Chronic diseases are diseases of long duration, and slow progression [14]. Chronic diseases such as, Diabetes, Asthma and Cancer are rarely cured completely and could result in severe complications and hospitalization which might lead to death if not properly monitored and treated.

Diabetes: Recent research in Saudi Arabia shows that the number of patients with Diabetes Mellitus is increasing significantly and reached a point where it is considered to be an epidemic. Lack of awareness of the disease and its consequences had caused many complications and hospitalizations where these side effects could've been prevented otherwise [15].

Diabetes is a chronic disease that is controlled through strict medications regimen that requires adherence. Rates of adherence for individual patients are usually reported as the percentage of the prescribed doses of the medication actually taken by the patient over a specified period. None-adherence is directly affecting diabetic patients' ability to control glucose levels in blood. It can result in false indications that current medications are not effective and can mislead physicians' diagnostic decision. The ability of physicians to recognize non-adherence is poor, where it requires several direct and indirect assessment methods. Direct assessment includes the measurement of glucose level in blood because it reflects adherence to regimens with these medications, while indirect assessment includes patients self-report, and pills count [16, 17]. Mobile telecommunication systems have been used in the care of children with type 1 diabetes. In Norway, Gammon et al. [18] demonstrated how mobile phones could be used to increase interaction between children and their parents by developing a mobile and wireless system which automatically transfer readings from a child's blood glucose monitor to their parent's mobile phone.

Asthma: Asthma is "a chronic lung disease that inflames and narrows the airways." [19]. In Saudi Arabia, the rate of growth of this disease is very alarming with its prevalence exceeding 20 percent of the population in certain regions of the Kingdom [20]. The researchers recognized the severity of asthma, thus, they gathered their efforts in order to find better ways to prevent or handle this chronic disease, as it led to4.2 million deaths on 2008 only [21].

Mobile and Internet technology is currently used for Asthma monitoring, however, web-based asthma diaries have been criticized for high rates of attrition. Mobile phones have been tested as an alternative to Web interface in the monitoring and self-management of asthma. Anhoj et al. [22] used the short message service (SMS) for asthma diary data collection in which patients were sent four SMS messages per day and were encouraged to reply to at least three of them daily. Messages included medication reminders, a request to enter peak flow, data on sleep loss and medication dosage. Responses were steady during the study period and did not decrease over time, with more than half of the participants reporting two-thirds of the requested data. This indicates that mobile phones may be a feasible method for self-monitoring [23].

Cancer: Cancer is a disease caused by the uncontrollable growth of abnormal cells in the body. Cancer cells grow and regenerate to form new abnormal cells. There are different types of cancer and each has a different treatment plan. It usually starts in one organ of the body and infects the near organs gradually if not treated. WHOMSa wireless monitoring system has been created by Bielli et al. [24]. The system created a method whereby structured questionnaires could be sent directly to the patient's mobile phone by their medical management team. Patient's answers are automatically transferred to an authorized website which then displays the patient's current state of health in graphical form, accessible by the medical team.

3 Technologies

Recent advances in computers have given rise to a large number of technologies that can assist people with special needs. These technologies range from specific sensors that can be embedded in systems such as location-based sensors (e.g. GPS) to standalone systems such as Electroencephalography (EEG) headsets that is worn to detect brain waves or physiological sensors that is used to detect vital signs of illness or emotional state.

3.1 Brain Interface EEG

Brainwave sensors (e.g. EEG sensors) measure and record the individual's brainwaves. This technology has the potential to help AD patients who suffer from attention deficits in the early stages of the disease. People with memory loss and especially AD patients have difficulties in concentrating on their tasks, and are distracted easily while performing their daily activities [25]. Studies suggest the use of brain training techniques such as playing games depend on maintaining a specific level of attention. This allows patients themselves to track and monitor their own EEG signals. And consequently improve their focus levels. Another application of EEG in Alzheimer is its use in the prevention or the delay of the disease [26]. This can also be achieved by using EEG headsets to track the patient's brain while doing memory training activities.

3.2 Galvanic Skin Response (GSR) Skin Conductance

When someone suffers from autism, a psychological wall blocks them from both verbally and physically communicating their emotions. Although they may appear withdrawn on the outside, inside, they may feel overcome with anxiety. By measuring the electrical conductivity of skin using GSRsensor such as Qsensors [27], it is possible to break through that wall, giving autism sufferers and those who work with them the ability to interact in a clearer, healthier manner.The GSR takes advantage of the body's natural response to stress. Before people start to sweat, the glands in the skin begin filling with water.

3.3 Wearable Face Recognition System

People with memory loss tend to forget people's names, phone numbers or faces. Currently, many technologies are developed to help them remember and recognize names, and faces. One of these technologies is face recognition systems that consists of wearable face recognition device and a consumer Bluetooth-enabled wristwatch. When the face recognition device identifies an indivisual, it vibrates the user's wristwatch and displays their names on the watch's text display via a wireless Bluetooth link [28].

3.4 Mobile Learning

The latest developed portable technologies for children with learning difficulties such as Dyslexia focuses on the different ways to help them indulge all their senses in the learning process. One of the assistive technologies used with reading and writing is portable word processors like Neo Keyboard [29]. With its functionality to enlarge text to fill the screen with only 2 lines of text, the child will be able to focus on fewer words to read. These portable word processors come preloaded with word prediction, spell checking and text-to-speech software. Another used technology is portable scanner pens [30]. They are used to hear words, lines or paragraphs spoken aloud in English by simply scanning and highlighting the text. This device can also displays the words on an easy-to-read screen, speaks them aloud, and provides definitions. So it will increase concentration of the child on a specific word when his vision and hearing senses are used simultaneously. Another technology used to help reduce distraction and increase concentration is the invisible clock [31], a device that is worn on the belt. The invisible clock is used to set a time limit for a specific task, such as 15 minutes to work on an assignment. After the specified time is up, the invisible clock vibrates or beeps. Talking calculator _as the name suggests_ read aloud each number, symbol and operation key as well as the answers. Audio books and reading software are also used in the learning process in which it would enable the students to have text read to them in a number of ways.

3.5 Mobile Applications

In recent years, many researchers have started to use mobile applications in their studies as an assistive technology for people with special needs [32]. These applications can serve people in different areas such as education, environmental monitoring, healthcare, or entertainment. For example, Sunny C. et al. [33] have developed a system, UbiFit Garden that can encourage individuals to be physically active. UbiFit Garden helps people with memory loss in managing their stress and anxiety levels by motivating them to exercise regularly. In addition, HealtheTrax application developed by Dynamic Solutions reminds people with memory loss to take medications, set up appointments and track their medical conditions [34, 35]. Navarro et al. [36] have developed ambient augmented memory system to assist elders with early AD. The system assists caregivers in tracking locations, and managing the patient's schedule by adding reminders for medications or events. The patients receive these reminders on their mobile phones. For example, Memory monitoring mobile application developed by Al-Muhanna et al. [37] measures memory decline in people with Alzheimer's disease and generates reports of performance-tracking to enable the specialists to monitor the patient's memory.

Recent studies have taken their experiments to the portable tablets like i-Pad. They have designed applications to enable communication for children with limited vocabularies by using pictures associated with a verbal recording. The child would choose the picture and the program would say the command associated with it to express their needs [38].

4 Mobility Enablers

4.1 Location Tracking: GPS

Today, the use of global positioning system (GPS) to track and monitor location-based services is increasing. GPS systems can be used by people with memory loss in order to track their current position as well as to direct them in case they get lost. For example, Guide Me project [39] integrates GPS and Global System for Mobile Communications (GSM) technologies into a viable locator and communication product that is specifically targeted at Alzheimer patients who are suffering from memory loss and their respective caregivers. This system uses two devices; one carried by the patient and the other by the caregiver. The patient can go for a visit without supervision under a physically present caregiver; also the caregivers can supervise and track the patient's location using their device.

4.2 Short Messaging Service (SMS)

SMS was used as mentioned in previous section for medical alert and notification in case of Asthma, cancer and diabetes.

In addition, Scanaill et al. [40] devised a monitoring system, based on mobile phone short message service(SMS) to remotely monitor the long-term mobility levels of older people in their natural environment. Each senior participant in the study have worn accelerometer-based portable units to measure their mobility and summaries were transmitted hourly in SMS messages, directly from the portable units to a remote server. For long-term analysis it possible to monitor mobility levels within an older population and alert appropriate medical personnel if mobility levels decreased.

More recently, Dalton et al. [41] conducted a small clinical trial with just six elderly people, and monitored their mobility over an eleven hour period. Again the SMS messaging service was used to alert health professionals to monitor sitting, standing and walking time patterns, although the study highlighted a need to assess practical issues regarding the size and weight of the equipment used.

4.3 NFC

The inclusion of new technologies as Near Field Communications (NFC) in the mobile devices offer a chance to turn the classic Augmentative and Alternative Communication boards into Hi-Tech systems with lower costs. [42, 43] have developed an augmentative communication system based on Android mobile devices with NFC technology, named BOARD (Book Of Activities Regardless of Disabilities) that enables direct communication with voice synthesis, and also through SMS to control the smartphone and home appliances, all in a simple way just by bringing the phone next to the pictogram.

5 Workshop Recommendation

During the workshop, the participants have rummaged through tens of papers related to mobile technology for special needs. They have been asked to categories each disability and technology used. Also they have been asked to rate each disability according to whether the requirements for mobile technologies are met or unmet as seen in the following chart, Fig. 2. They have found that awareness is one of the major factors that stop special needs from using mobile technology along with cost.

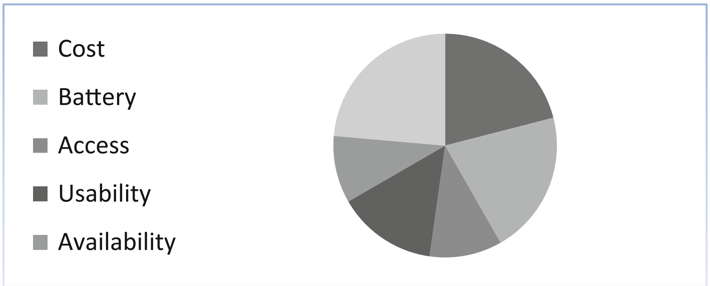


Fig. 2. Expressed unmet mobile technology requirements for special needs by participants.

Part of the workshop was dedicated to discuss recent technologies and common practices. We brainstormed for new ideas to use these technologies differently in which we picked each device and explored who and what it is used for. Then we suggested new ways to embrace the device to help other people with different disability. We have suggested the combination of several devices with slight adjustments to make a new technology dedicated for people with impairments, including:

- Brain interface EEG in combination with an alarm system can be used for ADHD children to help them focus on a specific task. So when EEG detects a change in brain waves the alarm should beep to help the patient refocus and get back to that task.
- GSR Skin Conductance to help children ADHD by predicting their emotion and try to change interaction so to keep them engaged as long as possible and identifies the things that mostly keep them interested for the longest period of time.
- Emotion detection could be used to help parents or caregivers monitor their autistic children's emotion by helping recognize the child emotion and then sending the information to the caregiver through Bluetooth or SMS.
- Motion detection technology can be used to indicate any movement on the room by making a beep sound.
- Near Field Communications (NFC) could enrich the visually impaired shopping experience by sending SMS messages indicating the stores he is walking by and the offers they have. Then it would be read by the screen reader software installed on his mobile phone.

At the end of the workshop each group presented their ideas on a poster as shown in Fig. 3 and gave a brief presentation explaining the recommendations.

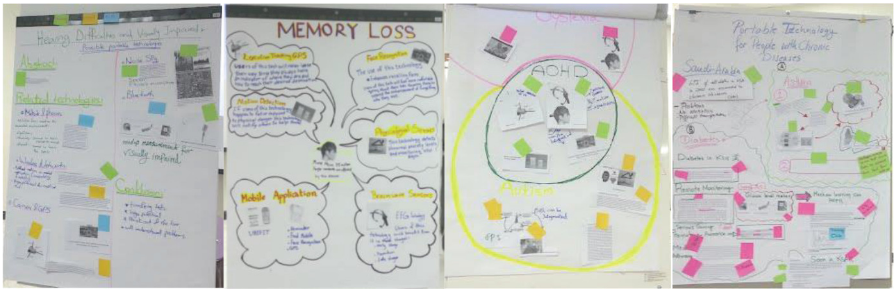


Fig. 3. Workshop Posters

6 Conclusion

This overview of current developments, although not exhaustive, has shown that research in this area is promising. Mobile and portable technologies are still developing to help people with special needs have a better quality life despite their inabilities. We will undoubtedly see a dramatic increase in the application of mobile technologies for special needs over the coming years, with many unevaluated interventions already currently in place. At present, mobile phone intervention is an emerging but rapidly advancing field. More quality research is needed to provide evidence of effectiveness for the impact of mobile phones on health knowledge, health outcomes and healthcare delivery for people with chronic diseases and elderly population. In this paper we have not just reviewed the current trends in utilising mobile technology for special needs, but also we have gave some glimpses of our current work in the area. Our collaborative workshop has proved to be successful in terms of bringing researchers with different technical backgrounds to recommend new use cases for modern mobile and sensor technology.

References

1. GTX Corp Two Way GPS Tracking Enterprise Solutions GPS Shoe GTXO. (2012). http://www.gtxcorp.com/
2. Tobii Technology Global Start Page. http://www.tobii.com/
3. Memory Loss. (2011). http://www.nhs.uk/conditions/memory-loss/Pages/Introduction.aspx
4. Dementia. (2010). http://www.nhs.uk/conditions/dementia/Pages/Introduction.aspx
5. Alzheimer's Disease. (2012). http://www.nhs.uk/conditions/Alzheimers-disease/Pages/Introduction.aspx
6. Dementia statistics. (2010). http://www.alz.co.uk/research/statistics
7. Apps For Blind And Visually Impaired. http://appadvice.com/applists/show/apps-for-the-visually-impaired
8. Apps For The Blind And Visually Impaired: iPad/iPhone Apps AppList. http://appadvice.com/applists/show/apps-for-the-visually-impaired. Accessed 2012 November 25

9. Kanjo, E.: NoiseSPY: A Real-Time Mobile Phone Platform for Urban. Springer Science, Heidelberg (2009)
10. AlGhamdi, N., AlOhali, Y.: The design and development of an interactive aural rehabilitation therapy program. In: 12th International ACM SIGACCESS Conference on Computers and Accessibility ASSETS 2010, Orlando, Florida, USA (2010)
11. Dyslexia. (2012). http://www.medicinenet.com/dyslexia/article.htm
12. Rogge, T., Zieve, D.: Attention deficit hyperactivity disorder (ADHD). (2012). http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0002518/
13. Autism Behaviour. (2012). http://alpinelearninggroup.org/about-us/about-autism
14. Chronic Diseases. (2010). http://www.who.int/topics/chronic_diseases/en/
15. Diabetes in Saudi Arabia. http://whatsupksa.net/v3/index.php/health/diabetes-in-saudi-arabia
16. Osterberg, L.: Adherence to medication. N. Engl. J. Medicen **353**, 487–497 (2005)
17. Al-Qasem, F.: Adherence to medication among chronic patients in middle eastern countries: review of studies. Eastern Mediterr. Health J. **17**(4), 356–363 (2011)
18. Gammon, D., Arsand, E., Walseth, O., Andersson, N., Jenssen, M., Taylor, T.: Parent-child interaction using a mobile and wireless system for blood glucose monitoring. J. Med. Internet Res. **7**(5), e57 (2005)
19. Moy, M., Israel, E., Weiss, S., Juniper, E., Dubé, L., Drazen, J.: Clinical predictors of health-related quality of life depend on asthma severity. Am. J. Respiratr. Crit. Care Med. **163**(4), 924–929 (2001)
20. Khan, G.: Asthma rate in Kingdom alarming, says specialist. (2009). http://www.a1saudiarabia.com/1094-asthma-rate-in-kingdom-alarming-says-specialist/
21. WHO mortality and morbidity. http://www.who.int/gho/ncd/mortality_morbidity/en/index.htm
22. Anhoj, J., Moldrup, C.: Feasibility of collecting diary data from asthma patients through mobile phones and SMS. J. Med. Internet Res. **6**(5), 567–578 (2004)
23. AlAjlan, M., Al-dowaihi, D., Al-Zahrani, N., Aljwiser, N., Al-qwifly, N., Kanjo, E.: Mbreath: asthma monitoring on the go. In: IEEE International Conference on medical Applications ICCMA, Tunisia (2013)
24. Bielli, E., Carminati, F., Capra, S., Lina, M., Brunelli, C., Tamburini, M.: A wireless health outcomes monitoring system (WHOMS): development and field testing with cancer patients using mobile phones. BMC Med. Inform Decis. Mak. **4**, 7 (2004)
25. Al-Barrak, L, Kanjo, E.: NeuroPlace: making sense of a place. In: Proceedings of the 4th Augmented Human International Conference (AH 2013), pp. 186–189. ACM, New York (2013)
26. Fisher, C.: Cognitive Training May Delay Onset Of Alzheimer's Disease Symptoms Through Brain Plasticity. (2011) http://www.bmedreport.com/archives/25400
27. Lisetti, C., Nasoz, F.: Using noninvasive wearable computers to recognize human emotions from physiological signals. J. Appl. Signal Proc. **11**, 1672–1687 (2004)
28. Face Recognition Device to Aid Early Stage Alzheimer Patients. (2011). http://www.sbir.gov/sbirsearch/detail/76119
29. Neo Direct Keyboard. http://www.neo-direct.com/NEO2/specialneeds.aspx
30. Portable Pen Scanner. http://portablepenscanner.2tee.net/
31. Gromisch, E.: Assistive technology for ADHD students: Invisible Clock. (2012). http://www.brighthubeducation.com/special-ed-neurological-disorders/74108-assistive-technology-for-adhd-students/
32. Kanjo, E., Bacon, J., Roberts, D., Landshoff, P.: MobSens: making smart phones smarter. IEEE Pervasive Comput. **8**(4), 50–57 (2009)

33. Consoly, S., McDonald, D.T., et.al.: Activity sensing in the wild: a field trial of UbiFit garden. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2008), pp. 1797–1806. ACM (2008)
34. HealtheTrax. (2010). http://www.dynamedsolutions.com/healthetrax.html
35. West, D.: How mobile devices are transforming healthcare. Issues Technol. Innov. **18**, 1–14 (2012)
36. Navarro, R., Favela, J.: Usability assessment of a pervasive system to assist caregivers in dealing with repetitive behaviors of patients with dementia. In: Proceedings of the 4th IPETRA 2011, pp. 28:1–28:8. ACM (2011)
37. Al-Muhanna, H., Al-Wabil, R., Al-Mazrua, H., Al-Fadhel, N., Al-Wabil, A.: An interactive multimedia system for monitoring the progressive decline of memory in alzheimer's patients. In: Stephanidis, C. (ed.) Posters, Part II, HCII 2011. CCIS, vol. 174, pp. 381–385. Springer, Heidelberg (2011)
38. Apps for Autism: Communicating on the iPad. (2012). http://www.cbsnews.com/8301-18560_162-57460553/apps-for-autism-communicating-on-the-ipad/
39. Loh, J., Schietecat, T., Kwok, T., Lindeboom, L.: Technology applied to address difficulties of alzheimer patients and their partners. In: Proceedings of the Conference on Dutch Directions in Human Computer Interaction, no. 18 (2005)
40. Scanaill, C., Ahearne, B., Lyons, G.: Long term telemonitoring of mobility trends of elderly people using SMS messaging. IEEE Trans. Inf. Technol. Biomed. **10**(2), 412–413 (2006)
41. Dalton, A., Scanaill, C., Carew, S., Lyons, D., Olaighin, G.: A clinical evaluation of a remote mobility monitoring system based on SMS messaging. In: Conference Proceedings IEEE Eng Med Biol Soc, pp. 2327–2330 (2007)
42. Al-Ofeishat, H., Al-Rababah, M.: Near Field Communication (NFC). IJCSNS Int. J. Comput. Sci. Netw. Secur. **12**, 1738–7906 (2012)
43. Colomer, J.M., et al.: Developing an augmentative mobile communication system. In: Proceedings of the 13th International Conference on Computers Helping People with Special Needs - Vol. Part II, pp. 269–274. Springer-Verlag, Heidelberg

A User-Centric Approach to Building Experience Platforms for Capturing Lifestyle and Wellbeing Information

Dana Pavel[1] and Dirk Trossen[2(✉)]

[1] TecVis LP, London, UK
dapa@tecvis.co.uk
[2] InterDigital Europe Ltd., London, UK
dirk.trossen@interdigital.com

Abstract. Lifestyle management solutions are of increasing interests due to the proliferation of mobile devices as well as wearables. The personalized nature of the recordings through such solutions, however, increasingly raises privacy concerns, particularly when relying on cloud-based storage. This paper presents our work on building a lifestyle management solution that not only addresses various privacy and control concerns at the design level but also incorporates key findings of user evaluations into the development of a refined mobile-based system.

Keywords: Lifestyle management · Privacy · Control · Personal data · Sharing

1 Introduction

Over the past years we have witnessed an explosion of solutions aimed at the area of self-recording for personal lifestyle management, driven by various socio-technological developments. The availability of new wearable sensors and devices lead to the availability of numerous systems that can record, store, process, visualise and share personal information. While initially the vast majority of such systems focused on fitness-related aspects, there is an obvious trend of moving towards more personal and private usages related to capturing and supporting health and wellbeing aspects [1]. Given that *wellbeing* is a complex state that involves various aspects of personal health, the need for collecting ever more private information will increase. However, the more sensitive the collected information becomes the more essential the challenges related to storing and sharing such information will be. Past as well as current developments in this area show that, when it comes to sensitive information such as health-related, there is a need for better solutions that put individuals' privacy concerns in the centre both through technological as well as legal frameworks (as emphasized in [1]). In the past years we have witnessed failed or struggling attempts from Google and Microsoft to provide cloud-based solutions where people and organizations would store health-related data [2, 3]. More recently, Apple started to take a very careful approach for the

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 93–105, 2015.
DOI: 10.1007/978-3-319-17136-4_10

HealthKit, by introducing restrictions on how the collected data is used by third-party developers as well as on how such data is stored in the cloud [4].

While new legal frameworks are being developed to cope with the explosion of applications collection various types of user data [1] and given that the area will continue to develop, it is clear that we need a better *privacy by design* process, where such solutions can offer increased benefits to individuals, organizations and societies while also providing an adequate protection to the parties involved, especially to the ones that the data refers to.

In this paper, we argue that when it comes to such solutions, the focus should shift from the act of recording and storing through cloud-based systems to the ability to *purposefully* share information with a process of recording and storing that preserves the patients' need for *privacy* and *control* while also creating an environment where such data can be used for multiple purposes within a climate of trust and mutual benefit. For this, we developed purposeful sharing interfaces in collaboration with test users, an approach we see at the heart of privacy-compliant lifestyle management platforms. After defining the problem space and challenges, we outline the approach for our work from design to in situ user studies, before discussing the specific findings that influenced the creation of the privacy and control mechanisms in our mobile-based platforms.

2 Problem Space and Challenges

The Problem Space. *Lifestyle management* focuses on individuals becoming more aware of how what they do has an effect on their wellbeing. With self-awareness being an essential step in achieving self-change [5], this area has become increasingly important during the past years due to the predicted impact on healthcare systems due to people living longer and with various chronic conditions [6]. Support through lifestyle management can have a significant impact both at individual as well as societal levels, as most of the patients living with chronic diseases fall into the low risk category, meaning that, with the right support, they can learn how to manage their disease.

Beyond educating people in making better lifestyle choices, various self-monitoring solutions have been created, greatly helped by the advances in wearable technologies [7]. Such solutions can record, store (either locally or remotely), and analyse patient data as well as trigger alerts (e.g., telehealth and telecare [8]). Using such systems for outpatient monitoring benefits both healthcare systems and patients, as people can live normal lives and avoid hospitalization. The importance of empowering both patients and medical staff with more objective information obtained through outpatient self-monitoring systems is emphasised in recent reports such as [9]. The same report also documents a continuous shift in attitudes of patients as well as of medical staff towards using such technologies, especially as they become more unobtrusive and as their benefits (both social and economical) are better understood. Over half of the 1000 people interviewed for this report (from the UK, aged 16 +) were already using various means for self-diagnosis (60 %), and were interested in monitoring their own health (over 60 %), particularly for various parameters such as cholesterol and blood pressure.

Self-monitoring involves the recording and possibly remote storage of highly personal information, such as location, physiological parameters, activities during the day and many others. Privacy is often a primary concern when it comes to deploying self-monitoring solutions for lifestyle management, such as highlighted in [10] among many others. While monetary incentives and security measures (such as encryption) can counter these concerns, built-in privacy is of crucial consideration for the wide-spread adoption of any lifestyle management solution.

The Challenges. When considering solutions for lifestyle management platforms with an emphasis on *privacy by design*, we can define the following goals for their realization:

1. Provide means to create a holistic and correlated view of relevant lifestyle aspects, such as physical and emotional state, social interactions, interests, professional activities or movement;
2. Provide means to involve end users throughout all processes, from information gathering to processing, usage and sharing, in order to allow for better control, support self-awareness and self-understanding, create a sense of ownership, incentivise usage, and enhance creativity;
3. Allow users to control and share their information with various parties within their social and support networks, either for fun or for medical purpose;
4. Evolve during users' lives, by being able to deal with ever-changing needs and situations.

There are various challenges related to privacy concerns, which are introduced by such goals. These challenges are present in all system aspects such as information sensing, gathering, storing, processing, visualizing and sharing.

Many existing wellbeing solutions upload and store user data onto their Internet-based servers. Most privacy policies give the companies the rights to process, store and share certain user data with third parties for unknown purposes and at any time, even if the user decides to close the account. Cloud-based solutions for highly personal data storage (such as health data) are yet to prove successful, as offerings such as Google Health [2] or Microsoft HealthVault [3] show (Google decided to shut down this service in 2011 and HealthVault is still struggling to gain adoption). More recently, Apple announced their HealthKit platform, together with new rules about what third-party developers can do with the data collected as well as a differentiated policy for uploading to the iCloud [4]. Legislation in this area is catching up and several frameworks start being developed, recognizing the need for more responsibility of application developers with regard to data being collected and used with or without user consent [11]. Countering this trend of storing recorded information in network- or cloud-based systems, we instead argue for a solution where all the information recorded belongs and is under the control of the *main user*.[1] This is essential since issues of control and privacy are even more important when multiple types of information are collected and correlated.

[1] The main user is the one the recorded data is about or relates to. Other users can be various parties that data is shared with.

As also argued for in [12], people should be in control of their data and should be involved in gathering as well as in using the data collected by these systems, not only for maintaining control and awareness but also in order to be able to experience their own data. Specifically, we believe that data recorded should be stored locally, in a database fully controlled by the end user, and it it should not be transported off to any remote health platform or cloud storage provider by default. This does not mean that the system is meant to be used exclusively for individual use. Information can be shared, at various abstraction levels, if so desired by the user. Various sharing scenarios can been considered, specifically in the health context as shown in Fig. 1 and mentioned in [13]. Sharing considerations, however, expand beyond the pure storage of the recorded information. For instance, more diverse information also means more privacy and data security concerns, due to the possibility of creating more revealing correlations (e.g., heart rate data alone provides less information than when correlated with other context data, such as social interactions or activity).

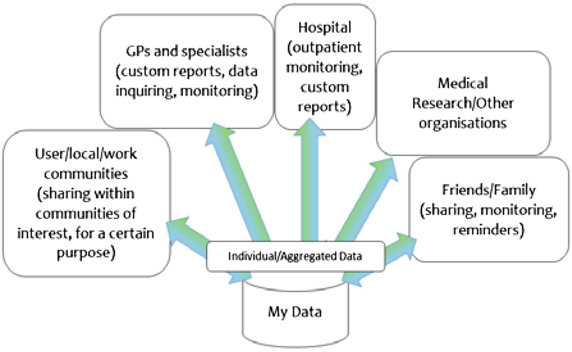


Fig. 1. Sharing scenarios

We strongly believe that such challenges need to be addressed at the design level and not as an afterthought. For that, we need to create systems that have user control measures embedded into all phases of data flow, from gathering to sharing. Furthermore, we need to provide appropriate mechanisms and interfaces that allow users to control what and how to share: e.g., means to specify what to share, for how long, ways to transform certain information before sharing.

In the following, we outline our approach to designing such user-centric solutions for lifestyle management systems, keeping such considerations in mind from the very beginning as well as the user studies we performed in order to refine our solutions and better understand what end users expect from such systems and how they can be further improved.

3 A User-Centric Approach to Designing Privacy Solutions in Lifestyle Management Systems

Our Approach. Based on the challenges outlined before, we created the MyRoR platform with a design that puts user privacy and control at the centre while also aiming to bring together multiple and relevant lifestyle aspects within an interactive and supportive system [14]. The MyRoR system was tested and improved through our in situ user evaluations that allowed us to explore various aspects of designing and using such systems [15]. Outcomes of this work are reflected in our mobile-based solutions: *AIRS*, which includes the recording and storage aspects of the MyRoR work, and *Storica*, which was created based on the desktop-based processing and visualization side of MyRoR. In this paper, we focus on issues around privacy and control that were explored through our whole platform work and how they were embedded and addressed within the system design. In order to do this we start with a short description of the MyRoR platform and work, with more information to be found in [14, 15].

The MyRoR platform is able to capture a varied range of lifestyle-related information within realistic usage scenarios, as users move between personal and professional activities (see Fig. 2).

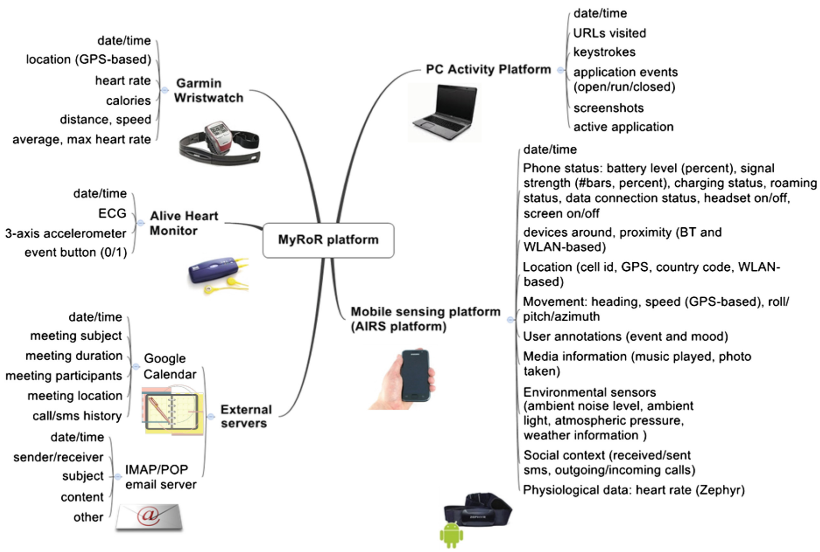


Fig. 2. Types of information recorded through MyRoR

Privacy as well as realistic usage conditions were a starting point, leading us to considering factors such as: (1) minimizing the effort for setting up the recording system while also increasing the number of information types to include; and (2) choosing a design where the end user feels in full control over where the data is stored and if/when/how the data is shared, meaning that the recorded data is stored on a user trusted machine and not automatically uploaded to a cloud server, as in most existing solutions.

Such privacy considerations were even extended to our in situ evaluations, by only uploading user-recorded data to users' own machines and examining it together with the participants. Given the invasive character of recording certain types of data, our participants felt more comfortable with such arrangement. The in situ evaluations were done based on six volunteers, 2 females and 4 males, with ages ranging from 25 to 80, each using the system for at least 2 consecutive days and in two phases: one aimed mainly at recording data, visualizing it with common means such as graphs, tables and word clouds and the second phase focused on creating and discussing a novel story-inspired visualization paradigm where all recorded information was processed and correlated within an event-based multimedia story [15]. Both phases were followed by semi-structures interviews, aimed to explore issues around meaningful data and how various visualizations support self-understanding and remembering.

Our Findings. An important aspect of the evaluations was to capture various usages of the system as a lifestyle experience platform, focused on accommodating changing needs. The design of the recording setup as well as the semi-structured dialogue during the follow-up interviews provided a flexible environment that allowed for capturing participants' suggestions regarding envisioned usages as well as for observing how the participants used the system to remember and reflect on their daily situations.

The main learnings derived from these evaluations were that: (1) when recording so many and varied types of information it is desired to have an abstract interface that can correlate interpreted information as well as provide personalized representations of user information; (2) the platform needs to allow for various levels of information abstraction and various means of interrogating the available information (i.e., queries, abstract visualizations, detailed visualizations, correlated visualizations); (3) as it is not possible to envision all possible usage scenarios, it is essential to provide means for adding/removing information, processing algorithms and new visualizations; (4) incorporating user-provided information into the visualizations and processing algorithms creates added incentive for contributing such information; (5) personalization is desired on different aspects of the platform.

Based on results derived from these user studies, we have created means that allow users to control *what* as well as *how* their data is being recorded and shared. Given that, as found in [15], the importance of data changes with person and situation, we have further developed means to create custom templates for recording as well as visualisations, allowing only for certain data to be recorded or explored.

Furthermore, the studies emphasized the need for allowing users to select what information they want to share, for being able to customise information specifically for sharing, for allowing users to select people or groups to share information with and for providing means for specifying scope and duration of sharing.

In the following, we elaborate on these various aspects of our findings as derived through the user studies.

Not a 'one size fits all': On Control and Customization. One of the most important learnings derived through the in situ user studies and the following semi-structured interviews was that the importance and relevance of information changes depending on the context it was recorded in (i.e., it differs from situation to situation) as well as on the users' needs and interests (i.e., people with a certain predominant condition might want to see how the recorded information relates to a primary observed parameter, such as heart rate).

In terms of the purpose of such systems, all participants said that they should be given the flexibility to decide what to use it for, meaning that they should be able to decide what should be recorded and when. No matter how they used the system during the study, they were all convinced that in time their interests and recording behaviour would change. As one user said, "every user would find an own way to look at the system so the system should allow the user to find its role and meaning depending on what fits him/her best". Therefore, as it is not possible to envision all possible usage scenarios, it is essential to provide means for adding/removing information, processing algorithms and new visualizations.

Throughout the user studies, the MyRoR system became more interactive, allowing the participants to include own annotations, such as current event description and mood. During the interviews it became evident that such user-contributed information took a central place, as it was considered that when someone feels the need to annotate a certain event, these manual annotations mean more to them than the automatically recorded data. Involving users into the whole process of gathering information and providing meaning created a higher sense of *ownership*. Further incentive for annotating was observed when the users were able to explore their own data via detailed and abstracted visualizations (i.e., MyRoR stories [16]), as these visualizations incorporated user-contributed data. Various types of control were discussed, such as being able to decide what data to be recorded, visualized and shared. However, while customization was desired, the constraint was that it should not require much time and effort; therefore, the templates and skinning were proposed as solutions.

Based on such findings, we have derived the following system requirements:

1. In order to accommodate various interests as well as concerns, the platform has to allow end users to customize what information is recorded and how (e.g., sampling rate, input source, granularity level) while limiting the effort required by such processes. For that, the system can provide *recording templates*, where the user selects a certain recording mode that fits best. For example, such templates can be based on certain focus (e.g., movement vs. emotion vs. social) or on certain battery profile (e.g., battery saving vs. high accuracy).
2. The system should use information about the current situation (e.g., user is at home or at work) in order to adapt the recording process. For example: (1) certain information can stop being recorded in certain situations (e.g., once at work, GPS is not needed anymore); (2) certain information is recorded differently based on situations (e.g., once at work, WiFi is only recorded once every 30 minutes); (3) certain information starts being recorded only in specific situations (e.g., if in a meeting, start taking snapshots in order to capture meeting agenda).
3. The system has to allow end users to add various types of media into the platform: own photos, videos, audio tracks, as well as annotations (text or audio) either during the recording or later.

4. The system has to allow end users to create various correlations dynamically, such as through allowing the user to select two or more types of information to be correlated through detailed graph-based visualizations.

Sharing Information. Sharing aspects have also been investigated during our user-based evaluations focusing both on sharing low-level data, such as heart rate and on sharing correlated information, such as in stories. User 1, for instance, did not see anything bad in sharing stories as long as he can control how and what is shared. He thought that he would be especially interested in sharing stories within certain situations, such as travelling, in order to show aspects such as path during the day, how noisy the environment was, how his heart rate changed. User 1 and 5 both talked about their interest in having the possibility to select parts of their stories to be shared based on situation and not necessarily based on what information is shown. For example, User 5 said that he would be perfectly fine in sharing his story, showing various types of information recorded while he was at a garden party, as the situation, not necessarily the type of data, defined what was acceptable to be shared. User 1 said that, most of the times, he would prefer his shared stories to only include abstracted information, not detailed, such as how much he was typing as opposed to what he was typing, etc. However, he also saw the possibility of sharing detailed information, such as heart rate, movement, location and so on, if it served to make a certain point (i.e., that his heart rate was constantly higher than normal during the flight). This system usage as evidence was also mentioned by User 5 after one incident where he had an argument with a bus driver that he took a different route than usual. User 3 thought that the stories would be perfect to be shared within social networks. While he thought that his stories might be a bit boring, as he considered his days uneventful, he said he would really like to see his friends' stories. User 4 was also interested in sharing her stories, especially if the system would allow for customizing them based on the intended purpose and audience, such as allowing her to create a different persona through stories.

4 A Mobile-Based Lifestyle Monitoring Platform Solution

While the findings derived from the user-based studies have been used to constantly improve the MyRoR system, they were also essential for improving our mobile-based recording platform, AIRS [20], as well as for creating Storica [21], a mobile-based version of the processing and visualization concepts developed in MyRoR. Storica operates on data recorded through AIRS and stored in its device-local database. This access is embedded into the Android security framework, which only allows such access for applications that share the same secure key. Both AIRS and Storica[2] implement means for privacy and control for individual and shared usage, as discussed below.

Controlling Recordings. AIRS was built with user privacy I mind: when using AIRS to record, the user is aware such process is ongoing as an icon is all the time visible in the Android notification panel. Hence, stealth recording is not possible. Another aspect

[2] Both applications are available for the Android mobile operation system.

of control is that of being able to specifically enable and disable the recording process by the end user. For this, AIRS does not record automatically but based on explicitly starting the recording (e.g., by starting AIRS or simply starting a shortcut to a recording template).

As already outlined in the findings, the evaluations suggested the usage of *templates* that would capture the needs for recording different information in different scenarios changing over time and with each user. Generally, AIRS provides comprehensive means to not only select sensors and other information to be recorded (see Fig. 2 for a subset of the over 60 different data types that AIRS can record) but also to configure particular parameters for a wide variety of these data types, such as accuracy of the location or the intervals for WiFi scans and many others. A recording template allows a user to specify what should be recorded in certain situations, such as Work, Travel, Car and so on. For simplifying the process of changing such templates quickly, AIRS also allows for creating shortcuts to these templates, which are placed on the home screen of the user. AIRS also provides means to download such templates from a server (e.g., for controlled experiments).

The recording process can be further customized and optimized through using certain parameters, such as user-defined WiFi access points that represent well-known locations, such as home or work. When being nearby these defined locations, AIRS switches off the GPS-based location recording (if enabled for recording), therefore improving on battery lifetime.

Customization. Apart from customizing the recording process itself (i.e., through creating templates in AIRS), Storica also provides a number of customizations for the various visualizations it offers.

For instance, annotations in the form of text as well as audio notes can be added to individual days of recordings. Furthermore, specific locations, either defined by GPS coordinates or through WiFi or BT beacon names, can be associated to personal backgrounds. These backgrounds are then used in the digital stories [16] to improve the experience through personalization. Similarly, mood annotations can be associated with specific backgrounds as well (e.g., if the user annotated the recording with ‘Happy’ the defined background is chosen for that event).

While Storica was created to explore new ways of interpreting and correlating lifestyle aspects within a fun and engaging multimedia format, it also provides means for obtaining detailed visualizations of data types through common means such as timelines and word clouds. Based on the user studies we have incorporated means for correlating two such timelines, allowing end users to explore how certain data, such as heart rate, relates to other data, such as ambient level, temperature or movement. Within the interviews, such correlations were used to observe the effect of movement on the heart rate sensors. Such correlations are created dynamically and can also be observed only during a certain time interval, by changing the start and end time. Figure 3 shows a correlation between ambient noise (red line) and heart rate (green line).

Fig. 3. Correlations in timeline views

Furthermore, Storica allows for querying data recorded over an entire month with regard to certain values, such as mood, event annotations, heart rate and many others (Fig. 4). Query conditions such as 'how often', 'where' and 'when' are available, providing valuable support for better understanding own data.

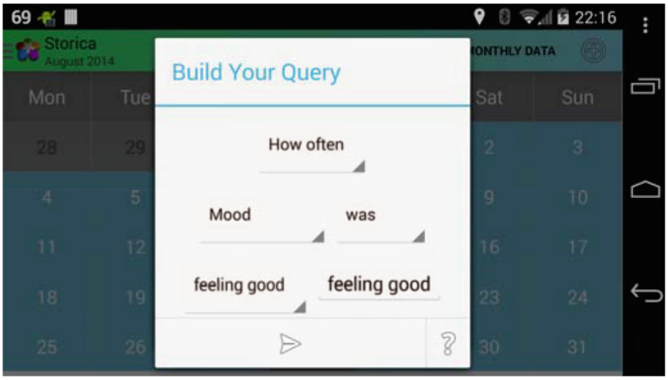


Fig. 4. Customized search queries over an entire month of recording

Sharing Information. Storica provides various kind of ways of exploring personal data through the Story View (as described in [16]), Photo View (context-annotated photos- Fig. 5b), Map View (context-enriched tracks on maps - Fig. 5a) and Detailed View (timelines and word clouds as in Fig. 3). Each view provides means to explore the information available in different ways with more or less detail. Low-level data can be explored by clicking on the corresponding icon. Also, each view provides means for information to be shared both at abstract level as well as at detailed level. End users are able to use the standard Android sharing mechanisms. Hence, by selecting the Sharing menu (see encircled menu item in Fig. 5a), the visualization is shared to any application

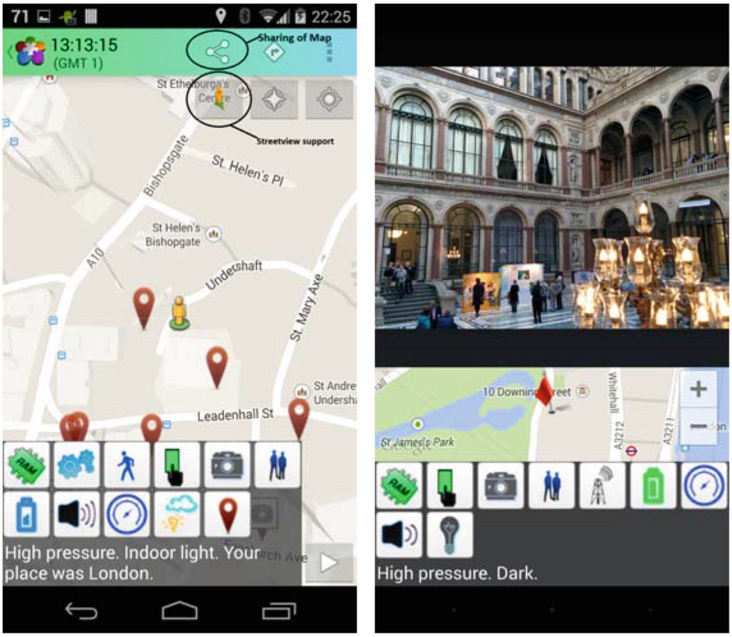


Fig. 5. Context-enriched Map (a) and Media Gallery (b)

that is able to process images, ranging from Facebook, Twitter and LinkedIn to internal image processing applications for further refinements.

Whole recordings can be shared from the mobile device through AIRS as well as being periodically uploaded to a personal Google Drive in user-selectable intervals. Storica allows recordings to being imported from other devices, enabling a true multi-device experience where one device is used for recording and others for visualizing.

Within a shared scenario, we can also imagine that, if so desired, recordings are shared between different people for a joint experience.

5 Conclusions

Given that increased self-awareness is the prerequisite for self-change [1, 12, 17] and that lifestyle management systems do help people to become more aware of what happens in their lives [18, 19], it is crucial to better understand how to design such systems for longer-term usage. In this paper we focused on certain aspects that are important for building such systems, such as providing means for controlling how personal information is captured, visualized and shared. While some of these aspects were addressed through our initial platform design, many more were derived through our in situ user evaluations, also leading to the creation of two mobile-based solutions that allow for multiple levels of control over the recording as well as the usage of personal data. These solutions allow for easily controlling the extent of recordings and adapt them to certain situations, for personalizing aspects of the visualizations as well as for purposeful sharing of information at different levels of aggregation and with different parties. Beyond the specific solutions that resulted from our work, the platform refinements also validated the suitability of the user-centric approach in terms of capturing and finally addressing user concerns such as those related to privacy.

References

1. European Commission: Green Paper on mHealth, 10 April 2014. http://ec.europa.eu/digital-agenda/en/news/green-paper-mobile-health-mhealth. Accessed on 24 Oct 2014
2. Lohr, S.: Google to End Health Records Service After it Fails to Attract Users. New York Times (2012)
3. Microsoft: Microsoft HealthVault (2013). https://www.healthvault.com/gb/en. Accessed on 16 Oct 2014
4. Faas R.: Why Apple's HealthKit and HomeKit rules are a huge advantage, 3 September 2014. http://www.citeworld.com/article/2601907/mobile-byod/why-apples-healthkit-and-homekit-privacy-rules-are-a-huge-advantage.html. Accessed on 24 Oct 2014
5. Fogg, B.J.: Persuasive Technologies: Using Computers to Change What We Think and Do. Morgan Kaufmann, San Francisco (2003)
6. Department of Health: Improving chronic disease management. http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4075213.pdf. Accessed on 16 Oct 2013
7. Department of Health: Supporting Self Care–A Practical Option: Diagnostic, Monitoring and Assistive Tools, Devices, Technologies and Equipment to Support Self Care. http://webarchive.nationalarchives.gov.uk/20090120141703/http://dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4134006. Accessed on 16 Oct 2013
8. NHS Choices: Telecare and telehealth technology. http://www.nhs.uk/Planners/Yourhealth/Pages/Telecare.aspx. Accessed on 10 Dec 2012
9. The Future Vision Coalition: A future vision for mental health, July 2009
10. Ramanathan, N., Swendeman, D., Comulada, W.S., Estrin, D., Rotheram-Borus, M.J.: Identifying preferences for mobile health applications for self-monitoring and self-management: focus group findings from HIV-positive persons and young mothers. Int J Med Inform. **82**(4), e38–e46 (2013). doi:10.1016/j.ijmedinf.2012.05.009. Epub 14 June 2012 (2014)
11. EU Article 29 Working Party: Press Release, Brussels, 14 March 2013. http://ec.europa.eu/justice/data-protection/article-29/press-material/press-release/art29_press_material/20130314_pr_apps_mobile_en.pdf. Accessed on 24 Oct 2014
12. Shneiderman, B.: Leonardo's Laptop: Human Needs and the New Computing Technologies. MIT Press, Cambridge (2002)
13. Bacon J., Singh J., Trossen D., Pavel D., et al.: Personal and social communication services for health and lifestyle monitoring. In: First International Conference on Global Health Challenges (Global Health 2012), Venice Italy (2012)
14. Pavel D., Callaghan V., Dey A.K., Sepulveda F., Gardner M.: The story of our lives: from sensors to stories in self-monitoring systems. In: The 4th Computer Science and Electronic Engineering Conference (CEEC 2012), Colchester, UK (2012)

15. Pavel D.: MyRoR: Towards a story-inspired experience platform for lifestyle management scenarios, Ph.D. thesis (2013). http://dalore.me.uk/Dana/wp-content/uploads/2014/01/MyRoR_final_Jan2014.pdf
16. Pavel, D., Trossen, D., Holweg, M., Callaghan, V.: Lifestyle stories: Correlating user information through a story-inspired paradigm. In: Pervasive Health 2013, pp. 412–415 (2013)
17. Picard, R., Papert, S., Bender, W., Blumberg, B., Breazeal, C., Cavallo, D., Strohecker, C.: Affective Learning-A Manifesto. BT Technol. J. **22**(4), 253–269 (2004). doi:10.1023/B:BTTJ.0000047603.37042.33
18. Ståhl, A., Höök, K., Svensson, M., Taylor, A.S., Combetto, M.: Experiencing the Affective Diary. J. Pers. Ubiquit. Comput. **13**(5), 365–378 (2009)
19. Mcduff, D., Karlson, A., Kapoor, A., Roseway, A., and Czerwinski, M.: AffectAura: An intelligent system for emotional memory. In: Proceedings of CHI 2012, Austin, TX, USA, 5–10 May 2012
20. Trossen, D., Pavel, D.: AIRS: A Mobile Sensing Platform for Lifestyle Management Research and Applications. Res. Art. EAI Endorsed Trans. Mob. Commun. Appl. **13**(3), e8 (2013)
21. Storica (2014). https://play.google.com/store/apps/details?id=com.storica&hl=en_GB

From Silos to the IoT via oneM2M, a Standardized M2M Service Platform

Alan Carlton[1], Rafael Cepeda[1](✉), and David Trousdale[2]

[1] InterDigital Europe Ltd,
64 Great Eastern Street, London EC2A 3QR, UK
{alan.carlton,rafael.cepeda}@interdigital.com
[2] Buckinghamshire County Council, InterDigital Europe Ltd.,
64 Great Eastern Street, London EC2A 3QR, UK
dtrousdale@buckscc.gov.uk

Abstract. Local Authorities in the UK are facing the requirement of opening their data assets, which are not completely integrated and might come from different sources and sensors. In the view of future smart cities, these data assets should be highly integrated between different sectors and regions to enable accurate prediction and recommendations to users. We explore this problem using Buckinghamshire and the transport sector as a case study to propose a solution that will enable the future Internet of Things (IoT) while incorporating legacy and future systems.

Keywords: M2M · IoT · Sensor networks

1 Introduction

The central government in the United Kingdom is requesting Local Authorities to open their data assets to the public. However, since budgets and resources are limited, Local Authorities need to prioritise actions. Taking a real-life example, the transport directorate at Buckinghamshire County Council (BCC) is currently exploring which of its data assets should be offered to the general public first and what format suits the needs of most future data customers. On the last point, BCC has received varied requests from private companies to access the county's data assets.

BCC has deployed several sensors across the county to monitor buses, congestion and other traffic conditions. Most of these sensors are compatible with the Urban Traffic Management & Control (UTMC) programme. Launched in 1997, UTMC was envisioned as the main programme of the UK Department for Transport (DfT) to establish an open approach to Intelligent Transport Systems (ITS) in urban areas [1].

Recently, with the proliferation of cheaper and specialized electronic sensors, BCC has opted sometimes for cost-effective Ethernet-based solutions. However, as integration with other systems was not a requirement or necessity, there is little current integration between data from different sources, though all data is UTMC compliant and some of it is aggregated through systems providing transport information dashboards.

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 106–109, 2015.
DOI: 10.1007/978-3-319-17136-4_11

The variety of data and information does not stop here. Only considering transport information, BCC also holds dynamic data from planned road works, social feeds, reported events, congestion maps, etc. Looking at the future, BCC hopes to install more sensors to monitor different aspects of mobile and static traffic conditions, recognising that more accurate transport data aids transport planning and enables road users to plan their journeys more effectively.

The popularity of machine-to-machine (M2M) communications is also boosting the availability of cheaper and innovative electronic sensing devices. Unfortunately, solutions come in different shapes and flavours, and mainly in the form of proprietary solutions. If we look at the wealth of data that is, and will be, available from all these sensors and systems, it is only natural to think about the immense possibilities for innovative services and accurate predictions and recommendations if data assets from these systems were well integrated. These data sources would not only come from the transport sector, but also from other sectors such as health, environment and security, with the long-term objective of integrating data from multiple cities. However, to achieve this long-term integration goal, the first milestone is to truly integrate isolated data sources from one sector using an open and inclusive solution. Once this is achieved, other sectors and cities/regions can become part of the solution by also incorporating their data assets into an open system.

With our long-term objective in mind, in the following sections we explore a real case study for conquering the initial milestone, or the integration of information from the transport sector in Buckinghamshire using oneM2M, a global, open and standardized M2M service platform.

2 Transport, Mobile Sensors and a Common M2M Platform

Data from mobile sensors need to be available to different services and business models to stimulate healthy competition. However, current plurality and isolation of platforms and solutions make integration difficult. In addition, the Transport industry today parallels the earlier telecoms industry. In the 1980s, the telecoms industry was characterized by monopolies of local champions and manufacturers. This *strangled* innovation and growth, creating a situation that did not ebb until after progressive acts of deregulation, and the advent of standardized global technologies like GSM.

Today we are not only facing the incompatibility between different solutions for the transport sector, but also the deployment of proprietary M2M solutions in different cities. With the recent UK initiatives for driverless cars, for instance, getting an autonomous car to drive from one city to another, grant a parking space at destination, and avoid traffic jams on the way, would be difficult due to *incompatibility* with end or transit cities.

To achieve an integrated data future, we propose the use of oneM2M, a global standard created with the intention of breaking down silos and enabling the possibilities of the internet of things (IoT). oneM2M is commonly referred to as a Service layer standard. This means that its core function is to provide a set of service capabilities that enable manageable data sharing to foster new services and application development. oneM2M is based on a “store and share” paradigm. The data may be made available in the platform to other applications. Interested applications are notified by means of subscription. Access rights, usage and privacy are ensured through defined service capabilities.

3 oneTRANSPORT, from Silos to IoT

The oneTRANSPORT project, or "oneM2M-based open ecosystem for Transport Modal Shift," is result of a granted fund from the 'Integrated Transport: In-Field Solutions' UK Technology Strategy Board (TSB) feasibility study competition. The oneTRANSPORT consortium consists of **InterDigital Europe** (Lead Partner and technology platform provider), **BCC** (primary stakeholder), **ARUP** (transport industry), **Worldsensing** (transport sensors) and **Traak Systems** (transport analytics).

OneTRANSPORT is unique and complementary to legacy transport technologies (e.g. UTMC, DATEX II [2]). It introduces a new standards-based "layer" of functionality that has never existed before in the Transport industry (Fig. 1). This new layer serves to open up the deep big data that many Local Authorities currently have locked behind legacy systems. It is the fundamental hypothesis of oneTRANSPORT that the answers to the many challenges facing the transport industry today lies in the opening of this data (on a national scale) to the innovative power of the application development community. oneTRANSPORT will enable new transport applications to be developed on a large scale, delivering both local and national impact. The challenge here is doing this in an economically attractive manner to Local Authorities. To this end, oneTRANSPORT proposes an innovative cloud based model of data producers and consumers to enable an "open-once-sell-to-many" vision. Local Authorities today are already being *hassled* for their data assets (e.g. freedom of information requests) by an eager development community. oneTRANSPORT delivers a working model to enable this need to be fulfilled in a "win-win" configuration.

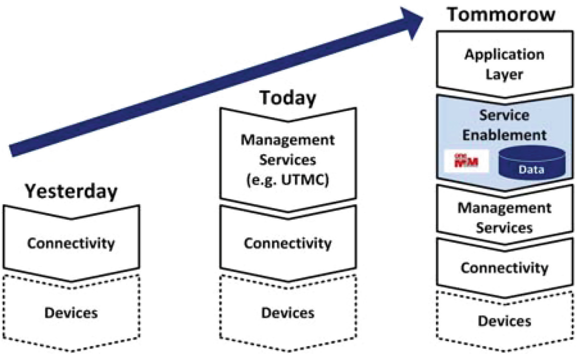


Fig. 1. Value chain evolution for transport industry.

4 The Future IoT

The evolution from M2M to a truly IoT will happen once integrated data from different sectors leads to accurate predictions and recommendations to users. Taking the current transport sector situation as a model, we believe the following points need to be fulfilled to reach this goal:

- **Avoid proprietary systems** – to reduce the risk of downstream vendor lock in, but rather **use globally-standardized technology** (i.e. not just UK or Europe) – to open up the global market;
- **Support multiple existing infrastructures**, rather than being 'clean slate' solutions – so it can operate across diverse legacy systems, supporting counties with and without legacy systems (e.g. UTMC installations);
- **Involve multiple (Transport) Authorities** – so the above can be demonstrated;
- **Deliver new sources of revenue** into the (transport) ecosystem – so that Local Authorities find it (at a minimum) cash neutral and hence rapidly adopt it;
- **Encourage solutions that facilitate new, open, competitive markets** – to create opportunities for existing (transport) industry players, to encourage their buy-in;
- **Encourage Authorities to open up their (transport) data** – by creating new possibilities for them;
- **Employ an open, standardized, interface for new sensors** – to support and make use of data from future sensors deployed outside of sector and to encourage interface standardization (lower costs) amongst sensor and system suppliers;
- **Provide measures of the modal shift effectiveness of services** – to allow their comparison; and
- **Enable Local Authority services beyond sector (transport)** – to support the next moves to smart counties and smart world.

5 Conclusion

The evolution from M2M to IoT requires an efficient and coordinated use of data. However, legacy systems and use of locked M2M solutions prevent the realization of the IoT. We introduced key IoT enabling factors and oneTRANSPORT, a project to integrate the Transport sector, with the long-term vision of integrating it with other sectors and cities using oneM2M, a globally standardized M2M service platform.

Acknowledgments. The Technology Strategy Board (TSB) for supporting the oneTRANSPORT Feasibility Study. The KTN Transport Community, ITS-UK and participants in oneTRANSPORT workshops.

References

1. http://www.utmc.uk.com/
2. http://www.datex2.eu/

Decentralising Internet of Things Aware BPMN Business Processes

Dulce Domingos, Francisco Martins(✉), and Lara Caiola

Large-Scale Informatics Systems Laboratory (LASIGE)
and Departamento de Informática, Faculdade de Ciências,
Universidade de Lisboa, 1749-016 Lisboa, Portugal
{dulce,fmartins,lcaiola}@di.fc.ul.pt

Abstract. The increase in computation and communication capabilities of sensor devices made possible their use as active participants in business processes. In this setting, sensors can execute parts of these processes in a decentralised way. However, business processes are still defined following a centralised approach, making it difficult to integrate the capabilities of these devices.

In this paper we provide an automatic procedure to decentralise Internet of Things aware business processes defined using the Business Process Modelling Notation (version 2.0). We depart from a centralised description of a business process and transform it by generating pools with the business logic that sensors are going to execute, while keeping the original process semantics. We generate the code to run on the sensor network and then we deploy it together with the business process and the middleware configuration that enables the communication (via web services) between the sensor network and the business process engine.

1 Introduction

Nowadays, organisations use more and more business processes for capturing, managing, and optimising their activities. In Portugal, for instance, according to the results of the Business Process Management (BPM) Observatory survey, 83 % of the top 371 biggest Portuguese organisations have some kind of BPM related procedures [4].

In areas such as supply chain management, intelligent transport systems, domotics, or remote healthcare, business processes make use of information and functionalities of wireless sensor and actuator networks (WSNs). Context information is used to optimise business processes execution and to adapt them to context changes. In addition, the increase in computation and communication capabilities of sensors suggests that they can be included in business processes as active participants, making business processes aware of the context they operate on (IoT-aware business processes).

Sensors can be used to aggregate and filter data, to make decisions locally, and to cooperate with actuators to take actions in the real world. This way,

E. Kanjo and D. Trossen (Eds.): S-Cube 2014, LNICST 143, pp. 110–119, 2015.
DOI: 10.1007/978-3-319-17136-4_12

sensors and actuators can execute parts of the business logic, whenever central control is not required [8,9].

Decentralisation promotes central system scalability, as it reduces the number of exchanged messages and centralised processing. Another important advantage in many scenarios is that the lower network traffic between the central system and WSNs improves battery lifetime. The decentralisation of business processes through WSNs requires their decomposition at design time as well as their distribution at execution time.

At design time, current approaches use the high-level Business Process Modelling Notation (BPMN) language [12] to define both business processes and WSN behaviour at the same level of abstraction [1–3,15]. BPMN already provides the concepts to define the behaviour of various participants, by using different pools. The interaction amongst participants is specified through collaboration diagrams. To support the execution of these hybrid processes, these approaches convert the BPMN sensor pools to WSN code.

Despite the benefits of decentralisation [7,8] business processes are still defined following a centralised approach. In this paper, we provide an automatic procedure for decentralising business processes that can use WSNs to execute some parts of the business logic. We decompose the business process into several pools, one for the central process execution engine and others (one per sensor network) for the WSNs.

We use techniques based on partitions, which group together activities in sub-processes and assign them to separate participants. These techniques were previously applied to generic workflow models [7,14]. These works simplify their approaches by omitting data dependencies [7] or by letting designers to define the execution location of activities [5]. We are using BPMN diagrams to determine data and control dependencies, as well as execution location of activities.

In addition, unlike more generic works in this area, we take into account WSN resource limitations when distributing parts of business logic into WSNs. This way, to determine if sensor capacity is enough to execute the partition assigned to it, we translate the BPMN model into Callas [10], a high-level sensor programming language.[1] Indeed, if we can generate Callas code, we can distribute it. If sensors cannot execute the Callas code, we provide a middleware (named MuFFIN) that can execute the code on behalf of the sensor network [13].

This paper is organised as follows: the next section presents related work; Sect. 3 describes the business process decomposition illustrated via a use case scenario; and in Sect. 4 we describe a prototype that implement our proposal. Finally, Sect. 5 concludes the paper and presents future work directions.

2 Related Work

Initial works on decentralisation of business processes apply program partition techniques to BPEL processes, such as the ones based on program dependency

[1] http://gloss.di.fc.ul.pt/pati/.

graphs, to reduce the amount of data that needs to be exchanged between participants and the central process execution engine. These works propose the creation of new sub-processes for each service of the main process and perform direct communication amongst sub-processes, keeping messages from being sent to the central process execution engine, i.e., avoiding centralised control [11]. However, they disregard the possibility to group together services in a sub-process.

Partition-based techniques group activities into sub-processes and assign each sub-process to a separate process execution engine. Information about location of activities is given by designers or inferred from the process definition. Sadiq et al. [14] and Fdhila et al. [7] apply partition based techniques to generic workflow models. While Sadiq et al. do not consider data dependencies, Fdhila et al. generate transitive dependency tables resuming data and control causalities between activities to define sub-processes that are executed by the same participant.

The approach of Duipmans et al. aims at placing in the cloud less sensitive data and computational-intensive activities [5]. They use a graph transformation approach to divide the process between two execution engines: the on-premise engine and the one in the cloud. The technique uses a distribution list that states the execution location of each activity.

In [6], the authors go a step forward and use heuristics to optimise the communication overhead, while maximising the quality of service.

In this work, we apply partition-based techniques to decentralize BPMN processes as in [7,14]. We firstly generate an intermediate graph model and use BPMN diagrams to determine control and data dependencies, and the execution location of activities. In addition, to determine if sensor capabilities are enough to execute the partition assigned to the sensor network, we use the BPMN to Callas translation procedure, unlike the pre-defined distribution list used in [5].

3 Business Process Decomposition

This section describes our BPMN process decomposition by means of a perishable goods transportation use case scenario, such as strawberries.

3.1 Use Case Scenario

An organisation receives client orders and performs the transportation of goods. During transportation, the organisation monitors the container's temperature with a sensor network. In case the temperature changes in a way that it might affect the good's quality, the organisation can, for instance, change the route to a faster one or change the delivery destination to a closer client. Finally, at the end of transportation, the temperature history is used to evaluate goods' quality and to determine the final price.

Figure 1 illustrates a simplified BPMN process of this scenario. The process model comprises two pools: the transportation process pool executed in the BPMN engine (e.g., JBoss jBPM) and the WSN pool meant for the sensor

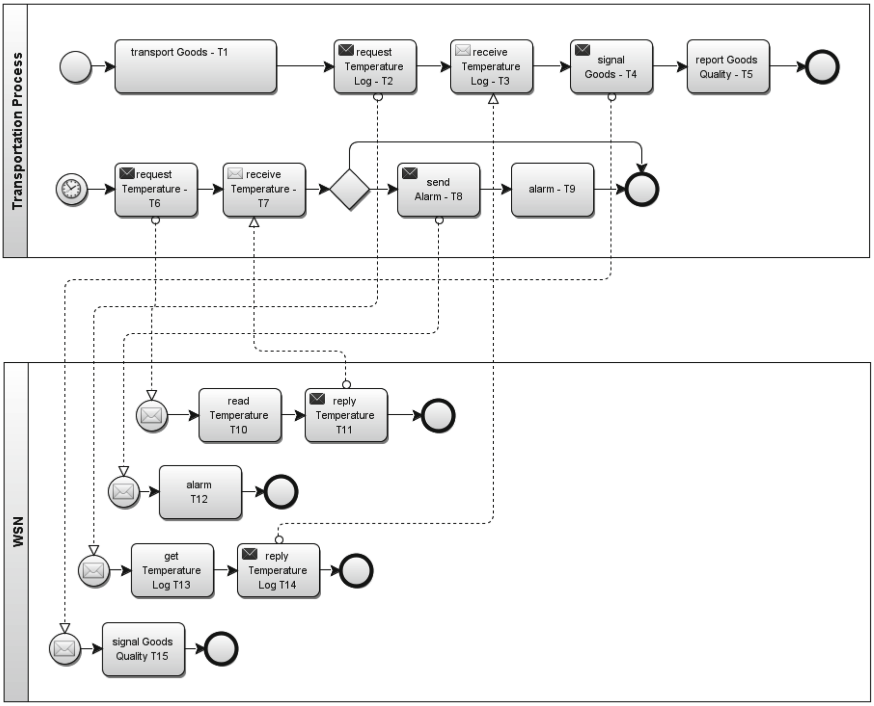


Fig. 1. A simplified BPMN process example

network. The transportation process pool abstracts the delivery process in task *transport goods*. After, it collects the temperature log from the sensor network (tasks *request Temperature Log* and *receive Temperature Log*). Finally, it computes goods quality, signals the WSN, and reports goods assessment to the user. A second process in this pool periodically tracks goods temperature, by inquiring the WSN (tasks *request Temperature* and *receive Temperature*), and in case the value is above a threshold it triggers a sound alarm (task *send Alarm*), and reports the incident to the user (task *alarm*). The WSN pool is a set of four event handlers, triggered by messages. From top to bottom, the first senses and reports the container temperature; the second activates an alarm; the third reports the journey's temperature log; and the last informs the user of the quality of the goods, for instance, using green (good), yellow (acceptable), and red (perished) LEDs.

3.2 Decomposition Steps

In order to optimise the message between the BPMN process engine and the sensor network, we apply partition-based techniques, used for generic graph-based workflow models [7,14], to decompose the process definition. For that, we perform the following steps:

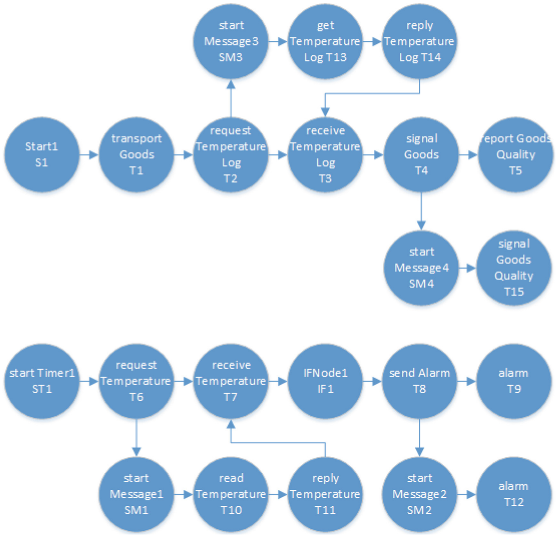


Fig. 2. Intermediate graph

1. Generate a graph model from the BPMN business process definition that captures tasks' control flow dependencies.
   In our approach we use an intermediate graph model in which nodes represent activities and edges denote control flow between the nodes. The same approach can be used to represent data flow. The control flow graph for the BPMN process (Fig. 1) is depicted in Fig. 2. The semantics is that a task is ready to execute after the predecessor tasks conclude. For instance, task T2 executes after task T1, whereas task T3 executes after T2 and after T14.
2. Generate the Direct Dependency Table.
   Unlike other approaches, we do not require additional pre-defined information: we use uniquely BPMN process definitions to determine activity locations as well as control and data dependencies to generate transitive activity dependency tables. Firstly, from the intermediate graph model, we determine direct control-flow and data-flow dependencies between activities: each edge represent a dependency. Table 1 presents an excerpt of the direct control-flow dependency table for our running example. Each task element is both listed in the rows and in the columns, and an `x` entry indicates that the element in the column precedes the element in the line.
3. Generate the Transitive Activity Dependency Tables.
   Transitive activity dependencies result from the transitive closure of the activity dependency table that includes pairs of communication tasks, like `T6` → `SM1` or `T11` → `T7`, and constructs that we can translate to sensor code, such as time events and control flow operators (e.g., gateways). For instance, from our example, we get the following transitive activity dependencies:
   - `T2` → `SM3` → `T13` → `T14` → `T3` → `T4` → `SM4` → `T15`
   - `ST1` → `T6` → `SM1` → `T10` → `T11` → `T7` → `IF1` → `T8` → `SM2` → `T12`

Table 1. Direct dependency table

	S1	T1	T2	T3	T4	T5	SM3	T13	T14	SM4	T15
S1											
T1	x										
T2		x									
T3			x						x		
T4				x							
...											
	ST1	T6	T7	IF1	T8	T9	SM1	T10	T11	SM2	T12
ST1											
T6	x										
T7		x							x		
IF1			x								
T8				x							
...											

4. Redefine pools
   We redefine process pools by moving activities to sensor pools. Starting from the transitive activity dependencies computed in the previous step, we eliminate communication tasks by relocating each task closure on the sensor pool and insert communication tasks to maintain the control flow semantics of the original process. For instance, the *start timer 1* event that precedes task `T6` can be moved to the WSN pool, since sensor devices are able to timely trigger tasks. This step eliminates the need for the communication `T6` → `SM1`. Alarm trigger can also be handled at WSN level, so gateway *IF1* can be relocated at the WSN pool, allowing us to remove the *send Alarm* communication (and related tasks). Nevertheless, task *T9* can only execute after sensing the temperature (task *T10*) and emitting an alarm (task *T12*), so a communication still need to occur from the WSN to the transportation process pool in order to retain the original control flow semantics. The result of this step is illustrated in Fig. 3. Notice the new tasks for enforcing the original control flow.

As sensors exhibit computational restrictions, we determine if they have enough computational capacity to execute the sub-process assigned to it through the BPMN to Callas code transformation: in this first approach, we consider that if we can generate the Callas code for a sub-process, we can distribute it. At the end, if sensors cannot execute the Callas code, the MuFFIN middleware is able to execute it in their behalf.

Listing 4 presents the Callas code for the WSN pool. Due to space constrains we omit the details of the Callas language, but the interested reader can refer to [10] for details.

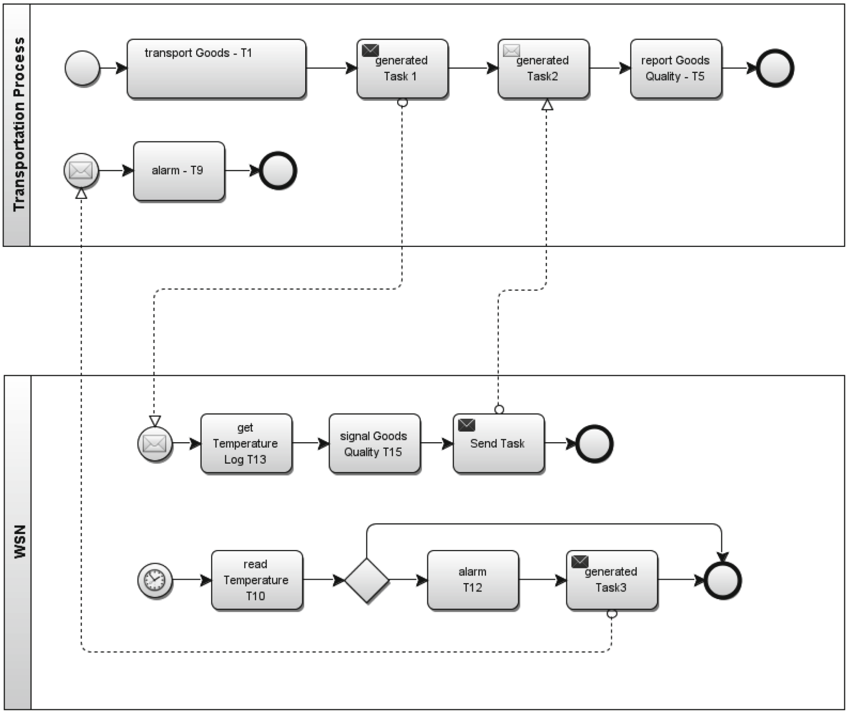


Fig. 3. Final result of the decomposition

4 Prototype

The prototype of the work we present in this paper uses the BPMN to Callas translator and the MuFFin middleware [13].

The Callas sensor programming language takes, as a pattern, the path followed by the Java programming language and its virtual machine, proposing a virtual machine for sensors that abstracts hardware specificities and makes executable code portable among WSNs from different manufacturers. Callas also supports remote sensors (re)programming.

The Middleware Framework For the Internet of Things (MuFFIN) includes several bundles, such as the *Things-Gateway* that connects MuFFIN to WSNs, the web service interface that provides sensors and MuFFIN functionalities to applications, and the MuFFIN-CVM that can run code on behalf of WSNs.

Within this framework, business modellers can put together the complete process definition using the graphical BPMN language, including the parts to be executed by sensor networks, modelled via different pools.

The BPMN to Callas translator takes as input a BPMN process part defined within sensor pools identified by the modeller, and generates the Callas code that sensor devices execute.

```
defmodule Nil:
  pass
defmodule WSN:
  Nil tempLogProcess()
# declare module WSN, install it, and call monitorTempProcess() periodically
module wsn of WSN:
  def monitorTempProcess(self):
    curTemp = extern readTemperature()
    log (curTemp)
    if curTemp>THRESHOLD:
       extern alarm()
       send triggerTaskT9()
  def tempLogProcess(self):
    tempLog = extern getTemperatureLog()
    extern signalGoodsQuality()
    send generatedTask2(log)

mem = load newMem          # load the sensor memory
newMem = mem || wsn        # update mem module
store newMem               # replace the sensor memory
# invoke monitorTempProcess() every two minutes
monitorTempProcess () every 60  2
```

Fig. 4. A Callas implementation of WSN pool.

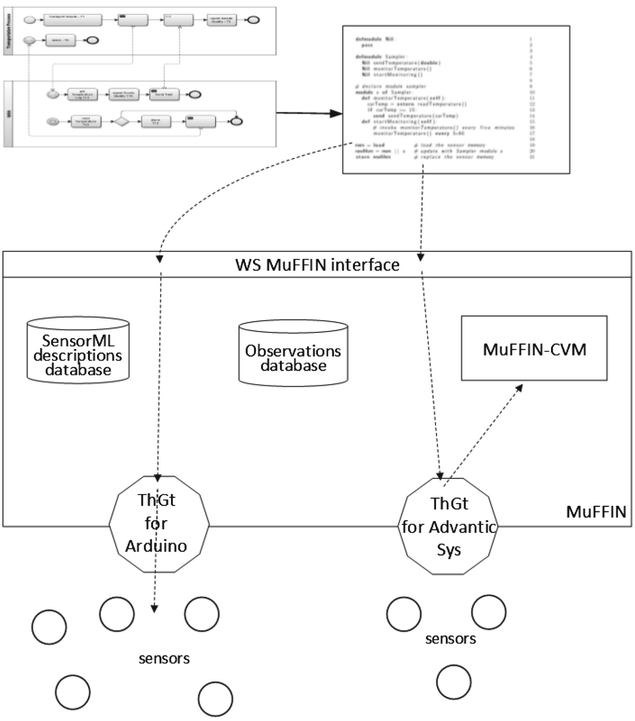


Fig. 5. Prototype framework

We distribute the business process parts targeted at WSN through the MuFFIN middleware, which provides a web service that receives bytecode and sends it to sensors, when sensors can execute the Callas Virtual Machine. Otherwise, MuFFIN executes the Callas code on behalf of WSNs. These steps are illustrated in Fig. 5.

BPMN also specifies the interactions between participants. When these interactions include the central process execution engine, they are performed with web services, which the MuFFIN middleware also provides. If both participants are sensors or sensor networks, MuFFIN supports the communication between them. With this functionality, sensor networks can communicate with each other, without needing the coordination of a central process execution engine.

5 Conclusion and Future Work

In this paper we present an approach to decentralise BPMN business processes that make use of the Internet of Things. The increase in computing power and communication of WSN devices opens the possibility of decentralising parts of business processes, shifting the execution (of processes) from central servers to WSNs. This displacement reduces the number of messages exchanged with central execution servers.

Our approach consists in analysing the BPMN model and generating WSN code (notably in the Callas programming language). This code is then deployed in different WSNs via a middleware that abstracts WSN idiosyncrasies (notably MuFFIN). In case the WSN does not support the Callas virtual machine, the middleware can run the code on behalf of the WSN.

Currently, we are in the process of testing the overall solution, in particular, the automation of the deployment process and the interaction between WSN and BPMN central execution servers. As for future work, we plan to use heuristics to optimize WSN communications and computational capability usage.

Acknowledgments. This project is supported by the portuguese Foundation for Science and Technology (FCT) through the Macaw project (PTDC/EIA-EIA/115730/2009) and the LaSIGE Strategic Project, ref. PEst-OE/EEI/UI0408/2014.

References

1. Caracas, A.: From business process models to pervasive applications: Synchronization and optimization. In: Proceedings of PERCOM 2012, pp. 320–325. IEEE (2012)
2. Caracas, A., Bernauer, A.: Compiling business process models for sensor networks. In: Proceedings of DCOSS 2011, pp. 1–8, June 2011
3. Casati, N., Daniel, F., Dantchev, G., Eriksson, J., Finne, N., Karnouskos, S., Montero, P.M., Mottola, L., Oppermann, F.J., Picco, G.P., Quartulli, A., Römer, K., Spiess, P., Tranquillini, S.: Towards business processes orchestrating the physical enterprise with wireless sensor networks. In: Proceedings of ICSE 2012 (2012)

4. Coelho, J.S., Ravesteyn, P., Machado, D., Morley-Pegge, H.: Results of the BPM Observatory of Portugal, Netherlands and France (2013). http://www.ipbpm.pt/pt/observatorio_bpm
5. Duipmans, E., Pires, L., da Silva Santos, L.: Towards a BPM cloud architecture with data and activity distribution. In: Proceedings of EDOCW 2012, pp. 165–171. IEEE (2012)
6. Fdhila, W., Dumas, M., Godart, C., García-Bañuelos. Heuristics for composite web service decentralization. Softw. Syst. Model., 1–21 (2012)
7. Fdhila, W., Yildiz, U., Godart, C.: A flexible approach for automatic process decentralization using dependency tables. In: Proceedings of ICWS 2009, pp. 847–855. IEEE (2009)
8. Haller, S., Karnouskos, S., Schroth, C.: The internet of things in an enterprise context. In: Domingue, J., Fensel, D., Traverso, P. (eds.) FIS 2008. LNCS, vol. 5468, pp. 14–28. Springer, Heidelberg (2009)
9. Jedermann, R., Lang, W.: The benefits of embedded intelligence – tasks and applications for ubiquitous computing in logistics. In: Floerkemeier, C., Langheinrich, M., Fleisch, E., Mattern, F., Sarma, S.E. (eds.) IOT 2008. LNCS, vol. 4952, pp. 105–122. Springer, Heidelberg (2008)
10. Martins, F., Lopes, L., Barros, J., Silva, M.S.: A calculus for programming wireless sensor networks. In: Proceedings of SENSORCOMM 2007. IEEE (2007)
11. Nanda, M., Chandra, S., Sarkar, V.: Decentralizing execution of composite web services. ACM Sigplan Not. **39**(10), 170–187 (2004)
12. OMG. Business Process Model and Notation (BPMN), Version 2.0. Technical report, Object Management Group (2011)
13. Pires, R., Martins, F., Domingos, D.: Homogeneous wireless sensor network programming using muffin. In: Proceedings of Sensornets 2014 (2014)
14. Sadiq, W., Sadiq, S., Schulz, K.: Model driven distribution of collaborative business processes. In: Proceedings of the 2006 IEEE International Conference on Services Computing, pp. 281–284. IEEE (2006)
15. Tranquillini, S., et al.: Process-based design and integration of wireless sensor network applications. In: Barros, A., Gal, A., Kindler, E. (eds.) BPM 2012. LNCS, vol. 7481, pp. 134–149. Springer, Heidelberg (2012)

Author Index