Smart Sensors, Measurement and Instrumentation

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Pervasive and Mobile Sensing and Computing for Healthcare

Technological and Social Issues

Springer

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Guest Editorial

The need for a new healthcare system based on health monitoring in anyplace and anytime is growing due to the paradigm shift from health supervision to health preservation, the increasing number of the elderly and associated healthcare costs and rapid advancements in information technology. The creation of novel smart environments, context-aware assistive devices, and activity monitoring systems provide great opportunities to improve quality of life, to increase independence in daily living, and to support a wide range of applications and services including mobile telemedicine, patient monitoring, location-based medical services, emergency response and management, personalized monitoring, social support and pervasive access to healthcare information. Pervasive health technology has been identified as a strong asset for achieving the vision of user-centered and preventive overall lifestyle health management. The pervasive healthcare system focus towards achieving two specific goals: the availability of eHealth applications and medical information anywhere and anytime and the invisibility of computing. Furthermore, pervasive health system encompasses new types of sensing and communication of health information as well as new type of interactions among health providers and people, among patients, among patients and researchers and patients and corporations. One central, often unspoken question is whether pervasive health technology is viewed as one more in the long list of technologies that modern medicine has effectively accommodated over the years without great disruption or whether it is something fundamentally different, a potentially transformative force that ultimately will bring about a radical redesign of the processes by which care is delivered. Therefore, an important action towards pushing forward the knowledge on pervasive health monitoring and pervasive healthcare is promoting the systematic exchange of ideas in a coordinated way. This book aims at promoting the discussion on current trends in technologies and concepts that help integrate health monitoring and healthcare more seamlessly to our everyday lives, regardless of space and time, but also present cutting edge perspectives and visions to highlight future development.

After a peer-review processes we have selected 15 work presentations that cover various technological and social aspects of pervasive health and mobile monitoring. The book presents not only the state of the art technologies and solutions to tackle the critical challenges faced by the building and development of the pervasive health system but also potential impact on society at social, medical and technological level. In first chapter is presented a brief literature review on healthcare challenges, unobtrusive sensors that may be used as part of pervasive sensing system for cardiorespiratory functions, daily motor activity and environmental monitoring, mHealth applications and pervasive computing for pervasive health monitoring. Various technology for unobtrusive, remotely sensing of motor activity and physiological signs, emotion and wellness recognition are described in chapter 1-9: 1) examples of hardware and software for unobtrusive cardiorespiratory functions and motor activity sensing as well as smartphones and tablet computers applications for health and environment monitoring designed and implemented in Portugal; 2) technology assisted smart home to care elderly people based on low-cost sensors and wireless technology developed in New Zeeland - the system can recognise the emotion as well as determine the wellness of the elderly; 3) the SensFloor System realized and commercialized by Future-Shape GmbH, Hoehenkirchen-Siegertsbrunn, Germany that may be used for a variety of different applications in the domain of Ambient Assisted Living , like fall detection, activity monitoring, energy savings, control of automatic doors, intrusion alarm and access control; 4) SmartShoe for physical activity monitoring developed in USA; 5) the photoacoustic sensor for continuous non-invasive monitoring of blood glucose level implemented in Japan; 6) body sensor networks designed and implemented in Spain that use sensors based on bioelectrical impedance spectroscopy (BIS), and CMOS technology for physiological parameters monitoring; 6) architecture of wireless device for ECG, EEG, EOG, EGG monitoring are described by team from Poland; 7) wireless system for recognizing physiological state and behaviour in daily life developed in Japan; 8) system for automatic sensing of speech activity and correlation with mood changes designed and implemented in Italy. In Chapter 10 and 11 is described the potential of Positive Technology and social media to promote individual and social well-being. Through Interreality (which uses biosensors, activity sensors and mobile devices) tracking of the individuals' general and psychological status over time in several settings may be possible. The information collected during the assessment phase may be constantly used to monitor individuals' progress and to precisely calibrate their treatment sessions thanks to a decision support system. It is suggested in these chapters that Interreality and social media may transform health guidelines and provision in meaningful and engaging experiences. Standards for eHealth architectures and communication, challenges related with interoperability, security, privacy and trust issues, the progress in terminology and classification systems adoption and the ways to overcome the security threats are described are presented in chapter 12. The work presented in chapter 13 and 14 highlighted the necessity to focus our researches also on potential harmful effect and defects of these new technologies. Methods and technology to quantify the induced current/field and specific absorption rate associated with electromagnetic environment and defects in health information technology are presented in these chapters. The knowledge on electromagnetic environment for better characterisation of his influence on biological function and health is important for future of our society when wireless networks and smartphones will become ubiquitous. A stepwise approach for modeling dependability of IT services is presented in chapter 15 taking into account legacy system's dependability, the additional safety functions and the safety operation functions. It is an original and very important model for understanding and manage defects in IT services that influence social and economic activities. The model is encouraging for future approaches to prevent occurrence of faults and the spread of negative effects caused by faults in IT services for healthcare and for future health information technology development tools. Finally, a survey of literature on requirements and barriers for health information technology adoption is presented in chapter 15. It is suggested that the requirements for adoption of pervasive healthcare system should be analyzed from a sociotechnical perspective, that combines the social aspects of system development and technical solutions which address how the new technologies for pervasive healthcare may enhance the delivery of care.

This book is written for researchers and graduate students that work in the field of healthcare technologies and sociology, university professors and also for industry professionals involved in pervasive health monitoring, intelligent emergency management system, pervasive healthcare data access and mobile health monitoring and telemedicine.

We would like to express our appreciation to our distinguished authors of the chapters whose expertise and professionalism has certainly contributed significantly to this book.

We do sincerely hope that the readers will find this book interesting and useful in their research as well as in practical engineering work in the area of biomedical sensors network, pervasive sensing and pervasive computing, mHealth, eHealth.

We are very happy to be able to offer the readers such a diverse issues, both in terms of its topical coverage and geographic representation. We hope that this book can shed light on various technological aspects related with Pervasive Health and stimulate further research in this field.

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Contents

Pervasive Sensing and M-Health: Vital Signs and Daily Activity Monitoring

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Abstract. Recent advances in pervasive sensing, mobile, and pervasive computing technologies have led to deployment of new smart sensors and smart sensor networks architectures that can be worn or integrated within the living environment without affecting a person's daily activities. These sensors promise to change vital signs and motor activity monitoring from snapshot mode to continuous monitoring mode, enabling clinicians, therapists but also accompanying persons of elderly or people with chronic diseases or disabilities to provide healthcare services based on remote continuous monitoring of the patient, pervasive health monitoring or pervasive healthcare. Using computer resources expressed by networks of servers, storage applications and Web services health monitoring and healthcare might be rapidly provisioned and released with minimal management effort or service provider interaction by using computational intelligence and Semantic Web.

A brief literature review on healthcare challenges, the deployment of unobtrusive sensors that may be used as part of pervasive sensing systems for vital signs and daily motor activity monitoring, mobile health applications and pervasive computing for pervasive health monitoring and pervasive healthcare are presented in this chapter. The chapter encompasses examples of unobtrusive sensors for health and motor activity monitoring as well as Android OS and iPhone mobile applications from Apps Store for vital and sensory function test, emergency, stress management, brain activity management, nutrition, and physical exercises. Mobile healthcare architectures developed with the contribution of the authors for vital signs and motor activity remote monitoring as well as for indoor air quality monitoring and alert on respiratory distress, which includes wearable devices (wrist worn device) and sensors integrated in objects such as walker and wheelchair are also presented in this chapter.

The presented pervasive sensing and pervasive computing approaches for health monitoring and care underscore the capabilities of this kind of systems to assure more closely coordinated forms of health and social care provision as well as personalized healthcare for better quality of life.

Keywords: pervasive sensing, mHealth, cardiorespiratory assessment, motor activity, pervasive computing.

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1 Introduction

The combination of reducing birth rate with increasing life expectancy has raised the need to urgently address aging population pressure on healthcare systems. This healthcare "time bomb" has accelerated the growth in pervasive distributed healthcare technologies that should reduce health interventions costs and improve quality of care for elderly. Strong evidences exist now showing that declining the disability among the elderly for the past several decades [1] was mainly related with improved medical technology and behavioural changes. As is known, disability is closely tied to medical spending, so that reductions in disability can lead to an offset in public and private medical costs. For instance, the United State of America spends $250 billion annually, or 2.5 per cent of the gross domestic product (GDP), on medical care for the elderly [1]. Furthermore, the new health information technology (HIT) for elderly enables a paradigm shift from the established centralized healthcare model to a pervasive, user-centred and preventive overall health management.

Across the developed world, we are witnessing the healthcare environment changing towards integrated and shared care, in which besides the responsibility of health professionals and other caregivers, each individual has the responsibility in managing the issues related with their health. This vision of the future healthcare system may be mainly achieved by deployment of pervasive health monitoring and pervasive healthcare technologies that may allow more closely coordinated forms of health and social care provision as well as personalized medicine. Pervasive healthcare (PH) is an emerging field with considerable technological breadth that is expected to have a strong impact for the quality and efficiency of healthcare. This field is still a nascent one, with a good deal of exploratory research [2]. Pervasive healthcare may be defined from two perspectives: i) as the application of pervasive computing technologies for health care, and ii) as making health care available everywhere, anytime and to anyone [3]. The pervasive healthcare applications include pervasive health monitoring, intelligent emergency management system, pervasive healthcare data access, and ubiquitous mobile telemedicine. Pervasive health monitoring and pervasive healthcare combine various type of health information technologies as: mobile health (see section 4. mHealth), personal health records (PHRs), patient centered medical home (PCMH), e-Patient (health consumer who uses the Internet to gather information about a medical condition of particular interest to him, and who uses electronic communication tools - including Web 2.0 tools - in coping with medical conditions, see http://en.wikipedia.org/wiki/E-patient), eHealth Collaborative (community wide health information exchanges, e.g. www.maehc.org). For large adoption of these technologies, researches and pilot deployment should emphasize the added value to health and social care, the cost-effectiveness of implementation, the security and the privacy of patient health data storage and communication, as well as 'clinical proof-of-concept'.

Sensor-enhanced health information systems may provide subject-centered services in a semantically interoperable environment (see section 5. Pervasive Computing). Smart sensors technology has been identified as a strong asset for achieving the vision of pervasive healthcare. Using unobtrusive smart sensors based on inexpensive, unobtrusive low-power sensors and embedded processors with large-scale storage and reasoning for semantic data as well as communication network combined with cloud computing, the pervasive healthcare may improve overall quality of life, increase independence, prevent emergencies, and motivate healthy behaviour and disease prevention.

We present in this chapter a brief literature review on healthcare challenges, the deployment of unobtrusive sensors that may be used as part of pervasive sensing systems for cardiorespiratory and daily motor activity monitoring, mHealth applications and pervasive computing for pervasive health monitoring.

2 Healthcare Challenges

Demographic developments, social changes, increasing cost of healthcare services (the cost of healthcare services has reaching values between 10% to 15% of the Gross National Product in USA or EU [4,5]), and an exponential increase in the elderly population in developed countries [6] have created major challenges for society, policy makers, healthcare providers, hospitals, insurance companies, etc. According to Population Division, DESA, United Nations report [7], the life expectancy in the 21st Century will increase, by important increasing of the 60 or over age group. The report underscores the increasing in developed regions of the 60 or over age group from 21.4% in 2009 to 27.4% in 2025, and referring to the whole world population from 8.5% to 12.5%. This tendency means also the increasing of healthcare demands, which can be solved by increasing the home-telecare services using pervasive sensing and pervasive computing technologies. Moreover, despite the growing complexity in healthcare, there is limited online support at the bedside to help healthcare professionals deliver the best standard of care for each patient. In addition, while controlled clinical trials remain the staple of progress in biomedical science, the additional wealth of information that might be reaped from millions of encounters in day-to-day medical practice remains untapped [8]. This need for effective individualized health monitoring and delivery has resulted in the new concepts - ‘personalized healthcare’ and ‘personalized medicine’. Personalized medicine is a medical model that proposes the customization of healthcare, with all decisions and practices being tailored to the individual patient by use of genetic or other information. Michael O. Leavitt defined Personalized Healthcare [8] as a model that may: predict our individual susceptibility to disease, based on genetic and other factors; provide more useful and Personalized tools for preventing disease, based on that knowledge of individual susceptibility; detect the onset of disease at the earliest moments, based on newly discovered chemical markers that arise from changes at the molecular level; pre-empt the progression of disease, as a result of early detection; and target medicines and dosages more precisely and safely to each patient, on the basis of genetic and other personal factors in individual response to drugs. A more holistic definition for personalized healthcare was proposed at ISPOR International Meeting in 2011 [9] where it was stated that it should extend beyond genetic profiles and incorporate what is known about each patient/person in order to know which interventions are most effective for which patients under what conditions. Personalize healthcare should also incorporate personal needs, preferences, healthcare access, and adherence attribute [9]. Personalized healthcare is envisioned as a system in which doctors, pharmacists, and other healthcare providers customize treatment and management plans for individuals. It will be founded upon vast amounts of information that will be readily accessible at clinics and hospital bedsides. The driver are the many applications of information technology that have blossomed during the biomedical revolution. For example, tools related to electronic health record may allow easy dissemination and flow of data about medical history, genetic variability, and even patient preferences. Patients will ultimately receive this information, specifically as it applies to them [8]. Personalized healthcare could help address difficulties associated with the public health promotion and care delivery by using broader and deeper patient information and applying more complete clinical knowledge to help promote patient-centered health and predict, prevent, aid in early detection of diseases, treat and manage diseases. Through scientific progress, personalized healthcare has great potential to improve quality and reduce overall costs of health promotion and care delivery [10].

Environmental conditions, mainly the indoor air quality, are key factors in wellbeing of the persons that stay for long periods inside buildings. Moreover, changes in climatic conditions and increases in weather variability affect human wellbeing, safety, health and survival in many ways [11]. Although some vector-borne diseases will expand their range and seasonality, and death tolls will increase because of heat waves, also the indirect effects of climate change on basic human needs such as food, water and shelter will be likely to have a big effect on global health [12]. The health of millions of people will be compromised through an increase in the frequency of intense hurricanes, cyclones, and storm surges causing flooding and direct injury, increasing the health risk among those living in urban slums and where shelter and human settlements are poor [13]. With this will come unemployment, homelessness, dislocation, migration, and conflicts. All of these may substantially increase levels of stress, anxiety and depression, impairing mental as well as physical health [14]. Although the World Health Organization (WHO) has identified climate change as an issue to be addressed, funding for rigorous vulnerability assessments that focus on the health effects of climate change remains minimal [14]. Environmental factors are a priority now in the research of complex non-communicable diseases (such as asthma, heart disease, cancer, diabetes and obesity), with the purpose of assessing the impact of the environment on human diseases, in what constitutes the environmental exposure science, today [15].

The importance to fuse the information regarding vital signs, daily motor activity and environment conditions is mainly related to the fact that daily variations in ambient air pollution have been consistently associated with variations in daily mortality, and cardiopulmonary and cardiovascular morbidity [16,17]. This scenario was also stimulated by the realization that Genome Wide Association studies (GWAS) failed to explain most of the variability and heritability in human diseases [18]. Due to this fact, a new concept emerged, the notion of the Exposome [19]. In the Exposome, we ideally have a characterization of the entire lifetime exposure history in a person's life, including lifestyle factors and social habits, external sources of pollution, diet and internal sources (such as inflammation, infection and microbiome – defined by the totality of microbes, their genetic elements and environmental interactions in a particular environment). Therefore, remote-sensing, personalized health monitoring, geographical information systems (GIS), and spatial analysis may be used as tools for standardized programs surveillance and implementation [20,21]. This is important, taking into account that understanding which group of population and where at-risk population is becomes fundamental for implementing any control program and appropriate geographical targeting of resources and cost-effective control.

Although the major area of public concern and government policy, in terms of the impact of air pollution on human health, continues to be the outdoor air, in the last two decades indoor air quality has caused increasing concern due to the adverse effects that it may have on human health. The term "indoors" is used in relative literature to refer to a variety of environments, including homes, workplaces, and buildings used as offices or for recreational purposes. Indoor air quality pollution represents one of the factors associated with the etiology of respiratory distress, the second most common symptom of adults that request emergency transportation to the hospital, associated with a relatively high overall mortality before hospital discharge [22,23].

Summarizing, the achievement of personalized healthcare rests on a dual foundation: the growing base of knowledge on public health and the adoption of interoperable health information technologies. To this foundation must be added the development of clinically useful products [8]. Based on sensors miniaturization, embedded signal processing, and networking technology combined with active research in smart materials and nanotechnology, the implemented systems may provide long-term monitoring of health status and healthier lifestyle. In order to achieve that goal, appropriate infrastructures might be necessary to support innovation and adoption of safe and effective diagnostic and therapeutic and procedures.

3 Is Pervasive Health Monitoring Possible?

Various studies emphasize the need for a new healthcare model [24,25,26], that uses unobtrusive smart systems for vital signs and physical activity monitoring [27,28,29,30] in many applications of mHealth technologies [31] for pervasive health monitoring and pervasive healthcare. These technologies may reduce the long-term monitoring cost of healthcare services and improve quality of life. The design, implementation and testing of smart objects for physiological parameters and motor activity measurement channels, as part of pervasive sensing and computing systems for healthcare interventions represent an important challenge considering the particular interaction between the assisted person and the objects, but also the personalized response provided by the systems for different users (assisted person, observer, caregiver).

Several systems for physiological parameters sensing in unobtrusive way are referred in the literature. For instance, various wearable solutions for vital signs monitoring have been described and commercialized in the last years. Some examples are: SmartLife (UK, 2003); ECG shirt GEOView and FALKE KG (Germany, 2004); VTAM (France, 2004); WEALTHY (FP6 EU project); ECG Shirt (Finland, 2006); Sensatex (USA, 2007); MyHeart (FP6 EU project); Philips ECG body vest (2009); SMART VEST (India, 2008), Proetex (FP5 EU project, 2008); VitalJacket, Biodevices (Portugal, 2009); Smartex ECG (Italy, 2009); ECG, EMG, breathing rate and muscular activity (Swedish hi-tech clothing, 2009). The smart T-shirt [32] for electrocardiogram (ECG) and electromiogram (EMG) monitoring use textile electrodes located on the chest for ECG recording, and additional dry electrodes (Roessingh Research and Development) for EMG acquisition. However, wearable systems based on e-textile, characterized by high degree of mobility, continue to have some drawbacks such as the discomfort, which can cause when these are daily used. Moreover, washing to clean the used T-shirt can change the characteristics of the conductive textile fibre, and in this case, the conditioning system associated to the dry electrodes will require adjustments or even major changes.

In the last decade, the deployment of technology for unobtrusive sensing of vital signs and daily activities monitoring is focused on networks of sensors embedded in furniture, appliances, floor, etc. For instance, a non-contact ECG measurement system for cardiac activity monitoring using capacitive coupled electrocardiogram device embedded in the bed was presented [33,34]. Junnila et al [35] developed a ballistocardiographic (BCG) chair that uses an EMFi-film sensor [36] to measure the health status in unobtrusive way. The authors also developed an EMFI based vital signs monitoring system, embedded in an office chair, including advanced processing of cardiac information using wavelets transform [37]. The EMFi sensor was also used for smart wheelchair implementations. Our team have developed a set of smart wheelchair prototypes characterized by various unobtrusive sensors that provide vital signs and motor activity accurate information and also different methods for artefact removal techniques [38,39]. Unobtrusive solutions for simultaneous measurement and transmission to a remote medical server of bio-signals (ECG, BCG) and kinetic signals (acceleration) were also presented [40,41]. The video camera of the smartphone was used to extract information on cardiac activity through the ability to record and analyse the varying color signals of a fingertip placed in contact with its optical sensor [42]. This type of imaging can be described as reflection photoplethysmographic (PPG) imaging and used to extract heart rate (HR), respiration rate, and oxygen saturation based on the dynamics of a pulse oximetry signal [42]. This solution for short-time assessment of cardiac and respiration function is non-invasive and requires special attention concerning the measurement procedure. However, the level of accuracy and reproducibility of this method may be low for long term measurement. Other implemented sensor for unobtrusive measurement of the vital signs is based on microwave radar. Important development of this kind of system was presented by the Lubecke groups [43,44]. For instance, the Doppler radar sensor is used to monitor both the heart rate and the respiration. An interesting application of the microwave radar was reported by Matsui et al [45]. They propose a system for non-contact measurement of heart rate that prevents secondary exposure of medical personnel to toxic materials under biochemical hazard conditions using a 1215 MHz microwave radar, a high-pass filter, and a personal computer.

Other option being explored is the integration of the sensor for unobtrusive sensing into non-clothing items that patients already wear. A ring sensor developed at the Massachusetts Institute of Technology (MIT), for example, might act as an ambulatory telemetric continuous health monitoring device [46]. This wearable biosensor uses photoplethysmographic techniques to acquire data on the patient's heart rate and oxygen saturation. This ring sensor contains an optical sensor unit, an RF transmitter and a battery connected to a microcomputer in the ring itself. This ensures onsite data acquisition, filtering, low-level signal processing, and bidirectional RF communication with a cellular phone that can access a website for data acquisition and clinical diagnosis. Shoes that measure plantar pressure between the foot and shoe during dynamic movement in real-time, which can be used in clinical gait analysis and user's behaviour monitoring were also proposed [47,48]. Moreover, the Wyss Institute at Harvard University has been developing shoes that can sense and ward off an acute medical crisis. The gentle vibrations delivered by the insoles in these shoes have been shown to improve gait and reduce the risk of falls among elderly users. Users could realize numerous benefits including: improved efficiency for performance athletes with less variability in gait and stride length, improved tactile sensation for diabetics to reduce the risk of ulcerations which often lead to amputations, and a clinically proven improvement in balance for both healthy wearers and the elderly who are at a much higher risk of falls [49].

The motor activity sensing and the user identification and localization tracking for healthcare are important requirements for pervasive sensing. In Ambient Assisted Living applications the indoor localization is done mainly using remote sensing technologies (non-mechanical contact technologies) expressed by ultrasound [50] and RF [51,52,53]. Several solutions were presented for smart floor system. RFID technology represents one of the options. Thus, a set of RFID transponders (usually LF RFID passive tags) were integrated in the floor typically in a regular grid. The RFID reader attached to daily used objects (e.g. wheelchair) reads the memory contents of the detected tag that stores the (x,y) coordinates which correspond to the objects position. These kinds of implementations were reported for robot position estimation [54]. The technique was applied by the authors particularly for wheelchair localization [55]. Indoor localization with a footwear system based on RFID and smart floor and an RFID glove for activity monitoring in house was also proposed [56]. Smart floor solutions based on load cells, steel plate sensors and data acquisition modules have been also reported [57,58,59]. However, the associated costs made this kind of solution less attractive. The use of large area proximity sensor arrays embedded in carpets to perform localization and identification tasks, as the latest technology promoted by Future-Shape GmbH [60] presents advantages such as low costs, reliability and flexibility. The use of a smartphone camera for indoor localization was also presented [61]. It combines the image recognition system with a distance estimation algorithm to gain a high-quality positioning service independent from any infrastructure. Stone and Skubic [62] evaluated the accuracy and feasibility of using the depth data obtained from the Kinect (movement sensing system from Microsoft) for passive fall risk assessment. Results showed good agreement between gait measurements computed using the Kinect, those computed using an existing Web-camera based system, and those from a Vicon motion capture system. Furthermore, the depth image from the Kinect not only addresses a major issue in foreground extraction from color imagery (changing lighting conditions), but significantly reduces the computational requirements necessary for robust foreground extraction for fall risk assessment.

Despite important advances in unobtrusive sensing, there are several challenges for pervasive health monitoring: cost reduction; small sensor size; MEMS integration; power source miniaturization and efficiency; low-power wireless transmission; context awareness; data mining; secure data transfer and integration with therapeutic system.

The authors have developing various smart sensors for unobtrusive vital signs and activity monitoring. These smart objects might be used to assist three categories of users: 1) with no or low limitation of motor activity; 2) with moderate and medium limitations of motor activity; 3) with severe limitations of motor activity. We design and implemented a smart wheelchair, a smart walker, smart crutches and a wrist-worn vital signs monitoring device. These objects are augmented with health status and motion sensing by using particular sensors (e.g. radar based ballistocardiography sensor, optical photoplethismography sensors, and accelerometers). Additional functionalities such as user identification (RFID technology, real time data processing (based on microcontroller or DSP platforms), wireless data communication (Wi-Fi, ZigBee data communication protocol) characterize these designed and implemented smart objects. The RFID technology was employed in these systems for the detection and identification of system users, which allows the computation of co-presence to be embodied within the real–world. The system architecture follows as much as possible, the requirements and the characteristics of ambient information systems (AIS) [63]. Therefore, the main goal of our implemented systems was to present the information from the smart sensing modules associated with smart objects such that minimum distraction of the users from their usual tasks may be achieved. The architecture specification is based on the detection of persons involved, mostly in their everyday life activities, with passive interactions, which can be considered as natural and “incidental”, with sensing augmented objects (e.g., wheelchair, walker) and the computational platforms (e.g. smartphone, tablet computer) (see Figure 1).

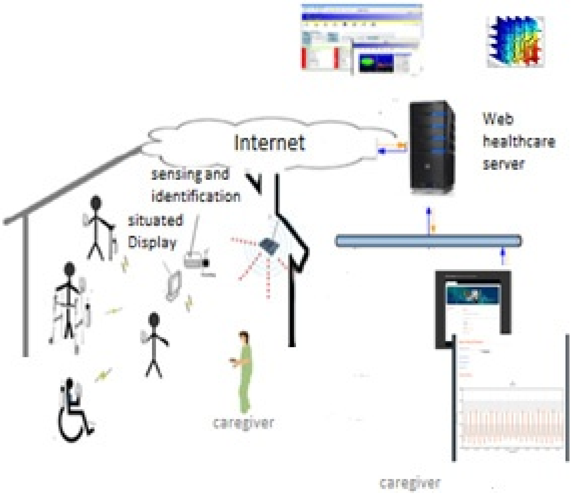


Fig. 1. Diagram of ambient intelligent based on our implemented smart objects

The notion of "incidental interactions" describes actions that are co-opted by the system to serve a purpose other than the one initially thought [64]. An incidental interaction can be seen as a situation where actions, executed for another purpose, are interpreted to improve future interactions in everyday life. In the pretended scenario of application, the basic aim was to ensure that only the detection of the user's co-presence near (or using) the smart object will activate the presentation of healthcare information on the smartphone or tablet computer.

The computing platform is used to update the acquired values on a server through database synchronization procedures between the mobile device database and the server's database. As it is presented in Figure 1, the implemented architecture may contain a public situated display for general usage and smart mobile devices, including touch screens, casually available to the users of the space, distributed closely to the smart objects (e.g., wheelchair). A RFID reader attached to the situated display is used to identify a user, or a wheelchair, and, afterwards, it requests the server personalized information. The application for the presentation of information and interaction with the user in the smart wheelchair was designed for a touch panel, while for the other smart objects, such as the walker, the walking stick or even the wrist-worn vital sign and motor activity monitor device was done using a smartphone. The situated displays are used to provide contextual information at decision points. It is presented information about the smart object identification and localization, the last verification of the smart object measurement channel, the smart object registered, statistics of the measured data during the latest measurement session (e.g. maximum heart rate, minimum heart rate, number of detected impacts between the smart object and other objects), the time of the latest utilization session. The software components are associated with two main layers: the ambient intelligence healthcare layer (AIH-L) and the user layer (U-L) (Figure 2).

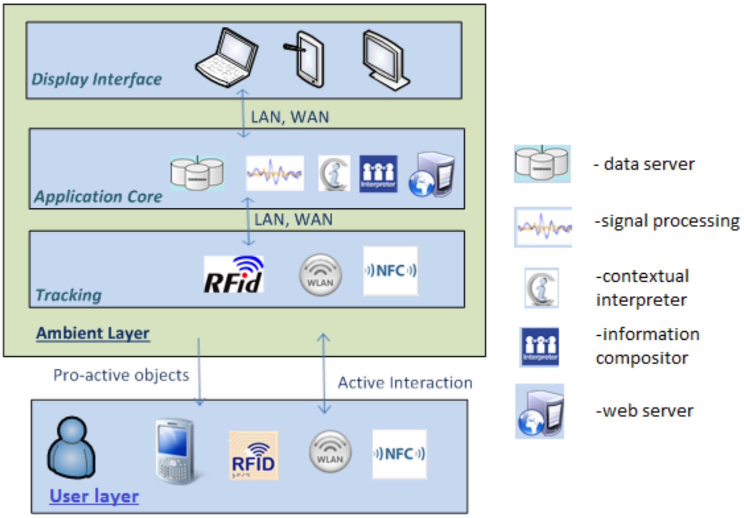


Fig. 2. Software component architecture

The AIH-L includes the software components that serve the smart objects (e.g. wheelchair, wrist-worn device) used by elderly or persons with motor disabilities, the touch panels, situated display or other pervasive computing devices such as smartphone or tablet computers. Regarding the AIH-L implementation, one of the main requirement is the pro-activity [65] in relation to the users, which means to understand the intent of the user in order to predict his/her future behaviour. Thus a tracking software component is implemented for identification and localization of the user of a smart object that delivers appropriate information (e.g. fall warning, time for medication) through the available HMI (human machine interfaces) associated to the system, in order to minimize the user's administrative overheads and assist the user to achieve his/her goals. The display interfaces are expressed by computing devices such as laptops, tablet computers or situated displays. As components associated with the user layer are mentioned the smartphone (the main interaction device), RFID tag or reader, wireless LAN and near field communication capabilities. The application core component performs analysis of the information given by the tracking component, and the data fusion with contextual information related to the object, the user profile, the processed data associated with vital signs and motor activity monitoring. According to the above-mentioned functionalities the application core includes:

- database server,
- signal processing unit,
- contextual interpreter,
- information compositor module,
- Web server.

3.1 Smart Wrist Worn Device for Vital Signs and Motor Activity Monitoring

The smart wrist-worn device that was designed to enable multi-parametric monitoring, in non-invasive and unobtrusive way, includes vital signs measurement channel (cardiac activity through photopletismography) and body-kinematics measurement channel associated with daily motor activities assessment. A set of warning digital outputs connected to LEDs signalise the low quality of the signals, battery low charge and critical values of measured parameters (e.g. values of heart rate higher than 95bpm when the user is resting). The computing of the signal in the implemented smart wrist device is made by a PIC24F microcontroller platform that is also responsible for signal acquisition, primary processing, data storage, and data communication. The signals provided by the sensors are Analogue processed before they are acquired.

3.1.1 Sensing and Signal Conditioning

The vital signs are sensed using a reflective photoplethysmography sensor based architecture. It includes two infra-red IR (940nm) - Red (660nm) LEDs and a light to voltage converter (Figure 3). A switching and current driver module was implemented using bipolar transistors to assure optimal control of two bicolour LEDs (Infrared- λ_{IR}=940nm, Red- λ_{Red}=660nm). The control signals (PULSES, N_PULSES, CTRL_RED, CTRL_IR) are provided by a microcontroller using the appropriate digital output lines and PWM output followed by low pass filter characterized by fc=0.5Hz. Alternating between “1” and “0” as values of PULSES and N_PULSES, the RED and IR LEDs paths are activated allowing the measurement of light absorption by blood during the cardiac cycle. A broadband radiation light to voltage converter (LVC) from Nelcor is included between the two LEDs delivering a photoplethysmography (PPG) voltage signal during the IR and Red light excitation. The use of two bi-colour LEDs increases the repeatability, robustness and PPG signal quality independently of the position of PPG sensor on the wrist.

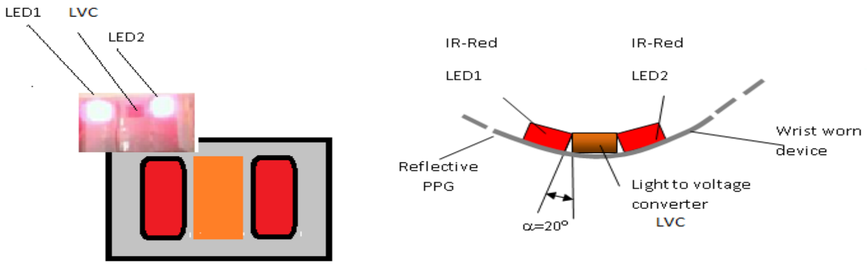


Fig. 3. Reflective photoplethismography sensor

The PPG signals from the light to voltage converter are filtered using a low pass filter (LPF) and high pass filter (HPF). LPF and HPF based on LM324 operational amplifier are used to diminish the influence of signals base-line wondering and to increase the signal to noise ratio (SNR). Some of the characteristics of the implemented filters are: LPF- 2-poles Butterworth, cut-off frequency of 20Hz; HPF- 2-poles Butterworth, cut-off frequency of 0.05 Hz. Considering the PPG dynamic range, an automatic gain control scheme (AGC) was implemented using a digital potentiometer (CAT5114 from Catalyst) and an instrumentation amplifier (INA122). Based on the implemented scheme, PPG amplitude values are in the 0.4 to 2V interval. An inertial sensor (MEMS accelerometer MMA7260) is used both to sense the daily motor activity - expressed by the activity index of the person , and for fall detection. It provides information on patient motion as Vax, Vay and Vaz voltage signals. These signals are low pass filtered and applied to analogue inputs of the microcontroller (Figure 4).

3.1.2 Microcontroller Platform

In figure 4 are presented the sensing and signal conditioning components of the microcontroller platform that were previously described. Important tasks such as signal acquisition, primary processing, LEDs user interface control, and data storage and data communication are performed by the PIC24F microcontroller based on an implemented firmware developed in MPLAB C30 compiler from Microchip. The LEDs switching and digital potentiometer control are done using a set of digital lines (RA3, RA4 for LED on/off function, RA5, RA6, RA7 digital potentiometer adjustment through the CS, UD, INC of DPOT). Regarding the light intensity control, a two channel current driver is implemented using the microcontroller RD1 and RD2 PWM outputs. The AC and DC components of the PPG signal are acquired using the AN3 and AN2 analogue input channels of the microcontroller. The acquisition rate is 200S/s and the programming recurs to TIMER2 of the microcontroller. The voltage signals delivered by the MEMS accelerometer through the Vax, Vay, Vaz outputs are acquired using the AN9, AN10 and AN11 analogue inputs and the same sampling rate that is used in the PPG acquisition case.

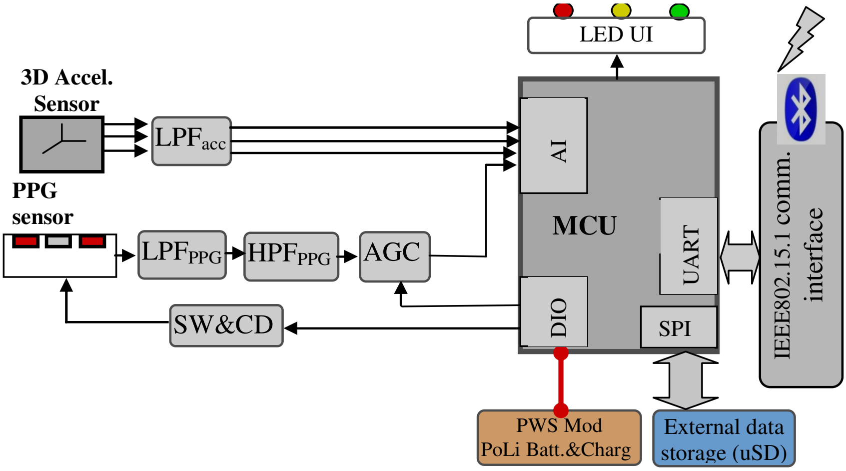


Fig. 4. Smart wrist worn - Microcontroller platform and conditioning circuits block diagram (AI – analog input, MCU-PIC24F microcontroller, SPI – serial peripheral interface, UART – universal asynchronous receive-transmit interface, DIO – digital input output port)

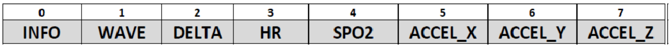
The implemented embedded primary processing software uses the PPG acquired samples to extract the HR value and blood oxygen level (SpO_2 values). An adaptive threshold peak detection algorithm was used to obtain more accurate values of HR. The main steps of the implemented algorithms are:

i) computation of the average value of 2.5s PPG acquired data, mean(V_ppg(t));
ii) calculation of the maximum value of the 2.5s PPG data, max(V_ppg(t));
iii) adaptive threshold th_a calculation:

$$th_a\Big|_{\Delta t} = \frac{1}{2}\left(mean(V\_ppg(t)) + \max(V\_ppg(t))\right) \tag{1}$$

iv) determination of peak locations that exceed the threshold level for 2.5s time interval;
v) peak localization calculation and average time interval calculation between two successive detected peaks for Δt=5s time interval;
vi) HR calculation.

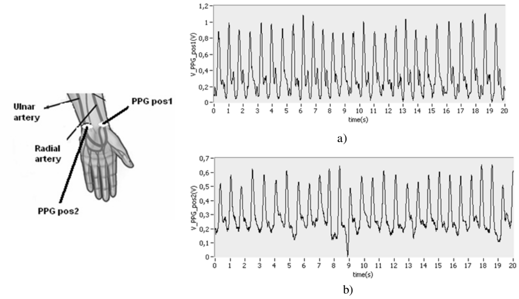
The SpO_2 calculation procedure uses the "normalized ratio", R, and a polynomial model of SpO_2=SpO_2(R) empirical characteristic. The microcontroller data, including the PPG samples (wave), the time interval between two successive PPG peaks (DELTA), the HR, the SpO_2 value, and the 3D accelerometer voltage values digital codes (ACCEL_X, ACCEL_Y and ACCEL_Z) are stored in an 8 bytes data array as shown in Figure 5.



0	1	2	3	4	5	6	7
INFO	WAVE	DELTA	HR	SPO2	ACCEL_X	ACCEL_Y	ACCEL_Z

Fig. 5. Smart wrist-worn device data array format

The INFO byte is used to store additional information regarding the smart bracelet functioning (e.g. battery low). Two data synchronization bytes (00 and FF) constitute the preamble joining the data bytes assuring the data reading robustness at the smartphone side. The formatted data is radio transmitted to the smartphone using an ARF32 Bluetooth module connected to the USART port of the PIC24F microcontroller. The update rate used in the preliminary tests was higher than 20 updates/s and lower than 200 updates/s for a programmed USART baud rate up to 19200bps. The robustness of the implemented solution was tested for different positions of the optical sensing device on the wrist. Example of signals obtained by implemented wrist-worn is presented in figure 6.



a)

b)

Fig. 6. The PPG signals for two positions of the sensing module on the wrist: a) PPG pos1 b) PPG pos2

Activities of Daily Living (ADLs) that refer to daily self-care activities within an individual's place of residence are sensed using the 3D programmable accelerometer embedded on the wrist-worn device. Thus, for a normal activity when the patient is holding an object (e.g. book) the evolution of acceleration for the X,Y,Z axis are presented in Figure 7. Based on statistics calculation additional information regarding the performed activity can be extracted. In this application the standard deviation was used. Particular information about standard deviation (SD) evolution calculated for time intervals of Δt =5s is presented in Figure 8.

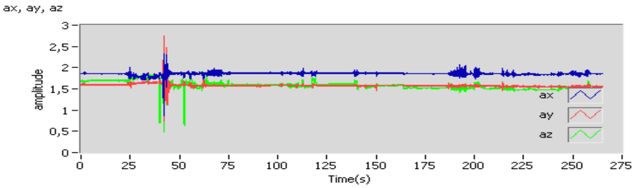


Fig. 7. The evolution of ax, ay, az acceleration during ADL

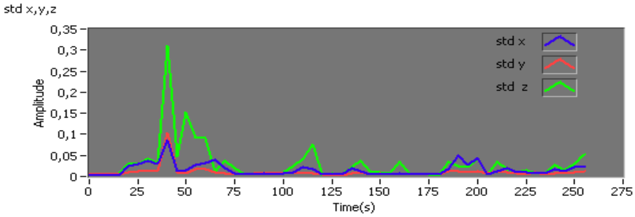


Fig. 8. The evolution of std x, std y, std z standard deviations of the measured accelerations during ADL

Imposing an activity standard deviation threshold, the activity and non-activity intervals for x, y and z axis are calculated and graphical represented in Figure 9.

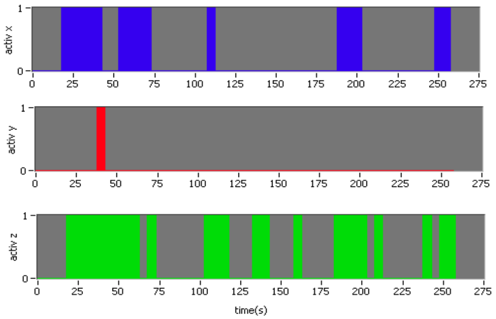


Fig. 9. Activity and non –activity associated with the x, y and z axis expressed by boolean activity indexes

Considering the whole time and the time intervals characterized by $activ_x$, $activ_y$ or $activ_z$=1 the activity index expressed in percentage is calculated. Thus, for the particular case of normal activity presented in Figure 9 the activities values are $activ_x$=28.85%, $activ_y$=1.92% and $activ_z$=46.15%.

3.2 Smart Wheelchair for Vital Signs and Daily Activity Monitoring

The necessity to obtain the information on health status and motor activity for people with severe motor disabilities has been leading to various smart wheelchairs prototypes developed by the authors' research group - important results related with hardware and software implementation being published. One of the implementation is presented in Figure 10. Various types of sensors for cardiorespiratory and motor activity assessment were used in smart wheelchair architectures implemented solutions: sensors for photoplethysmography (PPG) [66]; EMFit based ballistocardiography (BCG) [67]; capacitive coupled electrocardiography (ccECG) [68]; contact electrocardiography (ETX-ECG) and skin conductivity based on e-textile electrodes [69]. Taking into account that a way to increase the flexibility, modularity and the reliability of a system is to reduce the size and number of sensors without diminishing significantly the number of measured parameters, we developed a smart wheelchair and smart walker based on use of microwave Doppler radar sensors as non-electrical and non-mechanical contact sensors for cardiorespiratory but also for motor activity monitoring [39]. Measuring in an unobtrusive way the respiration and cardiac activity represents a challenging issue taking into account that non-invasive but obtrusive methods interfere with normal cardiorespiratory pattern at an unconscious level when a subject is aware of their vital signs monitoring [70]. There are approaches for non-invasive respiratory assessment as the use of smart spirometer with Bluetooth communication capabilities [71] or by processing the signal from plethysmography, electrocardiography (ECG) [72] or photoplethysmography [73]. The used Doppler radar is able to perform unobtrusive measurement both of respiratory rate and heart rate. The smart wheelchair includes a set of measurement channels related with two microwave Doppler radar sensors (DRS1, DRS2). The intermediary frequency signals are filtered and acquired by an acquisition and communication module (see Figure 12). The Doppler radar sensor is positioned back to the wheelchair backrest for user cardiorespiratory function assessment and wheelchair motion monitoring. Thus, DRS1 radar sensor is fixed in a plastic base mounted back to the backrest of the wheelchair (5 to 15 cm distance to the backrest) and 40 cm over the wheelchair seat (see the Figure 10) and it is oriented to capture the heart and the chest motion, while DRS2 is fixed on a plastic base parallel to one of the wheels, 30 cm apart from the wheel centre capturing the information about the wheels motion. To assure modularity and portability, various implemented smart objects (smart wheelchair, smart walker) use the same acquisition and Bluetooth communication solution expressed by a microcontroller based on ACM (Acquisition and Communication Module). After signal acquisition and data coding, the data is transmitted to a mobile pervasive computer platform that runs a mobile operating system (Android OS in our system prototype). The embedded software application performs graphical user interface functionalities but also assure the data storage in a local database.

The information related to cardio-respiratory activity and physical activity of the wheelchair user is stored in a smartphone or tablet computer database and is synchronized from time to time with the Web based healthcare information system database. Additionally, the remote database provides electronic health record information regarding the user profile (e.g. name, age, diseases, medication) and also hardware and software specifications regarding the use of the smart object (e.g. wheelchair in this case).

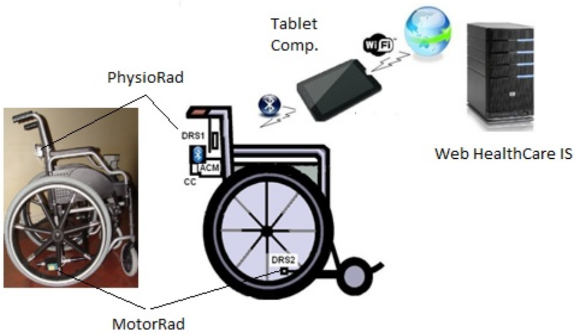


Fig. 10. System architecture based on a smart wheelchair (CC – conditioning circuit, DRS1, DRS2 - Doppler radar sensors, ACM – acquisition and communication module)

A brief description of the microwave Doppler radar of the conditioning circuit (CC), and of the acquisition and data communication module is presented in the following paragraphs.

3.2.1 Microwave Doppler Radar Sensor

A Frequency Modulated Continuous Doppler radar sensor (DRS1) was embedded in the wheelchair to perform the non-contact measurement of chest motion caused by the respiratory and cardiac activity. The requirement of small motion amplitudes detection associated with cardiac and respiration motions (cardiac amplitude motion are less than 0.15mm, respiration amplitude motion are less than 2mm), and also the necessity to minimize the size of the used Doppler radar device including the antenna for easily integration in daily used objects, make from the 24GHz FMCW Doppler Radar (IVS-162 DRS) an appropriate solution [39]. Moreover, the 24GHz microwave Doppler radar assures better resolution of low amplitude motion comparing with 2.4GHz - 10.5GHz which are mainly used for remote respiration monitoring in rescue scenarios [74]. The block diagram of the used radar is presented in Figure 11. The main components of the FMCW radar are: transmit TX and receive RX antennas; a low noise amplifier LNA connected to the RX antenna; two mixers (direct mixer M1 and quadrature M2) that are used to extract the direct or in-phase (I(t)) and quadrature (Q(t)) signals that are used to estimate the direction of the target motion (e.g. body motion).

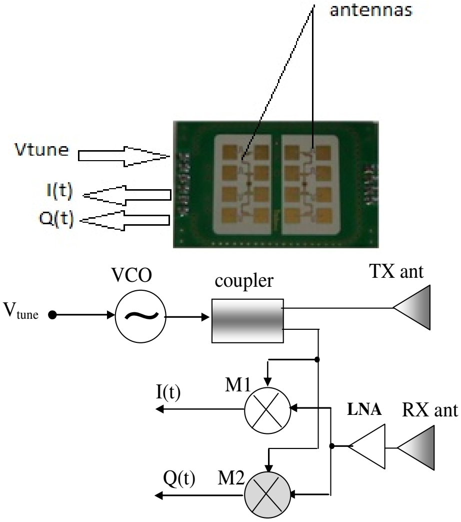


Fig. 11. FSK/FMCW Doppler radar sensor block diagram: M1, M2-mixers, TX, RX-transmit and receive antenna, VCO - voltage controlled oscillator, LNA-low noise amplifier

According to Choi et al. [75], the cardiac small motions, which correspond to blood pumping on the vessels, and the respiration motion are modulating the reflected RF signal that is acquired by the RX antenna. Thus the V_{RX} voltages associated with RX antenna is given by:

$$V_{RX}(t) = A_{VRX} \cdot \mathrm{Re}\left(e^{j2 \cdot \pi \cdot f_0 \cdot t + \Phi(t)}\right) \tag{1}$$

where A_{VRX} represents the amplitude of the reflected wave and Φ(t) represents the time varying phase caused by the periodic displacement due to breathing and cardiac activity. In this case, Φ(t) can be expressed by:

$$\Phi\,(\mathrm{t}) = 2\pi \frac{2\,d(t)}{\lambda_0} = 2\pi \frac{2}{\lambda_0}\left(n\lambda_0 + x_{resp}(t) + x_{cardio}(t)\right) \tag{2}$$

where d(t) is the distance between the radar antenna plane and the body of the user seated on the wheelchair, λ_0 is the wavelength of the Doppler radar wave - λ_0=12,5mm for 24GHz , $x_{resp}(t)$ represents the motion associated with respiratory activity, $x_{cardio}(t)$ represents the small motion associated with cardiac activity. Since the change of the respiration and cardiac motion amplitudes (less than 2mm) are small compared with wavelength, the demodulated signal, $V_{out}(t)$, depends on respiration and cardiac motion:

$$V_{out}(t) \propto \mathrm{Re}\left(e^{j\left(n4\pi + \frac{4\cdot\pi\cdot\left(x_{resp}(t)+x_{cardio}(t)\right)}{\lambda_0}\right)}\right) \tag{3}$$

where $x_{resp}(t)$, $x_{cardio}(t)$ being extracted from the V_{out} by analogue filtering. The ballistocardiography signal, $x_{cardio}(t)$, [39], is originated by small movements of the body, induced by ballistic forces (recoil and impact) associated with cardiac contraction and ejection of blood.

3.2.2 Signal Conditioning, Acquisition and Wireless Communication

The conditioning circuits associated with the radar system encompass a set of analog active filters that perform the respiration and the cardiac signal extraction. In the respiration case a 2nd order active low pass filter, Butterworth type, characterized by fc=0.3Hz cut-off frequency was designed and implemented. To extract the cardiac signal a 2nd order, band pass active filter, Butterworth type characterized by f_{c1}=0.7Hz and f_{c2}=15Hz was implemented. To adapt the signals to the acquisition module voltage input range a set of programmable gain amplifiers (PGA1 and PGA2) were also implemented. It includes INA122 instrumentation amplifier and CD4051 that perform the switching actions under the control ACM through the digital lines. In the particular case of microwave Doppler radar sensor (DRS2) system, which measures the distances travelled by the wheelchair during a specified period (hours, day, week), the I2(t) output signal provided by the radar is filtered using a 1st order high pass filter HPF2 (1st order fc=0.3Hz) and amplified by the A3 amplifier. In order to sense the motion the Q2(t) signal can be used and the phase difference between two signals, $\Delta\varphi_{I2,Q2}$ indicate the motion sense (moving in front, moving back).The block diagram of the implemented conditioning, acquisition and data communication module is presented in Figure 12. The ACM performs an analogue to digital conversion using a 16bit ADC (ADS8344) that communicates through the SPI bus with the MCU (16F673 PIC). The digital values of the acquired samples are delivered in hexadecimal form to the mobile device using Bluetooth communication. Additional processing of the signals delivered by the DRS1 microwave Doppler radar is done mainly at the mobile device level (smartphone, tablet computer) in order to extract the respiration rate, the heart rate and the activity index. The activity index is calculated based on the evolution of the V_{RX} signal amplitude and frequency variance in time, when the cardiac activity is not estimated due to large movement artefacts. The acquired I2 signals delivered by DRS2 microwave Doppler radar are also used for activity index (e.g. wheelchair motion and the related parameters such as the distance and the average velocity).

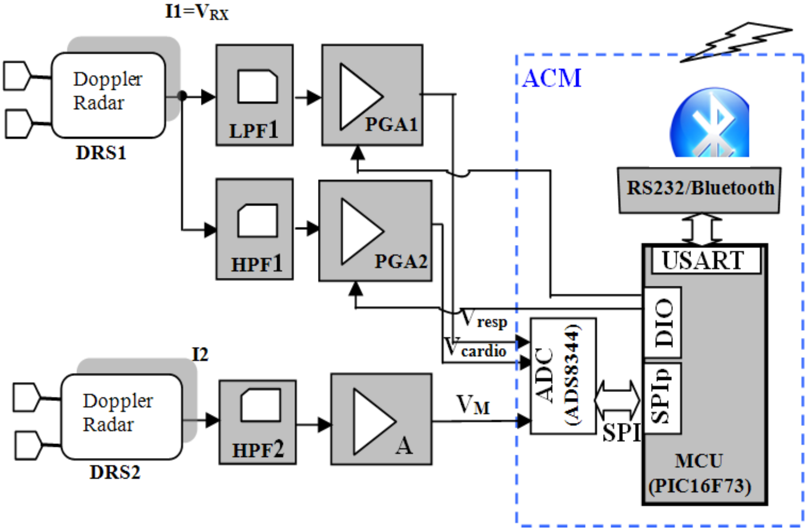


Fig. 12. Signal conditioning, acquisition block and wireless communication block diagram (HPF1, HPF2 – high pass filters, LPF1 – low pass filter, PGA1, PGA2 – programmable gain amplifier, A – instrumentation amplifier, ACM-BS- acquisition and data communication module Bluesentry Architecture)

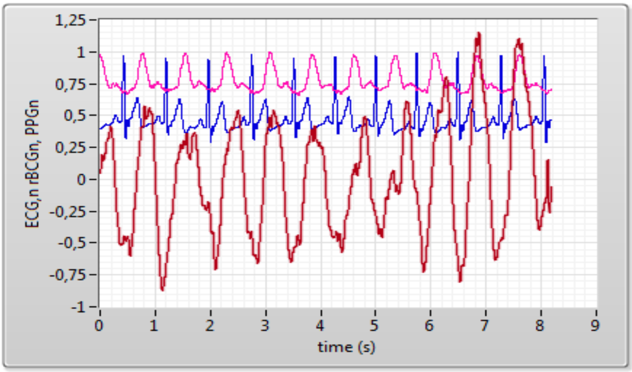


Fig. 13. Cardiac signals provided by the Doppler radar sensor module (dark-red) and standard PPG (magenta) and ECG (blue) standard cardiac activity measurement devices

A graphical representation of cardiac signals obtained using references equipment for ECG, and implemented radar based device is presented in figure 13. In the Figure may also be observed correlation of the shape and time of the peak changes in amplitude of the radar signal with PPG signal that underlines the capacity of the radar device to be used in mechanocardiography.

3.3 Smart Walker for Motor Activity Analysis

As part of the ambient intelligent for healthcare a smart walker was implemented. Based on the sensors such as microwave Doppler radar, force sensors, accelerometers the rehabilitation process is assisted in order to highlight the progress during the physiotherapy sessions by using the smart walker. Thus the gait recovery might be evaluated based on data processing of the signals acquired from the sensors that are wirelessly transmitted to a host computer or a mobile device. The sensors, the conditioning circuits and the acquisition and communication module are integrated in the walker which measures, through the radar, the kinematic of the body in unobtrusive way, without mechanical and electrical contact. The mechanical coupling between the user and the walker during the training session made possible extraction of information on applied force related with walker usage, acceleration imposed to the walker that can be associated with gait cadence and gait velocity, and also impact force. The walker velocity and the travelled distance are obtained using a radar that is positioned near one of the walker wheel. Measuring the motion of a metallic target fixed on the wheel the number of turns is measured. The distribution of the sensors and the smart prototype implementation is presented in Figure 14. The contact forces applied by the user on the walker hand supports are measured using a set of four piezoresistive sensors (Flexiforce A201-100 from Tekscan) [76], while the acceleration imposed to the walker during usage is measured by a 3D MEMS accelerometer ADXL335 from Analog Device.

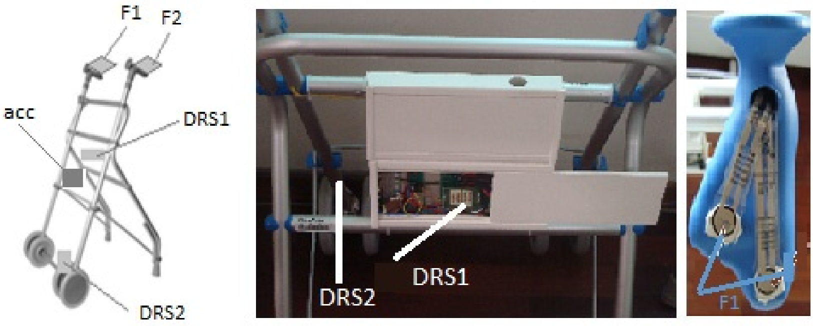


Fig. 14. Smart Walker implementation: DRS1, DRS2 – Doppler radar sensor, accelerometer sensor, F1, F2 – force sensors

The use of four force sensors - two for each hand support - is justified both by reduced active region of a disk (9.53mm), making necessary the extension of active contact region joining the surfaces from multiple piezoresistive sensors, as well as the necessity to obtain differential signal input associated with differences in hand region forces applied by the walker's user. The correlations between applied force, gait (measured by using the same type of Doppler radar sensor, already used in wheelchair prototype) and walker acceleration are captured. In the implemented architecture only the direct intermediary frequency signal was used to extract the kinematics and kinetics of legs. The forces applied on the walker hand support are different during the training gait according with the user rehabilitation stage (the force is up to an imposed threshold - Fth>150N when the user strongly grabs the walker, and is less 150N when user lightly grabs the walker). Taking into account the piezoresistive characteristics of the sensors, a conditioning circuit including a four channel non-inverter amplification scheme based on LM324 and a reference voltage was designed. The dependence between VFij (i,j ={1,2}) output voltage signal and the applied force was obtained using a calibration scheme base on a load cell (DDE 500N from Applied Measurements Limited). Taking into accountthe analogue input requirements of the analogue to digital converter, an amplification/attenuation scheme based on INA 122 was designed and implemented for the I1(t) output channel of DRS1. Taking into account the intermediary frequency signals I2(t) associated with DRS2 a Schmitt Trigger scheme was implemented and obtained pulse are acquired by one of analogue inputs of the acquisition and data communication module (ACM). Considering the uniformity of the solution the ACM architecture is the same that was used for the smart wheelchair implementation, the frequency acquisition rate being up to 200S/s and the communication rate through Bluetooth is up to 115200bits/s. A set of remote control commands are used on the mobile device or the host computer side to configure the number of channels and the sampling rate. Thus to start the acquisition, the microcontroller receives through the wireless communication (Bluetooth communication protocol) a command from the host unit. The digital values of the acquired samples from different measurement channels are delivered in hexadecimal form to the mobile device or computer that performs hexadecimal - to decimal voltage values conversion, normalization, voltage - to- force conversion, voltage - to- acceleration conversion. Referring the gait signal sensed by the Doppler radar (DRS1) a set of statistical parameters such as variance or kurtosis, are calculated as features that are used together with the values provided by force, acceleration and motion channel (DRS2) for gait type recognition that is performed at a server level. The physical activity is also estimated through the values of the travelled distance and velocity of the walker during the training session.

3.4 Pervasive Sensing of Environmental Impact Factor on Health

Smart sensors and pervasive computer technology may enable new model of healthcare delivery that can use information obtained through pervasive sensing on physiological parameters, motor activity but also information about monitored patient localization, or about environment conditions (e.g. air quality parameters).

Human exposure to indoor air pollution is difficult to quantify due to the fact that it is largely determined by micro-environmental characteristics. Pollution levels in one home may be quite different from those in another, depending on the presence and usage of sources of pollutants and on the ventilation habits. Many different methods can be used to measure the level of gaseous air pollutants by mobile or portable device. For example, gas chromatography (GC) and mass spectroscopy (MS) devices provide a high degree of data accuracy, but require some kind of sample preparation that limits its utilization in field measurement scenarios. However, most of these above mentioned techniques measure average concentrations over several hours or even days, at one sampling location, which limits their use in studies of pollutants with acute effects. As is reported in the recent approved European project SYNPHONIE www.synphonie.eu, no reference methods for indoor monitoring presently exists. In their proposal, indoor air quality will be monitored mainly using diffusive sampler, techniques routinely used for measuring ambient air pollution, but that are not suitable for large scale indoor surveys because of cost, bulk, noise or amount of air displaced. Different measurement systems has been developed recently for indoor use [22,23,77]. Laser-inducted breakdown spectroscopy (LIBS) offers real-time response and high accuracy and does not require sample preparation. Recent LIBS devices are small enough to be used as mobile units. Semiconductor sensors are not as accurate as spectroscopy-based devices but they are much smaller and easy to integrate with a data collecting unit. A distributed architecture including smart sensor network that deliver data to a Web server for air quality monitoring and advanced data processing software modules was described by authors [22]. The data from the sensors may be visualized on the smartphone display. The graphical user interface implemented in a smart phone permits the selection of relative humidity and respiration graphs Figure 15.

a) b)

Fig. 15. The graphical user interface implemented in the smart phone for chest belt sensor case a) relative humidity selected graph, b) respiration selected graph

Analysing Figure 15.a) can be observed the evolution of the relative humidity in time while Figure 15.b) presents the evolution of the respiration wave (for a moving time window of 20 s). The numerical values of the calculated respiration rate as well as the air quality condition expressed by temperature and relative humidity values are also included on the application dashboard developed based on Android SDK. Additionally, an audio alarm was implemented for critical air quality conditions and anomalous respiration behaviour (e.g. asthma attack).

4 mHEALTH

Mobile eHealth or mHealth broadly includes the use of mobile telecommunication and multimedia technologies in health care delivery. The term mHealth was coined by Professor Robert Istepanian as use of "emerging mobile communications and network technologies for healthcare" [78]. mHealth: includes the use of mobile devices for collecting and summarizing subject's health data, providing healthcare information to practitioners, researchers, and patients, real-time monitoring of patient vital signs, and direct provision of care (via mobile telemedicine) [79]. A definition used at the 2010 mHealth Summit of the Foundation for the National Institutes of Health (FNIH) was "the delivery of healthcare services via mobile communication devices" [80].

Are included in mHealth technologies the use for health services and information, of the fixed line telephone, cell phone, tablet computer, MP3 or MP4 players, microcomputers, laptop computers, PDAs as well as mobile operating system technologies. Technologies relates to the Operating Systems that orchestrate mobile device hardware while maintaining confidentiality, integrity and availability are required to build trust. This may foster greater adoption of mHealth Technologies and Services, by exploiting lower cost multipurpose mobile devices such as tablets PCs and smartphones. Operating Systems that control these emerging classes of devices include Google's Android, Apple's iPhone OS, Microsoft's Windows Mobile, Nokia Symbian OS and RIM's BlackBerry OS. Advances in capabilities such as integrating voice, video and Web 2.0 collaboration tools into mobile devices, may significantly benefits the delivery of healthcare services. Smartphones or tablet computers, as pervasive computing component, provide interesting HMI for user, accompanying person or health professionals. Application software running on smartphones, which supports different type of mobile OS (e.g. iOS, AndroidOS, Windows Phone) may provide clinical information on patient state but also may give tools to the patients to take better care of themselves. Biofeedback procedure based on data from the sensors might be processed on the mobile platform or can be sent to the Cloud [31] that might perform advanced data processing, data storage and integrate the feedback on biofeedback system. There are open issues on Cloud Computing acceptability related with his availability and security of data. It is discussed the necessity to create a 'Healthcare-specific Cloud' [81] that specifically addresses the security and availability requirements for healthcare system.

The mHealth field operates on the premise that technology integration within the health sector has the great potential to promote a better health communication to achieve healthier lifestyles, improve decision-making by health professionals (and patients), enhance healthcare quality by improving access to medical and health information, and facilitate instantaneous communication in places where this was not previously possible [82,83]. It follows the hypothesis that the increased use of technology can help to reduce healthcare costs by improving efficiencies in the healthcare system and promoting prevention through behaviour change communication [98]. With greater access to mobile phones to all segments of a country, including rural areas, the mHealth has potential of lowering healthcare costs. Mobile phones have made a recent and rapid entrance into many parts of the low- and middle-income world, with the global mobile phone penetration rate drastically increasing over the last decade. Moreover, the mHealth approach that is rapidly gaining ground in many developing countries, allow real time data access and management in locations with no infrastructure other than a cell phone tower [84]. Moreover, countries with relatively poor infrastructure are utilizing mobile phones as "leapfrog technology" to bypass 20th century fixed-line technology and jump to modern healthcare technology. Mobile phones are spreading in low- and middle-income nations because the cost of mobile technology deployment is dropping and people are, on average, getting wealthier [85]. At the end of 2011, there were 6 billion mobile subscriptions, estimates The International Telecommunication Union (2011) [86]. That is equivalent to 87 per cent of the world population. And it is a huge increase from 5.4 billion in 2010 and 4.7 billion mobile subscriptions in 2009. Mobile subscribers in the developed world has reached saturation point with one or two cell phone subscription per person. This means market growth is being driven by demand developing world, led by rapid mobile adoption in China and India, the world's most populous nations. These two countries collectively added 300 million new mobile subscriptions in 2010 - that’s more than the total mobile subscribers in the US. At the end of 2011 there were 4.5 billion mobile subscriptions in the developing world (76 per cent of global subscriptions). Mobile penetration in the developing world now is 79 per cent, with Africa being the lowest region worldwide at 53 per cent. Mobile subscriptions outnumber fixed lines 5:1 (more so in developing nations); Mobile broadband outnumbers fixed broadband 2:1. With stats like this, it is easy to see why the experts predict that mobile Web usage will overtake PC-based Web usage. This will happen more quickly in developing nations (if it isn’t happening already) where fixed Web penetration remains low. In developed nations, this will happen more slowly [87]. International Data Group (www.idc.com) believes that mobile Web usage will not overtake PC Web usage in the US until 2015. Regardless of the timescale, this inevitability makes mobile Web strategy more important than PC Web strategy in the long term. Smartphone technologies are now in the hands of a large number of physicians and other healthcare workers in many countries. Adoption of smartphone for mHealth in low and middle income countries is conditioned by deployment of the infrastructure that enables web browsing, GPS navigation, email, availability and efficiency in both voice and data-transfer systems in addition to rapid deployment of wireless infrastructure.

Within the mHealth space, projects operate with a variety of objectives, including: increased access to healthcare and health-related information (particularly for hard-to-reach populations); improved ability to diagnose and track diseases; timelier, more actionable public health information; and expanded access to on-going medical education and training for health workers. Although far from ubiquitous, the spread of smartphone technologies opens up doors for mHealth projects such as technology-based diagnosis support, remote diagnostics and telemedicine, Web browsing, GPS navigation, access to Web-based patient information, and decentralized health management information systems. The mHealth field houses the idea that there exists a powerful potential to advance clinical care and public health services by facilitating health professional practice and communication and reducing health disparities through the use of mobile technology. Overall, mobile communication technologies are tools that can be leveraged to support existing workflows within the health sector and between the health sector and the general public [88]. For instance, education and awareness programs within the mHealth field are largely about the spreading of mass information from source to recipient through short message services (SMS). In education and awareness applications, SMS messages are sent directly to users' phones to offer information about various subjects, including availability of health services, lifestyle management, testing and treatment methods, and disease management. For instance, Text4baby Russia (SMSmame in Russian) is a public health information service for new and expectant mothers intended to improve maternal and child health indicators. Subscribers to the free service, available throughout the Russian Federation, receive health information tailored to their baby's due date/birth date about nutrition, exercise, smoking prevention, mental health, government benefit packages, etc. This program is implemented by a Russian NGO, the Health and Development Foundation, and was developed under the auspices of the U.S.-Russia Bilateral Presidential Commission [89] on the basis of the U.S. text4baby program and sponsored by Johnson & Johnson (see more project in http://en.wikipedia.org/wiki/MHealth). SMSs has also the advantage of being relatively unobtrusive, offering patients confidentiality in environments where disease (especially HIV/AIDS) is often taboo. Additionally, SMSs provide an avenue to reach far-reaching areas - such as rural areas - which may have limited access to public health information and education, health clinics, and a deficit of healthcare workers [90].

The potential of mHealth lies also in its ability to offer opportunities for direct voice communication (of particular value in areas of poor literacy rates and limited local language-enable phones) and information transfer capabilities that previous technologies did not have. That is, there is evidence that the existence of a so-called “digital divide” along the socio-economic gradient is less pronounced in mobile phones than in other communication technologies such as the Internet [91]. There are applications related with the use of in-built smartphone sensors (e.g. phone camera, accelerometer, etc) that already have thousands of users. In the table 1 and 2 are presented application that we identified in App Stores, which focus in various health issue, based on technological capacity of smartphone.

Table 1. Android OS applications for health monitoring and care

Android OS		
Name	**Developed by**	**Role**
Vital and Sensory Function Test		
Instant Heart Rate	Azumio Inc	heart rate meter.
Cardiograph	Macro Pinch	heart rate meter.
Handy Logs Heart	Handy Logs	heart rate meter.
iBP	Leading Edge Apps LLc	is a blood pressure tracking and analysis tool. iBP uses color icons to indicate when BP values are normal, high, or hypertension.
Breath Biofeedback	Android Research	respiration biofeedback.
Breath Pacer Lite by Android Research	Android Research	respiration.
MT Health Test	MT DevTeam	includes color blindness test, hearing test, stress test, psychological test.
Vision Test	3 Sides Cube Eye	allows brief tests to measure visual acuity, test for astigmatism and ability to distinguish colors.
Test Your Hearing	EpsilonZero	easy hearing tests are presented to test frequency range and frequency differentiation.
NHS Direct	NHS Direct	facilitates an assessment, information on health condition and give advices for health preservation.
Emergency		
BHF Pocket CPR	Zoll Medical Bio-Detek	teaches Hands-only CPR skills according to the latest American Heart Association and European Resuscitation Council CPR and ILCOR Guidelines.
ICE: In case of Emergency	Appventive	store important information about user medical needs in case of an emergency.
ICE	Sera-Apps	the first helper is able to see who to call and which person he deals with in only a few clicks.
First Aid	Health Team	first aids is designed for helping to follow the right procedures in an emergency.
Stress Management		
Stress Check	Azumio	quantify level of stress, determine the effects of different stressors, allow control of stress.
My Calm Beat	Brain Solutions	training respiration for relaxation.
Cardiac Coherence	Haraweb	training on how breathing can reduce stress.
Respiroguide Pro	Vital-EQ	training respiration for better concentration, stress anxiety, ADHD and trauma healing.

Table 1. (*Continued*)

Stress Management Guide	Bigo	stress management.
Buddhify	21awakeLtd.	it's a introduction to meditation and the techniques involved.
Sleep Deeply	Hypnotherapists Direct Ltd	helps to relax and drift to sleep quickly and easily.
Brain Activity Management		
Brain Booster-Mind Refresher	Imoblife Inc	brain wave stimulation
Brainwave Tuner Lite	Imoblife Inc	brain wave stimulation application that generates tones with binaural beats, which can change brain frequency towards the desired state, allow relaxation or enhance attention.
Sleep Talk Recorder	MadINSweeden	offers a window into the subconscious, "those mumbling you can never quite remember the morning after could be your inner genius coming out. By placing the smartphone near the bed it will automatically turn on and begin recording when it senses sound during the night."
Nutrition		
WWDiary	Canofsleep.com	food tracker and weight tracker.
Carbs&Cals	Chello Publishing	encompasses over 1400 foods with images. This enable to determine visually the number of calories and carbs by selecting the appropriate food type and portion size in the application.
Calory Calculator	Benjamin Lochmann New Media GmbH	calories calculation.
E Numbers Cal	TappyTaps: Food Additives	information on E numbers and artificial additives, including side effects, and rates over 500 additives on a scale of 1-5 based on how bad they are for health. It also explains why they're used, what they do, where they come from and more.
Additives v3	Lyubozar Dimitrov	provide quick reference to simplified information about food additives labeled on foods.
DietPoint.Weight Loss	SimpLabs Ins	weight loss assistant with largest collection of diet plan and community support.
BMI Calculator	Androidcrowd	body mass index calculation.
BMI Calculator	Zileex Media	body mass index calculation.
BMI Calculator	You Droid	body mass index calculator that supports both English and Metric measurement units.

Table 1. (*Continued*)

Easy Weight Loss	Hypnotherapist Direct Ltd	help users to relax and feel comfortable with the decision to loose weight.
Weight Loss Tips	aap_swap	weight loss tips from the expert in diet, exercices, beauty, health, food&nutrition.
Physical Exercices		
Fitness Buddy: 1700 exercise	AppOneCause	by selecting the area of the body that user want to work is possible to select from a variety of exercices and all come with pictures and animations to ensure that are executed correctly. Performing exercises incorrectly can often do more harm than good and there are more than 3000 images and animations to makes sure this does'nt happen. The apps allow to add new exercices and to save the preferred ones to a favorite list. There are also exercices designed specifically for men and women.
Streth Exercices	Imoblife Inc	exercices for users with constant back-aches and waist pains.
MapMyWalk+	MapMyFitness	measures how far a subject walk (based on GPS) on a daily basis, and how many calories are burning.

Table 2. iPhone applications for health monitoring and care

iPhone OS		
Name	**Developed by**	**Role**
Instant Heart Rate	Azumio Inc	heart rate meter.
iTriage	Heathhagen	the application make Microsoft HealthVault (Microsoft Personal Health Records) data viewable via an iPhone app. Empower consumer with control and convenience to effectively manage their personal health care, and improve health care delivery for provider and payers.
Kaiser Permanente	Kaiser Permanente	the KP app gives Kaiser Permanente health plan members the tools to access their medical records, make appointments, refill prescriptions, view most lab test results, send non-urgent messages to their doctors, and more.
Cure A-Z	Plum Amazing Software LLC	shows how to combine the best of natural and prescription therapies to live in optimal health.
Heath4Me	United Health Group	health services management.

Table 2. (*Continued*)

Meal Planning by Food on the Table, Fast Food Calories	Abs Workout	calories calculation, meal planning.
Calories counter & Diet Tracker	My Fitness Pal	calories calculation.
DrinkTracker - The Breathalyzer Simulator & BAC Calculator, Outta Here!	Drink Traker Zazzle	keeps a record of what the user have been drinking with the fully editable one-tap drinks list. Apps automatically compares alcohol intake and metabolic removal rate and updates current Blood Alcohol Content every 60 seconds. Use Google Maps to get travelling directions (home or to the next pub), find a taxi in immediate vicinity of user, or email a friend with current location for a pickup. It also allows for phone or SMS contact via Contacts list from within the application.
Pedometer Free GPS+	Arawella Corporation	physical exercices meter.
Fitness Buddy:1700+ Exercices	AppOneCause	by selecting the area of the body that user want to work is possible to select from a variety of exercices and all come with pictures and animations to ensure that are executed correctly. Performing exercices incorrectly can often do more harm than good and there are more than 3000 images and animations to makes sure this does'nt happen. The apps allow to add new exercices and to save the preferred ones to a favorite list. There are also exercices designed specifically for men and women.

Apple AppStore, Android Market, Microsoft Mobile Marketplace, Nokia Ovi have made possible not only for start-ups but small research Laboratories and even individual developers to quickly attract a very large number of users. Also, the Apps Store allows developers to deliver new applications to large populations of users across the globe leading to the deployment of new applications and the collection and the analysis of data far beyond the scale of what was previously possible.

New included sensor in smartphone such as HD video and audio capabilities, accelerometers, GPS, ambient light detectors, barometers and gyroscopes enhance the methods of describing and studying cases, close to the patient or consumer of the health care service. In *participatory sensing* the user actively engages in the data collection activity (i.e., the user manually determines how, when, what, and where to sample). In *opportunistic sensing*, the data collection stage is fully automated with no user involvement. The benefit of *opportunistic sensing* is that it lowers the burden placed on the users mainly when the application is complex or not personally appealing [92]. *Personal sensing* applications are designed for single individual, and are often focused on data collection and analysis [92]. This could include diagnosis, education, treatment and monitoring. For instance Scully et al. [42] recently have shown that the technology available in a standard mobile phone camera has the potential to be used as an accurate multi-parameter physiological monitor – heart rate, breathing rate, oxygen saturation. However, various open issue exist in designing application for health monitoring and health care related with technologies that can support the continuous sensing on mobile phones, the programmability of the phones and the limitation of the operating systems that run on them, the dynamic environment presented by user mobility, persuasive user feedback.

Although mHealth application is still considered in its infancy is very important to focus more our research on testing the efficacy and reliability of the proposed application in order to diminish the possibility to reinforce entrenched knowledge gaps. The research should try to respond to questions as: What are the added value of mHealth application for person health and healthcare system? What breakthroughs are needed in order to perform robust and accurate classification of health state and subject behaviour using continuous sensing data? How can be performed privacy-sensitive and resource-sensitive reasoning and to provide useful and effective feedback to users in applications when noisy data and noisy labels are part of the information? What are the designing that may motivate more a change of behaviour or habit? How the privacy and security of data can be better protected? For instance the heart rate, respiration rate or hemoglobin oxygen saturation measured performed by smartphone using embedded camera can be acquired at least 5-10 time more cheaply using the commercial devices (pulse oximeters). Moreover, commercial devices have better sensitivity and specificity in acquiring these values because hardware and software include function for reduction of movement and skin color artefact during measurement. The added value that can be obtained towards heart rate and respiration function measurement using smartphone is continuously, pervasive monitoring of person for long time as we deployed with our applications. While smarphones continue to provide more sensing and communication bandwidth, computation, memory, storage, the cell phone is still a resource-limited device if complex signal processing and inference are required. The need of continuous sensing when using smartphone for pervasive health monitoring raises considerable challenges in comparison to sensing applications that require a short time window of data or a single snapshot (e.g. a single image or short sound clip). There is also an energy tax and resources associated with continuously sensing. Various solutions for this problem are presented in recently works [93,94,95]. However, more research is needed to exceed limitation of continuous sensing, to diminish the communication overhead and for privacy and security of stored and communicated data.

In our Lab we implemented applications for continuous sensing of heart rate, respiration, daily activity by developing a system that accurately acquired and process data from the smart sensors developed in our Lab. Figure 16 presents a model of implemented architecture that join pervasive sensing and pervasive computing elements that were used for cardiorespiratory and motor activity sensing system.

Mobile pervasive computing devices are completely connected and constantly available. In the presented intelligent ambient for healthcare scenario, mobile devices are expressed by smartphones and tablet computers. The embedded software for mobile devices was developed considering the following requirements:

- intermediate processing of the data acquired by the sensors integrated in the smart objects;
- human computing interfacing including graphical representation of locally processed data and data provided by the server,
- data communication including the communication between the mobile device and smartphone through Bluetooth and bi-directional synchronization with the web healthcare server using the Wi-Fi or 3G-UMTS internet connectivity.

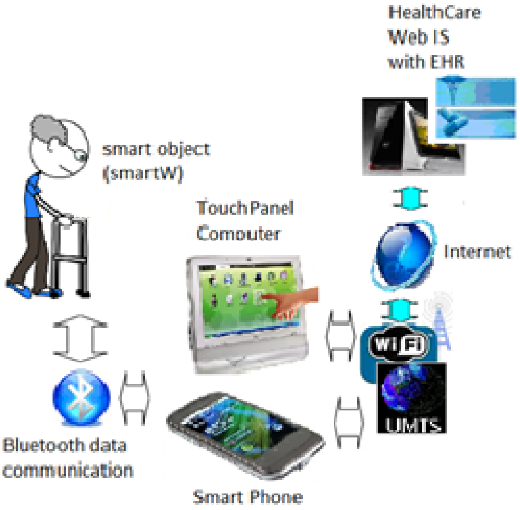
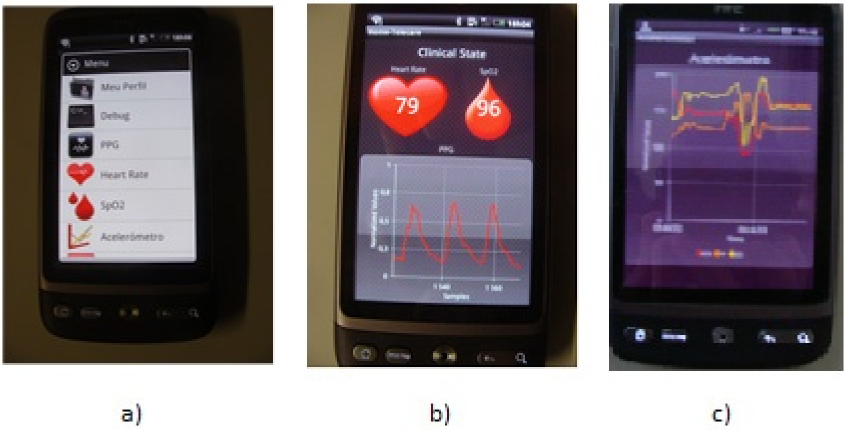


Fig. 16. M-Health architecture for vital signs and body kinematics monitoring (smart W-smart walker, HealthCare Web IS – web based information system for healthcare)

Important part of health monitoring systems implemented in our Lab is the computation unit materialized by low power, low-cost low processing capabilities devices as microcontrollers (e.g. MSP430 series) or Digital Signal Processors (e.g. ADI's new low power SHARC® 2147x) that are able to perform advanced signal processing algorithms (e.g. DWT, CWT).



a) b) c)

Fig. 17. The graphical interface of the pervasive computing device (Android OS smart phone) a) main menu, b) 0vital signs interface, c) motor activity interface

The acquired and processed data are transmitted through the communication interfaces (e.g. Bluetooth, ZigBee or Wi-Fi) to the HMI, generally expressed by smartphone or tablet computer (e.g. HTC Desire and a Toshiba Folio were already used).

Appropriate software was implemented on the mobile computing platform in order to process and display the data from the smart object sensors. In the smart wrist-worn device case the formatted data transmitted using a Bluetooth interface to a smartphone, which includes the application for communication, intermediary data processing and user interface developed under Android OS. A dashboard and a general menu board of the smartphone embedded software application are presented in Figure 17. In Figure 17.a. is presented the Android OS application main menu that is used to select the vital signs and motor activity monitoring interfaces. Figure 17.b presents the implementation of vital signs monitor graphical interface that includes the heart rate and SpO_2 digital display the PPG wave being visualized in a graphical display while the Figure 17.c includes the acceleration values evolution during the daily motor activity. For the particular case of smart wheelchair the graphical user interface was implemented on the tablet computer level and presents the evolution of cardiac signal (radar ballistocardiography), the respiration and the values of the heart rate and respiration rate (Figure 18).

The general graphical user interface of the application embedded in the smartphone is presented in Figure 19. As can be observed, the main menu of the BlueSentry 1.0.2 application embedded on the smartphone level, includes different categories such as smart object (e.g. smart walker) measuring channel control, data synchronization, user profile and preferences. The smart object measurement channel control permits to select the visualization of one single or multiple measuring channels according to the user or health professional necessity. Thus, "single" selection permit to visualize the evolution in time of only one measurement parameter with higher resolution, while for "multiple" selection two of the measured channel can be selected and the evolution of measured quantities is presented in a set of comparative graphs.

Clinical State

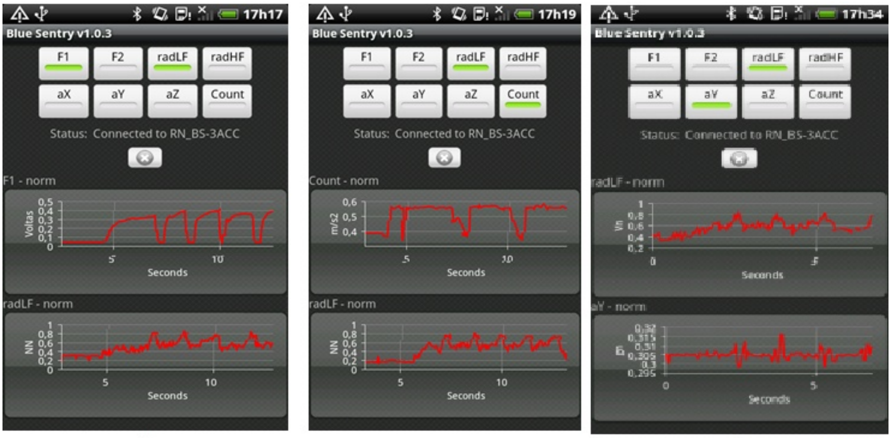
Heart Rate: 70 BPM

Breathe Rate: 17 Breath/min

Fig. 18. Cardiac, respiratory and motor activity graphical interface implemented on the Android OS Tablet computer

Fig. 19. The dashboard of the implemented AndroidOS software for walker user

In Figure 20 are presented a set of two BlueSentry application panels that are obtained after the selection of "Multiple" button. In Figure 20.a is presented simultaneously the evolution of the left arm support applied force and the detected legs motion using the radar sensor while Figure 20.b is presented the evolution of detected legs motion together the counter signal evolution, and Figure 20.c the applied force and the walker acceleration during normal usage are presented.



a) b) c)

Fig. 20. The BlueSentry application GUI a) radar motion sensor – force wave visualization, b) radar motion sensor – radar counter visualization c) radar motion sensor – acceleration wave visualization

The preferences are used to set-up particular parameters associated with particular walker' user training or to the particular physiotherapy exercises associated with smart walker use. The data obtained from the smart walker measurement channel is transferred automatically (from time to time e.g. 2 min) or manually by direct command to the HealthCare Web IS database for advanced processing (e.g. gait pattern recognition). The synchronization permits to actualize the information on the smartphone side concerning measurement data processing algorithms, thresholds, alarms, user profile and preferences.

The Android SDK and the Java programming language were used in our work as software technologies to implement data communication, data processing and representation on the smartphone display as well as the data management. A set of Activity Classes were considered: *ServerSync* that permits to manage all the information regarding the application; *SingleChannel* that assures the graphical representation of individual wave associated with smart object measurement channels (e.g gait wave from smart walker radar channel); *MultipleChannel* that assures multiple graphical representation of clinical status. A flowchart associated to the *SingleChannel* activities classes interaction with Java methods of Bluetooth Service is presented in Figure 21.

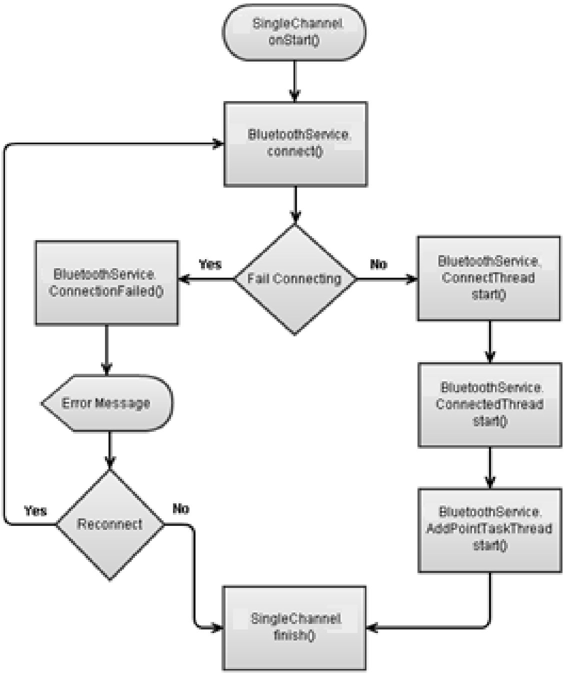


Fig. 21. DashBoard.java flowchart

Activity classes that also were implemented in the smartphone: *Main* that shows a menu associated with the selection of the main application classes; *Profile*, related to the patient profile, includes personal information and clinical data such as medical exams, registered illnesses, and indicated medication; *DatabaseList* that presents a list of particular elements for each patient shown on the smartphone display; *BluetoothService* that is related with Bluetooth data communication; *BluetoothDebug* that permits to display the data that is received from the acquisition and communication module in numerical format. If a set of smart objects with Bluetooth communication compatibility are present in our designed ambient intelligent for healthcare, a list of available devices is shown to the caregiver using the touch panel computer. The user is able to choose the smart object according to the ID of the person that is associated with the smart object. The selection can be done automatically according to the healthcare assessment schedule that is daily updated on the computing device (PC) of health professional (e.g. nurse, physician) or accompanying person mobile platform (e.g. tablet PC or smartphone).

The identification of smart objects is done in the present scenario using the MAC address of the Bluetooth device. Using the aiCharts graphical library, a graphical representation of the signals acquired by the acquisition and communication module integrated in the smart objects is carried out. Thus in the wrist worn case, the evolution of PPG wave as so as the acceleration values are presented while in the walker case gait wave (obtained through the radar), force wave and acceleration waves are presented on the display. The mobile device software also includes a database that was developed using the SQLite library, while the bidirectional data synchronization with a server database was done using a set of methods included in a synchronization class. The *contextual interpreter* developed as a server application manages the data coming from wireless acquisition and communication modules, or from RFID tag making all the needed associations between the user, corresponding profile and the values of vital signs and motor activity parameters for a given smart object assigned (e.g. smart walker) to the user. The data from the contextual interpreter is transmitted to the information compositor module using XML format that will provide complete information (users, smart object localization, and adapted HMI needed for a given context). The information obtained on the compositor side is provided to the Web server that will provide the information according with the human machine interface and refreshed every time when the user is detected for the first time using a smart device (e.g. smart wheelchair), or when a specific sensor make a measurement. It also happens every time when an observer is detected in front of a situated display. A simplified materialization of above presented hardware and software architecture is presented in Figure 16. Thus the user is using a smart walker which communicates the data through Bluetooth to a smartphone (which software can be considered on the user layer too). The data received on the smartphone from the walker (values measured by the walker sensors) is delivered through the Wi-Fi/3G-UMTS Internet to the server side (ambient layer) where the data is processed and sent to the contextual interpreter and information compositor software modules. The Web server receives the appropriate information to be presented to the patient or caregiver when using the elements of the display layer. Tests on reliability were realized through the progress of design and deployment of the system and we are going to publishe the results.

A smartphone application for indoor air quality and respiratory function monitoring was also implemented by the authors (see Figure 15). By utilizing community sensing technologies with mobile telephone, public health research can exploit the wide penetration of mobile devices to collect data that can give information on impact of environment on health. For instance, projects such as the PEIR project from the University of California (UCLA) used sensors in phone to build a system that enables personalized environmental impact reports, which track how the actions of individuals affect both their exposure and their contribution to problem such as carbon emission [96]. By aggregating the data from mobile phone of different users, from *personal sensing* and from distributed sensing nodes for indoor air quality, more insight on environmental impact on human health can be obtained and public health policy shall be able to craft initiatives to mitigate risk associated with indoor and outdoor air pollution. Integrating use of GIS and GPS with mobile technologies adds a geographical mapping component [97] that is able to "tag" voice and data communication to a particular location or series of locations. These combined capabilities have been used for emergency health services as well as for disease surveillance, health facilities and services mapping, and other health-related data collection.

There is a paucity of studies that evaluate effectiveness of mHealth application. Gurman et al. [98] analysing the evidences on effectiveness of mHealth behaviour change communication (BCC) interventions in developing countries have shown that studies did not consistently demonstrate significant effects of exposure to BCC mHealth interventions on the intended audience. Although most publications described interventions that used two-way communication in their message delivery design, less than half described tailoring the content or targeting [99]. Moreover, evaluation of efficacy of a mHealth campaign using SMS as a platform to disseminate and measure HIV/AIDS knowledge and to promote HIV/AIDS testing at clinics in rural Uganda has shown that only one fifth of the mobile subscribers responded to any of the questions. The campaign had proportionately limited success in increasing knowledge levels on a mass scale [99]. A variety of techniques are designed recently for mHealth that can motivate a change of behaviour or a habit as: the use of games, competitions among groups of people, sharing information within a social network, or goal setting accompanied by feedback. We are working on design and deployment of a serious games model, taking into account elements such as the use of RFID for game playing, tablets for interaction and patient's physiological vital signals monitoring, personalization and adaptation issues. The first prototype is a type of a memory and mahjong based game designed for a tablet PC attached to the wheelchair. It is directed to address therapeutics activities in aphasia and alexia, the most common speech and language disturbance in stroke and head trauma [55].

Understanding which types of metaphors and feedback are most effective for various persuasion goals is still an open issue. Building mobile phone sensing systems that integrate persuasion requires interdisciplinary research that combines behavioral and social psychology theories with computer science, sensors and communication network engineering.

Withal privacy and security of data stored and transmitted through mobile phone will remain a significant problem in the foreseeable future. Although there are approaches that can help with these problems (e.g. cryptography, privacy-preserving data mining) they are now insufficient [100,101]. While this research field can leverage evidence and insight from data mining, machine learning, standard on communication of data, best clinical practice and ethical issue, health information system policy it present challenges is not addressed by this present work.

5 Pervasive Computing

Over the past decade, miniaturization and cost reduction in semiconductors have led to computers smaller in size than a pinhead with powerful processing abilities that are affordable enough to be disposable. Similar advances in wireless communication, sensor design and energy storage have meant that the concept of a truly pervasive 'wireless sensor network', used to monitor environments and objects within them, has become a reality. Ubiquitous computing means network connectivity everywhere, linking devices and systems as small as a drawing pin and as large as a worldwide product distribution chain [102]. Pervasive computing (the term used in some recent literature with the same meaning of ubiquitous computing) relies on the convergence of wireless technologies, advanced electronics and the Internet. The pervasive computing abilities may allow continuous monitoring of human health in any environment, be it home, hospital, outdoors or the workplace.

Pervasive computing shares many application fields in common with mobile computing such as mobile networking, mobile information access, adaptive applications, location sensitivity. However it addresses four key issues expressed by smart spaces, invisibility, localized scalability and masking uneven conditioning [103]:

- *Smart Spaces*: embedding computing infrastructure in building infrastructure brings together two worlds that have been disjoint until now. The fusion of these worlds enables mutual sensing and control of these worlds.
- *Invisibility*: the ideal expressed by Weiser is complete disappearance of pervasive computing technology from a user's conciousness. In practice, a reasonable approximation to this ideal is minimal user distraction. If a pervasive computing environment continuously meets user expectations and rarely presents him with surprises, it allows him to interact almost at a subconcious level.
- *Localized Scalability*: as smart spaces grow in sophistication, the intensity of interactions between a user's personal computing space and its surroundings increases. This has severe bandwidth, energy and distraction implications for a wireless mobile user. Scalability, in the broadest sense, is thus a critical problem in pervasive computing. Like the inverse square laws of nature, good system design has to achieve scalability by severely reducing interactions between distant entities. This directly contradicts the current ethos of the Internet, which many believe heralds the "death of distance."
- *Masking Uneven Conditioning*: uniform penetration, if it is ever achieved, is many years or decades away. In the interim, there will persist huge differences in the "smartness" of different environments – what is available in a well-equipped conference room. This large dynamic range of "smartness" can be jarring to a user, detracting from the goal of making pervasive computing technology invisible. One way to reduce the amount of variation seen by a user is to have his personal computing space compensate for "dumb" environments. As a trivial example, a system that is capable of disconnected operation is able to mask the absence of wireless coverage in its environment.

Pervasive computing devices should be completely connected and constantly available. Hence, pervasive computing stimulates and reinforces deployment of smart products that communicate unobtrusively. The smart sensors for pervasive heath monitoring and care may be connected to the Internet and the generated data may be easily available. Therefore pervasive health monitoring and pervasive healthcare systems may generate a wealth of information for the healthcare provider above and beyond what is currently available. How this information will be acquired, stored and interpreted, and how healthcare systems will respond to adverse events and to improve quality of care must all be considered. It is important to appreciate that at present while much patient information is collected by continuous monitoring, for example during hospital admission, most of this information is lost. As pervasive health monitoring systems will collect a vast amount of information, separating this into 'important' and 'non-important' is going to require very accurate context sensing and data mining. Reacting to this information is going to require major process automation and structural change to existing healthcare systems. Traditional approaches for handling data are often based on large dedicated computer systems which store all required data at one single location and handle all incoming requests from applications and their users. While this is a valid approach for limited amounts of data, it is no longer functionally and economically viable for large scale pervasive health monitoring and care. The apparent solution is to distribute both data and requests onto multiple computers. In this case, a method to create coherence between computers is required, designed to make the distributed appear like a single large units to its users [104]. The Cloud Computing [31] that is a specialized form of distributed computing that introduces utilization models for remotely provisioning scalable and measured information technology resources. Analyzing the main characteristics of the cloud computing such as on-demand self-service, broad network access, resource pooling and rapid elasticity can be underlined that the usage of this kind of technology fit well with the pervasive healthcare. Thus smart object as patient assistants can access to the cloud computing capabilities in order to obtain the processed metrics associated with the values measured by the sensors that can used to generate warning up message translated in audio and/or video signaling forms. Based on cloud computing models the computing resource are pooled to serve multiple consumers using multi-tenant model [105] with different physical and virtual resource dynamically assigned and reassigned according with smart object demand or mobile platform demand. Taking into account the reliability requirements for the healthcare systems the cloud computing provides increased reliability through the use of multiple redundant sites, which makes Cloud Computing suitable for health system continuity and disaster recovery. The first steps in Cloud Computing technology application for healthcare are already done especially related to the usage of cloud storage facility; however fewer steps were done in the healthcare data analysis side where the usage of computational intelligence and semantic Web technologies represent the next step in the future of healthcare system. Computational Intelligence (CI) [106] is a set of nature-inspired computational approaches that primarily includes Fuzzy Logic Systems (FLS) [107], Evolutionary Computation (EC) [108] and Artificial Neural Networks (ANN) [109]. The Evolutionary Computation may deal with the vastness and tractability issues in storing, querying, reasoning and mapping semantic data in pervasive health monitoring, Fuzzy Logic may effective for management of vagueness and uncertainty in pervasive healthcare while Artificial Neural Network may improve the learning capacity of the pervasive health system and solve inconsistent issues with regards to data mapping and the data alignments in pervasive health monitoring and care.

In the early sixties, the concept of Semantic Network was firstly introduced as a knowledge representation model by cognitive scientists Allan M. Collins, linguist M. Ross Quillian and psychologist Elizabet F. Loftus [110]. In 1998, the term Semantic Web (SW) was coined by Web inventor Tim Berners-Lee as an extension of the current Web [111]. It was described as a giant global semantic network of data that is directly consumable and understandable to machines. In contrast to a hypertext Web that indicates texts linked to other texts in other places by hyperlinks, the Semantic Web projects a hyperdata Web that indicates data objects linked with other data objects across the Web through formal semantics and ontologies [112]. It enables the formation of a global web of data or open linked data [113] that interlinks distributed data at a Web-scale. The Semantic Web is led by the World Wide Consortium (W3C) as an international collaborative movement [114]. According to Tim Berners-Lee et al. [111] the Semantic Web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users as clinical diagnosis advice. Regarding the principle of "how" Semantic Web is defined [115] a layered architecture expressed in Figure 22 was proposed by Tim Berners-Lee.

In Figure 22 *Unicode* represents the standard for computer character representation, and *URIs*, the standard for identifying and locating resources (such as pages on the Web*); XML* form a common means for structuring data on the Web but without communicating the meaning of the data; *RDF (Resource Description Framework)* represents a simple metadata representation framework; *Ontologies* represents a richer language for providing more complex constraints on the types of resources and their properties; *Logic and Proof* represents an (automatic) reasoning system provided on top of the ontology structure to make new inferences ; *Trust* represents the final layer of the stack addresses issues of trust that the Semantic Web can support.

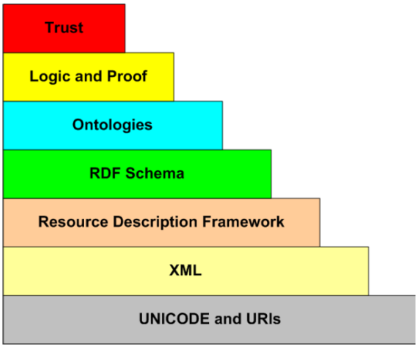


Fig. 22. Semantic Web layered architecture

Like the Web architecture, the pervasive healthcare is going to be decentralized, vast, uncertain, and incomplete. Generally, manually configuring and operating large-scale distributed systems that potentially comprise thousands of nodes is no longer feasible. Self-organizing distributed systems are able to operate autonomously [116]. The approaches developed for handling vast Web data may be adapted for pervasive health monitoring and care taking into account the specificity of data store and communicated. For instance, new approaches are recently proposed for handing with vast data: the eRDF (electronic *Resource Description Framework)* that provides the evolutionary algorithms for querying, and a swarm algorithm for logical entailment computation [117]; swarm intelligence model to store and analyze the massive amounts of semantic data and collective behavior of swarm individuals for reasoning over a fully decentralized and self-organized storage system [118]; tractable reasoning services for ontology application using tractable profiles in OWL2 (*Web Ontology Language*) and some of their fuzzy extension and reusable reasoning infrastructure called TrOWL for mashup, process refinements validation, software engineering guidance for tractable applications of fuzzy and crisp ontologies [119]; use of cloud infrastructure for scalable reasoning on top of semantic data under fuzzy pD* semantics (i.e. an extension of OWL pD* semantics with fuzzy vagueness) [120].

6 Conclusion

Driven by quality and cost metrics, the healthcare systems will change radically in the near future from current healthcare professional-centric systems to distributed networked and mobile healthcare systems. In this movement, the leading part is attributed to the pervasive technologies. Pervasive healthcare tries to change the healthcare delivery model: from doctor-centric to patient-centric, from acute reactive to continuous preventive, from sampling to monitoring.

The pervasive or ubiquitous access to healthcare data is essential for diagnosis and treatment procedure in healthcare system of the future. It requires unobtrusive sensing and convenient on-demand network access to a shared group of configurable computing resource. We describe in this chapter unobtrusive sensing solutions based on optical sensors, microwave Doppler radar, or MEMS technologies as well as Android OS software applications. The smart objects, characterized by the unobtrusiveness of sensing and computing in a pervasive system for health monitoring may deliver information to mobile platforms such as smartphone or tablet computers programmed to locally process the received data and to perform data synchronization with Web healthcare servers as Cloud computers components. These computer resources expressed by networks servers, storage applications and Web services might be rapidly provisioned and released with minimal management effort or service provider interaction, by using computational intelligence and Semantic Web.

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Are Technologies Assisted Homes Safer for the Elderly?

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Abstract. The elderly population of the world is growing rapidly, creating the increasing need for elderly care. The aged people expect that this increased longevity will help them to enjoy living an independent and high quality life. Yet, at the same time they know there is a high risk of injury as many unforeseen accidents can take place. Surely, with the technology of today, there is a better way for these people in the society to resolve this problem. The chapter will present the development work and implementation details of a wireless sensors network based safe home monitoring system targeted for the elder people to provide a safe, sound and secured living environment in the society. The system is designed to support people who wish to live alone but, because of old age, ill health or disability, there is some risk in this, which worries their family or friends.

Keywords: wireless sensors network, safe living environment.

1 Introduction

In recent times, there are many incidents reported in newspapers and in different other medias. A few of them taken from newspapers are:

> **Dead couple lay in home for 13 days,** New Zealand Heard, Feb. 25, 2005[1]
>
> **Old tenant lay dead in flat for more than 10 days,** NZ Herald, Apr. 20, 2006 [2]
>
> **Elderly man lay dead for days, National,** Jun. 14, 2011[3]
>
> **Forgotten man lay dead in flat for six years,** The Guardian, Apr. 6, 2005[4]
>
> **Pensioner's body lay in flat for months,** TVNZ, Feb. 23, 2012[5].

With the above news headlines, we feel very sad and start thinking that there is no one who thinks of the elderly population and no care is taken for them in the society. The reason of such unfortunate happening is due to increased number of ageing population.

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The average life-expectancy has gone up resulting in more number of people in the old age category as is seen in figure 1[6].There are currently 510,000 people over the age of 65 yrs in New Zealand [7], 90 million people over 60 years in India [8]. In the United States alone, the number of people over age 65 yrs is expected to hit 70 million by 2030, almost doubling from 35 million in 2000 [9].

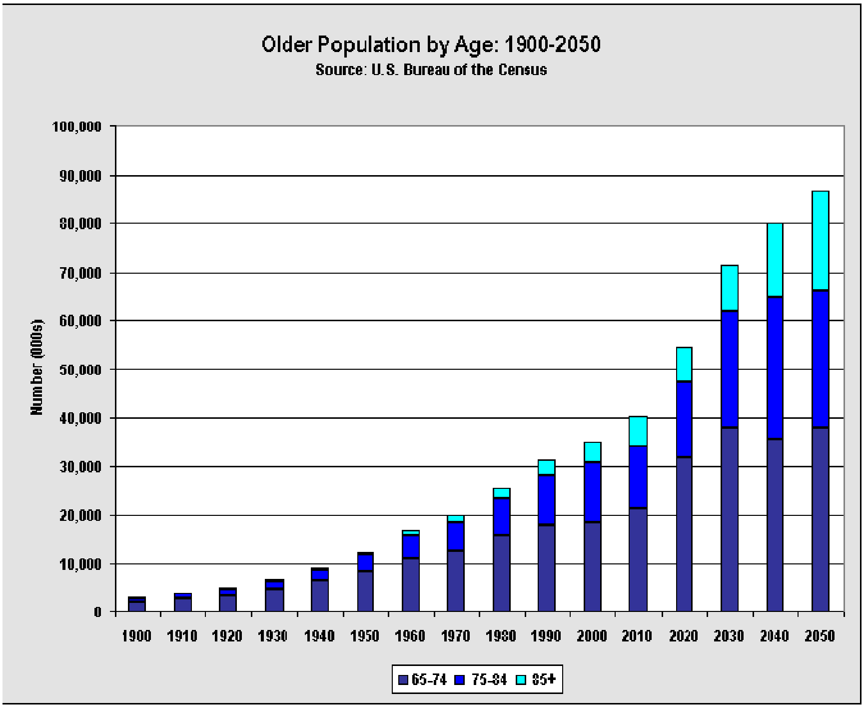


Fig. 1. The percentage of old people in different countries [6]

The increased life-expectancy has been possible due to different reasons, such as availability of healthy foods and medicine and increased self-awareness of human beings of their health. This is of course very good for the society as we can enjoy our life much longer than our earlier generations. But there are some consequences of this increased life-expectance. The cost of health care is increasing at a very fast rate. The expenditures of the US for health care will project to rise to 17.9% of the GDP ($2.9 trillion) by 2015 [10].

Not only the cost of health-care, due to different accidents happened at the old age, many elderly people are forced to consigned to expensive retirement homes. This may not be possible for everyone and also it leads to sacrificing their own privacy/dignity issues. So many elderly people choose to stay at home.

2 On-Going Researches on Smart Home Technology

The health-care is one of the most important research topics in recent times and many universities are involved towards developing system for proving care to the elderly people. Their main purpose is to monitor elderly with motor, visual or cognitive disabilities. Smart home technologies or home healthcare systems have gained academic and industrial attention in the context of self-care and remote care giving with the potential to effectively monitor, manage and motivate behaviours that lead to better health outcomes.

With the advancements in sensing technologies, embedded processors and communication networks development of technological systems for the home environment has been made possible. The use of such technologies in healthcare is increasing in many ways: service delivery, in-home monitoring, interactive communication, information transfer, and peer support.

Technology-enabled solutions have gained recognition as an effective and efficient solution as well as a sustainable support structure enabling self-care and remote care giving for independent, active and healthy aging. The development in ICT (Information and Communication Technology) has resulted in trimmed and enhanced function of sensors, computation and networking technologies. When smart home is united with live research and growth of chic fabrics, latest textiles, smart papers, power supplies, abrasive devices and digital imaging it enables people to have greater care at home.

Wide range of smart home research is carried out in the entire world. The Georgia Institute of Technology in USA has structured an ‘Aware Home’ using ubiquitous computing method that feels and identifies imminent emergency that aids in deteriorating aged memory and looks for behavioural inclinations [11].

‘Gator Tech Smart House’ is a product of ‘Florida University’ which provide intelligent house of disabled and aged persons [12]. It consists of environmental sensors which provides ease & energy competency, wellbeing and protection, movement supervision, stimulating and prompting technologies, intelligent device, fall recognition system, social distant dining with family members, biometric technologies for physiological supervision like temperature & weight and appliances like intelligent mail box, intelligent phones. Place Lab is a fragment of MIT’s house n project or ‘house of the future’ [13]. It supervises the actions and key signs of inhabitants; manage energy utilization, and offers knowledge, amusement and interactions by the usage of ever-present sensors and wearable devices.

Systems have been developed in European nations and UK. A supported interactive residence house is built for aged and disabled individuals. The sensor system evaluates key signs & actions and offers security surveillance and response. It also utilizes environmental control technologies with doors, windows and curtains. Similarly a smart apartment is developed by the University of Ostrava in the Czech Republic by implementing infrared (IR) sensors [14]. In France project on PROSAFE at Toulouse aspires to support independent living and activates alarms at the time of emergency [15]. The infrared sensors are implanted in ceilings of flat enabling the evaluation of actions and movements.

Health Insight Solutions (HIS) project at Grenoble is an apartment having IR sensors to evaluate actions. A model house is developed in Eindhoven satisfying the needs of Dutch Senior Citizens Label in 1995 [16]. These dwellings can be supervised with supportive technologies with the main objective of utilizing Information Technology (IT) to aid interaction amid older people and their caregivers.

Japan aspires to amplify the utility of supportive technology, helping older individual to live independently at residence by cultivating intelligent and secure surroundings. A total of 13 ‘Welfare Techno-Houses’ (WTH) have been developed by the Japanese Ministry of International Trade and Industry. Information on inhabitants actions are gathered by researcher by embedding rooms with IR sensors, bathrooms with totally independent biomedical devices, doors with magnetic switches [17]. Likewise, Tiger Place – Smart Home for the Elderly at University of Missouri-Columbia [18], CASAS Smart Home Project at Washington State University and MavHome [19] smart home projects.

Not only the research works carried out at different universities, there are quite a few patents on the topic available [20-27]. A few patents are concept patents as the problem of practical implementations have been overlooked. Many patents reported systems with a huge number of sensors which does not allow making it a low-cost system. The pictures from a patent [23] as shown in figure 2 and figure 3 use camera to implement a home monitoring system for monitoring inhabitants at home. The camera is really a good device for surveillance application but to use it in a home environment for monitoring elderly for 24 hours 7 days and 365 days lacks a huge acceptability among the elderly.

Based on the above situations there is still need to develop a monitoring system for the elder care which will be accepted by the elderly.

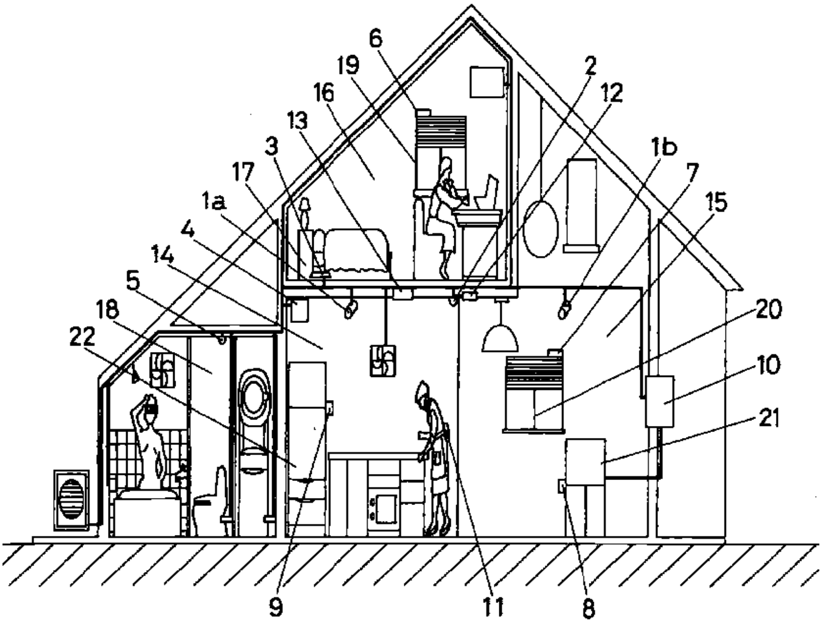


Fig. 2. Pictorial representation of a monitoring system [23]

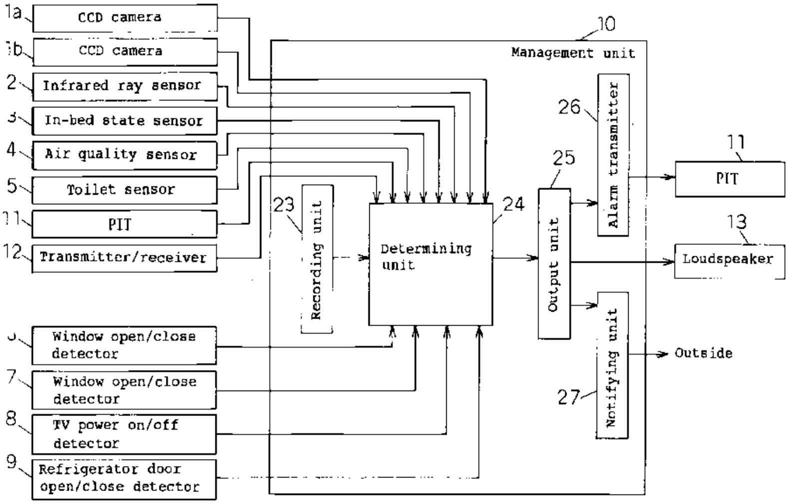


Fig. 3. The sensors involved in a monitoring system [23]

3 Directions of Elder-Care

The researches on smart home for elder care can be divided into following four categories.

a. Use of Camera and Vision-based [28],
b. Wearable-sensors based [29],
c. Appliance Monitoring for newly-build home [30],
d. Sensors to be fitted in an old-home.

The category from (a) to (c) has either has the problem of acceptability or not practically feasible. So the research reported in this work is based on the category (d) in which necessary sensors are fitted in a home to make it a smart home which provides a safe, sound and secured living environment to the elderly. The developed system doesn't have any camera or vision based system [31]. A low-cost system has been developed that can be affordable by almost everyone.

4 Technology Assisted Home Monitoring System

The functional description of the technology assisted developed home monitoring system is shown in figure 4. The system uses wireless sensors to monitor the state of different appliances which are used by the elderly for their day-to-day life. The devices may be electrical or non-electrical appliances [31]. For example, the bed which is used by the elderly to sleep in the night is monitored by a wireless sensor network. When the elderly going to sleep on the bed, when he/she gets up in the night to go to toilet and when he/she gets up in the morning are all recorded on real-time. Similarly, the toilet, chair, sofa, toaster, hot-water kettle, refrigerator are all recorded of their uses.

The monitored sensors data are transmitted using zigbee based wireless protocol to a central data acquisition system configured around a laptop computer. The requirements for the developed system are: Non-Invasive, Low Cost, Flexible, Portable, Wide Acceptance among the elderly and Confidentiality [32-33]. From the monitoring of the appliances, the behaviour of the elderly are annotated and consequently any irregular activities are recorded. Depending on the situation a warning signal is sent to the care-giver [34].

The technology assisted home monitoring system integrated with sensing units and intelligent software identify daily activity pattern and irregular situation of elderly in real-time. There is a considerable debate about the irregular situation of the elderly as the situation leading to irregular condition may not be unique for everyone. In order to make the developed system to be used by elderly irrespective of ethnicity and country of residence, the wellness of the elderly are defined and determined by the current system [35-36]. The system also analyses the activities of the person and can predict the future trend of the activities.

Changes is normal daily activities can be easily known with respect to the time i.e. regular usage duration with allowable residuals of certain objects can indicate the regular behaviour of the elderly and if there are any changes to the usage duration then we can say that this is an abnormal activity. Therefore, we model a system in terms of time series analysis for forecasting the usage duration of objects in smart home monitoring environment.

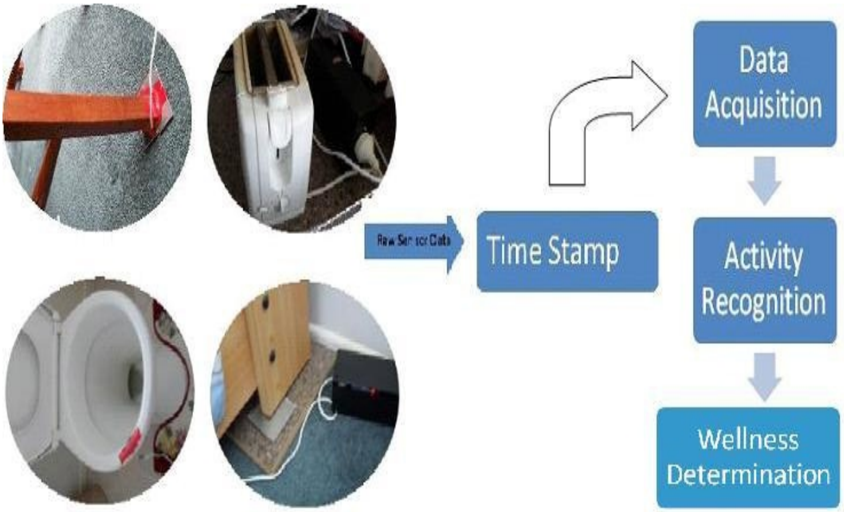


Fig. 4. Functional description of the technology assisted developed home monitoring system

Figure 5 shows the zigbee coordinator configured at the com port of laptop computer. The programme is written using .net programme to store and analyse the data. Figure 6 shows the schematic representation of the sensors placed at different locations of a home. This is the graphical representation which is displayed at the monitor of the laptop.

Developed Graphical User Interface shows the sensor status with their respective icons and information about individual sensor usage like: number of times used daily, minimum usage duration, average usage duration, maximum usage duration, last active time used and inactive duration since last used. Also, console window show the sequence of sensors usage. Program simultaneously stores the data in the coordinator system for further processing of data in terms of determining wellness indices and prediction of activity usages.

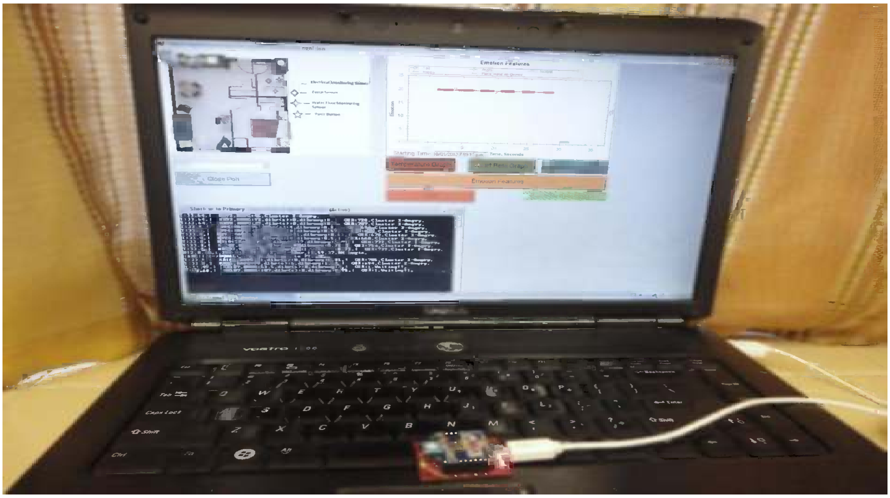
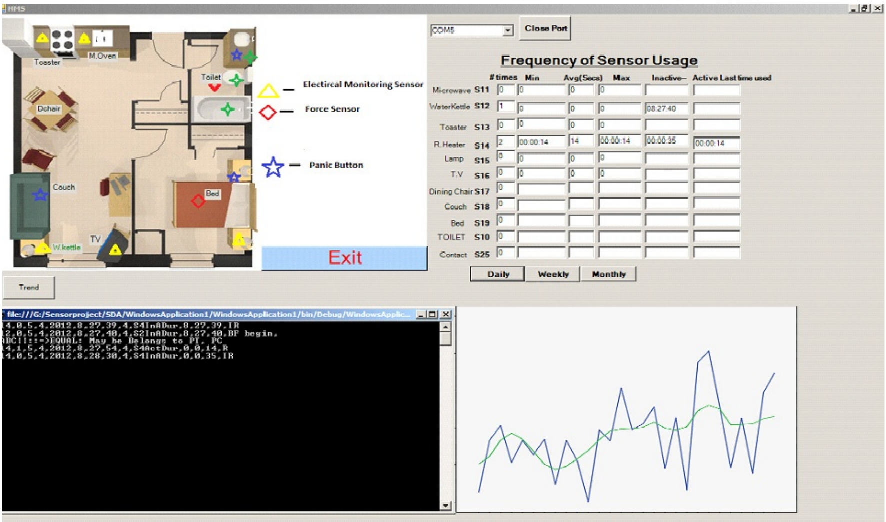


Fig. 5. Zigbee coordinator based on a laptop computer



Frequency of Sensor Usage

		#times	Min	Avg(Secs)	Max	Inactive–	Active Last time used
Microwave	S11	0	0	0	0		
WaterKettle	S12	1	0	0	0	08:27:40	
Toaster	S13	0	0	0	0		
R.Heater	S14	2	00:00:14	14	00:00:14	00:00:35	00:00:14
Lamp	S15	0	0	0	0		
T.V	S16	0	0	0	0		
Dining Chair	S17	0					
Couch	S18	0					
Bed	S19	0					
TOILET	S10	0					
Contact	S25	0					

```
file:///G:/Sensorproject/SDA/WindowsApplication1/WindowsApplication1/bin/Debug/WindowsApplic...
14,0,5,4,2012,8,27,39,4,S4InADur,8,27,39,IR
12,0,5,4,2012,8,27,40,4,S2InADur,8,27,40,DF begin.
ABC!!==>EQUAL: May be Belongs to PI, PC
14,1,5,4,2012,8,27,54,4,S4ActDur,0,0,14,R
14,0,5,4,2012,8,28,30,4,S4InADur,0,0,35,IR
```

Fig. 6. The schematic representation of the placement of sensors

The collected data from all sensors are presented on a 24 hour representation for a trail run in an elderly house and is shown in figure 7. The appliance has been labeled for the particular hour if it used in that hour, it doesn't mean that it has been used for the full duration of that hour. The details of the short form representation of different appliances are labeled at the right hand side of figure 7. Due to the winter time, it is seen that the heater is used quite longer duration for the day.

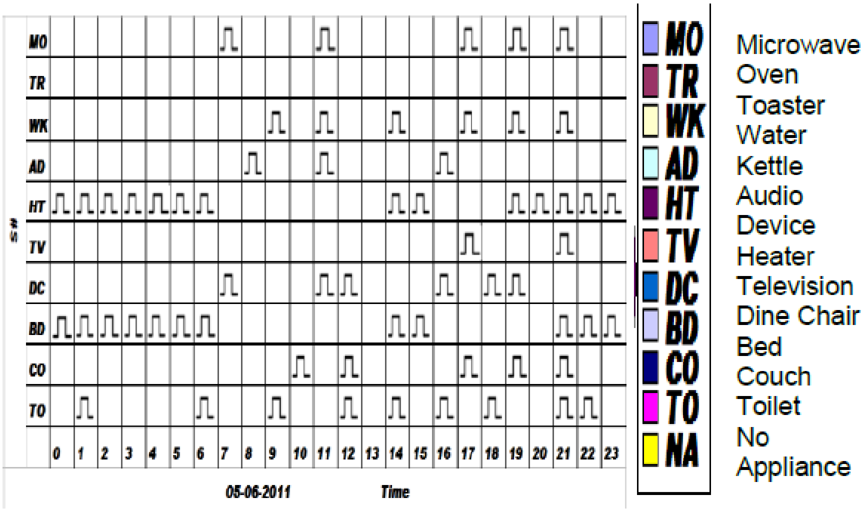


Fig. 7. Representation of sensors data for 24 hours run in an elderly home

5 Wellness Determination of the Elderly

A lot of researches have been reported and are still going on the behavior determination of the elderly. In our earlier works the emphasis was put on the bahaviour determination of the elderly [34]. But, it has been realized that the behaviour is not unique for all elderly and it changes from person to person. So to look into the bigger picture it is important to understand whether the elderly is safe at the technology assisted home.

Hence the following questions are examined to get an answer:

- How "Well" the elderly living alone in Technology Assisted Home is able to perform their essential daily activities in terms of using household appliances?
- Performance of Daily Activities indicates Performance behavior.
- Livelihood activities are Cyclic

Monitoring usage of house-hold appliances for recognizing the habitual nature of the person is very useful to determine how well or safe the elderly is leading his/her life. Two types of wellness functions have been defined [36], one is based on no-usage of any appliances (β_1) and another based on over-usage of appliances (β_2). If the elderly uses different appliances continuously it means that the elderly is physically fit though continuous use of bed means the elderly is not well.

The wellness function β_1 is defined as $\beta_1 = 1 - (t/T)$ (1)

Where β_1 = Wellness function of the inhabitant based on the inactive usage measurement of appliances,

t = Time of Inactive duration of all appliances (i.e.) duration time no appliances are used.
T= Maximum inactive duration during which no appliances are used.

If β_1 is equal to 1.0 indicates the inhabitant is in healthy situation. If β_1 is less than 1.0 and goes below 0.5 the situation indicates some unusual situation and can be used to send a warning text message to the care-giver. Though a threshold value of 0.5 is chosen based on the trail run, it may be trimmed based on a few runs.

Figure 8 shows the wellness function β_1 of a trail runs of the monitoring system at a few technologies assisted home. It is seen for the subject#3; the wellness function β_1 has gone below 0.5. It was observed that on that particular day, the person went out of the house for quite some time and no appliances were used during that duration.

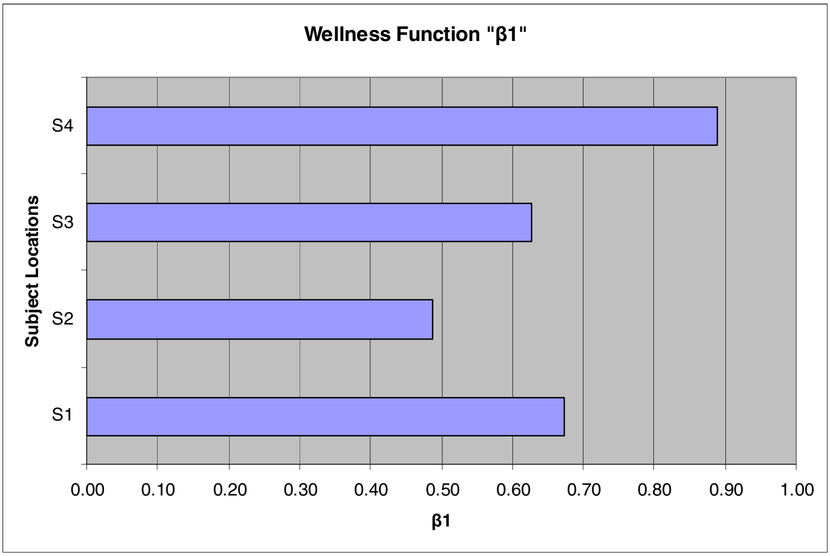


Fig. 8. Wellness function β_1 of a few human trials runs [36]

The wellness function 'β_2' is defined by the following equation

$$\beta 2 = 1 + \left(1 - \frac{Ta}{Tn}\right) \tag{2}$$

Where β_2 = Wellness function of the elderly based on excess usage measurement of appliance.

T_a= Actual usage duration of any appliance.
T_n =Maximum usage duration use of appliances under normal situation.

Under normal condition, $T_a < T_n$; No Abnormality. Only if $T_a > T_n$ then β_2 is calculated using the eq.(2). The value of β_2 close to 1 to 0.8 or so may be considered as normal situation. If β_2 goes less than 0.8, then it indicates the excess usage of the appliance corresponding to an unusual situation.

In ideal case, β_1 and β_2 equals to one indicate the elderly activities are recurring with equal durations every time. However, human behavior is not consistent; hence the optimum alarm level for β_1 and β_2 are determined so that false warning messages are minimized.

In figure 9 it is seen β_2 for subject 2 has gone to very low value for the use of chair. It has been observed that on that particular day, the elderly had a visitor and took lunch sitting on the chair for a long duration. For the subject 3, it has been observed that the elderly slept quite a long time as he was not feeling well.

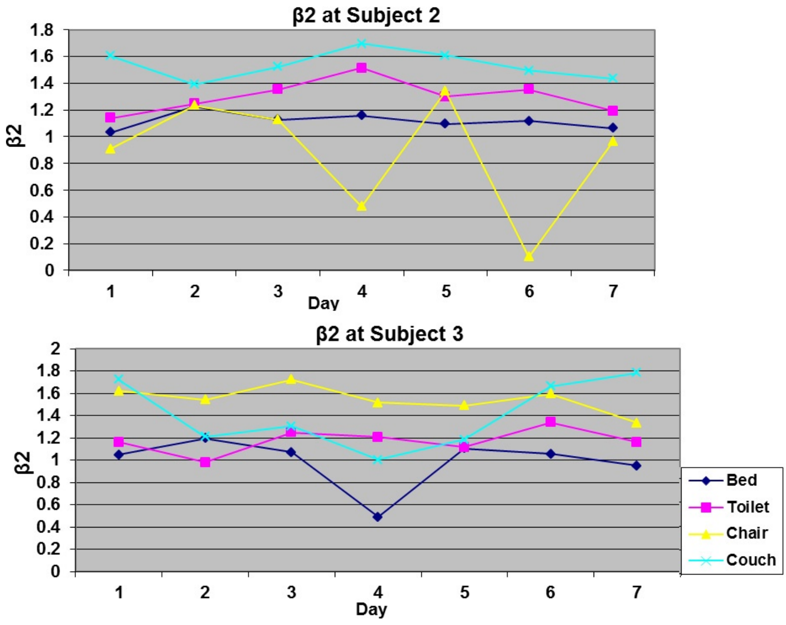


Fig. 9. Wellness function β_2 of a few trial runs [36]

The above two wellness functions are calculated based on the data collected during the interview about the life-style of the elderly. But with time, the life-style gets changed so there is a need of updating the parameters for the determination of the wellness functions. This is done based on the trend analysis of the previous data.

Based on the time series of past data, a suitable method considered for predicting the near future values was "Seasonal (cyclic) Decomposition". It is used primarily as a preliminary tool when attempting to analyze trend. It is also suitable for exhibiting seasonal pattern which may be existing in the series and useful for forecasting process.

Trend component is estimated by using the principle of moving average. The Exponential Moving Average considered in the analysis is given by the equation:

$$MA_{t+1} = \alpha X_t + (1-\alpha)MA_t \tag{3}$$

MA_{t+1}-Moving average prediction
MA_t - Previous Moving average
α -- Smoothing Constant
X_t -- Observed quantity at time 't'

'α' smoothing constant, is derived from the number of sensor observations from the start of the system to the recently observed value. The advantage of this moving average is that a smaller smoothing constant gives more relative weight to the observations in the more distant past and a larger smoothing constant provides more weight to the most recent observation.

For demonstration purpose, we considered forecasting using additive model which identifies the excessive amount in the sensor duration dependent variable with respect to the time. The basic features like trend and seasonality of Time Series describe a time series by its degree. After estimating the internal components like trend and seasonality of a time series, we have extracted errors by detrending. Smoothed Trend Curve (STC) for bed sensor usage duration is derived by applying eq (3).

Seasonally Adjusted Factor (SAF) is resulted from the decomposition process considering one week as one season (cycle). Following the additive method for the forecasting process, the most appropriate fitted curve is computed by adding smoothed trend curve and seasonally adjusted factors (i.e. Fitted Curve=STC+SAF). Implementation of forecast model is further discussed in the following section.

Figure 10 shows the trend analysis for the four weeks of sleeping activity data for a trial run. An additive model has been used to determine the behaviour (in terms of usage of appliances) of the elderly for the 5th week. Table 1 shows the data obtained for the 5th week. The number of weeks can be changed to get an optimum representation of seasonal variation.

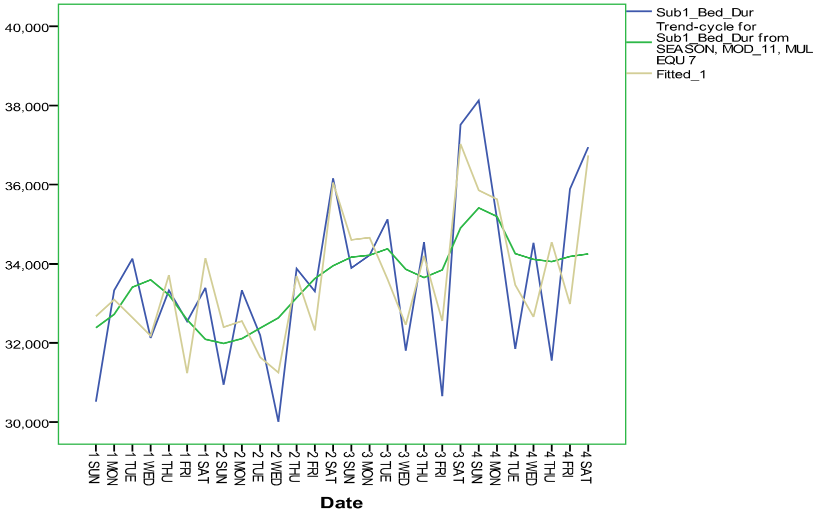


Fig. 10. Bed Sensor sequence, Trend and Fitting curve based on forecast model of sleeping activity of subject1 elderly person

Table 1. Prediction of the bed usage for the 5th week

Additive model	**Extended Trend value**	**+**	**Seasonal factor**	**=**	**Forecast value Week #5**
	T		**SAF**		**F**
5 SUN	9:46:53	+	0:10:42	=	9:57:35
5 MON	9:43:19	+	0:10:30	=	9:53:49
5 TUE	9:29:21	+	-0:11:35	=	9:17:46
5 WED	9:29:38	+	-0:25:22	=	9:04:16
5 THU	9:30:16	+	0:05:27	=	9:35:43
5 FRI	9:34:41	+	-0:25:02	=	9:09:39
5 SAT	9:36:53	+	0:35:23	=	10:12:16

Based on the trend, seasonal adjusted and fitted values from the four week bed sensor usage value, fifth week prediction of bed sensing usage values are computed for estimating bed sensor durations (see Table 1). The error distribution prevailing in the derived fitted curve is tested by following One-Sample Kolmogorov-Smirnov Test.

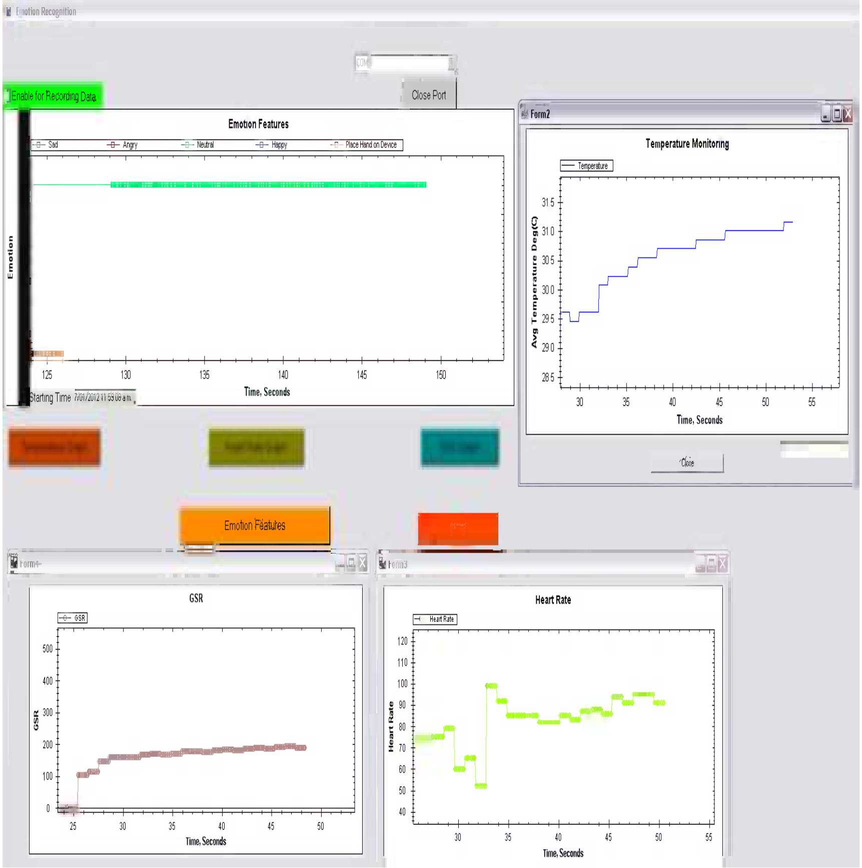
6 Human Emotion Recognition System

Monitoring emotions is important as it contains information that can help in improving human wellbeing. It is also important to monitor emotions as they are perceptions of bodily changes and can help in identifying matters of concern at an early stage before they become more serious. Emotion regulation is an important skill for coping with social and personal problems [37].

In this project, we have developed an emotion recognition system based on information provided by the physiological signals. These signals are obtained from a skin temperature sensor, a heart rate sensor, and a skin conductance sensor. This is an extension to the work presented in [37-39]. The four basic emotions observed in this project are happy (excited), sad (unhappy), angry (distressed) and neutral (relaxed).

The developed system can also be used for people at offices, school, universities and other institutions where wellbeing of computer users can be improved by continuous monitoring of emotions. Measured physiological parameters are wirelessly transmitted using Zigbee protocol. The range corresponds to the particular wireless system used. Figure 11 below shows graphs displaying real time signals from the sensor. These graphs show the real time signal for the three sensors for a particular time period. The amplitude of the signals is displayed on y-axis while the x-axis shows the time in seconds along with the starting time in text box.

A graphical user interface (GUI) has been designed to communicate with the hardware as well as display real-time emotion(s) for the monitored period. Based on the number of emotions to be recognized, it was decided to create four clusters using k-means clustering technique. In order to cluster the data, the training data collected from 40 individuals was used. The data has been collected from healthy individuals, including both male and female, with ages ranging from 18 to 72 years. This data was pre-processed for proper format to have effective cluster formation. For this study, Euclidean distance was chosen as the distance measure in forming the clusters.



Starting Time 7/01/2012 11:59:08 a.m.

Fig. 11. Sensor signal graphs of Skin temperature, Heart rate and Skin Conductance for determining Human emotions

Considering the five major attributes (variables), skin temperature (Stemp), heart rate (Beats per Minute (BPM)), first derivative of heart rate (d1bpm), skin conductance response (SCR) and absolute value of the first derivative of heart rate contributing to significant emotional changes values of the sensor readings, corresponding four clusters are visualized on a 2D plan as shown in figure 12 for effective generalization and computation. The matching clustered attribute values are specified in real time monitoring emotion recognition system for determining emotional status of the person.

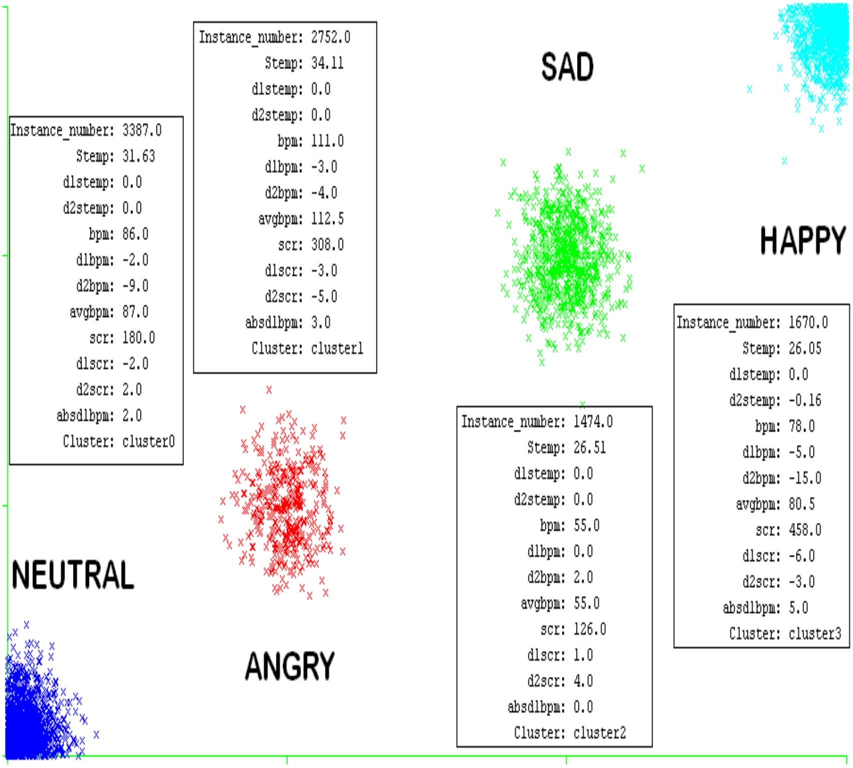


Fig. 12. Cluster formation using k-means algorithm

7 Practical Issues in Implementation

There are many issues involved while working on any technological system to be used by the elderly. There are some issues related to the acceptability of the system. The most important thing of practical implementation of this type of system is to convince the elderly that data of the individual life-style will not be misused. So a joint government-private enterprise may be able to bring the confidence among the elderly. Other issues such as use of camera or vision based sensors may not attract the acceptability among the elderly. The movement sensors having low-intensity light beam or the fan of the controller making noises may also put off the elderly.

A few practical issues have been faced while the trail runs are conducted:

1. The placement of the force sensor beneath the bed. Bed too heavy to lift for placing force sensor correctly in order to read status.
2. Sometimes No status change from Bed and Couch because of heavy weight.

3. Attachment of electrical sensor to the TV electrical plug point.
4. Some electrical sensor like TV and microwave were always ON due to the make feature of the respective electrical device.
5. Unable to plug Toilet force sensor to electrical point.

A lot of lessons are learnt from the above issues and necessary steps were taken to modify the system.

8 Conclusions and Future Works

A technology assisted smart home to care elderly people based on wireless sensor network has been investigated and developed. The system doesn't use camera or vision based system and thus acceptable to elderly community. The integrated system is able to support people who wish to live independently. The system can recognise the emotion as well as determine the wellness of the elderly. The developed system is robust and is possible to develop at a low cost.

Based on the building on the present system the improvement on the instrumentation system is carried out to develop a smart measurements system to reduce the size of the sensing system. The system will have the ability to incorporate additional household sensor. It is also planned to integrate the cellular modem into the controller.

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A Large-Area Sensor System Underneath the Floor for *Ambient Assisted Living* Applications

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Abstract. The SensFloor® is a textile-based large-area sensor system which is installed as an underlay underneath the flooring. It detects people moving across the floor, calculates their trajectories and distinguishes between foot steps and a fall. The use of capacitive proximity sensing instead of pressure sensing gives high flexibility in floor design. Besides elastic flooring like carpet and PVC, even non-elastic flooring like parquet or laminate is suitable. The SensFloor System enables a variety of different applications in the domain of *Ambient Assisted Living* (AAL) like fall detection, activity monitoring, energy savings, control of automatic doors, intrusion alarm and access control. Presence detection and self-test capabilities are additional features valuable in particular for security applications.

Keywords: smart floor, ambient assisted living, large-area sensor system, capacitive proximity sensors.

1 Introduction

Continued success in extending life through health care and shifts in the age structure of the population will lead to many more people reaching older ages than ever before. Longevity is a gain for the individual, a challenge for the social security systems, and a business opportunity, when developing new technologies, products and services for this underserved, and growing market.

The SensFloor project described here, is a typical example of *Ambient Assisted Living* (AAL) [1, 2]: An intelligent environment supports older people in their daily life and extends the time they can stay independently and safely at home [3]. The goal is to develop applications which assist people in their everyday life and to give the hardware needed to do this such a low profile that ideally it is completely hidden from view. This technology will therefore provide a platform for new services in the fields of building automation, comfort and convenience, as well as personal safety.

2 SensFloor Principle

SensFloor is a textile-based underlay with integrated microelectronic radio modules and capacitive proximity sensors. The underlay can be laid under practically

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any type of floor covering and is completely invisible. Whenever a person walks across the floor, the integrated sensors are activated and a sequence of location– and time-specific sensor events is broadcasted. These messages are received by one or more wireless control units. Depending on the application, the receivers can either be embedded devices or PC interfaces. Based on data processing algorithms such as pattern recognition, for instance, these signal patterns can be used to identify various types of events.

A schematic of the SensFloor system is shown in Fig. 1. When a person walks across the floor, sensor events are detected by the triangular sensor areas beneath the feet. Eight sensor areas are connected to each radio module in the SensFloor underlay. The sensor events are transmitted wirelessly (868 MHz) to the transceiver. Its function is to process the sensor events coming from the sensor modules, to analyse the time series and to reconstruct the movement trajectories of the people walking on the floor. Based on this information, the transceiver is able to control wireless switches which can operate e.g. automatic doors, alarm devices, lights, heating, and traffic counters. It is also possible to send commands to an already existing building control network. The proprietary message format contains the ID of the sensor and the information whether a change in signal intensity was detected. The message can be received and interpreted by any wireless device that works on the same frequency. In principle, missing a data packet due to collision in the transmission channel is possible. However, all applications of the SensFloor are based on evaluating whole populations of sensor events rather than single signals. Therefore, missing some events does not impair the overall function of the system.

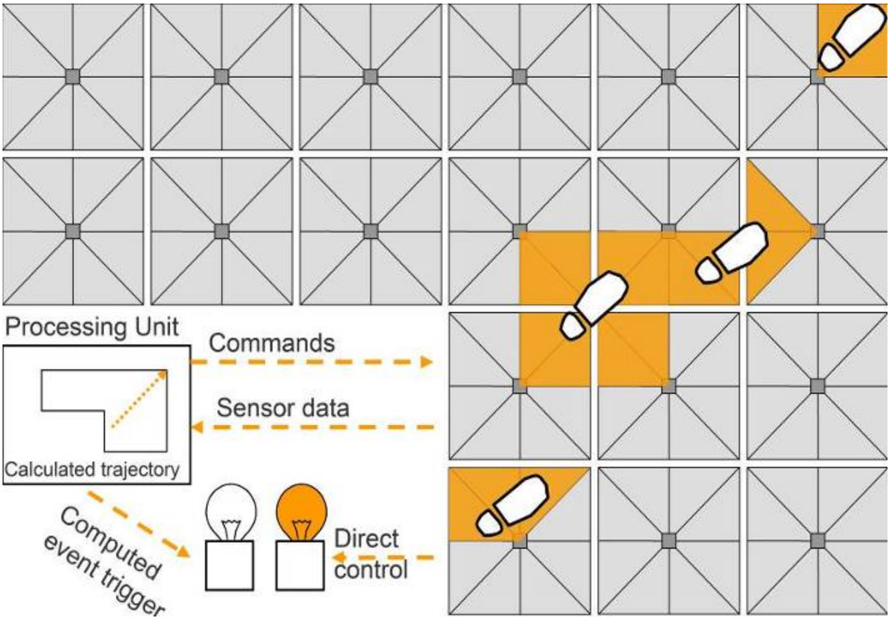

Fig. 1. Schematic of the system: Footsteps on the floor trigger sensor events The data are sent wirelessly (868 MHz) to the processing unit, which controls for instance home automation devices. Direct control of actuators is also possible (e.g. light or automatic doors).

For simple applications like the switching of light or the automatic opening of doors, signals from the microelectronic modules can operate actuators directly, without the necessity of a central processing unit. If required, bidirectional data transmission can be used to read the status of the sensor modules (self test), to reconfigure their transmission characteristics or to read the output of their internal temperature sensor. Based on this information, a temperature map of the entire floor can be obtained.

3 Capacitive Proximity Sensors

Several groups working on sensitive floors use pressure sensors for detecting persons walking on the floor [4]. High-resolution pressure sensing systems are also used to analyse gait for medical diagnoses [5]. Floor sensors which measure the pressure are often based on the piezo effect [6], change of resistance [7] or on the change of capacitance when a capacitor containing soft material is compressed [8]. However, a pressure-based floor sensor with high spatial resolution can only be realized underneath soft floor covering. To detect the presence of people through hard floor covering, it is necessary to find a measurement principle which works from a certain distance. Capacitive proximity sensors are ideal for this purpose.

Unlike a pressure sensor, a sensor underlay featuring capacitive proximity sensors can be installed even underneath tiles, stone or wood [9], has no mechanical parts and features self-test abilities and static signal recognition [10]. Basically, a capacitive proximity sensor comprises one or more sensor fields. Inside the SensFloor underlay, for instance, the sensor fields are formed by conductive textile-based triangular areas.

Every sensor field works like the plate of an ideal capacitor: simply spoken, the capacitance is determined by the proximity (d) of other conductive objects and the area (A) of geometric overlap between the plate and the objects. In addition, the capacitance depends on electrical characteristics of the plate, the object and the material between them. These so-called *dielectric characteristics* are usually expressed by the constant $\varepsilon_0 = 8.854.10^{-12}$ As/Vm and the value ε_r which describes the dielectric value in relation to the one of vacuum ($\varepsilon_r = 1$).

$$C = (\varepsilon_0 * \varepsilon_r * A) / d$$

The capacitance increases with the area of overlap and the dielectric value, and decreases with the distance of the object. Assuming constant material characteristics, the capacitance is directly proportional to the surface area of the objects and inversely proportional to their distance from the floor. Although the situation is more complex for non ideal capacitors such as the SensFloor underlay, the general principle can be used to detect the presence and even roughly the distance of objects such as the human body, which are at least partly conductive (see figure 2, left panel).

The capacitance C can be measured in many different ways [11]. One possibility is to let the sensor plates be part of electrical oscillators the resonance frequency of which is shifted when conductive objects approach the plates [12].

Another possibility is to probe how much electrical charge can be stored on the conductive plate when an electrical power source is connected [11]. The charge at a specific point in time t can be determined indirectly by measuring the charging voltage U(t) based on the following equation:

$$U(t) = U_0 * [1\text{-exp}(-t/RC)]$$

Here R is the constant combined resistance of the charging circuit and U_0 is the initial voltage at t=0. As U(t) increases from 0 towards U_0 over time following the defined function depicted in figure 3, right panel, the capacitance C can be determined by connecting the sensor field to a power source with known idle voltage and to measure the time t_c it takes until U(t) has reached a fixed value, e.g. 70% of U_0. Mostly, one is not interested in the absolute value of C but only in relative changes introduced by objects approaching the sensor field. Therefore, the actual values of U_0, R and ε_r are not important.

The charging time t_c is a measure for the presence and distance of the object as indicated by the three different situations ①, ② and ③ in figure 2. The approaching hand (Fig. 2, left) increases the capacitance C_2 and therefore the charging time is increased (Fig. 2, right). The charging time can be used as a measure for the distance and/or the conductivity of the approaching object.

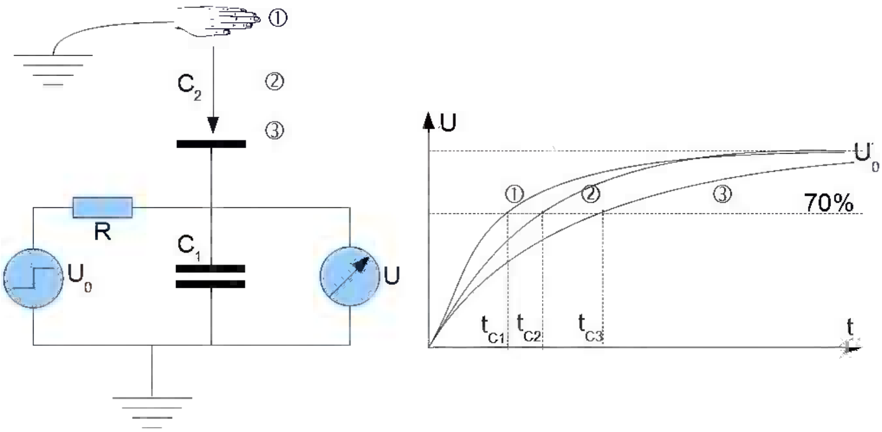

Fig. 2. Illustration of the measurement principle with a hand nearing the surface of a capacitor: The approaching hand (left) increases the capacitance C_2 and therefore the charging time is increased (right). The charging time is used as a measure for the distance and/or the conductivity of the approaching object.

As described in [11], the IO-pins of an ordinary microcontroller on a sensor module can be used alternatingly as power source to charge the sensor fields and as input to determine when the fixed voltage level is reached. The capacitance is measured by counting the processor cycles during the charging process.

Depending on the required spatial resolution, the SensFloor underlay, for instance, comprises up to four sensor modules per square meter. Each module is connected to power supply, ground and eight triangular sensor areas the capacitance of which is continuously measured by a microcontroller which is also used for the wireless data transmission and for filtering the sensor data.

In practical applications, the capacitance is influenced by slow variations of temperature and humidity in the environment and fast variations induced by noise from external electrical fields or jitter of the power supply. Therefore, the main task of the sensor module's signal processing is the reliable computation of the relative capacitance C_{rel} by means of drift compensation and filtering of noise. Principle steps of the signal processing are illustrated in figure 3. The absolute capacitance Cabs and relative capacitance Crel without noise are depicted in Fig. 3a). Fig. 3b) shows Crel derived from the difference between Cabs and Cref. The scale factor converts the difference into the desired range of 1 Byte. In Fig. 3c) the drifting Cref due to slow changes of environmental parameters is shown. A low pass reduces noise in Cabs with higher frequencies; an additional offset operation is used to distinguish between significant and non-significant changes of the signal variations (see Fig. 3d)). The offset as well as the degree of the low pass filter is controlled by the variance of the input signal Cabs.

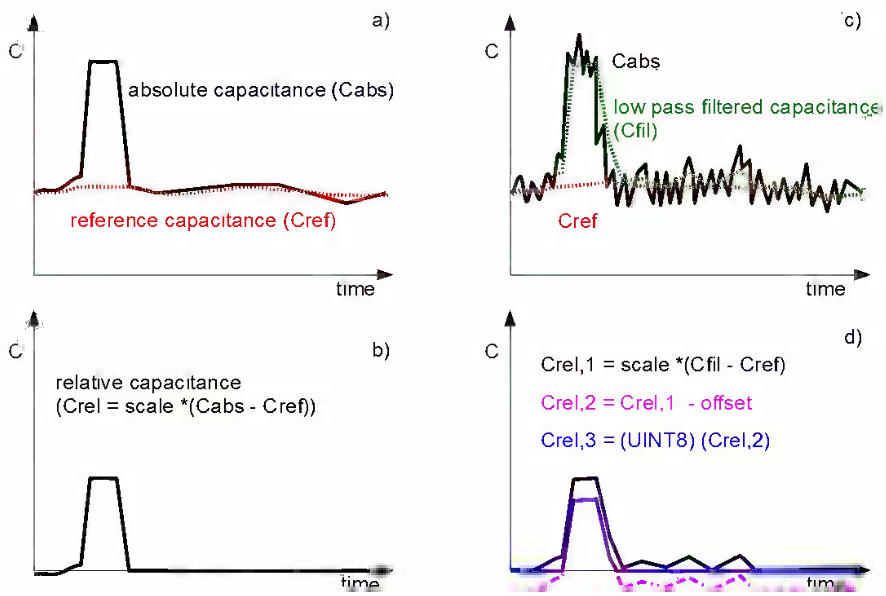

Fig. 3. Signal processing: a) absolute capacitance Cabs and relative capacitance Crel without noise b) Crel derived from the difference between Cabs and Cref. The scale factor converts the difference into the desired range of 1 Byte; c) drifting Cref due to slow changes of environmental parameters; d) a low pass reduces noise in Cabs with higher frequencies; an additional offset operation is used to distinguish between significant and non-significant changes of the signal variations. The offset as well as the degree of the low pass filter is controlled by the variance of the input signal Cabs.

If the sensor module detects a significant change of the relative capacitance an *event message* is generated and sent wirelessly to the central processing unit. Each event message contains an identification number of the sending module, an identification number to address the receiver, the actual state of the relative capacitance of the eight connected sensor fields and further information about the state of the sender. Additional to the event messages each module can generate messages periodically or on request. This helps to reduce the impact of data loss and provides self-test functionality.

Figures 4 illustrate the performance of the presented capacitive proximity sensor for real measured data in the situation of an approaching hand towards the SensFloor underlay. A first measurable increase of the capacitance occurs at a distance of 5cm. The sensor module delivers relative capacitances with 1 Byte resolution, the capacitances are measured with 10 Hz sampling rate, which is sufficient for tracking fast walking persons.

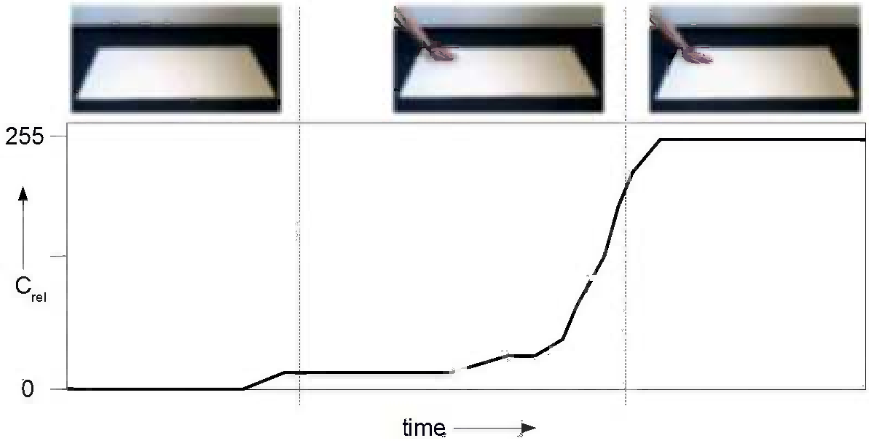

Fig. 4. Illustration of real measured capacitances, using a sensor patch of the size 50cm x 50cm with eight triangular sensor areas: sensor patch covered with PVC flooring, empty (left), approaching hand, no direct contact to the sensor patch (centre), hand directly in touch with the PVC surface (right)

4 Presence Detection and Tracking

The sensor modules of the SensFloor underlay deliver low noise continuous distance values in the range of 1 Byte with a default temporal resolution of 10 Hz and spatial resolution depending on the design of the textile-based underlay. Typically, resolutions of 32 sensor fields per square meter are used. If several sensor modules are combined in a larger installation, the SensFloor provides detailed information about the sensor activity in a room.

In order to support ambient assisted living applications, like fall detection, activity monitoring, energy savings or control of automatic doors, higher level information such as the presence of persons, their location, their movement direction, the number of persons and specific emergency situations must be extracted from the low-level information of the spatially distributed sensor data.

The following section presents a heuristic approach to detect and track single persons from the received sensor messages. The approach is able to track persons from their first step into the sensor area until they leave the installation. Therefore, it is possible to distinguish several persons in parallel, assuming that the persons keep a suitable distance to each other.

The algorithm uses two object levels to represent the information coming from the sensor floor. The lower object level represents footsteps generated by a person walking across the floor. As one step usually generates many sensor events, the algorithm tries at first to assign a newly received message to the representation of previous footsteps located in the direct neighbourhood. If no near footsteps exist, a new step is added to the representation. To account for the lifting of a foot, all sensor areas, which change their state from covered to free, are removed from the representation.

The second object level represents single persons which generate the footsteps of the first object level. If footstep data can not be assigned to an existing person, the database is enriched by the representation of a new person. The assignment bases on the evaluation of distances. By means of the variation of the footstep representation over time a person is tracked when walking across the sensor floor. If no footstep data can be assigned to the representation of a person for a given time period, this person will be removed from the database. It is important to note that an identification of an individual person is not possible.

Fig. 5 a) shows the video sequence of activated sensor areas for a person crossing a SensFloor mat in the size of 100cm x 150cm from left to right. The sensor density is 32 per square meter. The graphical user interface at the PC (Fig. 5b)) shows activated sensors and their intensity as different shades of green triangles and foot step cluster as magenta rectangles. In Fig. 5c) the representation of a person is indicated by a cyan rectangle and the trajectory in a blue line.

5 Smart Textile Fabrication

The integration of a microelectronic functionality into *Smart Textile*s requires all components, which are used in state-of-the-art printed circuit boards (PCBs) of the electronic devices we use today. Similar to PCBs, conductive lines for the power supply, data lines, and contact pads for the electronic devices, as well as connectors are required. If more than one layer is needed to avoid line crossings in the electronic circuit, via holes between the different layers are necessary. For wireless applications an antenna must be designed according to the chosen frequency.

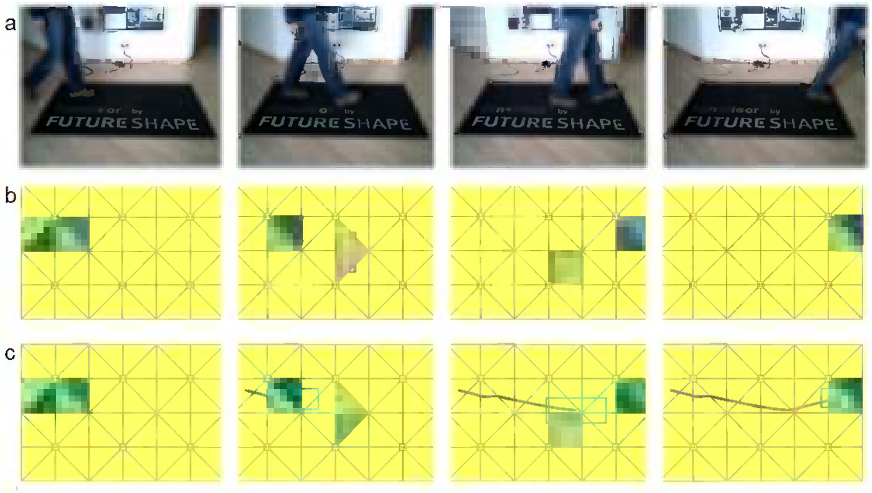

Fig. 5. Illustration of the implemented presence detection and object tracking a) video sequence of a walking person crossing the SensFloor mat from left to right b) visualization of the sensor signals (green triangles) and the computed footstep clusters (magenta rectangle); c) visualization of the sensor signals (green triangles), the representation of a person (cyan rectangle) and its recorded trajectory (blue line)

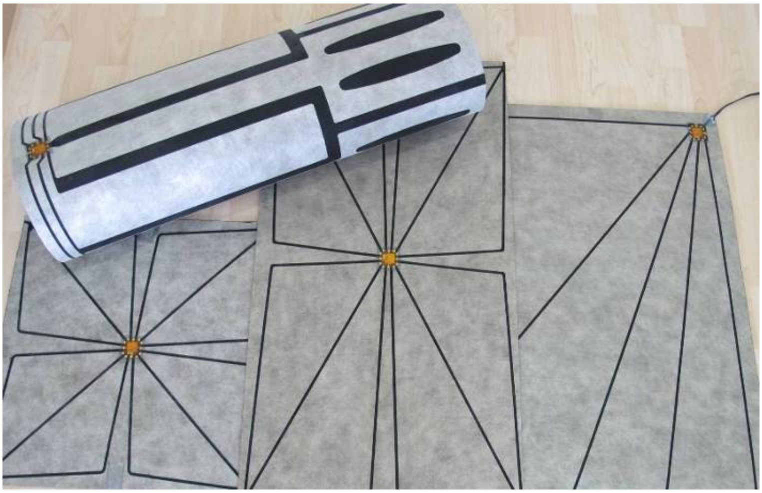

Fig. 6. SensFloor mats with different sensor pattern show the flexibility of the described *Smart Textile* technology, where the conductive surface layer is structured by cutting or laser abrasion. The roll features the key pattern of a floor piano.

An interdisciplinary approach on both, the microelectronic and the textile fabrication process is necessary to develop robust and marketable systems. In research, the materials have to be selected not only according to their electrical properties, but also regarding their feasibility during textile production, interconnect properties and life time endurance.

There are different technologies suitable for producing *Smart Textile* structures. A visionary approach is the 3-D weaving technology of conductive, non-conductive and even semiconducting threads, which could lead to interactive weave crossings and therefore enabling the formation of electronic circuits similar to array structures formed in silicon chips [13].

The textile industry already developed the weaving technology for implementing conductive fibres into fabrics. Many trademarks of fabrics are commercially available that contain different amounts of conductive filaments such as carbon, polymers, polymers with additional nickel, copper and silver coatings of varying thickness [14], steel or copper wires [15]. Their mechanical, chemical and electrical properties vary with the core material, diameter of the fibre, coating and doping materials [16]. Therefore a direct comparison between the different commercially available fibres is almost impossible. They have to be chosen according to the intended application. Less conductive materials are sufficient for sensor areas or electrostatic discharge protection (ESD). Whereas, highly conductive materials like metal filaments or metal-clad fibres are used for power and data lines, as well as antenna structures. Copper filaments are usually silver-plated to improve the corrosion resistance. For their use in textiles exposed to humidity they are insulated by an additional polyester or polyamide coating. Depending on the diameter of the interwoven metal filaments, they are used as single filaments or spun together with materials such as polyester to yarns. The suitability of such textile constructions for a reliable data transmission up to 100 MHz was shown in [17].

As an example, a self-organizing sensor network based on a Polyester fabric with interwoven silver-plated copper wires and embroidered capacitive sensor areas is described in [18]. The Advantage of this textile is that the interwoven copper wires have a very low resistance and are very robust during mechanical degradation tests. The disadvantage of this kind of *Smart Textile* is that the layout of the circuitry is either depending on the given weft and warp direction of the weaving process or an additional embroidering process has to be introduced, which needs aligning to the initial woven pattern. Embroidering of the whole conductive lines is a quite slow production process and is usually not compatible with roll-to-roll textile fabrication processes.

The method which is used for fabricating the SensFloor underlay described in this paper is laminating a uniform conductive layer on an insulating base material. The designed layout of the electronic circuit is delineated by cutting the conductive layer and removing it mechanically in the parts which must not be connected. This removing of the conductive layer can also be done by laser abrasion. Figure 6 shows different sensor pattern fabricated of an insulating polyester fleece, laminated with a conductive fleece with copper and tin plating. However, this technology will be suitable only, if most of the pattern is conductive and only small parts have to be removed for isolating purposes. Its big advantage is the high flexibility for creating new patterns for the sensor areas.

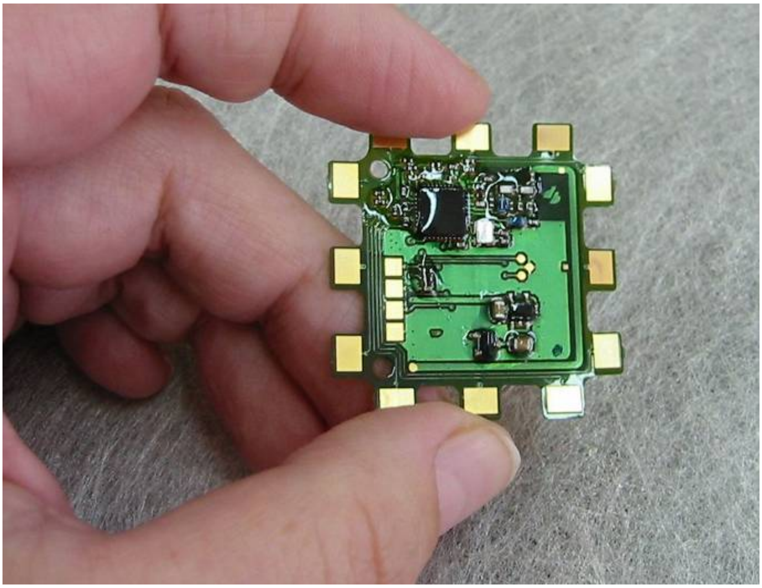

Fig. 7. The flexible Future-Shape radio module designed for the integration into a textile environment (size 3.5 x 3.5 cm²) featuring eight pads for sensor areas and four for the supply voltage, as well as an integrated antenna adapted to 868 MHz

For microelectronic integration into *Smart Textiles*, the difference in size and flexibility of textile fabrics and silicon based electronic devices must be considered. Further, the interconnect must have a low-ohmic characteristic, as well as high mechanical and chemical robustness. Moreover, short process cycles are a prerequisite for roll-to-roll production. The contact dimensions of integrated circuits are approximately 80 to 100 microns, leading to a contact pitch of 160 to 200 microns. Considering, that several conductive fibres within the fabric are needed for one contact to ensure failure tolerance, the resulting pitch of contacts in the textile is in the range of millimetres. There are different possibilities to bridge this gap and provide a smooth adaption of the soft and flexible textile to the solid microelectronic components.

A new packaging technology platform for stretchable electronics compatible to textiles has been developed in the European project STELLA [19]. Here an elastic conductive paste and a suited printing process for elastomeric films and non-woven carriers were developed. Depending on the kind and percentage of electrical conductive fillers the sheet resistance is in the range of 0.1 to 0.2 Ohm/square.

Commercially available flexible printed circuit boards, which are typically found in applications like cameras, printers, mobile phones, automotive and antennas, are a more straight forward approach. They are suitable for *Smart Textile* applications where no permanent stretch ability is required. Kapton® (Dupont) is one of the most commonly used polyimide-based films used here and can sustain the high temperatures of conventional soldering processes. The mounted flexible radio module used for the SensFloor application is shown in Figure 7. It has eight contact pads for connecting the capacitive sensor areas, as well as two contact pads for each, ground and power line. For the electrical interconnect, conductive adhesive, anisotropic adhesive or solder processes are possible. The choice is depending on the planned application and integration technology. Figure 8 shows the roll-to-roll bonding process where the integration of the radio modules into the sensor underlay is done.

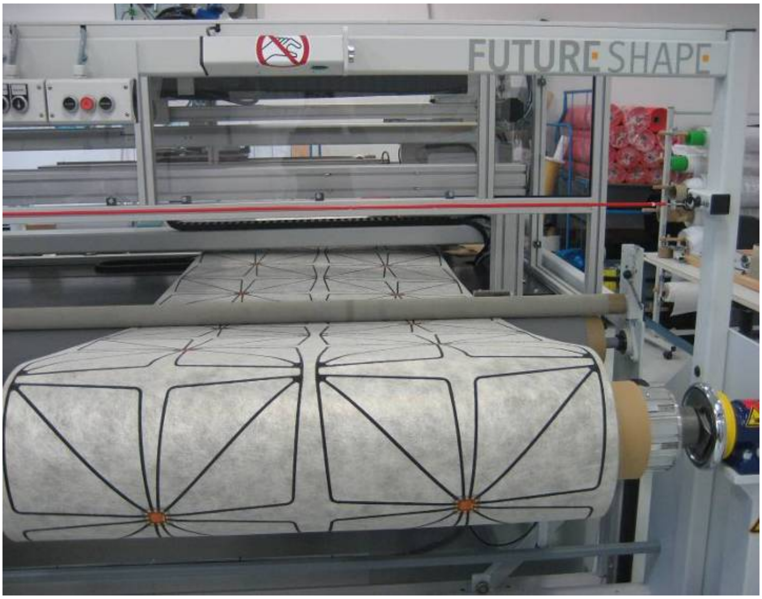

Fig. 8. Roll-to-roll production of the SensFloor underlay. In this picture the integration of the radio modules (four per square meter) into the sensor underlay is done.

6 SensFloor Installation

The SensFloor underlay is installed using a double-adhesive foil. The reels are connected electrically to each other ensuring redundancy for the power supply of the integrated modules. A second layer of the double-adhesive foil is used for the installation of the visible flooring. There are several advantages of this method compared to dispersion adhesives. The foil has very low emissions, the covering is immediately ready to accept traffic and loading and in case of a failure of the system, the flooring can be removed partially without destroying the flooring or the SensFloor underlay. Therefore it is possible to repair defective modules of the sensor floor easily. Figure 9 shows the installation of the SensFloor underlay within an apartment in a home for assisted living in Bremen, Germany. The reels are already electrically connected to each other.

Fig. 9. SensFloor underlay installation under progress at the assisted living apartment, which floor plan is depicted in Fig. 12 (living room, corridor). The underlay has four radio modules and 32 sensor areas per square meter.

A built-in power supply for 12 V DC is used to power the system (see Figure 10, left side). The power dissipation is approximately 0.21 Watt per module. Transceiver depicted in Figure 10, (right) analyses the wirelessly transmitted data from the sensor underlay and controls up to eight 240 Volts consumer directly or uses two potential-free relays as an interconnect to the home automation system. The interconnect via a serial interface to a PC is also possible.

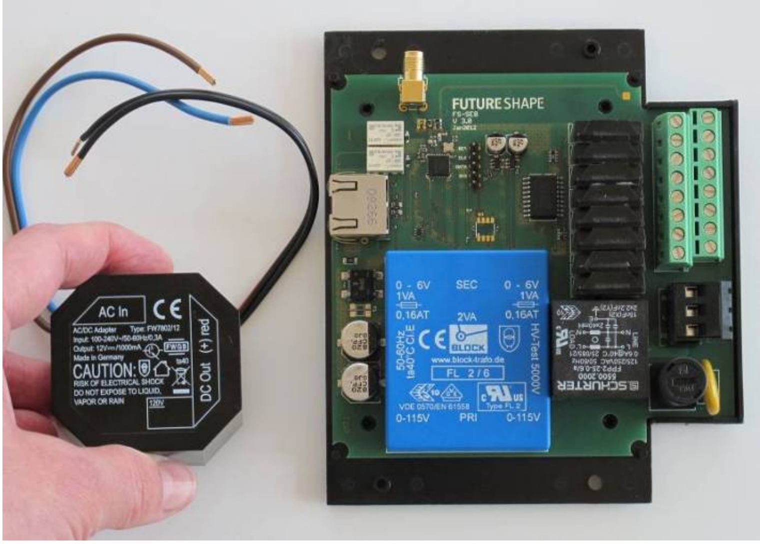

Fig. 10. The built-in power supply for the SensFloor underlay (left) and the SensFloor transceiver (right) for the controlling of *Ambient Assisted Living* applications. It features eight relays for 230 Volt devices, 2 potential-free relays, as well as a serial interface.

Fig. 11. Apartment from Fig. 9 after installation of carpet flooring on the SensFloor underlay. The SensFloor underlay is completely hidden from sight.

The areas outside of the active sensor underlay will be covered with a non-functional underlay in the same thickness as the SensFloor underlay before installing the visible flooring. Figure 11 shows the same room as depicted in Figure 9 with a carpet flooring on top. The SensFloor underlay is completely invisible. Moreover, the softness of the underlay improves the damping comfort for walking and reduces the impact in case of a fall.

7 Functions for Ambient Assisted Living

Figure 12 show the floor plan of the assisted living apartment in Bremen, Germany. The following applications can be supported by the SensFloor system and are depicted in numbers in Figure 12:

(1) In combination with radio-frequency identification (RFID) or an electronic key access control at the entrance door the SensFloor systems achieves a higher security level, because after authorised opening the door the floor detects if no one, one person or more persons enter the room. This gives additional information and therefore more accuracy to the presence detection of the system.

(2) Activity monitoring is a typical application for large-area sensor systems. For instance, even if there are rooms where no sensor floor is installed (here beneath the tiles in the bathroom), knowing that a person has entered the bathroom and did not get out for a longer period as usual, an alarm is triggered. Another typical example is that the person did not get out of the bed for long time.

(3) Switching on an orientation light as soon as someone is in contact with the floor is an easy task for a sensor floor. However, in case of a patient with dementia, disorientation when getting out of bed at night in the dark is a frequent reason for falls and serious injuries.

(4) The installation of an additional bed sensor provides data about sleep movements and is able to analyse situations where the patient became unconscious or suffers a seizure or a stroke. This allows for a faster respond of the system compared to activity monitoring.

(5) Pattern recognition and evaluation of the intensity of the signals from the capacitive proximity is used for the fall detection on the SensFloor [10].

(6) The control of automatic doors can be improved easily, because when analyzing the direction of the movement, it opens solely if a person walks directly towards it and saves unnecessary opening cycles for persons walking in parallel to the door or merely standing in front of it.

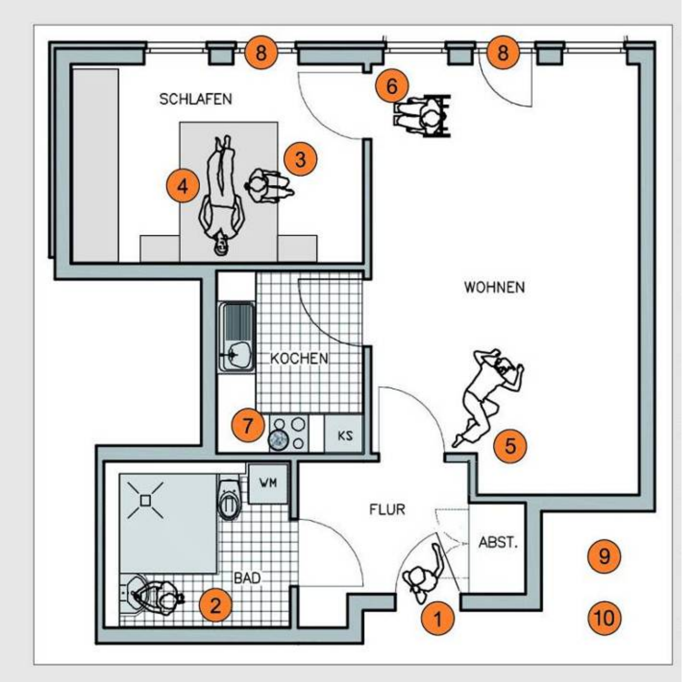

Fig. 12. SensFloor installation within an assisted living apartment: (1) access control, (2) activity monitoring, (3) orientation light, (4) bed sensor, (5) fall detection, (6) control of automatic doors, (7) switch-off at leave, (8) intrusion alarm, (9) energy saving by switching lights and (10) heating control based on presence detection

(7) Using presence detection, it is possible to switch-off dangerous heating appliances when the last person leaves the apartment or goes to bed.

(8) Intrusion alarm is set, when foot steps are starting at the windows.

(9) Consequently switching off the light if the last person leaves the room is an important feature for saving energy.

The presence control of the light and the heating system for energy saving is also possible. For several application scenarios the capacitive proximity sensors have distinct advantages compared to the already existing pressure sensors [4]. By adapting the application software the system is also able to count people.

8 Results

If demographic change is to be considered an opportunity rather than an issue, it is necessary to ask more than just how to enable senior citizens and care-dependent patients to stay at home as long as possible before they are inevitably admitted to care facilities. An approach such as this only leads to delayed perpetuation of the current state rather than account for the fact that not only the needs but also abilities, lifestyles and financial resources of senior citizens change over time. They participate in technological progress, thus benefitting not only from both additional safety as well as state-of-the-art medical treatment but also from increased comfort and enhanced quality of life.

The growing market for high-grade, accessible and cross-generational housing, for age-appropriate mobility and communication solutions as well as wellness options proves that demographic change can even open up new market opportunities. For technical systems to be successful they must manage to combine the basic need for personal and health protection with the pursuit of an increased quality of life, including aspects such as data privacy and protection of personal integrity. It is therefore important that the use of technical assistance systems is discreet and private.

While systems like the sensor mats are established in professional care for e.g. patients suffering from dementia and considered as a helpful support for carers, the large-area sensor floor is a new and relatively unknown technology. However, first pilot installations show its high potential and acceptance in public buildings.

For private care things might be different: Former and current projects in the field of AAL have shown, that it often proves difficult to convince the actual users, namely care-dependent citizens, of the necessity and advantages of an innovative assistance system even when it meets all above-mentioned criteria. Reservations rarely pertain to technical systems in general but rather to changes in the users' personal environment and in their daily routine when AAL components are installed at home. While younger builders and those not in need of care less frequently make these types of reservations, they seldom show adequate far-sightedness concerning the care necessary at a later stage of life.

This conflict can be neatly avoided by developing systems that already appeal economically and technically to younger people and can be upgraded easily to provide assistance functions if necessary as the needs of the users change with time. Base components could already be installed individually during the construction or renovating phase and would provide standard home automation functions such as burglar alarm, light control and comfort functions that quickly become a natural part of the resident's life. AAL functions such as fall prevention, emergency detection systems and activity monitoring as provided by SensFloor, for example, can then easily be added at a later stage without further adjustment by the user.

Table 1. Application scenarios for different user groups

AAL Application Scenarios	Hospital	Nursing home	Private care	Assisted living home	Elderly singles
Prevent dementia patients from straying away	♦	♦	♦		
Leaving the bed triggers alarm for persons at risk to fall	♦	♦	♦		
Prevents falls by switching on light	♦	♦	♦	♦	♦
Fire prevention by switching off heating appliances at leave			♦	♦	♦
Fall detection	♦	♦	♦	♦	♦
Activity monitoring	♦	♦		♦	♦
Energy savings	♦	♦	♦	♦	♦

To achieve this goal the system must present more than just specialised AAL functions as younger builders are rarely open to advice in that regard. Once local installers are acquainted with the system, however, knowing its advantages and how it is to be installed, and if the system proves compatible with existing technology, easily integrating itself and its functions into standard construction procedures, these installers will recommend it to the builder or architect, as is done with in-floor heating systems, for example.

In conclusion, the ideal assistance system is characterised by providing improved safety, comfort and health while at the same time only being noticeable because of its functions. It is otherwise invisible as it is integrated individually into the personal environment of each user. Furthermore it supplies younger target groups with appealing functions that can be upgraded easily, installed by trained professionals and are compatible to existing technology. A variety of possible applications scenarios for different user is summarized in table 1.

9 Conclusions

The SensFloor system described in this chapter is a typical example of an ambient technology. It is installed underneath the flooring and therefore completely hidden from sight. It enables a variety of different applications in the sense of *Ambient Assisted Living* like fall detection, activity monitoring, energy savings, control of automatic doors, intrusion alarm and access control. Presence detection and self-test capabilities are additional features valuable especially for security applications. First pilot installations show its functionality and potential for future home automation and care systems.

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Footwear-Based Wearable Sensors for Physical Activity Monitoring

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Abstract. Monitoring of posture allocations and activities is important for such applications as physical activity management, energy expenditure estimation, stroke rehabilitation and others. At present, accurate devices rely on multiple sensors distributed on the body and thus may be too obtrusive for everyday use. This chapter presents an overview of a novel wearable footwear sensor (SmartShoe), which is capable of very accurate recognition of most common postures and activities while being minimally intrusive to the subject. SmartShoe relies on capturing information from patterns of heel acceleration and plantar pressure to differentiate weight-bearing and non-weight-bearing activities (such as for example, sitting and standing, walking/jogging and cycling). Validation results obtained in several studies demonstrate applicability to widely varying populations such as healthy individuals and individuals post-stroke, while achieving high (95%-98%) average accuracy of posture and activity classification, high (root-mean-square error of 0.69 METs) accuracy of energy expenditure prediction, and reliable (error of 2.6–18.6%) identification of temporal gait parameters. High accuracy and minimal intrusiveness of SmartShoe should enable its use in a wide range of research and clinical applications.

Keywords: smartshoe, energy expenditure prediction, temporal gait parameters.

1 Introduction

Monitoring of Physical Activity (PA), Energy Expenditure (EE) and human gait is used in a variety of clinical and research applications. For example, measuring of daily PA and EE has been widely used in obesity research. Many adults worldwide are overweight or obese [1]. Obesity is due to a sustained positive energy balance (energy intake > energy expenditure) and is typically coupled with low levels of physical activity (i.e. sedentary lifestyles) [2]. Weight management programs designed to prevent and treat obesity recommend increased energy expenditure via lifestyle alterations that increase physical activity levels. There is also evidence that sedentary posture allocations may be related to obesity. For example, [3] reported that obese individuals spent more time seated and less time ambulating than lean individuals. Overall, obesity researchers are constantly looking for better ways to quantify PA and EE of individuals in their natural environment.

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Physical Activity Classification (PAC) and gait monitoring also have direct applications in post-stroke rehabilitation. People who experience a stroke are less active than healthy individuals and many of them require assistance to walk [4]. Even individuals with relatively good recovery of walking ability are often inactive and may not be able to effectively access their community. This inactivity leads to further deconditioning, which in turn plays a role in the development of secondary complications and may increase the risk of another stroke and an increased dependence in activities of daily living. Common goals of stroke survivors' are to improve their physical activity level and social participation [5]. Monitoring of physical activity of during post-stroke rehabilitation may provide important insight into the effectiveness of rehabilitation interventions. Monitoring of gait and comparing the performance of the affected limb versus the unaffected one during walking provide important information on the symmetry of the person's walking pattern. These measures provide an assessment of motor recovery after stroke [6].

Accelerometry has emerged as one of the most popular approaches to PA monitoring and EE prediction [7–10]. Although useful, single accelerometers have one major drawback in that they are not very accurate in recognition of static postures and thus tend to significantly underestimate the energy cost of such postures (e.g., household tasks) and non-weight-bearing activities (e.g. cycling). As a result, they fail to explain a considerable portion of energy expenditure variability in daily living tasks. Accelerometers also do not behave well in estimation of gait in individuals with neurological disorders due to the disease-related changes in the gait patterns.

One strategy to improve PA, EE and gait estimation has been to use multiple sensors. For example, wrist, upper arm, hip, ankle and thigh accelerometers were used in [11]; chest and wrist accelerometers were used in [12]; 9 different sensor locations on the body were used in [13]. Such multi-sensor systems typically have very limited practical applicability due to high intrusiveness and high subject burden. Several attempts have been made to recognize postures and activities using multiple sensor modalities concentrated in a single location on the body. In [14] authors achieved 90-95% accuracy of recognizing 8-10 various activities from a single unit including 8 different sensors: accelerometer, audio, light, high-frequency light, barometric pressure, humidity, temperature and compass. However, not all activities are recognized equally well by the current devices. For example, [12] did not differentiate between sitting and standing, grouping these postures together. Other studies [13] reported challenges in recognizing such activities as cycling and ascending and descending stairs. Overall, reliable recognition of static postures and typical daily activities, energy expenditure and gait from a single location of the body remains a challenge.

Shoe-based sensors have been used in several studies with the focus of these efforts to detect gait characteristics rather than classify activity or estimate energy expenditure [9], [15], [16]. An array of 32 plantar pressure sensors was used in [17] to classify locomotion (walking, running and up/down stairs) with reported accuracies of ~98%. A study reported in [18] used a foot-contact pedometer to estimate daily energy expenditure but did not attempt to classify postures or specific activities with the device. These results suggest that shoe-based sensors have the potential to accurately classify posture/activity and estimate energy expenditure, while also being minimally obtrusive.

This chapter presents the SmartShoe – a sensor system integrated into conventional footwear and its applications for monitoring of PA, EE and gait, which has been developed in the Laboratory of Ambient and Wearable Systems at the University of Alabama. The chapter is organized as follows. First, the hardware of SmartShoe sensor system is presented. Second, two human studies, one on healthy and one on individuals recovering after stroke are presented as fundamental datasets for development of the classification and estimation models. Third, a method for PA classification both in healthy and post-stroke individuals is presented. Fourth, a method for measuring gait parameters in post-stroke and healthy individuals is described. Fifth, a branched approach for accurate prediction of EE from SmartShoe data is presented. Finally, the concluding remarks summarize the findings.

2 Sensor System

SmartShoe sensor system combines a 3D accelerometer and several pressure sensors placed in the insole of conventional footwear. The choice of sensing modalities and placement in the insole serves several purposes.

First, in most cultures people wear shoes or equivalent footwear throughout the day, every day. SmartShoe presents zero additional burden to wear in comparison to conventional activity monitors that require additional effort to attach to wrist, waist, hips, chest, etc. From research perspective, reducing the wear burden improves compliance and reduces the observation effect where subjects change behaviour in response to monitoring. From consumer perspective, reducing wear burden enhances usability of the product and improves chances for long-term use.

Second, the body support in many postures and activities comes fully or partially through feet. Thus, monitoring plantar pressure can tell volumes about postures and activities of a person. Specifically, use of pressure sensors can differentiate between weight-bearing and non-weight-bearing postures and activities such as sitting and standing, walking and cycling that many accelerometer-based PA monitors fail to distinguish.

Third, motion of the feet is characteristic to different activities. For example, the trajectory of a foot during cycling is substantially different from trajectory during walking. Using an accelerometer provides additional information about the activity being performed as well as delivers a metric of intensity of motion in a given activity.

Fourth, positioning of the sensor system in footwear enables monitoring of several important human characteristics such as gait parameters (for example, very important characteristic of rehabilitation progress for stroke patients) or body weight. Overall, the sensor system of SmartShoe provides a highly informative data stream that is capable of extensive characterization of human PA.

Over the years, several variations of the SmartShoe design have been assembled and tested in human studies. The following description refers to one of the most recent designs used in [19], [20]. Each shoe incorporates five pressure-sensitive resistors (0.5” FSR, Interlink Electronics, Camarillo, CA, USA) embedded in a flexible insole and positioned under the critical points of contact: heel, 1st, 3rd and 5th metatarsal heads and the great toe (hallux) – total of 10 sensors from the two shoes. In addition to pressure sensors, a 3-dimensional ±3g MEMS accelerometer (ADXL335, Analog Devices, Norwood, MA, USA) was attached to the heel of each shoe.

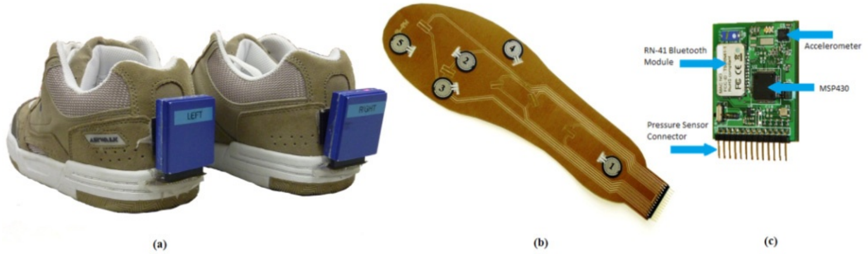

Fig. 1. SmartShoe device: (a) Overall view of the shoe device with attached accelerometer, battery and power switch on the back; (b) Pressure-sensitive insole with 5 pressure sensors: heel (1), 3rd metatarsal head (2), 1st metatarsal head (3), 5th metatarsal head (4), hallux (5); (c) The wireless electronics board

All sensors were sampled at 400Hz by a microcontroller from MSP430 series (MSP430, Texas Instruments, Dallas, TX, USA), averaged to effective rate of 25Hz and sent to a Windows Mobile smart phone via a Bluetooth link implemented by using a Serial Port Profile communication module (RN-41, Roving Networks, Los Gatos, CA, USA). The phone contained custom-designed software that performed time synchronization of the data coming from the shoes and logging of the data as text files [21].

3 Human Studies

Since SmartShoe’s primary purpose is monitoring of humans in their everyday life, human studies are necessary to develop and validate computer algorithms that process sensor information. The methods presented in this chapter have been developed in two human subject experiments, which were conducted at the Clarkson University, Postdam, NY, USA. All studies were approved by the Institutional Review Board and informed consent was obtained from all subjects participating in the studies.

In the first human study (Human Study 1, HS1) data collection was performed on a group of 16 human subjects, 8 males and 8 females (Table 1) with stable weight (<2 kg weight fluctuation) over the previous 6 months [19], [22].

Individuals were healthy, non-smokers who were sedentary to moderately active (< 2-3 bouts of exercise/wk or participation in any sporting activities < 3 hr/wk). Participants reported to the laboratory in a fasted state (>4 hours) for a single three hour visit. Each participant was asked to perform a variety of postures/activities while wearing a portable metabolic mask system and the appropriately sized SmartShoe. The postures included sitting and standing and the activities included walking, jogging, stair ascent/descent and cycling (Table 2). Each posture/activity trial was six minutes in duration and subjects were allowed five minutes rest between trials. Trial order was not randomized. Metabolic data was not collected during stair ascent/descent, as this activity was performed in two-story stairwell which did not allow establishment of metabolic steady-state. Participants were not restricted in the way they assumed postures and or performed activities. Standing did not require any specialized equipment; a chair with a rigid back was used for sitting; walking/jogging was performed on a motorized treadmill (Gait Trainer 1, Biodex, Shirley, NY); cycling utilized a bicycle ergometer (Erogomedic 828E, Monark, Sweden). During the fidgeting trials, subjects were allowed to make small, normal leg movements (e.g. crossing legs or shifting weight). To determine metabolic rate and associated EE during each trial, we measured the rates of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) using a portable open circuit respirometry system (Oxycon Mobile, Viasys, Yorba Linda, CA). Before the experimental trials, the system was calibrated with known gas concentrations and volumes. For each trial, the subjects were allowed four minutes to reach steady state (no significant increase in VO_2 during the final two minutes and a respiratory exchange ratio (RER) <1.0) and calculated the average VO_2 and VCO_2 (ml/sec) during minutes 4-6 of each trial. We calculated gross metabolic rate (W/kg) from VO_2 and VCO_2 using a standard equation [23]. Energy expenditure was then calculated from VO_2 and RER.

The subjects also performed two experiments where they were asked to walk over a GAITRite® commercial test system (CIR Systems, Inc.). This commercial system provides reliable automated means of measuring spatial and temporal parameters of gait consisting on an electronic walkway with a useful area of 61x366 cm (24x144 inches) connected to a Windows based PC.

Table 1. Subject characteristics of HS1

	Men (N=8)		Women (N=8)	
	Mean ± SD	Range	**Mean ± SD**	Range
Weight, kg	86.8 ± 20.0	59.0-119.8	66.9 ± 16.8	48.6-100.9
Height, in.	69.3 ± 1.8	67.0-72.0	64.3 ± 2.8	61.0-70.0
BMI, kg·m^{-2}	28.0 ± 5.9	18.9-35.8	25.4 ± 7.3	18.1-39.4
Age, yr	25.6 ± 8.6	18-44	24.4 ± 3.9	18-29
Shoe size, US	10.3 ± 0.6	9.5-11.0	7.9 ± 0.7	7.0-9.0

Table 2. Protocol of HS1

Trial	Description	Assigned Posture/Activity Group
1	Sit quietly	Sit
2	Stand quietly	Stand
	Level Treadmill Walking/Jogging	
3	0.67 m/s (1.5 mph)	Walk/Jog
4	1.11 m/s (2.5 mph)	Walk/Jog
5	1.56 m/s (3.5 mph)	Walk/Jog
6	2.00 m/s (4.5 mph) - jogging	Walk/Jog
7	Ascend/Descend stairs*	
8	Sit with fidgeting	Sit
9	Stand with fidgeting	Stand
	Treadmill Walking	
10	1.11 m/s +1.5% grade	Walk/Jog
11	1.11 m/s -1.5% grade	Walk/Jog
12	1.11 m/s with 10% of body weight held in bags (5% held by each hand)	Walk/Jog
	Cycling:	
13	50W, 50 rpm	Cycle
14	100W, 75rpm	Cycle

* Metabolic data not collected during stair ascent/descent

In the second human study (Human Study 2, HS2) data was collected from subjects with stroke who had completed their rehabilitation [20]. Inclusion criteria were: at least three months post stroke, able to walk in their home and/or community without physical assistance, able to stand without physical assistance for >60 seconds, able to transition from sitting to standing from a standard height chair without physical assistance, and Mini Mental State Exam score >=24. Subjects were excluded if they had some other health condition, which affected their ability to stand or walk independently. Subject characteristics are listed in Table 3. All subjects wore appropriately sized SmartShoe during the experiment. Sensor data were collected in three main postures: sitting, standing, and walking. Within the sitting posture there were four positions that the subjects assumed: self-selected comfortable position, sitting with both feet on the floor, sitting with legs crossed so that one foot was on the floor and one foot off the floor, and reaching forward while sitting. In standing there were also four positions the subjects assumed: static standing in a comfortable position, standing while reaching towards the unaffected side, standing while reaching towards the affected side, and standing while reaching forward. Data was collected in four different positions within sitting and standing in order to better mimic real life conditions. Subjects walked under two conditions: self-selected, comfortable pace and fastest, safe pace. Subjects walked continuously over a level surface for 1 minute. Each position and walking condition was performed 4 times. During the data collection process all subjects were supervised by a physical therapist for safety. The order in which each position trial was performed was randomized. The degree of motor and mobility function of the subjects was tested by the following clinical tests: Berg Balance Scale, lower extremity motor section of the Fugl Meyer, and Stroke Impact Scale 16.

Table 3. Subject characteristics of HS2

Age (years)	60.1 (9.9)
Time since stroke (months)	51.7 (45.1)
Berg Balance Scale	44.3 (11.7)
Fugl Meyer LE motor score	25.8 (5.9)
Self-selected gait speed (m/s)	0.69 (0.35)
Stroke Impact Scale 16	65.4 (22.0)
Mini Mental State Exam	28.7 (2.1)
Ankle Foot Orthotic Use (yes:no)	2:6

Post-stroke subjects were also asked to walk over GAITRite® in two different manners: walking comfortably and walking as fast as they could. Both of these experiments were repeated four times.

It should be noted that the sensor hardware on SmartShoe devices in HS1 and HS2 was slightly different. Specifically, the shoes in HS1 were equipped with currently discontinued accelerometer LIS3L02AS4 and the wireless connection was performed over WISAN link [24] rather than Bluetooth. The difference in type of used accelerometer does not interfere with general principle of operation of SmartShoe, but due to differences in calibration does allow use of models developed in HS1 for subjects in HS2.

4 Models for Posture and Activity Recognition

Posture and activity recognition models were developed for subjects participating in HS1 and HS2. In both cases the developed models were group models that could be applied to any subject without individual calibration. The goal was develop PAC models for healthy individuals and for individuals post-stroke and show that SmartShoe can reliably perform classification in healthy individuals and individuals with neurological impairment affecting lower extremity.

Before training of classification models, minimal pre-processing consisting of feature vector forming and normalization was applied to the sensor data. Feature vectors were formed to represent a time period (epoch) of two seconds in duration. Time histories of pressure and acceleration from both shoes were used as follows. A single sample of data from a shoe is represented by vector

$$\mathrm{S} = \{\mathrm{A}_{\mathrm{AP}}, \mathrm{A}_{\mathrm{ML}}, \mathrm{A}_{\mathrm{SI}}, \mathrm{P}_{\mathrm{H}}, \mathrm{P}_{5\mathrm{M}}, \mathrm{P}_{3\mathrm{M}}, \mathrm{P}_{1\mathrm{M}}, \mathrm{P}_{\mathrm{HX}}\},$$

where A_{AP} is anterior-posterior acceleration, A_{ML} is medial-lateral acceleration, A_{SI} is superior-inferior acceleration, P_{H} is heel pressure, $\mathrm{P}_{\mathrm{M5}}, \mathrm{P}_{\mathrm{M3}}, \mathrm{P}_{\mathrm{M1}}$ are pressures from 5th, 3rd and 1st metatarsal head sensors, respectively, and P_{HX} is pressure from the hallux sensor. The time series of data from both shoes were combined as

$$\mathrm{f_i} = \{\mathrm{S_L}, \mathrm{S_R}\}_\mathrm{i}, \mathrm{i} = \{1, \dots, \mathrm{M}\},$$

where $\mathrm{S_L}, \mathrm{S_R}$ are the data samples from the left and right shoe, respectively, and M is the length of time series. Depending on sensor configuration, the data samples either included all or just some of the sensor signals from $\mathrm{f_i}$.The size of the feature vectors with all sensors included consisted of 800 values (2 shoes x 8 sensors x 25 samples per second x 2 seconds = 800 samples). The features vectors from all epochs in the experiment were combined in a feature matrix $\bar{F}_{e,d}$ and all columns of the matrix were normalized to the scale of [0,1]. Normalization used max values of acceleration and pressure acquired over all subjects and experiments.

The pairs of feature vectors and class labels $\{F_{e,d}, L_e\}$ were presented to a supervised classification algorithm for training and validation. The labels L_e represented a distinct class {1-sitting, 2-standing, 3-walk/jog, 4-ascending stairs, 5-descending stairs, 6-cycling}. The selected classifier was a variation of Support Vector Machine (SVM) implemented as a Matlab package (libSVM, [25]). The SVM classifier utilized Gaussian kernel $(\exp\left(-\gamma * (\boldsymbol{u} - \boldsymbol{v})^{2))}\right)$.) The best values of parameter C=10 (cost of misclassification) and $\gamma = 0.0156$ (width of Gaussian kernel) were found in grid search procedure varying C as $C = 10^x$, $x = \{-1, \dots, 3\}$ and γ as $\gamma = 2^y$, $y = \{-8, \dots, -2\}$.

A four-fold holdout cross-validation procedure was used to develop six-class ('sit', 'stand', 'walk/jog', 'cycle', 'ascend stairs', 'descend stairs') prediction models for HS1. In this procedure three quarters of the data was used to train the SVM classifier. The remaining one-quarter of the data was tested against the SVM classifier to determine accuracy. The folds were organized by including the full dataset from each individual subject that belonged to a fold. Data from the same subject were never split between training and validation sets.

Due to a smaller dataset, a leave-one-out cross validation procedure was used to develop three-class ('sit', 'stand', 'walk') PAC models for HS2. All the data in one posture for all the subjects except one were used to train the group SVM classifier. The data from the one subject that was not used to create the SVM classifier was validated for accuracy using the group SVM classifier created by the data from the other subjects. This process was repeated such that the acceleration and pressure data from each subject was validated for accuracy against the group SVM classifiers created from all the other subjects combined.

Accuracy of PAC models in both cases were estimated by building cumulative confusion matrices that combine validation results from all subjects in the population. Postures predicted by the SVM classifier were compared against actual postures. The rows of the table correspond to actual postures/activities assumed by subjects and columns correspond to predicted postures/activities made by the classifier from the sensor data. Results from four folds or leave-one-out validation were averaged for reporting. The average classification precision was defined as the ratio of the sum of diagonal elements of the confusion matrix (True Positives) to the sum of all elements of the confusion matrix (True Positives + False Positives).

Figure 2 shows 6-class average validation accuracy obtained by the group model obtained for healthy individuals in HS1. The population average accuracy for a model that included data from all acceleration and pressure sensors was 95.2±3.5%. The highest recognition accuracy of 98.1%±2.3% was achieved in a configuration using sensors $\{A_{AP}, A_{ML}, A_{SI}, P_H, P_{1M,}P_{HX}\}$. The population-cumulative confusion matrix for recognition using the best sensor configuration is presented in Figure 3.

Figure 4 shows 3-class cumulative confusion matrix for recognition of postures and activities in post-stroke individuals from HS2. The recognition accuracy is comparable to that achieved on healthy individuals, thus indicating ability of

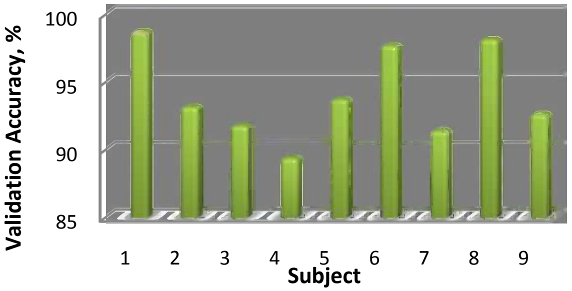

Fig. 2. Average validation accuracy in 6-class recognition for each healthy individual from HS1

Predicted class

Actual class	Sit	Stand	Walk Jog	Ascend	Descend	Cycle	**Class-specific recall**
Sit	*3202*	*2*	*0*	*0*	*0*	*14*	**0.99**
Stand	*7*	*3191*	*2*	*7*	*0*	*0*	**0.99**
Walk/Jog	*0*	*0*	*10647*	*74*	*0*	*0*	**0.99**
Ascend	*0*	*0*	*34*	*500*	*15*	*1*	**0.90**
Descend	*0*	*0*	*41*	*60*	*405*	*0*	**0.80**
Cycle	*146*	*3*	*0*	*0*	*0*	*2539*	**0.94**
Class-specific precision	**0.95**	**1.00**	**0.99**	**0.78**	**0.96**	**0.99**	**0.98**

Fig. 3. Population-cumulative confusion matrix showing classification accuracy for the best sensor configuration { A_{AP}, A_{ML}, A_{SI}, P_H, P_{M1}, P_{HX}.} for healthy individuals in HS1. Numbers in italic show the quantity of 2-second time intervals for each class. Class-specific recall is the proportion of a class instances that were correctly identified. It is defined as a ratio of the respective diagonal value to the sum of a row. Class-specific precision is the proportion of the predicted class cases that were correct. It is defined as a ratio of the corresponding diagonal value to the sum of a column.

		Sit	Stand	Walk	**Class-specific recall**
Actual class	Sit	*3515*	*21*	*86*	**0.97**
	Stand	*7*	*3409*	*290*	**0.91**
	Walk	*0*	*22*	*1548*	**0.99**
	Class-specific precision	**0.99**	**0.98**	**0.82**	**0.95**

Fig. 4. Population-cumulative confusion matrix for 3-class PA recognition for individuals post-stroke (HS2)

SmartShoe accurately classify PA both of healthy and individuals with neurological disorders.

Overall, SmartShoe in these experiments achieved greater recognition rates than previous experiments that used similar postures and activities in healthy individuals. For example, [26] demonstrated 88% percent accuracy with 6 postures and activities and [7] reported accuracies of 87% (cycling) to 100% (running) using a single hip-mounted accelerometer. SmartShoe also matched or outperformed other single-location methodologies such as [14] which reported a 95% accuracy across 8 postures and activities. SmartShoe also demonstrated excellent recognition rates for identifying basic postures (sitting, standing, and walking) in people with stroke. SmartShoe is unique compared to other accelerometer-based sensors that have been studied in people with stroke to detect movement as they required multiple sensor placements that may not be comfortable or convenient for patients to wear [10], [27], [28]. While further tests and development of SmartShoe system are needed for large-scale validation, these results show high accuracy of PA monitoring across different population indicating robustness of the proposed approach.

5 Detection of Temporal Gait Parameters

Algorithms for extracting gait parameters were developed to show that SmartShoe is capable of accurate estimation of temporal gait parameters both in healthy and in individuals post-stroke and thus can be used in place of a stationary gait lab that is typically used to assess gait of individuals.

Data obtained from the pressure sensors was used to estimate the following temporal gait parameters: cadence, step time, cycle time, percentage of gait cycle in swing for each lower extremity, percentage of gait cycle in stance for each lower extremity, percentage of gait cycle in single limb support for each lower extremity, and percentage of gait cycle in double limb support for each lower extremity. The algorithm for estimation of gait parameters was based purely on pressure signals as methods based on inertial sensors may present significant differences between unaffected and affected limb in subjects with gait abnormalities due to stroke and significant individual traits [27].

The first step in estimation of gait parameters is detection of Heel-Strike (H) and Toe-Off (T) events as these events define contact of the foot with the ground. To detect H and T events, for each foot the sum of all 5 pressure sensors was calculated as:

$$sumFSR(t) = \sum_{s=1}^{5} FSR_s(t)$$

Next, an adaptive threshold τ was calculated by defining the average maxima and minima of the *sumFSR* signal. For the *sumFSR* signal, all the local maxima and local minima were obtained. The average of this data points defined maxima and minima thresholds as:

$$Th_{MAX} = \frac{1}{k}\sum_{a=1}^{k} Max_a; Th_{MIN} = \frac{1}{l}\sum_{b=1}^{l} Min_b,$$

where Max_a, for *a*=1,2,…,*k*, are the local maxima data points found and Min_b, *b*=1,2,…,*l* are the local minima data points found. The difference between Th_{MAX} and Th_{MIN} defined the threshold used to obtain the H and T:

$$\tau = Th_{MIN} + \alpha(Th_{MAX} - Th_{MIN}),$$

where α=0.1725 was a free parameter that resulted in the highest accuracy of recognition of temporal gait parameters. The intersection points of the threshold τ with the *sumFSR* signal correspond to H and T events (Figure 5).

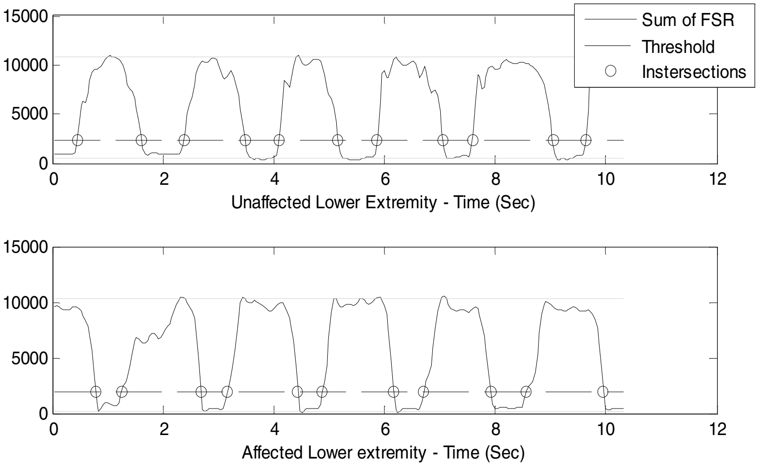

Fig. 5. Heel-strike and Toe-off detection for unaffected (top) and affected (bottom) lower extremity of a post-stroke subject from HS2

To discriminate detection of H from T, a simple criterion was met: immediate points located before a local minima were considered T and those located immediately after a local minima were considered H. After all H and T points were identified for both feet, they were used to obtain the corresponding temporal gait parameters (Table 4).

Table 4. Temporal gait parameters calculation from detected H and T events. The second letter indicates the foot (L for left and R for right).

Parameter	Left	Right
Gait cycle time	$GTL_i = HL_{i+1} - HL_i$	$GTR_j = HR_{j+1} - HR_j$
Step time %	$SL_i = HL_i - HR_j \quad (HL_i > HR_j)$	$SR_j = HR_j - HL_i \quad (HL_i < HR_j)$
Stance %	$STL_i = \frac{TL_i - HL_i}{GTL_i} x100$	$STR_j = \frac{TR_j - HR_j}{GTR_j} x100$
Swing %	$SWL_i = \frac{HL_{i+1} - TL_i}{GTL_i} x100$	$SWR_j = \frac{HR_{j+1} - TR_j}{GTR_j} x100$
Single support %	$SSL_i = \frac{HR_{j+1} - TR_j}{GTL_i} x100$	$SSR_j = \frac{HL_{i+1} - TL_i}{GTR_j} x100$
Double support %	$DSL_i = \left(\frac{(TL_i - HR_j) + (TR_j - HL_i)}{GTL_i} \right) x100$	$DSR_j = \left(\frac{(TR_j - HL_i) + (TL_i - HR_j)}{GTR_j} \right) x1$

Sensor data from SmartShoe collected in HS1 and HS2 (healthy and post-stroke subjects, respectively), were collected and processed by the algorithm described above. The temporal gait parameters computed from SmartShoe sensors were compared to the data collected with the GAITRite® system. These results are shown in the Tables 5 and 6.

For healthy subjects, the statistical *t-test* using a confidence value of 95% was performed to compare data recorded with the GAITRite® system and the shoe-based wearable sensor; no significant difference in the mean across all subjects for cadence (p>0.35) and for parameters calculated for each lower extremity (p>0.18) was observed.

Results from the *t-test* statistical test with a 95% confidence for post-stroke subjects also did not show significant difference between GAITRite® and the shoe-based wearable sensor for cadence (p>0.29) and for parameters calculated for each lower extremity (p>0.51).

The relative difference between SmartShoe estimates related to the GAITRite® results was calculated for both types of subjects as:

Difference %= |Shoe– Gaitrite| / Gaitrite x 100,

where *'Gaitrite'* represents the GAITRite® reported gait parameters used as the gold standard and *'Shoe'* represents the gait parameters obtained from the shoe-based wearable sensor. Table 7 shows the relative error obtained for the healthy subjects. Table 8 shows relative error obtained for subjects post-stroke, separated by type of experiment, e.g. walking comfortable and walking fast.

Table 5. Comparison of temporal gait parameters measured by SmartShoe and GAITRite® system for the healthy individuals in HS1

	Healthy Subjects					
	GAITRite®			**SmartShoe**		
	Mean	**95% CI**		**Mean**	**95% CI**	
Cadente (Step/sec)	1.31	1.20	1.42	1.24	1.13	1.35
	Left foot					
	GAITRite®			**SmartShoe**		
	Mean	**95% CI**		**Mean**	**95% CI**	
Step time (Sec)	0.59	0.56	0.63	0.63	0.58	0.69
Cycle time (Sec)	1.17	1.06	1.28	1.17	1.07	1.28
Swing %	35.65	32.81	38.49	37.58	34.52	40.64
Stance %	60.77	56.07	65.47	59.17	54.54	63.80
Single support %	35.77	32.90	38.64	36.27	33.37	39.17
Double support %	24.75	22.32	27.18	22.58	20.11	25.05
	Right foot					
	GAITRite®			**SmartShoe**		
	Mean	**95% CI**		**Mean**	**95% CI**	
Step time (Sec)	0.61	0.58	0.64	0.61	0.58	0.65
Cycle time (Sec)	1.16	1.06	1.27	1.21	1.14	1.28
Swing %	36.01	33.10	38.92	37.18	36.18	38.18
Stance %	60.43	55.73	65.12	62.82	61.83	63.82
Single support %	35.89	33.00	38.77	37.07	36.13	38.02
Double support %	25.10	22.68	27.52	26.06	24.53	27.59

These results indicate that SmartShoe sensors were able to accurately identify temporal aspects of the gait cycle in both healthy people and individuals post-stroke. The relative difference from GAITRite® for these temporal aspects of the gait cycle, except for step time, were comparable to the error in other acceleration and pressure based methods of determining gait parameters [27]. Computation of temporal gait parameters using only pressure signals was used since pressure measurements from the insole of a shoe involve a more direct representation of the walking behavior. When using accelerometers the signal tends to be noisy since acceleration is the derivative of velocity and involves higher frequency components [9].

Table 6. Comparison of temporal gait parameters measured by SmartShoe and GAITRite® system for the individuals post-stroke (HS2)

	Subjects post-stroke					
	GAITRite®			**SmartShoe**		
	Mean	**95% CI**		**Mean**	**95% CI**	
Cadente (Step/sec)	1.07	0.95	1.18	1.00	0.92	1.07
	Affected Lower Extremity					
	GAITRite®			**SmartShoe**		
	Mean	**95% CI**		**Mean**	**95% CI**	
Step time (Sec)	0.67	0.59	0.74	0.65	0.59	0.71
Cycle time (Sec)	1.34	1.25	1.44	1.37	1.26	1.48
Swing %	32.80	30.58	35.02	33.73	31.67	35.80
Stance %	67.20	64.98	69.42	66.88	64.79	68.98
Single support %	34.17	32.36	35.97	34.66	32.74	36.59
Double support %	32.82	29.94	35.71	31.60	29.17	34.03
	Unaffected Lower Extremity					
	GAITRite®			**SmartShoe**		
	Mean	**95% CI**		**Mean**	**95% CI**	
Step time (Sec)	0.68	0.61	0.74	0.69	0.62	0.76
Cycle time (Sec)	1.34	1.24	1.44	1.37	1.25	1.48
Swing %	34.22	32.38	36.06	34.26	32.18	36.35
Stance %	65.79	63.95	67.62	65.75	63.66	67.84
Single support %	32.88	30.61	35.14	32.08	29.85	34.31
Double support %	33.26	30.42	36.11	33.99	30.78	37.21

Table 7. Relative difference between SmartShoe and GAITRite® estimates (healthy subjects, HS1)

	Healthy subjects		
Parameter	**Relative Difference %**	**95% CI**	
Cadence	10.4	8.4	12.5
Step time (Sec)	18.4	14.8	22.1
Cycle time (Sec)	3.1	2.4	3.9
Swing %	6.4	5.3	7.4
Stance %	3.6	2.9	4.4
Single support %	5.5	4.3	6.7
Double support %	10.9	8.3	13.6

Table 8. Relative difference between SmartShoe and GAITRite® estimates (post-stroke subjects, HS2)

	Comfortable Walking			Fast Walking		
Parameter	**Relative Difference %**	**95% CI**		**Relative Difference %**	**95% CI**	
Cadence	9.5	5.2	13.8	8.8	4.8	12.8
Step time	18.67	10.2	27.2	15.4	11.1	19.7
cycle time	2.70	1.6	3.8	2.6	1.7	3.4
swing %	8.56	5.9	11.2	10.7	7.8	13.7
stance %	3.37	2.7	4.0	5.2	3.7	6.8
S support %	7.78	5.3	10.3	9.9	7.1	12.6
D support %	10.3	8.3	12.2	12.4	9.5	15.3

As discussed in the literature, with the use of gyroscopes it is possible to estimate spatial gait parameters in addition to temporal parameters as long as its axis is parallel to the mediolateral axis [29]. However, it is important to notice that the use of gyroscopes require more sophisticated techniques for Heel-strike and Toe-off detection, i.e., wavelet transform, finite-impulse response, etc., since gait events are transitory signals that cannot be properly enhanced by simple traditional signal processing. Also, gyroscopes are more sensitive to temperature and mechanical shock that may be significant in non-laboratory conditions. Thus, use of pressure information in SmartShoe provides a simple and reliable way to estimate gait parameters.

6 Estimation of Caloric Energy Expernditure

Being capable of differentiating between weight-bearing and non-weight bearing activities, SmartShoe is capable of accurate energy expenditure estimation by reducing prediction error in sedentary postures (for example, sitting vs standing) and some activities (walking/jogging vs cycling). Presented below is a methodology for estimating EE of healthy individuals from HS1.

The EE estimation model was constructed as a group model: the data used for training were pooled from several subjects and such model was then tested on the validation set which included data from subject(s) that were not in the training set. The EE model was by branched activity (“Sit”, “Stand”, “Walk”, “Cycle”) where activity prediction was performed using the SVM classifier from Section 4 and each activity (branch) had its own regression for predicting EE (Figure 6). To match time resolution of the system used measure EE during the experiments, EE estimation was based on the sensor data collected during 1 minute intervals in which subjects were in metabolic steady state (minutes 4-6 of each trial of HS1). Each one minute recording resulted in approximately 1500 (25Hz·60s) points of pressure and acceleration data per channel. For the 16 subjects who participated in the study there were a total of 208 such recordings.

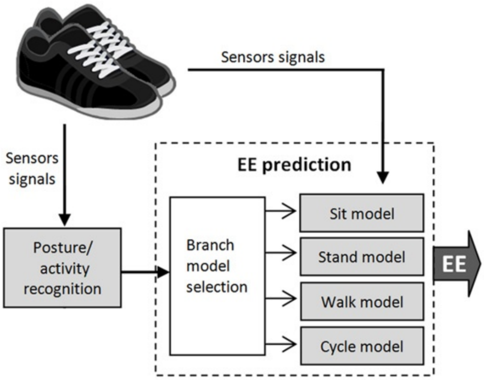

Fig. 6. Branched approach to EE estimation from SmartShoe sensors

The following data were available for each recording:

- response variable: energy expenditure, EE, kcal·min^{-1};
- anthropometric measurements (weight, height, BMI, age, gender, shoe size);
- triaxial accelerometer signals: superior-inferior acceleration ($\boldsymbol{A_{SI}}$), medial-lateral acceleration ($\boldsymbol{A_{ML}}$), anterior-posterior acceleration($\boldsymbol{A_{AP}}$);
- pressure sensors signals: heel (P_H), 3rd meta (P_{M3}), 1st meta (P_{M1}), 5th meta (P_{M5}), and hallux (P_{HL});

Accelerometer and pressure sensors signals expressed in ADC units (as digitized by a 12-bit analog-to-digital converter) were preprocessed to extract meaningful metrics to be used as predictors for the model. For each sensor all of the following metrics were extracted and tested for the inclusion into each model as predictors:

- coefficient of variation (*cv*);
- standard deviation (*std*);
- number of “zero crossings” (*zc*), i.e. number of times the signal crosses its median normalized by the signal's length;
- entropy H of the distribution X of signal values (*ent*) computed as: $H(X) = -\Sigma\, pk \log pk$, where pk is the relative frequency of values fallen into the k-th interval (out of 20 equally sized intervals) in the sample distribution of signal values.

These metrics were selected for the following reasons. Coefficient of variation and standard deviation of a signal should indicate the amount of motion produced during recording. Number of median crossings is an indicator of the frequency of changes in the signal, which is important to identify the intensity of motion (like speed of walking). Entropy reflects the distribution of the signal across the range of its values and is a valuable predictor for walking due to the fact that as speed of walking increases the time of feet ground contact decreases relative to the swing time and, thus, signal values become more uniformly distributed across the range, leading to an increased entropy. These metrics were used as possible predictors for the ordinary least squares linear regression. The transformed predictors (log, inverse and square root) and interactions (as products of 2 or more candidate predictors) were also considered as separate linear terms within regression. **A** separate model was constructed for each type posture/activity: “Sit”, “Stand”, “Walk” and “Cycle”. The selection of the most significant set of predictors was performed using the forward selection procedure. “Leave-one-out” approach was used for cross-validation when training and predicting the EE for each type of activity for every subject. For every left out subject all of the data related to this subject were removed from the training set for each model. Model (coefficients) computed using the rest of the subjects was then used to predict the EE for all trials of the left out subject. The best set of predictors had to provide the best fit (by producing the maximum adjusted coefficient of determination, R^2_{adj} and the minimum Akaike Information Criterion, AIC) in the training step and the best predictive performance (the minimum Mean Squared Error, MSE and the minimum Mean Absolute Error, MAE) in the validation step.

Two models were built using the described approach. First model, BACC-PS included metrics derived from signals from all shoe sensors. The second model, BACC did not include metrics derived from pressure sensors in the forward selection process. Comparison of BACC-PS and BACC models is performed to evaluate impact of pressure sensors on accuracy of EE estimation in SmartShoe.

Measured and predicted energy expenditure values in kcal·min^{-1} for each experiment were then converted to METs by representing the energy expenditure for any given epoch as a multiple of resting energy expenditure. Energy expenditure during quiet sitting was used as a valid estimate of resting metabolic rate for each subject. This conversion was performed to enable direct comparison of results obtained by SmartShoe with those that have been recently published [8], [30], [31]. Tables 9 and 10 show the regression coefficients obtained for EE estimation model for BACC-PS and BACC models, respectively. Per-minute error (Root-Mean-Square Error, RMSE) for BACC-PS and BACC models is shown in Table 11. Aggregated error of 0.69 METS for BACC-PS model that includes pressure sensor data is lower than 0.78 METS error for BACC model that uses only accelerometer signals. Figure 7 shows Bland-Altman plots constructed for both EE, kcal•min-1 and EE, METs prediction) for both models. The common characteristic for both models is that the accuracy of prediction is slightly better for small than for large EE values (i.e. better accuracy for sitting and standing).

Table 9. Regression coefficients in the BACC-PS model

Branch model	Predictors, units	Average values of coefficients	CV of coefficients
Sit	<Intercept>	5.2862	0.0687
	Weight, kg	0.0352	0.0504
	log(BMI), log(kg·m^{-2})	-1.7594	-0.0854
	log($A_{SI.CV}$)	0.1331	0.0550
Stand	<Intercept>	4.5758	0.1148
	Weight, kg	0.0364	0.0580
	log(BMI), log(kg·m^{-2})	-1.8339	-0.1147
	$P_{H.STD} \cdot P_{M3.STD} \cdot P_{M1.STD} \cdot P_{M5.STD}$, (ADC units)	$2.04 \cdot 10^{-12}$	0.0452
Walk	<Intercept>	0.8406	0.9662
	Weight, kg	0.0745	0.0387
	log(BMI), log(kg·m^{-2})	-2.0513	-0.1431
	$P_{M1.ZC} \cdot P_{M5.ZC}$	277.0277	0.1246
	$A_{AP.STD}$, ADC units	0.0001	2.3021
	$A_{SI.ENT} \cdot A_{ML.ENT} \cdot A_{AP.ENT}$	0.3542	0.0805
Cycle	<Intercept>	-2.7295	-0.6184
	Weight, kg	0.0770	0.1067
	log(BMI), log(kg·m^{-2})	-1.4837	-0.4172
	$A_{SI.STD}$, ADC units	0.0014	0.3445
	$P_{M1.STD} \cdot P_{M5.STD}$, (ADC units)	$8.7 \cdot 10^{-6}$	0.1069
	$A_{AP.ENT}$	1.9431	0.1685

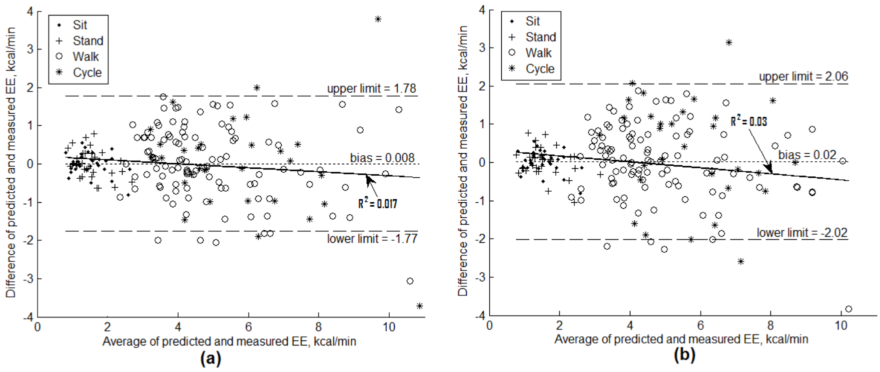

Fig. 7. Bland-Altman plots for BACC-PS (a) and BACC (b) models

Table 10. Regression coefficients in the BACC model

Branch model	Predictors, units	Average values of coefficients	CV of coefficients
Sit	<Intercept>	5.2862	0.0687
	Weight, kg	0.0352	0.0504
	log(BMI), log(kg·m^{-2})	-1.7594	-0.0854
	log($A_{SI.CV}$)	0.1331	0.0550
Stand	<Intercept>	6.5636	0.0713
	Weight, kg	0.0418	0.0525
	log(BMI), log(kg·m^{-2})	-2.2433	-0.0875
	log($A_{ML.CV}$), ADC units	0.1530	0.0513
Walk	<Intercept>	1.4050	0.5644
	Weight, kg	0.0798	0.0364
	log(BMI), log(kg·m^{-2})	-2.7433	-0.1086
	$A_{AP.STD}$, ADC units	0.0012	0.1661
	$A_{AP.ENT}$·$A_{ML.ENT}$·$A_{SI.ENT}$	0.5812	0.0248
Cycle	<Intercept>	11.4745	0.2013
	Weight, kg	0.1220	0.0703
	log(BMI), log(kg·m^{-2})	-5.4759	-0.1583
	$A_{SI.STD}$, ADC units	0.0058	0.0746

Table 11. Per-minute error (Root-Mean-Square Error, RMSE) for BACC-PS and BACC models

Model	Branch model	Number of 1-min recordings	$RMSE_{MET}$	Bias, METs
BACC-PS	Sit	31	0.26	0.0276
	Stand	32	0.32	0.0323
	Walk	103	0.76	0.0466
	Cycle	31	0.97	0.0617
	Aggregated	**197**	**0.69**	**0.0437**
BACC	Sit	31	0.26	0.0276
	Stand	32	0.33	0.0408
	Walk	103	0.75	0.0385
	Cycle	31	1.30	0.1517
	Aggregated	**197**	**0.77**	**0.0550**

These results suggest that SmartShoe can be used to accurately predict energy expenditure during typical postures/physical activities. The EE prediction accuracy of SmartShoe with activity-branched EE prediction models is similar to recent studies that have used single accelerometers, multiple accelerometers and heart rate/accelerometer combinations. Choi et al. [32] used Actigraph accelerometers placed at the hip, wrist and/or ankle and distributed lag and spline modeling to predict EE and reported RMSE of ~0.6 kcal/min (0.5 METs) across a range of activities with the accelerometer mounted at the ankle. Staudenmayer et al. [30] used a single hip-mounted accelerometer (Actigraph) and an artificial neural network to estimate EE of a variety of activites and reported an RMSE of 0.75 and

1.22 METs using activity and minute-by-minute estimates of EE, respectively. Brage et al. [8] used a device that measured heart rate and accelerometry (Actiheart) to estimate EE and found that the RMSE was within [0.87, 1.11] METs during walking/running activities. Thus, the results obtained from SmartShoe are at least as accurate or better compared to other recently proposed methodologies. These results also support use of plantar pressure as a way to improve EE prediction compared to a single accelerometer. As shown in Table 11, inclusion of pressure sensor metrics (BACC-PS model) reduced RMSE approximately 10% (from 0.77 to 0.69 METs). Inclusion of pressure metrics also improves EE estimation within an activity branch. In particular, there was a significant decrease in error rate in estimating cycling EE. This likely due to the changes in plantar pressure that are associated with changes in the intensity of cycling, something difficult to detect using an accelerometer. Overall, results of this experiment suggest that signals arising from acceleration and insole pressure of shoes can be used to accurately estimate the EE associated with common daily postures and activities.

7 Conclusions

The results from SmartShoe testing in various applications demonstrate its high accuracy and minimal intrusiveness. From the point of view of PA classification, SmartShoe was able to differentiate postures and activities that remain a challenge to other monitors (walking vs. cycling, sitting vs. standing, ascending stairs vs. descending stairs). SmartShoe demonstrated comparable accuracy of PAC both healthy and post-stroke individuals thus demonstrating applicability to various populations without a need for individual calibration. Temporal gait parameter estimation was reliable both in healthy and neurologically impaired individuals, justifying use of plantar pressure sensors for gait event detection. Branched approach to energy expenditure estimation resulted in accurate measurement comparable to the best methodologies available today. Again, use of pressure information improved the accuracy of EE estimation. Overall, SmartShoe is versatile multi-sensor system that is minimally intrusive through incorporation into everyday wear (shoes) and that can provide accurate monitoring of postures, activities, energy expenditure and gait of individuals in daily life.

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Continuous-Wave Photoacoustic-Based Sensor for the Detection of Aqueous Glucose: Towards Non-invasive and Continuous Glycemia Sensing

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Abstract. Measurement of blood glucose levels (BGLs) is a basic procedure that diabetic patients need to perform several times a day. The conventional standard protocol for on-site measurement, despite several advantages such as portability, low cost, fast response time, and ease of operation, is based on the finger-prick technique to extract blood samples. This process is invasive and cannot provide continuous monitoring.

Towards the achievement of non-invasive and continuous BGL monitoring, we have developed two measurement methods based on the continuous-wave photoacoustic (CW-PA) protocol and we performed preliminary *in vitro* tests with aqueous solutions. The first method relies on the measurement of the frequency shift induced by the change in the composition of the propagation medium. This method is equivalent to an acoustic velocity measurement and provides high sensitivity but no selectivity to glucose compound. The second approach utilizes simultaneous optical excitation at two wavelengths for compound-selective measurements. After correcting the frequency shift mentioned previously, this protocol allows measurements equivalent to a differential absorption coefficient one at the two wavelengths used. It then combines the advantages of absorption spectroscopy without the limitation from scattering due to the use of acoustic detection. Furthermore, the combination of the two methods can be generalized to systems involving more than one changing parameter by using not only two optical wavelengths for the excitation sequence but also several pairs of wavelength sequentially.

These methods then represent an important step forward the non-invasive, selective, and continuous measurements of glucose compound concentrations from a complex mixture, typically blood.

Keywords: photoacoustic method, continuous blood glucose level.

1 Introduction

Diabetes mellitus, often referred to as diabetes, is a metabolic disorder characterized by hyperglycaemia (raised blood sugar levels) as result of less control of the

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blood glucose level (BGL). Despite symptoms being first described several hundred years ago, this illness still remains a serious issue for an estimated affected population exceeding three-hundred million worldwide in 2011 [1,2], which is further increasing yearly. Despite extensive investigations covering a large span of expertise, the exact cause of diabetes remains unknown, and a cure has not been discovered yet. However, repeated and long-lasting exposure of internal organs to abnormally elevated blood glucose levels (*i.e.* hyperglycaemia) results in multiple complications and premature mortality [3,4]. Tremendous efforts have been dedicated to the design of an efficient way to manually monitor and control the patients' BGL.

Maintaining the BGL within the range of variation expected from a healthy person is the basic way to prevent any impact of diabetes on patient health. Every time the BGL exceeds the normal limit value (several standards for diagnosis, always in the range of 100-200 mg/dL, have been published by the American Diabetes Association [5,6]), adequate actions, which depend on the type of diabetes, should be taken to restore its level into the admissible range. However, the efforts and actions taken to lower the BGL also expose the patients to hypoglycemia, which corresponds to a BGL lower than the limit value in the range of 70 mg/dL. Accurate, on-site and real time detection of BGL then represents the first essential step for adequate decision making. Several commercially available sensors based on blood sample analysis have been developed by numerous companies over the past decades. Exhibiting compact size, low cost, good accuracy, and fast response [7-9], they have rapidly become popular around the world and have provided huge benefits to the diabetic population. However, despite tremendous efforts to reduce the blood sample volume and the discomfort of finger-pricking, they are still invasive and cannot provide continuous monitoring, which is the corner-stone for optimal BGL control [10,11].

As one step towards this ultimate goal, minimally invasive (MI) techniques have been developed, where the sensor head reduced to its minimum size is inserted subcutaneously in direct contact with body fluids, while the signal processing and so on are performed outside the body. This approach consequently reduces the invasiveness and enables continuous monitoring over several consecutive days [12-15]. Furthermore, systems coupling a MI sensor to a insulin pump [16,17] have been developed for automatic delivery based on continuous measurements and a complex algorithm [18].

At the time of this writing, three products have received FDA approval for commercialization in the US. However, two main issues limit their application: (1) the frequent need for calibration and (2) the lack of accuracy in some particular cases, so that patients are additionally advised to perform regular tests before taking any potential life-threatening action. Implanting a device in the body, despite the reduced size and minimizing discomfort, also poses the problem of biofouling [15]. As a result, the commercially available products claimed to provide accurate readings for at least three days, although researchers are developing strategies for long-term readings for at least several months [20,21].

Though less advanced than the MI protocols, the non-invasive (NI) methods remain without question the preferred solution for sensing mechanism [22,23]. However, two main issues should be addressed with particular care: sensitivity and selectivity. Among the various alternative techniques that have been extensively studied over the last few decades [24-29], near-infrared (NIR) absorption spectroscopy has probably received the most interest because the method takes advantage of the finger-print-like absorption coefficient of each compound in this wavelength range. Furthermore, recent development of multivariate statistical algorithms applied to chemical problems (chemometric-based methods) have further extended the scope of the NIR approach by allowing efficient extraction of parameters of interest from complex systems involving simultaneous measurements at several wavelengths. However, this method's sensitivity to the scattering properties of tissues has prevented, at the time of this writing, any device to reach the commercialization stage. In contrast, photoacoustic-based (PA) protocols, which use optical excitation and mechanical detection, show great potential, offering high sensitivity and robustness against the scattering properties of tissue [28]. As a result, despite several on-going issues specific to the PA approach, we chose to investigate it and have developed two methods that focus on a very specific part of the detection scheme.

This chapter provides an overview of these methodologies, from the basic concept of PA technique to the *in vitro* characterization of aqueous solutions. It then describes in detail the combination of the two methods, which opens the door to multivariate measurements, similar to the popular NIR absorption spectroscopy methods (with the possibility of using chemometrics as well) mentioned previously but without the limitation due to scattering.

2 Continuous-Wave Photoacoustic (CW-PA) Procedure

Among the potential techniques, the PA techniques also fulfill all the requirements for non-invasive sensing of blood glucose levels. The concept can be briefly described as follows. An amplitude-modulated optical source operating at an adequate wavelength illuminates an absorbing medium, where optical energy absorption yields a temperature increase due to the non-radiative relaxation photothermal effect. This temperature increase results in volume expansion that will locally generate a pressure disturbance. This pressure perturbation can then propagate as a pressure/acoustic wave through the medium to a mechanical sensor, where detection of signal characteristics and its proper post-processing enables one to characterize the absorbing medium. This method has been claimed to be highly sensitive to glucose because this compound affects several parameters that strongly impact the process described above at several stages: i) the optical energy absorption, which involves the optical absorption coefficient, thermal expansion coefficient, heat capacity, and acoustic velocity; and ii) the acoustic wave propagation until the receiver by the means of the acoustic velocity [30].

Figure 1 (left) shows a schematic view of the minimal setup required to perform PA measurements. Light source locally illuminates the sample under investigation, and a transducer senses the mechanical wave. On one side, the use of optical fibers is very convenient since it allows flexibility (alignment between the light source and sample) without impacting the signal properties (low propagation losses over the wide optical range, robustness, wide range of diameter cores). On the other side, several ways of detecting the acoustic waves have been developed, but the use of transducers, despite requiring a direct mechanical contact with the sample, remains the standard technique.

In terms of optical wavelengths, the PA technique allows the use of the entire infrared spectrum (typically, from 0.8 to 1000 μm) to generate acoustic waves through the photothermal effect. However, the mid- and far-infrared (MIR from 2.5 to 25 μm, and FIR from 25 to 1000 μm, respectively) can excite the fundamental vibrations and associated rotational-vibrational structure, while the NIR region (from 0.8 to 2.5 μm) is associated with overtone or harmonic vibrations. The MIR and FIR wavelength ranges are then more suitable for finger-print-like absorption spectroscopy, which is critical when measuring a solution with several solutes. However, the absorption coefficient should also be considered from the point of view of the PA technique as well as the final application. Water, as the main constituent of human tissue, strongly absorbs light in the infrared region. However, a minimum absorption is required in order to efficiently generate acoustic waves within the tissue (for wavelengths higher than 1300 nm), while a strong absorption (typically, for wavelengths in the MIR or FIR range or above 2500 nm) strongly limits the depth penetration of optical light to superficial layers of the skin. We then chose to use the wavelength range from 1300 to 2500 nm, which is also referred to as the tissue optical or the therapeutic window [24,31].

As shown in Fig. 1, two protocols using different optical excitation patterns have been used extensively: the pulse setup (pulse of light, very low duty cycle, and frequency (or repetition rate) below 1 kHz), and the CW one (excitation with square-wave signal, duty cycle about 50%, frequency up to 1GHz). Both techniques can potentially provide high sensitivity, but one issue remains of particular importance in choosing the most appropriate excitation sequence to the target application: the dominant origin of noise affecting the measurement [32,33]. The pulse setup operates in the time domain with time gating to suppress the noise contribution. This technique is particularly suitable when dealing with systemic noise. On the other hand, the CW setup operates in the frequency domain (with the use of closed-loop and lock-in detection), which allows the use of filters to suppress the noise contribution. This technique is particularly suitable when dealing with random noise.

With *in vivo* environment, where the sample size and properties are difficult to control and stabilize along time, the noise source may more likely be assimilated to random, which points to CW as the preferable excitation sequence. Moreover, CW-PA exhibits other advantages in terms of the potential to facilitate miniaturization down to a portable size [34-36]. With the recent development of solid-state laser diodes (LDs), compact high-power, high-resolution light sources covering this full range have become commercially available at reasonable cost and such light sources are particularly suitable components for CW-PA spectroscopy measurements. However, almost exclusively the pulse methodology has been cited in the literature dedicated to non-invasive glucose monitoring [27-29]. In fact, CW-PA methods were disregarded in a very early stage due to their dependence on cavity dimensions, which are parameters impossible to control precisely when it comes to dealing with real patients.

In this chapter, we describe, from the basic concept to the first *in vitro* results, two experimental protocols that allow CW-PA-based measurements whatever the cavity size and therefore solve the main issue usually associated with the CW-PA technique. Despite further optimization required to assess other characteristics such as detection limit and selectivity, these methods may represent a major breakthrough and initiate the future development of various types of sensors utilizing the CW-PA technology.

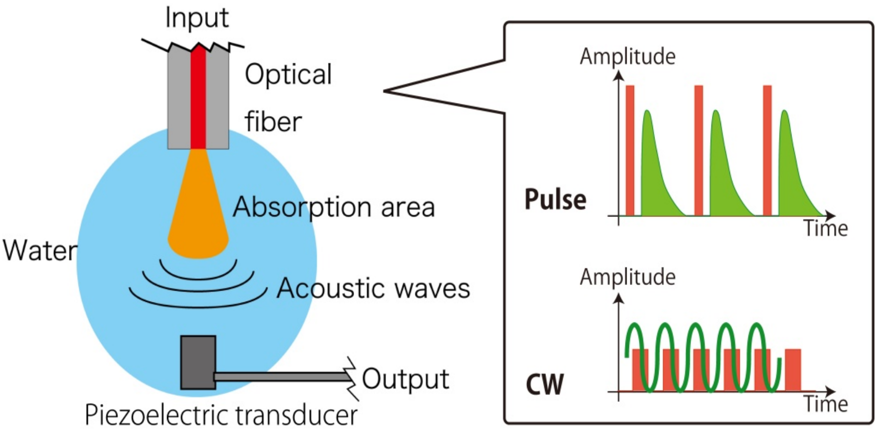

Fig. 1. Schematic view of the PA measurement cell (left), with the two optical excitation sequences used to generate the mechanical waves from photothermal effect (right)

2.1 Frequency Shift (FS) Protocol

The first protocol developed, called frequency shift (FS), relies on the measurement of the frequency shift at which acoustic resonance occurs when the glucose concentration of the sample solution is changed [37,38]. Figure 2 shows a schematic view of the experimental setup required to perform measurements based on the FS method.

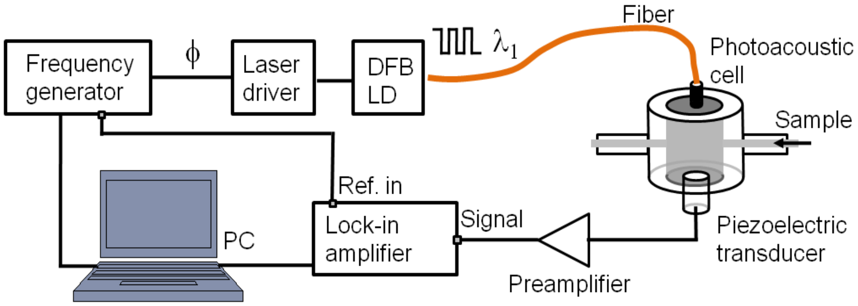

Fig. 2. Schematic view of the experimental setup used to perform FS-based measurements of various aqueous sample solutions

2.1.1 Concept

As stated above, the CW-PA technique generates standing acoustic waves within the cavity (volume with boundaries defined by strong acoustic impedance mismatch that consequently reflects acoustic energy). At certain frequencies, all the contributions will superimpose constructively and enhance the signal amplitude significantly. These frequencies depend on two factors: i) the boundary geometry, a geometrical factor that directly affects the acoustic wavelength, and ii) the mechanical properties of the sample liquid, all included within the acoustic velocity term. As a result, the resonant frequency can be described by the following equation:

$$f_{res} = {}^{v_{ac}}\!/_{\lambda_{ac}} \tag{1}$$

In some particular cases where the resonant cavity exhibits a simple geometry, analytical expressions have been derived to predict the resonant frequencies. With a one-dimensional cavity, the acoustic wavelength λ_{ac} of the m^{th} longitudinal mode can be defined as twice the cavity length divided by the integer m. With a cylindrical cavity, the analytical expression involves longitudinal as well as azymuthal and radial modes [39]. However, Eq. (1) still applies when all the geometrical factors within the λ_{ac} term are included.

When the glucose concentration of the sample solution is changed, the frequency at which the resonant occur shifts by a certain quantity Δf_{res}. However, from Eq. (1), as long as the geometry remains constant and the same mode is considered (peak in the closest vicinity of the previous one), the term λ_{ac} is constant, whereas adding glucose induces a change of the acoustic velocity. The shift of the frequency then comes exclusively from the acoustic velocity variation:

$$^{\Delta f_{res}}\!/_{f_{res}} = {}^{\Delta v_{ac}}\!/_{v_{ac}} \tag{2}$$

This protocol then enables one to measure the glucose concentration through its effect on the acoustic velocity whatever the cavity geometry, since Eq. (2) doesn't involve the acoustic wavelength anymore.

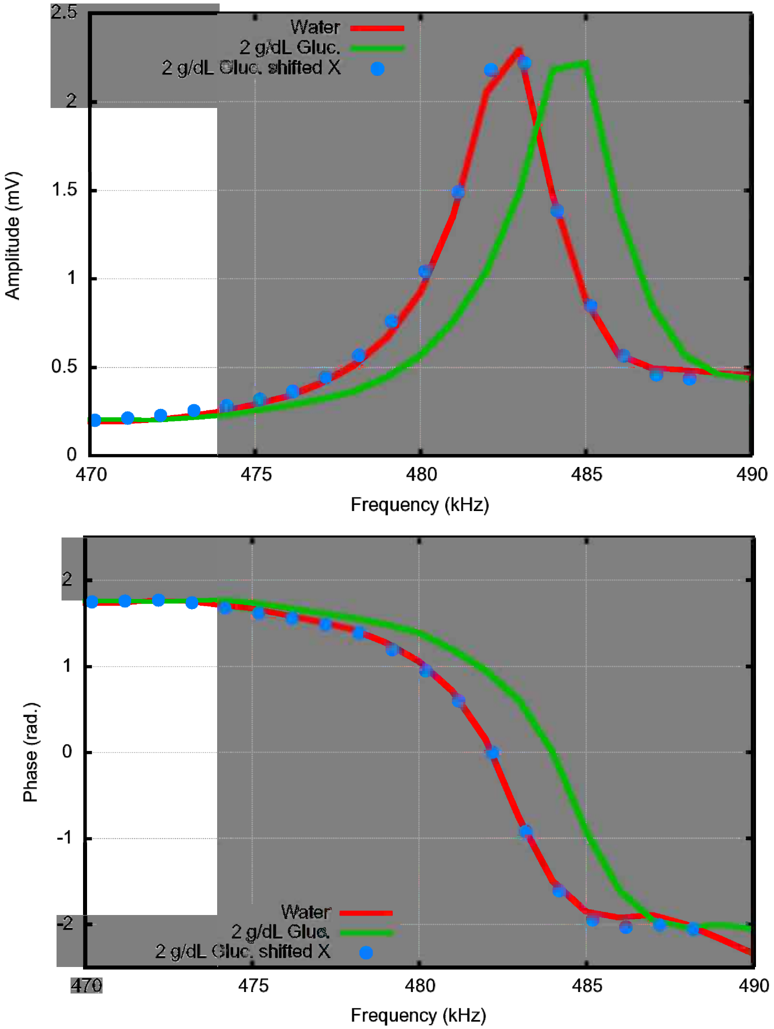

Fig. 3. Amplitude (top) and phase (bottom) raw results around one resonant peak at two glucose concentrations (0 and 2 g/dL, lines), and the 2 g/dL-response shifted to compensate for the effect of glucose concentration increase (dots)

2.1.2 Concept Proof of FS

The experimental setup shown in Fig. 2 allows the capture of both the amplitude and phase signals. Figure 3 shows raw experimental results around one resonant peak (arbitrarily chosen among several available resonant peaks within the full range spectrum (300-600 kHz)) when the glucose concentration is changed from 0 to 2 g/dL. These experiments were performed with the LD operating at 1382 nm. Despite the 1-kHz frequency step used to scan over a wide frequency range, the frequency shift induced by the change in glucose concentration is obvious on both the amplitude and phase signals. It should also be noted that the same frequency shift on both the amplitude and phase enables us to compensate for the effect of glucose (dotted response in Fig. 3). However, the phase exhibits a linear tendency locally around the resonant frequency that allows fast and easy measurement of the shift, while the Gaussian-like shape of the amplitude requires a more complex algorithm. The FS protocol then preferably uses the phase to measure the shift of the frequency.

Figure 4 shows a set of results for 1610-nm excitation wavelength and glucose aqueous solutions with concentration levels up to 15 g/dL. Once more, a similar overall shift appears on both the amplitude and phase signals, combined with a peak maximum variation on the amplitude signal. Despite a difference between the 0 and 15 g/dL responses of about 20 %, *i.e.*, a level about 10 times higher than the frequency shift from the same glucose concentration increase, the huge background level as well as the absence of a clear tendency doesn't allow easy and precise measurements from the amplitude variations.

The proposed FS protocol then provides better sensitivity and linearity than amplitude-based measurements.

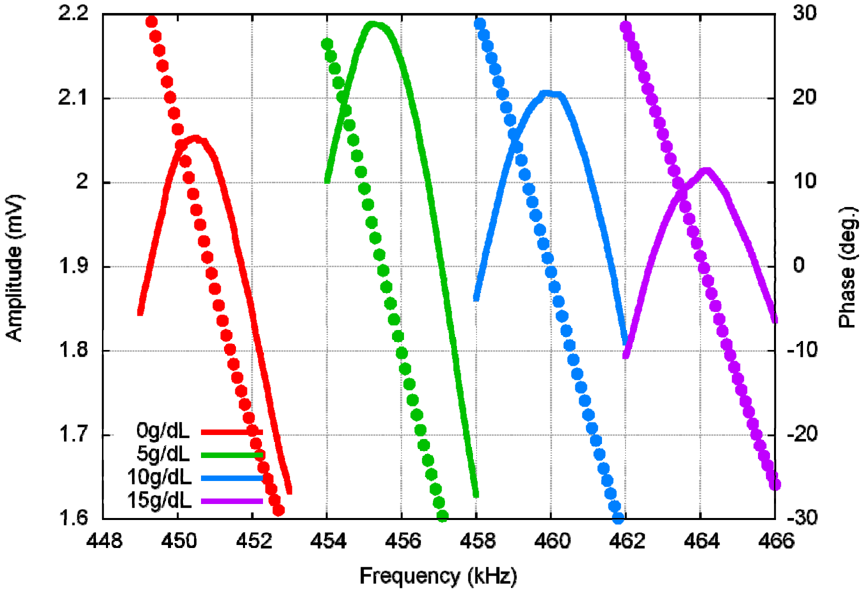

Fig. 4. Amplitude (lines) and phase (dots) signals of FS-based response performed with 1382-nm excitation wavelength and four glucose concentrations of aqueous solutions

2.1.3 Glucose Dependence at Various Conditions

The same experimental procedure was repeated several times with different cavity size (cylindrical shape with the length continuously varying from a few millimeters to few centimeters), optical excitation wavelength, and frequency (*i.e.*, different acoustic modes). The results shown in Fig. 5 reveal stable glucose concentration dependence with a linear response characterized by a 0.19 ±0.01 %/g/dL slope.

This result cannot be directly compared to results in the literature since this technique has not been used previously according to our knowledge. However, as mentioned previously, the proposed method is equivalent to a relative acoustic velocity measurement. Several papers deal with glucose concentration dependence of acoustic velocity, with results varying greatly between 0.15 [40], 0.20 [41], and 0.28 %/g/dL [28]. Despite the various methods (pulse photoacoustic, pulse-echo methods) and different accuracy, all the values are consistent with the FS response reported in this manuscript. The stable response despite changing the cavity geometry, the optical wavelength, and the mode considered also validates our first assumption that the FS method is equivalent to a relative acoustic velocity measurement.

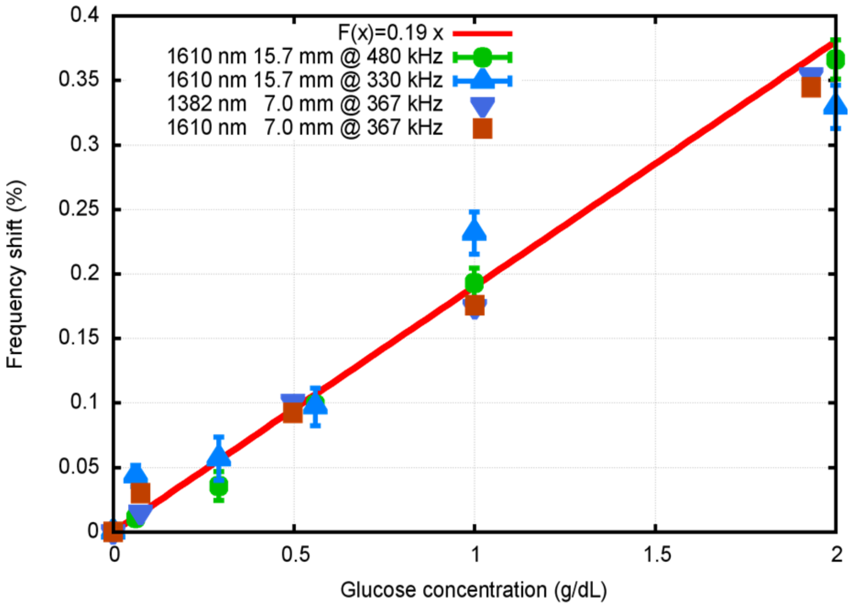

Fig. 5. Glucose concentration dependence of FS-based response at various conditions

This approach, by providing stability (versus optical wavelength, cavity size) and potential high sensitivity, then solves most of the issues usually associated with CW-PA technique. However, this approach also exhibits two main drawbacks: the impossibility to optimize the sensor response (a corollary of the previously mentioned stability) and the lack of selectivity to glucose compound in particular.

2.1.4 Issue of Selectivity to Glucose

The acoustic velocity depends on the glucose concentration, as well as other parameters such as temperature and other solutes' concentrations. Among the potential interfering parameters in clinical measurements, particularly concerns are related with the albumin and the temperature. We therefore further investigated the dependence of FS method to these two parameters. As an example, Fig. 6 shows the FS response with pure water at three different temperatures.

Despite changing exclusively the temperature, the effect on the sensor response is similar to the one induced by a change in the glucose concentration: a shift of the amplitude/phase signals and a variation of the maximum level on the amplitude.

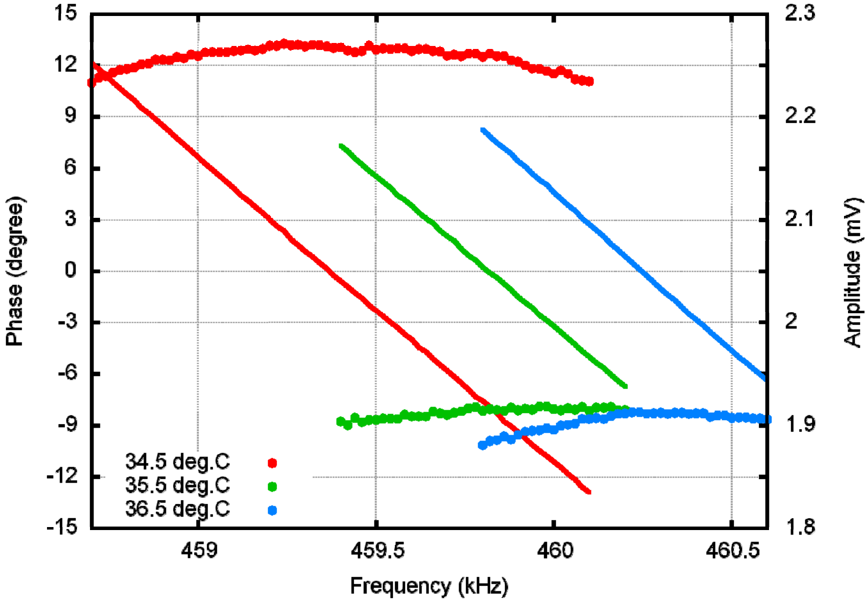

Fig. 6. FS response with pure water solution at three temperatures

As a consequence, the FS response exhibits sensitivity to temperature and albumin concentration with a slope of 0.16 %/°C and 0.15 %/g/dL, respectively. However, when dealing with a sample where several parameters can vary simultaneously and independently (particularly the case with *in vivo* experiments), it is impossible from the FS measurement, which is a scalar parameter, to separate the effect of glucose concentration change from temperature variations or albumin concentration changes. For example, a variation of 1ºC may be misinterpreted as an increase of glucose concentration by 0.84 g/dL from the FS measurement only. Therefore, the FS method is not sufficient to measure BGLs with satisfactory accuracy without the assumption that only one parameter is changing at a time.

2.2 Optical Power Balance Shift (OPBS) Protocol

The FS method relies on the measurement of the frequency shift of the phase signal. However, as shown in Figs. 4 and 6, the level of amplitude signals also varies in a irregular manner, depending on the glucose concentration. This non-trivial dependence results from the concomitant effects of several parameters (acoustic velocity, heat capacity, thermal expansion coefficient, optical absorption). The amplitude signal therefore contains valuable information about the sample solution characteristics that requires a specific measurement scheme. We then proposed the so-called optical power balance shift (OPBS) methodology in order to achieve a measurement that depends exclusively on the optical absorption coefficients.

2.2.1 Concept of Dual Differential Wavelength Excitation

From theoretical considerations, the pressure wave generated by illuminating the absorbing medium with an amplitude-modulated light beam depends on many parameters, such as the thermal expansion coefficient, acoustic velocity, heat capacity, optical absorption, and optical power [32,33]. Among these parameters, optical absorption is of particular interest because it provides a specific signature for every compound, and selection of the optical wavelength enables one to optimize the sensor response to a specific solute (the concept extensively used in NIR [42,43] and MIR spectroscopy [44,45] protocols). In the NIR region, water provides strong absorption that allows efficient generation of pressure waves by means of the photothermal effect. However, despite a concentration in the gram per deciliter range, consequently higher than the expected *in vivo* levels, the relative absorption of glucose and albumin compounds are several orders of magnitude lower than that of water. As a consequence, diluted compounds act as a perturbation to the huge background level provided by water solvent. Furthermore, glucose and albumin exhibit similar overall absorption spectra with slight differences at certain wavelengths (Fig. 7(a)). To overcome these two issues, we then used an excitation sequence with two optical beams at different wavelengths and devised a protocol that provides results equivalent to differential absorption coefficient measurements [Fig. 7(b)].

The concept of utilizing two optical wavelengths amplitude-modulated with two square waves operating at the same frequency but in opposite phase, was first introduced for aqueous glucose measurements based on absorption spectroscopy measurements [31]. This technique enables one to perform differential absorption coefficient measurements, leading to two benefits: i) suppression of the background provided by water solvent and ii) emphasis on the effects of the small difference in the optical absorption coefficients. To further develop this method and overcome the limitation inherent to the purely optical technique, a similar excitation sequence was combined with PA detection scheme [46]. However, despite promising results obtained *in vivo*, the proposed method still depended on several parameters other than the absorption coefficient.

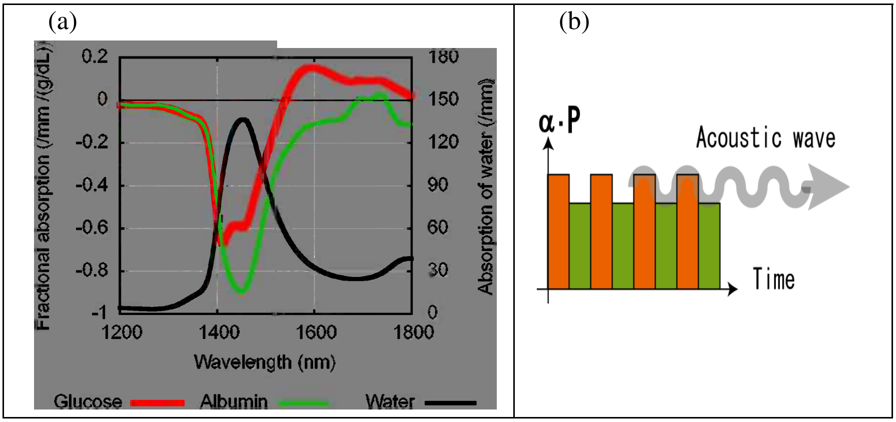

Fig. 7. (a) Spectrophotometer-based optical characteristic measurements of water, and glucose and albumin from aqueous phase and (b) a schematic view of the differential dual wavelength excitation sequence

2.2.2 Measurement Procedure

Figure 8 shows a schematic view of the experimental setup used to perform OPBS measurements with one pair of optical wavelengths. The system is similar to the one depicted in Fig. 2, except that this time, the frequency generator (FG) drives two laser diodes (LDs) drivers at the opposite phase. By using the two channels of the FG, amplitude levels on the two channels can be adjusted independently as well.

The use of two optical wavelengths according to the aforementioned scheme generates acoustic waves S in the medium, where the pressure S can be described as [33]

$$S \propto \frac{\beta v \alpha_1}{C_p} P_1 - \frac{\beta v \alpha_2}{C_p} P_2 = \frac{\beta v}{C_p}(\alpha_1 P_1 - \alpha_2 P_2) \tag{3}$$

with S is the acoustic signal (linearly proportional to the output voltage from the transducer), β the thermal expansion coefficient, v the acoustic velocity, C_p the heat capacity, α the optical absorption coefficient, and P the optical power; the subscript 1 or 2 relates parameters to optical wavelength 1 or 2. The acoustic wave generation still involves several parameters. In order to suppress the influence of all parameters except the optical absorption, we then proposed the OPBS protocol, which can be summarized in one sentence as follows: the change in optical absorptions at the two wavelengths coming from the change in the concentration is compensated by adjusting the optical output power of the LDs.

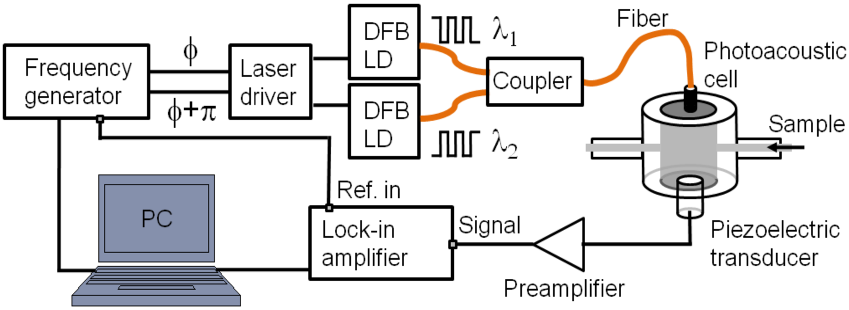

Fig. 8. Schematic view of the experimental setup used to perform OPBS measurements with one pair of optical wavelengths

Since the OPBS method is a relative measurement, and therefore requires a reference, the measurement sequence can be decomposed into two steps (Fig. 9). With a sample solution at a known concentration, a first amplitude/phase signal is captured by scanning over the driving voltage (DV) of the two LDs [Fig. 9(a)]. On the left side of the graph, the contribution from wavelength 1 (λ_1, orange) is dominant, and leads to a high amplitude signal level as well as a phase consistent with λ_1. On the opposite side of the graph, the contribution from wavelength 2 (λ_2, green) is dominant, leading to a high amplitude signal level and a phase consistent with λ_2. When comparing the signals on the two sides, the amplitude exhibits similar levels, while the phase shows a 180º phase difference because of the phase difference between λ_1 and λ_2. In between, the amplitude exhibits a minimum and the phase an inflexion point. At this particular condition, the DVs of the two LDs minimize the parameter $\Delta(\alpha P)$, which result in almost the non-generation of acoustic wave. This point then serves as a reference 0 at the known concentration level [X g/dL glucose concentration in Fig. 9(a)].

When the glucose concentration is changed (from X to X+δX g/dL), another scan of the LDs' DVs reveals a pattern similar in shape to the reference one but overall shifted by a certain amount [Fig. 9(b)]. This shift comes from the fact that changing the concentration of the dilute compound affects the two optical absorption coefficients α_1 and α_2. Therefore, the combination of LDs' output power that minimizes the parameter $\Delta(\alpha P)$, is no more at the 0-reference level, but shifted by a quantity proportional to the change of α_1 and α_2.

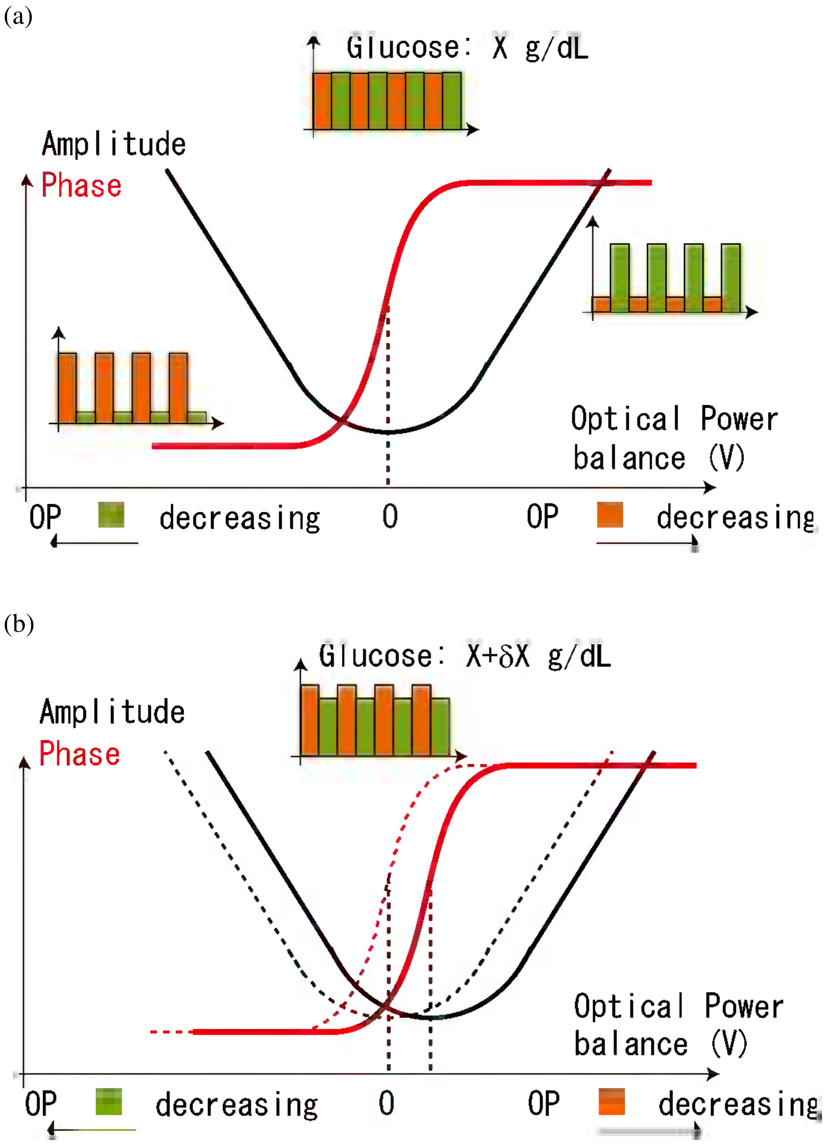

Fig. 9. Two-step process of the OPBS procedure: (a) measurement of a standard sample solution at known concentration, followed by (b) the measurement of sample solution at unknown concentration level

(a)

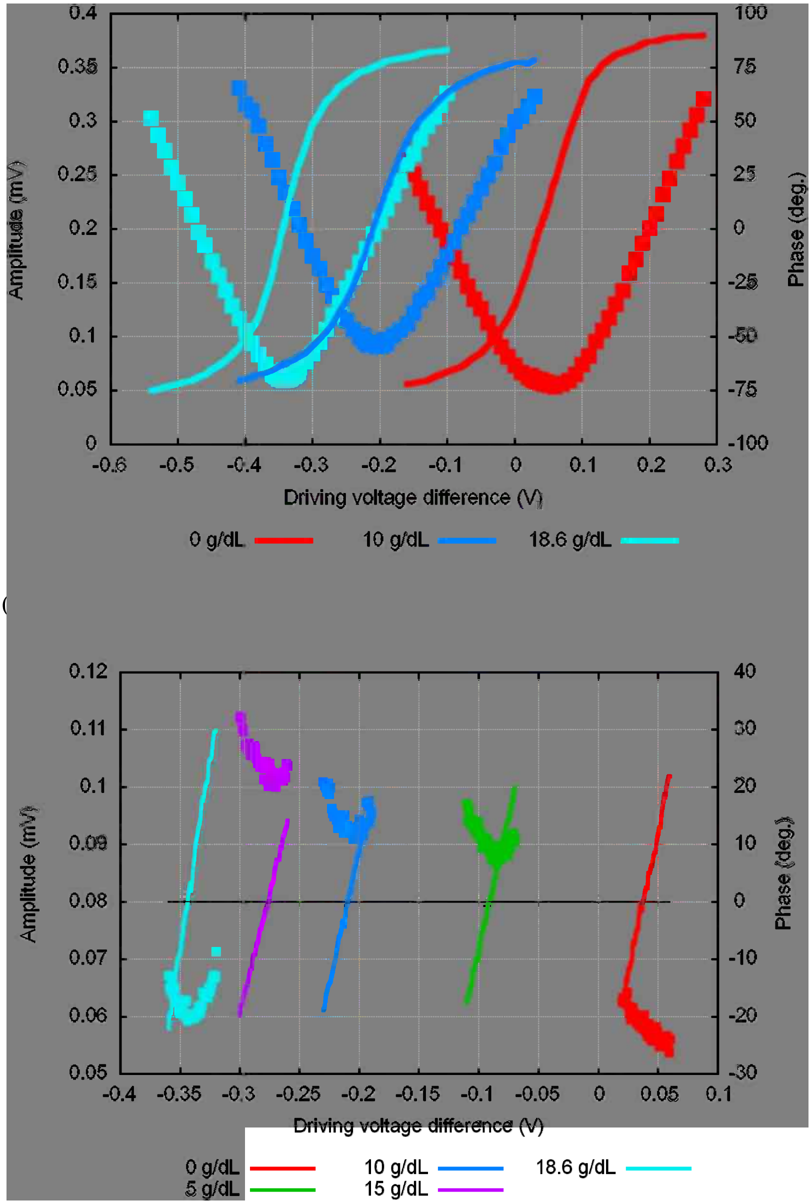

Fig. 10. Amplitude (dots) and phase (lines) signals from OPBS measurements of various aqueous solutions of glucose; (a) wide DV balance scan for three concentrations and (b) close-views around the phase inflexion points

According to this experimental procedure, only and exclusively the term between brackets in Eq. (3) plays a role. Unlike the process described elsewhere, where the signal level at one fixed DV balance was used [46], the effect of all the other parameters such as heat capacity and thermal expansion doesn't interfere with OPBS measurements.

The proposed approach then exhibits the advantages of optical absorption-based protocols (versatility from the optical wavelengths choice) and differential measurement (suppression of background), without the limitation inherent to purely optical measurement (scattering, light path length extended for improved accuracy, but limited by penetration depth).

2.2.3 Results for the 1382- and 1610-nm Combination

At the present time, only two LDs are available, leading to only one wavelength combination. Figure 10 shows the experimental raw results for glucose aqueous solution with concentrations ranging from 0 to 18.6 g/dL. The DV difference on the x-axis is arbitrarily defined as DV_2-DV_1. From a practical point of view, an LD's DV cannot exceed a certain threshold in order to operate within the linear range. For instance, once DV_1 has reached its maximum value, DV_2 is decreased instead of further increasing DV_1. Furthermore, a phase offset of 90 deg. was set on the lock-in amplifier so that the phase varied from -90 to 90 deg. with an inflexion point at 0 deg. Figure 10(a) exhibits an overall shape consistent with Fig. 9, and Fig. 10(b) only focuses around the inflexion point of the phase at the various concentration.

The phase exhibits linear behavior locally and enables easy and fast determination of the DV balance that corresponds to a 0-phase. On the contrary, the amplitude shows a minimum point, but the higher noise level makes the data processing difficult. Despite a remaining shift between the 0-phase and amplitude minimum point (unexplained at the present time), we chose to use exclusively the 0-phase point for the next results. Figure 11 then gathers all the $\Delta(DV)|_{phase=0}$ for each glucose solution, as well as equivalent results for albumin aqueous solutions at various concentration levels, all normalized to water.

The dependence is more pronounced for glucose. Despite our changing only the concentration of one compound at a time, the results are not perfectly aligned and the error-bars remain large. In terms of sensor response, we could then evaluate the slope between -20 and -27 mV/g/dL for glucose, and between -6 and -12 mV/g/dL for albumin (solid lines in Fig. 11 for both compounds). However, this behavior confirms the tendency expected from Fig. 7(a) with the two optical wavelengths used here (response to glucose about 2.41 times higher than the response to albumin). Furthermore, both uncertainties resulted from the same experimental issue about controlling the temperature during the measurement. The OPBS approach is also sensitive to temperature due to the temperature dependence of the absorption coefficient [47]. The detection cell containing the liquid sample was then fully immersed in large quantity of water in order to drastically increase the thermal inertia. The fast fluctuation of temperature could be suppressed, but a gradual and constant drift of the temperature could be measured during the daytime. The error-bars were calculated from temperature measurement of the water outside the cell and its potential impact on the PA signals inside the cell. Related with the experimental sequence (increasing the concentration levels during the day), the measurement errors increase with the concentration levels. Another drawback of the OPBS approach, which is not taken into account in the error-bar calculation, arises from the fact that it utilizes the PA amplitude levels. Therefore, any fluctuation of the output of the LD itself will affect the OPBS signal and can then be misinterpreted as a change in glucose compound concentration.

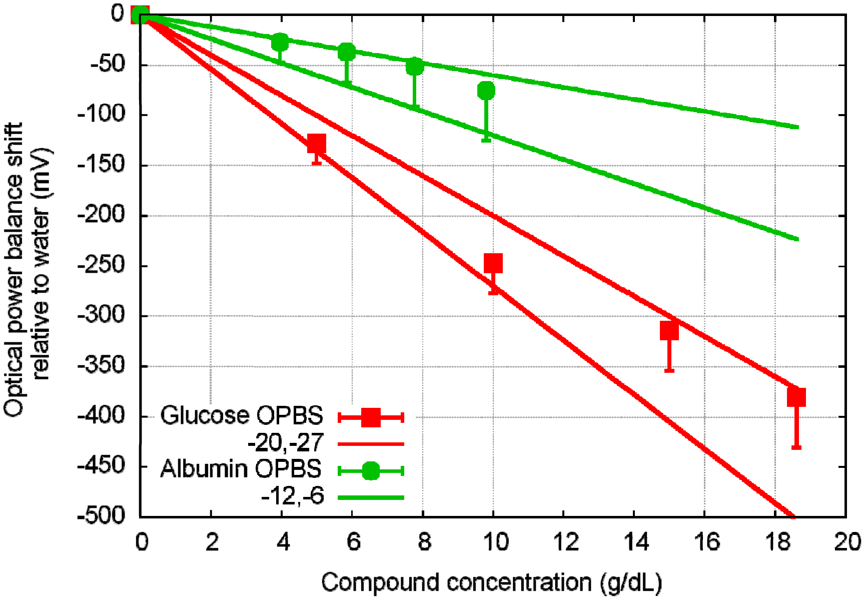

Fig. 11. OPBS results relative to water for various concentration levels of glucose and albumin aqueous solutions

3 FS+OPBS Combination

3.1 Comparison of the Two Approaches

The PA technique mixes optical excitation and acoustic detection. The two methods previously developed rely on the two aspects separately: the FS method depends exclusively on the acoustic part and characterizes the propagation medium through acoustic velocity measurements, while the OPBS method senses any change of the absorption coefficients at the two optical wavelengths. Therefore, the two methods exhibit very different characteristics. Table 1 shows the FS and OPBS dependence versus three of the main parameters regarding the issue of a non-invasive blood glucose sensor: glucose and albumin concentrations, and temperature.

Table 1. Comparison of the FS and OPBS dependence versus glucose concentration, albumin concentration, and sample temperature

	FS method	***OPBS method***
Glucose	0.19 %/g/dL	-20 ~ -27 mV/g/dL
Albumin	0.15 %/g/dL	-6 ~ -12 mV/g/dL
Temperature	0.16 %/degC	25 mV/degC

With the FS method, the sensitivity to the three parameters is about the same order of magnitude and no optimization is possible, since the results directly and exclusively depend on the acoustic velocity dependence versus these three parameters. However, the FS relies on a frequency measurement, which also provides high sensitivity and accuracy.

The combination of the two protocols may then be the best solution by bringing together the high sensitivity of the FS approach and the high selectivity to glucose compound of the OPBS method.

Regarding the OPBS protocol, the dependence versus the three parameters varies consequently. Furthermore, the method's response can be tuned by changing the optical wavelengths so that further optimization towards high sensitivity to one specific compound is possible. As a result, OPBS enables compound-selective measurements. However, the method relies on amplitude-based measurements, which limits its sensitivity due to noise and instability.

3.2 Creation of Linear System

From the results in Fig. 11, one can see that temperature fluctuation during the measurements makes quite difficult to estimate precisely the sensor response to the two compounds. However, the experimental protocol requires an evaluation of the frequency shift (FS) prior to any OPBS measurements. For the two FS and OPBS measurements performed within minutes from each other (Fig. 12), we can then reasonably assume a constant temperature and compound concentration.

From the four experimental sets of FS+OPBS data points, we then built a system of eight equations that involve twelve parameters for each set of data: the OPBS and FS slope responses to glucose (or albumin) and temperature and the four temperature differences and compound concentration differences.

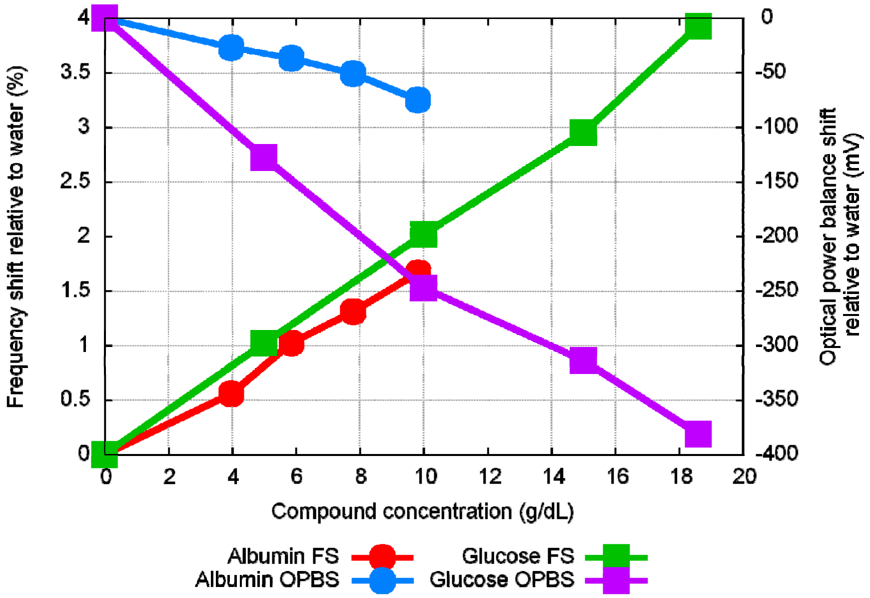

Fig. 12. Raw responses for the FS and OPBS methods versus albumin and glucose concentrations

Among these twelve parameters, the compound concentration differences are known (preparation of the sample solution), as are the FS slope response to the solute and the FS and OPBS slope responses to temperature. In this particular case, we then have an over-determined system with eight equations and five unknown parameters, which can be solved according to one of several mathematical tools already available. We then obtain the two sets of results: the temperatures profile (Fig. 13) and the OPBS response slope (Fig. 14).

Figure 13 shows the estimated variations of the temperature versus the experiment number. The experiments were performed sequentially with increasing concentrations, so that the low experiment numbers correspond to low-concentration samples. We obtained an increase of temperature as the experiment number increases, within a range that is compatible with our first observations except for the last data point with glucose. Figure 14 shows the experimental results superimposed with the fitting curves, whose slopes are -24 and -10 mV/g/dL for glucose and albumin, respectively. Because we took into account FS and OPBS data

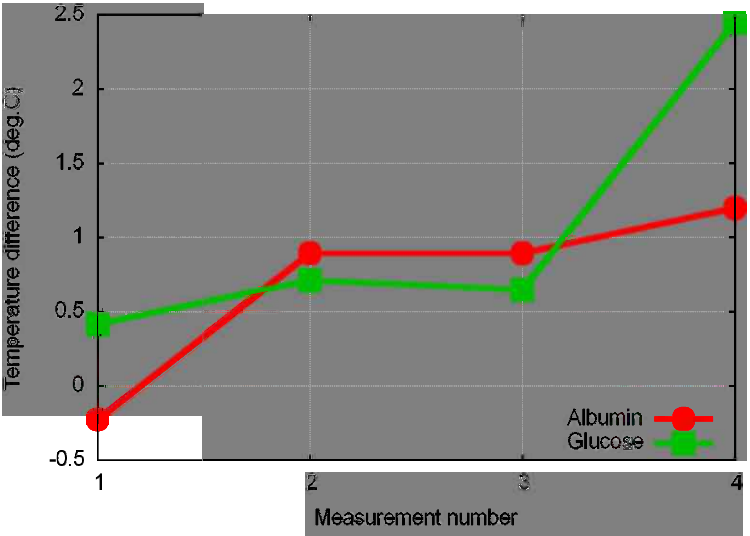

Fig. 13. Estimated temperature profile [redacted]ose and albumin solutions

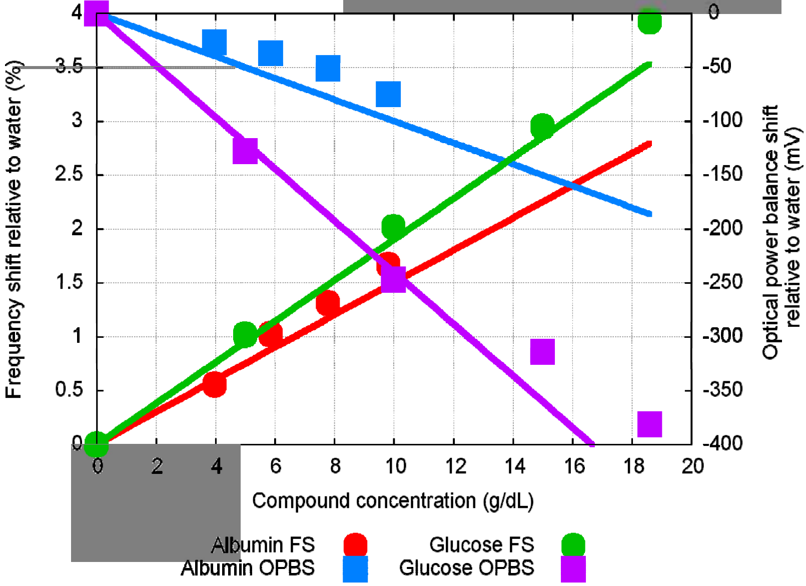

Fig. 14. Sensor responses for the FS and OPBS methods versus albumin and glucose (dots) with corresponding slopes obtained from solving the combined problem

simultaneously, the results do not really look intuitive when considering exclusively the OPBS method. However, we can compare those results with the spectroscopic data from Fig. 7(a): if we consider the slope ratio defined as the response to glucose divided by the response to albumin, we get 2.40 compared to the 2.41 value expected from optical absorbance measurement by calculating (relative absorption(λ_1) - relative absorption(λ_2))$_{\text{Glucose}}$ / (relative absorption(λ_1) - relative absorption(λ_2))$_{\text{Albumin}}$).

3.3 Solution to Multi-parameter Problem

However, the previously described process is just a demonstration of the concept. In real experiments, glucose is the target molecule, and the issue of the increasing the number of linearly independent equations will then be resolved by using several optical wavelengths combinations in parallel.

Similarly to the pulse oximetry protocol [48,49], we can extend the approach to N optical wavelengths to specifically measure the glucose concentration from an environment featuring several parameters varying simultaneously. With N LD operating at N different optical wavelengths, it is then possible to obtain N(N-1)/2 combinations of two optical wavelengths for OPBS measurements. Since the sensitivity to compounds varies as a function of the optical wavelengths, we can now get N(N-1)/2 equations versus the identified M unknown parameters. However, all these equations are not independent, and only (N-1) can be used to solve the problem. With the FS measurement at one optical wavelength (any wavelength can be used for this measurement), we then have a system including N independent equations and M unknown parameters. The M unknown parameters, already including the glucose and albumin concentrations, as well as temperature, can also be extended to take into account other compounds or parameters that may vary and influence the sensor responses in a detectable way. After fixing M, N can be adjusted freely with $N \geq M$ in order to get a complete system. Nevertheless, while the measurement accuracy increases proportionally to N, the sensor response time and cost will also increase as a consequence, so that a compromise may be found depending on the requirements in terms of accuracy and response time.

4 Conclusions

We proposed a novel concept of non-invasive glucose concentration measurement based on the CW-PA principle. One the one hand, the FS method provides a measurement equivalent to acoustic velocity monitoring, thus taking into account several different parameters (such glucose and albumin concentrations, and temperature). Despite having no selectivity to one compound in particular, it also enables to correct the frequency shift induced by the change of the acoustic properties of the medium and therefore provides a system that works with equal efficiency whatever the cavity size. On the other hand, the OPBS method is equivalent to a differential relative absorption coefficient measurement at the two wavelengths used and thus opens the door to optimization/customization based on the excitation wavelength choice. Finally, by combining the FS and OPBS protocols, which rely on different properties of the PA technique, we designed a tunable system that can potentially solve complex problems involving many parameters. Moreover, the PA detection scheme provides robustness against scattering properties of tissues. This method then appears suitable for *in vivo* BGL monitoring, where several compounds can bias the measurement of glucose, the primary target molecule, and the scattering of tissue cannot be neglected.

Furthermore, the properties demonstrated by the FS+OPBS method can potentially fulfill the requirements of numerous applications, where the noninvasive term may be replaced by other terms such as inline monitoring or contactless evaluation. In all cases, the basic idea remains the same: while the sample solution is inside a close container that does not allow direct access or contact with the liquid, FS+OPBS may provide a viable alternative for remote characterization by adapting the wavelengths to the solute/solvent considered, especially when scattering from the sample solution cannot be neglected.

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From Handheld Devices to Near-invisible Sensors: The Road to Pervasive e-Health

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Abstract. Pervasive computing refers to the increasing integration of information and communication technologies into people's lives and environments. In particular, pervasive technologies have been identified as a strong asset for achieving the vision of user-centred preventive healthcare. However, there are engineering problems to be solved before many of the envisioned applications in healthcare can become a reality. The objective of this chapter is to present future research demands in pervasive sensing by means of miniaturised wearable and implantable sensors featuring ultra-low power consumption, high portability, and robustness. At the same time, since many emerging non-invasive measurement techniques related to monitoring physiological and psychological status of individuals rely on bioelectrical impedance spectroscopy (BIS), we also consider the perspectives for bioimpedance applications, referring in particular to the use of CMOS technology for chip-scale integration of BIS readout electronics.

Keywords: bioelectrical impedance spectroscopy, CMOS technology, body sensor networks.

1 Introduction

Current economic, social, and demographic trends are demanding healthcare systems focused on prevention and early detection of illnesses, which should be able to provide an optimized medical response as well as a reduction in the number of visits to the hospital [1, 2]. eHealth – the beneficial application of information and communication technology (ICT) to the healthcare sector – stands out as a way to improve the operational efficiency of all the supporting processes involved in the delivery of healthcare. eHealth is not just about converting paper records to electronic ones, but also about making these electronic records available, as and when required, to healthcare providers across the chain. eHealth covers the interaction between patients and health-service providers, institution-to-institution data transmission, peer-to-peer communication between patients or health professionals, health information networks, electronic health records, telemedicine services, and personal wearable and portable systems for monitoring and supporting patients [3]. Therefore, eHealth systems can deliver high-quality information in real

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time and in a manner that is easily accessible everywhere, while at the same time they have the power if not to reduce, at least to manage this complexity. For instance, doctors can access patients' medical records more easily, get immediate access to test results from the laboratory, and deliver prescriptions directly to pharmacists. Patients with chronic conditions can carry monitoring devices which alert their doctor if their condition changes, yet being allowed to continue with their daily life activities.

Since its inception in the early 1990s, eHealth has shown a lot of successful examples [4, 5]. Wireless communication technology came to encourage different strategies of mobile and ubiquitous eHealth initiatives, ranging from doctor mobility, i.e., remote access to medical data, to patient mobility, e.g., remote monitoring of vital signals and wearable medical sensors, up to web based medical data access. By introducing pervasive computing systems that reason intelligently, act autonomously, and respond to the needs of individuals in a context- and situation-aware manner, the shifting of eHealth from desktop platforms to wireless and mobile configurations enables a distributed and pervasive care model for health and wellness management through the use of miniaturized ICT [6, 7].

Although there is no univocal description in the current literature, pervasive healthcare may be defined from two perspectives: i) as the application of pervasive computing technologies for healthcare and ii) as making healthcare available everywhere, anytime, and to anyone [8]. Accordingly, pervasive healthcare offers opportunities for future healthcare provision, both for detecting, treating, and managing disease and for patient administration [9]. For instance, remote sensors and monitoring technology might allow the continuous capture and analysis of patients' physiological data. Medical staff could be immediately alerted to any detected irregularities. Data collection on this scale could also provide for more accurate pattern/trend analysis of long-term health conditions. Wearable sensors may offer greater patient mobility and freedom within and even outside hospitals and save both time and money by reducing the need for repeated and intrusive testing. At the same time, sensors embedded in items of clothing, for example, might allow constant monitoring of heart rate, body-mass index, and other physiological variables.

Pervasive healthcare addresses a set of technologies and concepts that help integrate healthcare more seamlessly to our everyday lives, regardless of space and time. While there has been significant progress toward this vision, most research has focused on the development of small-scale systems, tested by a handful of users, interacting with a limited number of devices. The simple truth is that, in order to implement sustainable eHealth programs, pervasive eHealth must move from being simply an innovation in healthcare through a sustainable change process to ultimately transform healthcare delivery. Moreover, future pervasive systems need to encompass a large number of computational platforms, users, devices, and applications dealing with massive amounts of data. Diverse devices such as smart phones, tablets, laptops, desktops, wearable sensors, radio frequency identification tags, and embedded wireless sensors on the order of thousands, millions, and even billions of units, as envisioned in the future Internet, will enable a wide spectrum of applications, including those of pervasive eHealth [10].

Consequently, the research community needs to address the issue of scale, i.e., it is essential to consider the ability of eHealth services to maintain an adequate level of efficiency as they scale to entire national populations. In this context, ubiquitous health monitoring systems based on tiny wireless medical sensors are going to play a key role for pervasive healthcare. These systems will allow healthcare service givers to early detect and act on signs of patients' clinical deterioration, thus improving the quality of care in a reliable, unobtrusive, and cost effective way [11].

A pervasive health system will ultimately need information about individuals and their surrondings, which will be delivered by embedded sensors, thus integrating pervasive sensing with pervasive computing. In this sense, wireless sensor network (WSN), which has settled as a leading technology for various applications, exhibits one of its potential uses in the form of body sensor networks (BSNs) for remote measurement of physiological signals [12]. Unlike wired monitoring systems, BSNs provide long-term continuous monitoring of patients under their natural physiological state even when they move [13]. The successful realization of this vision requires innovative solutions able to remove the critical technological obstacles to implement wireless sensor nodes for biomedical applications. This chapter presents future research demands in pervasive sensing by means of wearable and implantable miniaturised sensors featuring ultra-low power consumption, high portability, and robustness. The rest of the chapter is organized as follows. Section 2 gives an overview of wireless technologies that have fundamental importance in supporting continuous and reliable long-term monitoring systems. The major design challenges of miniaturised, autonomous, and wireless medical sensors are discussed in Section 3. Since many emerging non-invasive measurement techniques related to the physiological status of individuals rely on bioelectrical impedance spectroscopy (BIS), perspectives for medical applications are highlighted in Section 4, referring in particular to the use of CMOS technology for chip-scale integration of BIS readout electronics. Finally, conclusions are drawn in Section 5.

2 Why Is a Sensor Network Important?

Sensor networks have been heralded as one of the 21 most important technologies for the 21st century [14]. Most researchers agree on the fact that a sensor network consists of a large number of inexpensive and smart devices with multiple onboard sensors, networked through wired or wireless links and densely deployed, that cooperatively collect information of the physical world in which they are embodied and may control the surrounding environment [15, 16]. The most perceptive reader will observe that this definition is not very specific. In fact, national power grids, with their many sensors, can be considered as a large sensor network although they were developed before the term sensor network came into vogue. Therefore, using a wide enough interpretation, almost anything fits the definition of a sensor network, even humans. When observing human skin on a microscopic scale, we are impressed by the diversity and density of embedded sensors.

This abundance includes sensors for pressure, acceleration, temperature, and so on. Despite their immense variety, all sensor networks have one fundamental feature in common: each sensor is limited in its ability to monitor a situation. The power of a sensor network comes from the fact that even though individual nodes are quite limited, the whole array becomes very powerful when networked. In this Section, we will focus on one of the most common applications of sensor networks in the context of eHealth, namely human vital-sign monitoring.

Let us think about the course of a typical day in a hospital. Lots of medical sensors like thermometers, blood pressure meters, electrocardiography (ECG) monitors, and pulse-oximeters are used to monitor the condition of patients. Some measurements, such as temperature reading, will be taken periodically, whereas others, such as ECG monitoring a patient with a heart disease condition, must be done continually. A significant amount of nurses' time is spent on measuring and recording temperature, blood pressure, and other values for patients' medical records in order to monitor progress and discover relapses. Moreover, one of the most time-consuming problems caused by cables is that when patients are moved, all wires must be unhooked during transport and then reattached when the patient reaches his or her destination. A close study of the intra-hospital transport of ECG monitored patients proposed using wireless ECG sensors to save time and trouble [17]. The same way, the need for removing cables is present when we consider another scenario, where a patient is recovering from a health trouble. Indeed, patients need to get out of bed as early as possible, which implies that cables restraining them to their beds during the recovery are problematic. Thus, clinicians request wireless sensor technology to propose appropriate solutions.

2.1 Wireless Sensor Networks

Traditional sensor networks in the medical sector focus on establishing network communication between mobile devices having great amounts of computational power and energy at their disposal, such as cell phones. These networks, which are referred to as mobile *ad-hoc* networks (MANETs), do not allow a sufficiently dense sampling of physical, physiological, psychological, cognitive, and behavioural processes so as to encompass the pervasive eHealth monitoring vision. Advances in hardware and wireless network technologies have led to low-cost, low-power integrated sensors with onboard processing and wireless data transfer capability, which are the basic components of already existing WSNs. One factor that distinguishes these networks from MANETs is that their end goal is the detection/estimation of some event of interest, and not just medical data communication. WSNs carry the promise of drastically improving and expanding the quality of healthcare across a wide variety of settings for different segments of the population [18].

Despite the interest in the application of WSNs to healthcare, a significant gap remains between existing sensor network designs and the requirements of medical monitoring. Most WSNs are intended for deployments of stationary nodes that transmit data at relatively low data rates, with the focus on best-effort data collection at a central base station. By contrast, medical monitoring requires relatively high data rates, reliable communication, and multiple receivers. Unlike many WSNs, medical monitoring cannot make use of traditional in-network aggregation since it is not generally meaningful to combine data from multiple patients. In fact, if the data from a sensor on one patient would find its way to a sensor on a different patient, it would be considered as a security breach. Moreover, in a medical sensor network, each sensor has a unique task of measuring a given phenomenon of a particular patient—other sensors measure either a different phenomenon on the same patient, or a similar phenomenon on a different patient.

Whilst WSN technology continues to evolve for the broad range of possible applications, it does not specifically tackle the challenges associated with human body monitoring and patient care. The principal reason is that most sensor network applications have very different data, communication, and lifetime requirements. Unlike conventional WSN applications, medical deployments are characterized by mobile nodes with varying data rates and few opportunities for in-network aggregation, as pointed out above. In addition, the human body environment is on a smaller scale and also requires a different type and a different frequency of monitoring. Numerous published research works succeeded in demonstrating how wireless medical sensors can be minimised and how this will be useful in the future eHealth sector. However, the problem of replacing cables with a wireless connection is affected by a rather complex interplay of problems, e.g., power consumption and security. The realisation that proprietary designed WSNs are not ideally suited to monitoring the human body and its internal environment has led to the development of body sensor networks [19].

2.2 Body Sensor Networks

Professor Guang-Zhong Yang was the first researcher who specifically defined the term body sensor network (BSN) [19]. BSN technology represents the lower end of power and bandwidth in the body area network (BAN) scenario [19]. A BAN is formally defined as a system of wireless devices in close proximity to or inside a person body that cooperate to enable monitoring for the benefit of the user [20]. When compared to conventional WSNs, BANs consist of a lower amount of smaller nodes, typically from 20 to 50 nodes, and provide less space coverage [21]. Figure 1 shows average power consumption and data rate for a number of popular wireless technologies. Notice that the range of BAN devices can vary significantly in terms of bandwidth and power consumption in order to support a great variety of medical and non-medical applications and, hence, data rates vary from few kbit/s for simple data to several Mbit/s in video streams.

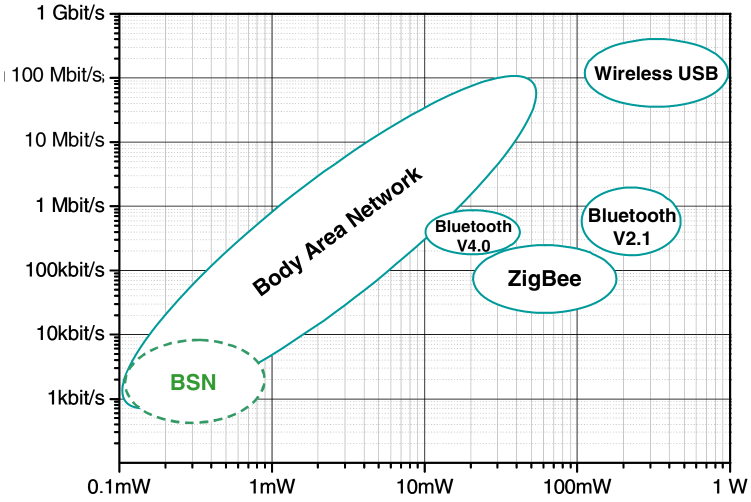


Fig. 1. Average power consumption *vs* data rate of available wireless technologies

As the application of BANs have been extended from connecting personal electronic consumer goods to implementing medical and healthcare applications, BAN has become a key element in the infrastructure for pervasive eHealth applications. The use of BANs in the medical area consists of wearable and implantable sensor nodes that sense biological information from the human body and transmit it wirelessly over a short distance to a control device worn on the body or placed in an accessible location. As shown in Table 1, the data rates needed for vital-sign monitoring are usually low for the individual sensor. Recently, several transceivers for BANs have been developed [23, 24]. However, their working distance and power consumption are beyond the optimal choice for monitoring health status. Moreover, due to the energy absorption in the human tissue, their transmitted signals around the human body significantly suffer from huge path loss [25]. The pursuit of long-term and continuous monitoring without human activity restriction has promoted the concept of BSNs. This specialized family of WSN has the potential to facilitate patient-centric healthcare.

Table 1. Human biopotential and biophysical signals [22] and their typical data rate, bandwidth, and accuracy

	Data rate	Bandwidth	Accuracy
ECG (12 leads)	288 kbit/s	0.1 – 1000 Hz	12 bits
Electromyogram	320 kbit/s	5 – 10000 Hz	16 bits
EEG (12 leads)	50 kbit/s	0.1 – 100 Hz	12 bits
Movement	35 kbit/s	0 – 500 Hz	12 bits
Temperature	120 bit/s	0 – 1 Hz	8 bits
Blood saturation	16 bit/s	0 – 1 Hz	8 bits

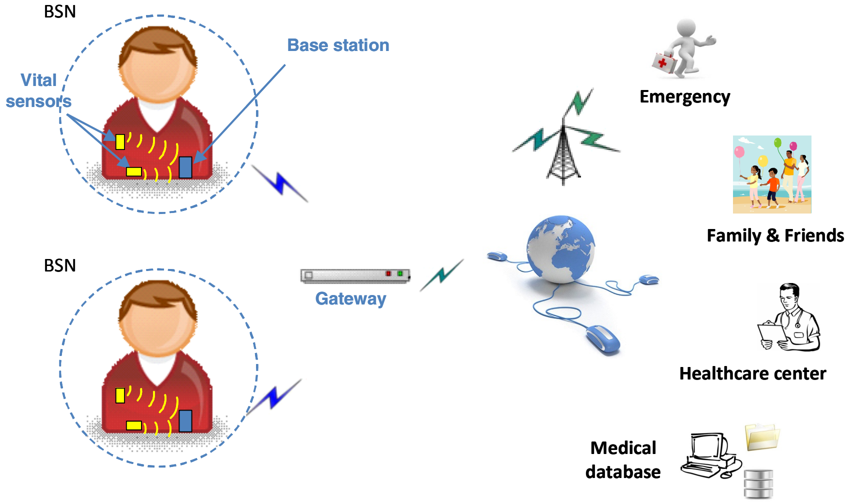


Fig. 2. Architecture of a BSN in a pervasive e-Health scenario

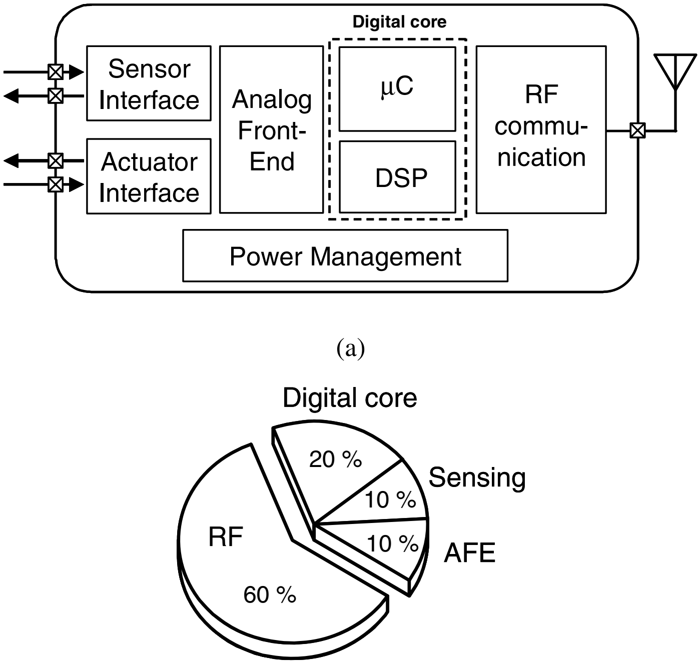
A BSN results from the fusion of sensing and wireless technologies, as it consists of a series of miniaturized low-power sensors wholly or partially covering the body area that collect, process, and communicate physiological information from the body [19], [26]. These sensors can be either wearable or implantable. As illustrated in Fig. 2, one of the sensor acts as a master node, i.e., as a base station, for central control, and a number of vital-sign sensors act as slave nodes. The base station thus plays a different role from the slave nodes in the network and has more resources in terms of physical size, available energy, radio-frequency (RF) communication range, and computing power. Although the challenges faced by BSNs are in many ways similar to those that are typical for BANs, there are several important differences between the very small low-power sensors of BSNs and their BAN counterparts. First, the body itself prevents the reuse of the same node across many roles due to the particular characteristics of physiological data measurements. Second, the close proximity of the base station makes node-to-node communication largely unnecessary. BSNs therefore tend to use star topology, with each sensor node communicating only with the master node. Third, sensor nodes have limited energy resources available as they have very small form factor. Finally, for most sensors it is not possible to recharge or replace batteries although a long lifetime of the node is required.

Most proposed prototypes of BSNs are largely based on commercially available off-the-shelf technologies [19], [27], [28], [29], which employ Bluetooth, ZigBee, or other RF communication protocols commonly used in BANs and WSNs.

However, there are great obstacles that prevent such solutions from gaining wide acceptance from its intended end users. One major obstacle is the physical implementation of the proposed sensor nodes, as all components are packed into a double-side printed circuit board reaching an area of several hundreds mm^2 [27], [28]. In addition, the typical power consumption is on the order of tens milliwatts [19], [29]. It should be pointed out that these sensor nodes support complex architectures in which many available resources are rarely or even never used. Therefore, a long-term continuous monitoring with wearable sensors is not yet feasible by using commercial off-the-shelf technologies. Nowadays, ASIC-based BSN sensors have been proposed for medical applications [30]. Custom BSN integrated circuit design is an emerging field. Despite intensive research efforts, few implementation works have been published so far. One reason may be that these custom nodes are heavily tailored to a specific application instead of being flexible and generic. BSN technology is not mature and there are several constraints limiting clinical possibilities. Moreover, sensor nodes will not be adopted if they are too inconvenient or uncomfortable. In next Section, the major challenges to be faced when designing miniaturized, autonomous, and wireless wearable sensors are discussed.

3 What Does a Medical Pervasive Sensor Look Like?

The purpose of a medical sensor is to provide information to a physician as to the function and performance of an organ, a group of organs, or system within the body of a patient. In the context of pervasive eHealth, the acquisition of biomedical signals, such as those for measuring vital signals, can be performed through BSN sensors attached on the patient's body or through special wearable sensors. Very often, the acquisition of a biomedical signal is not sufficient and it is required to process the acquired signal to get the relevant information buried in it. The transmission of the collected information to the base station is performed through an appropriate wireless technology. As shown in Fig. 3a, a BSN sensor can be divided into five major functional blocks: 1) the stimulating/sensing components for biomedical stimulation and sensing (sensor and actuator interfaces), 2) an analog front-end (AFE) for signal acquisition, 3) a digital core for control and local processing, 4) an active RF transceiver for data link, and 5) a power-management unit. Although power consumption depends on the specific nature of the application, energy is mainly spent on processing sampled data by the microcontroller and forwarding the data out via a wireless link. Fig. 3b highlights the power breakdown of a BSN sensor illustrating this statement, where in general communication accounts for the majority of the energy expenditure of a sensor.



(a)

(b)

Fig. 3. (**a**) Conceptual block diagram of a BSN sensor and (**b**) its power breakdown

At a first glance, a BSN sensor can be identified as an integrated smart sensor for human body monitoring with wireless communication capabilities. Nowadays, technological developments in materials and electronics have led to the miniaturisation and integration of sensors into intelligent devices and systems that not only measure and analyse, but also act on the resultant information. The size and the cost of smart sensors have decreased with time, and the improvement in the technologies for other important components, such as memory and radio transmitters, will allow more capable and long lasting devices, thus reducing their maintenance cost [31]. For example, a smart temperature sensor will convert the raw data signal to temperature information, e.g., Celsius degree, and automatically establish a network connection to pass on the information. Therefore, just an integrated smart sensor in the technology arena is a candidate for having the prefix *ubiquitous* or *pervasive* added to it. However, the wearable nature of the BSN sensor places unique constraints on its specification and design. Although it is rather difficult to draw general indications because of the wide variety of sensors in medical applications [32], some trends about present and future technical barriers can be highlighted.

3.1 Major Design Challenges

The nodes that constitute a BSN must meet certain requirements in order to minimize the adverse impact of the wireless network over the patient. There are three key challenges, namely extreme reliability, small size/weight, and very low power consumption, which can become a design complexity nightmare (Fig. 4).

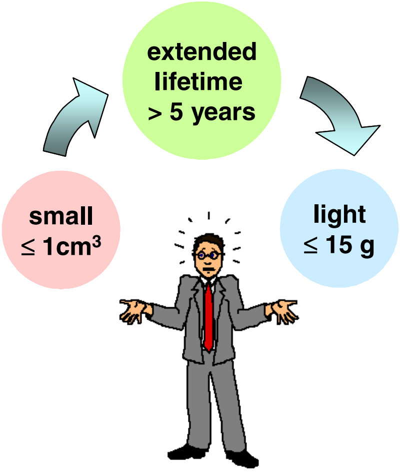


Fig. 4. Key design challenges of a BSN sensor

Reliability is defined as the probability, at a desired confidence level, that a device will perform a specified function, without failure, under stated conditions, for a specified period of time. According to this definition, reliability is a requirement in terms of both product longevity and confidence that the device is working as specified. Well-designed technology allows doctors, nurses, and other healthcare professionals to focus on caregiving functions and promoting the health of patients. This is crucial for the future market of devices used in remote monitoring. Since data need to be reliable and secure, BSNs suffer from the *reliability dilemma*, which means that the higher the reliability desired of data transmission, the higher the data overhead and, hence, the higher the power required.

The second challenge is the sustainable form factor for a BSN sensor. System designers must shrink the size of sensing nodes to the sub cubic centimeter level and give them conformal and wearable shapes that substantially disappear to the point that they are forgettable by the wearer. Size can be reduced by using a small cube or a smart band-aid, which requires new integration and packaging technologies [33]. In particular, chip-on-board assembly, chip-on-chip and, more recently, advanced 2-D and 3-D packaging technologies have improved in such a way that miniaturization is not only possible, but also cost effective while still maintaining adequate reliability.

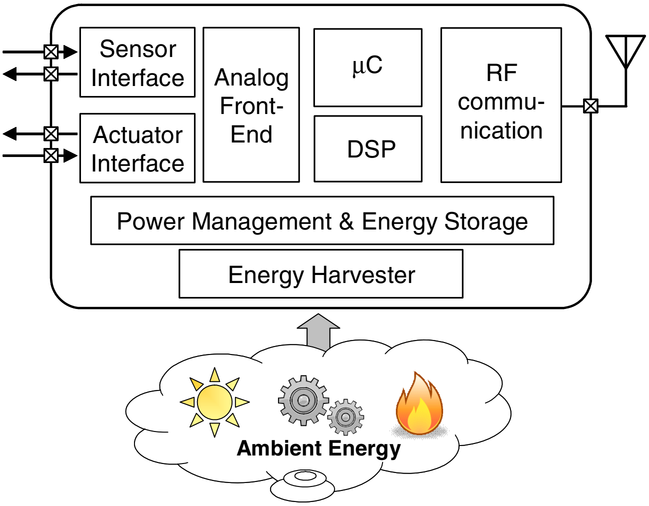


Fig. 5. Simplified block diagram of a self-powered BSN sensor

The third challenge is the sustainable power supply for the sensor. Although the research towards higher energy-density batteries is ongoing and new materials are revolutionizing battery dimensions, their energy density does not scale according to the target size, thus limiting their energy budget to the range of tens to hundreds of joules, i.e., 2 or 3 orders of magnitude less with respect to a cell phone battery [34]. As a result, the minimum required power consumption of sensor nodes often exceeds the rated current capacity of most battery types, thus leading to suboptimal battery lifetime. This drawback precludes the use of many existing solutions based on conventional electrochemical batteries. Moreover, there are also many applications where battery replacement is not practical, such as sensors implanted in the human body. To overcome this shortcoming, another energy paradigm is needed and energy harvesting (also referred to as energy scavenging) from the environment may provide a solution [35].

Energy harvesting is a means of powering sensor nodes by scavenging various low-grade ambient energy sources such as environmental vibrations, human power, thermal sources, solar sources, and wind energy sources and convert the obtained energy into useable electrical energy. Energy harvesting generally suffers from low, variable, and unpredictable levels of available power. Hence, it is likely that the sensor will be powered by a combination of different types of ambient energy sources and the energy thus obtained will be stored in rechargeable microbatteries for later use [35]. This approach is very promising, attracting interest from the scientific community and fostering the creation of new Companies which offer average power densities in the range of tens µW/cm^2 [36]. In particular, combining both energy storage and energy scavenging sources, the available power of a 1 cm^3 sensor is about 100 µW. This is illustrated in Fig. 5, where the sensor operates by scavenging energy from ambient power sources, e.g., a thermal [36], a vibration, or a solar energy source. The scavenged energy (after buffering on an energy storage element) is then used to power the sensing, computation, storage, and communication modules of the sensor. Since energy harvesters can be used efficiently in the 10 μW to 1 mW range [36], the development of BSNs is linked to a technological leap in the field of integrated-circuit design from low-power electronics (10 – 100 mW) to ultra-low power electronics (0.1 – 1 mW). Accordingly, highly aggressive low-power circuit design and efficient power delivery are required to meet the power constraints set by the sensor.

4 Improved Pervasive Sensing with Wearable Bioimpedance-Based BSN

Despite the high degree of development achieved by present solutions that ensure rigorous and reliable monitoring of certain vital signs, e.g., ECG, heart rate, breathing rate, etc., there is still lack of solutions designed to meet the demand of sensors which can be adapted to the particular characteristics of each individual for accurate and noninvasive monitoring of physiological parameters and emotional states as well as for reducing the impact of medical therapies in chronic patients [37]. From the set of available techniques for determining the physical and mental state of a person, bioelectrical impedance analysis (BIA) has qualities very attractive for personalized monitoring of patients and senior citizens during their daily life activity, besides being a non-invasive preventive diagnosis technique [38].

The term electrical bioimpedance (EBI), or simply bioimpedance*,* is used to describe the response of a biological material to the flow of an applied alternating electrical current with given amplitude and frequency [39], [40]. According to health issues, the amplitude of the excitation current is so low that EBI technology can be used even in neonates without causing any damage. When a biological material is included as a part of a well-known and well-characterized electrical circuit, valuable information can be derived about the microscopic structure of the material from the study of the behaviour of its electrical parameters, i.e., the magnitude and the phase of its bioimpedance. Needless to say, the knowledge gained about the relationship between the cellular-level structure and the electrical behaviour of living materials, as well as the high degree of maturity reached by silicon microelectronic technology, have allowed the recent progresses in EBI measurement techniques.

Although EBI technology can be applied in many fields, the segment of medical devices is one of its major working areas. In particular, EBI medical applications can be divided in the following three main categories.

- Bioimpedance spectroscopy (BIS), which consists in the study of electrical bioimpedance for tissue characterization and functional monitoring in a determined frequency range of the excitation current signal, typically from 1 kHz to a few MHz [41]. A particular case is the single-frequency bioimpedance analysis (SF-BIA), where a unique input frequency is used (typically 50 kHz). At this frequency, the internal current flows through the extracellular space as well as through the intracellular space, which provides valuable information about the health/integrity of cell walls. Practical applications of BIS and SF-BIA are body composition analysis, early detection of alterations in organs and tissues, assessment of the effectiveness of therapies and treatments, and so on.

- Impedance plethysmography, which consists in recording the instantaneous volume of an object by measurement of electrical bioimpedance [42]. In practice, the term of impedance plethysmography is mostly associated to the assessment of blood volume changes in any part of the body from changes caused in the electrical impedance of such body segment. Thus, typical applications of this method can be found in monitoring the stroke volume of the heart (usually referred to as impedance cardiography or transthoracic impedance cardiography) [43], in assessing peripheral blood flow [44] and arterial stiffness (i.e., the loss of the elastic properties of arteries), in respiration monitoring, and so on.
- Impedance imaging, which is based on multiple impedance measurements by injecting current and recording the voltage with a multiple electrode system located in a cross-section of the body [45], [46]. A reconstruction algorithm applied to the collected data generates an image which provides information about the conductivity inside the body. Depending on the collected data (transimpedance, resistance, or capacitance), the corresponding technique is referred to as electrical impedance tomography, electrical resistance tomography, or electrical capacitance tomography, respectively. In any case, although the resolution of these techniques is poor when compared to other medical image methods [47], impedance imaging is a very promising approach due to the advantages derived from the EBI technology, which are summarized below.

EBI technology presents advantages and drawbacks when compared to other medical diagnosis techniques. As for the first, it should be pointed out that EBI technology is relatively inexpensive, innocuous (non-invasive, non-ionizing, and non-destructive), and easy-to-use. As for drawbacks of EBI technology, it is worth to mention its limited accuracy, mainly when compared to other medical diagnosis techniques such as computer tomography and magnetic resonance, and lack of standardization in the procedures (multiple factors of influence), which makes it not easy to guarantee the repeatability of results.

4.1 Opportunities of Bioimpedance Technology

As a consequence of the demographic trend in the developed countries, the population segment of elderly people needs more and more healthcare services. Moreover, the rest of population segments also demands for higher quality of life (i.e., healthy lifestyle), which also calls for the availability of healthcare preventive programs. These considerations have an adverse impact, in principle, over the financial resources required by National Health Systems which, very often, must provide adequate response to citizens' demands in a social scenario characterized by a shortage of available resources.

The above circumstances are strongly promoting the development of new healthcare structures and strategies, whose success necessarily relies on the availability of diagnosis and assessment medical techniques with some of the following features:

- Medical techniques suited to be incorporated in Primary Healthcare Centres (ambulatory services) instead of being limited for use in specialized hospital services as a consequence of high cost and/or the need for bulky equipment and the necessity to be manipulated by skilled operators;
- Medical diagnosis (and even prognosis) techniques addressed to the detection of diseases as early as possible, which assures the effectiveness of the treatments and therapies at a lower cost;
- Medical techniques to be manipulated by patients with possibility of remote supervision, which also reduces the number of visits to Healthcare Centres.

In summary, there is an increasing interest in the development of medical devices featuring low-cost, light weight, and small size and being innocuous, autonomous, wireless, easy-to-use even by the own patient, and able to early detect alterations in the structure and functionality of organs and tissues as well as to assess the effectiveness of therapies and treatments. Consequently, terms such as Personal Healthcare (p-health), Home Monitoring, Wearable Medical Devices, Non-invasive Medical Technologies, etc. are currently associated to good business chances for healthcare providers and EBI technology occupies a privileged position for contributing to provide a satisfactory response to most of technological challenges.

4.2 EBI-BSN: New Perspectives for Bioimpedance Applications

In order to take advantage of the described social scenario for medical devices, a technology platform for a number of BSN applications based on EBI technology has been developed. In particular, a cost-effective CMOS silicon-chip implementation of a flexible high-performance EBI sensor has been considered as the only feasible way to fulfil the above objectives. Of course, appropriate low-power low-voltage CMOS circuit techniques were adopted in the design phase.

Fig. 6 illustrates the main circuit sections of an EBI wireless sensor, also referred to as EBI mote. The CMOS analogue front-end section (EBI sensor/spectrometer) injects an ac excitation current into the biological material under test (MUT), detects the voltages in two points of the MUT, and processes these two signals so as to provide two dc voltages proportional to the magnitude and the phase, respectively, of the MUT bioelectrical impedance. A tetrapolar system (two electrodes for current injection and two electrodes for voltage recording) is used so as to reduce measurement errors caused by the electrode/skin interface with respect to the case of its two-electrode counterpart [48]. A microcontroller section supervises the operation of the whole mote, controls the amplitude and the frequency of the excitation current according to the stored program sequence, and convert the ensuing dc voltages representing the magnitude and the phase of the measured EBI to a digital code. At the same time, the microcontroller supports the calibration task that aims at avoiding systematic measurement errors. The obtained digital words are transmitted by an RF section to the coordinator of the BSN following a low-power, short-range wireless protocol, such as ZigBee or Bluetooth low-energy.

The block diagram of the EBI sensor is shown in Fig. 7. Basically, its task consists in measuring the amplitude and the phase of a signal by using a gain phase detector. The excitation current is injected through two electrodes (I^+, I^-) to stimulate the tissue having an unknown impedance Z_x. The excitation current also flows through an integrated reference resistor R_s connected in series with Z_x. Two other electrodes (V^+, V^-) sense the voltage drop across Z_x, which is amplified by an instrumentation amplifier (IA). The voltage signal across R_s is amplified by a second instrumentation amplifier matched to the former. These amplified voltage signals are processed by the phase-gain detector so as to obtain two dc voltages proportional to their magnitude ratio $|K|$ and phase difference θ, respectively. If the two instrumentation amplifiers are identical and have infinite input impedance, it is straightforward to obtain that the unknown impedance Z_x can be expressed as

$$Z_x = R_s \cdot |K| \angle \theta \tag{1}$$

The excitation current magnitude is chosen to be small enough so as not to be perceived by the subject, but large enough to produce voltage signals that are above interfering noise which might arise from bioelectrical sources such as muscle tissues. In practice, relatively small current magnitudes are involved, i.e., less than 1 mA, which are below the threshold of human perception.

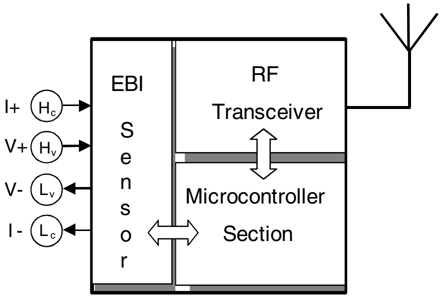


Fig. 6. Functional blocks of an EBI mote

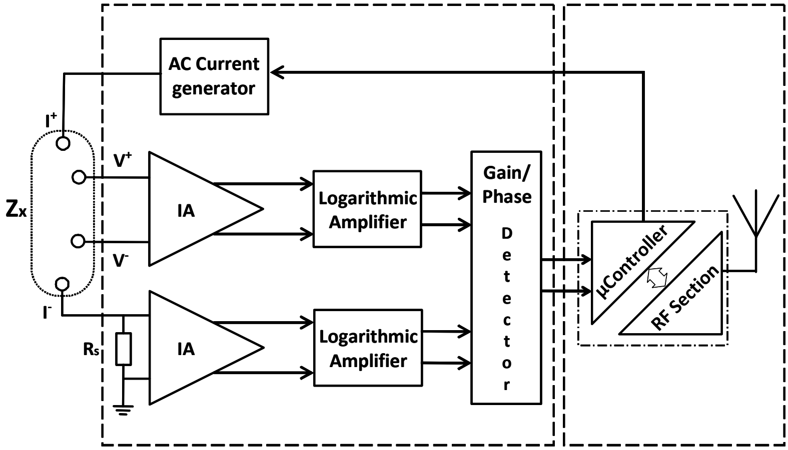


Fig. 7. Block diagram of an EBI-BSN mote (the EBI sensor is enclosed by the left dashed box)

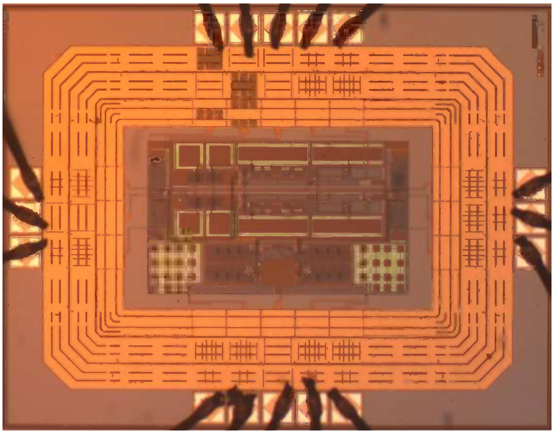


Fig. 8. Chip microphotograph of the high-performance EBI sensor

The EBI sensor was designed and fabricated in standard 0.35-µm CMOS technology. Fig. 8 corresponds to a microphotograph of the fabricated chip. The core of the proposed wireless section is the commercial solution CC2430 System-on-Chip from TI/Chipcon. The CC2430 is optimized for long-term battery operation and includes the CC2420 transceiver and an efficient 8051-based microcontroller, which implements the whole digital processing stage. The experimental performance of the developed EBI mote is summarized in Table 2.

Table 2. Experimental performance of the EBI-mote

Measuring system	Tetrapolar
Ranges of current excitation	• Amplitude: 5 µA to 1 mA • Frequency: 1 kHz, 2 MHz
Magnitude measurement range	1 Ω to 3.5 kΩ
Phase measurement range	0° to 90°
Analog front-end current consumption	0.8 mA
Analog front-end supply voltage	2V (single-supply)

Table 3. Programmable parameters of the proposed EBI-BSN mote

Parameter	**Options**
Type of EBI analysis	• SF-BIA • BIS
Frequency	• Single value (SF-BIA) • Sweep and interval (BIS)
Num. of analyses/sweeps	• Single (SF-BIA, BIS) • Analysis time interval (SF-BIA, BIS)
Amplitude excitation current	• Single value (SF-BIA, BIS) • Amplitude automatic tuning (SF-BIA, BIS)

Cardiovascular diseases (CVD) represent the leading cause of death in the population of developed countries. They constitute a very attractive application field for multi-channel electrical bioimpedance plethysmography, which allows the measurement of cardiac blood flow (cardiac output) and peripheral blood flow in selected parts of the body [49].

Multi-channel impedance plethysmography based on BSN can provide improved performance in the diagnostic of cardiovascular disorders as well as in other medical applications (it should be noted that two-channel systems represent the most common multi-channel impedance equipment in this area). An EBI-BSN based on the mote architecture of Fig. 7 performs highly flexible and scalable multi-EBI spectrometer architecture. Every mote can be independently adjusted (Table 3) so as to optimally measure the electrical properties of the underlying tissue and, hence, to register the physiological events that occur in a given body location. To follow the skin surface, the mote can be fixed over a patch or over a strap. Along with the sites for EBI measurements, the topology and the complexity of the BSN that result more appropriate for the study of a particular physiological event can be defined. A specifically tailored graphic software interface facilitates the user to program the operation of the motes and the topology of the BSN.

For illustration purposes, Fig. 9 corresponds to a basic and conceptual EBI-wireless BSN (EBI-WBSN) scheme for non-invasive assessment of hemodynamic parameters. Every mote is assumed to be positioned on top of one of the big arteries (carotid, femoral, brachial, etc.) of the arterial tree. Each mote, which carries out a bioimpedance analysis with appropriate values of frequency and amplitude of the excitation current, detects the arrival of the blood pressure pulse which generates a bioimpedance signal. The velocity of a pressure pulse that propagates through the arterial tree is known as Pulse Wave Velocity (PWV) and depends on the properties of the arterial walls. In particular, PWV is indicative of the arterial stiffness. Its clinical relevance consists in the fact that it represents an independent global marker of cardiovascular risk. Also, blood pressure can be measured by tracking the pulse wave transit time in an arterial segment.

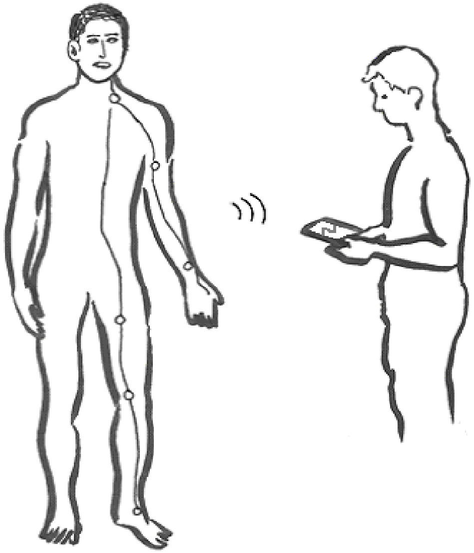


Fig. 9. EBI-BSN scheme for non-invasive assessment of hemodynamic parameters

PWV between the carotid to the femoral artery is accepted as a gold-standard of arterial stiffness in clinical practice [50]. However, PWV in any other arterial segment contains valuable clinical information, since the wall properties are not homogeneous along the whole arterial tree. An EBI-WBSN is able to measure the pulse transient time between any two motes, where pulse transient time refers to the time that a pressure pulse requires to travel through the corresponding arterial segment. All measurements of pulse transient time are carried out over the propagation of the same pressure pulse. The distances between motes can be precisely determined by their respective ZigBee transceivers. This way, the PWV between two any monitored arterial segments, i.e., the ratio of the corresponding distance to the pulse transient time in the considered arterial segment, is accurately derived.

Moreover, changes in cardiac output as well as in peripheral blood flows can be derived from the analysis of the corresponding bioimpedance wave signals and the well-known hemodynamic equations [51].

Finally, from a general point of view, wearable medical systems for pervasive health based on BSNs incorporate technologies that enable continuous and non-invasive monitoring of vital signs and biochemical variables [52], [53]. These systems are also taking advantage of the great improvement in the development of textile-electrode technology [54]. Medical monitoring systems involve monitoring one or more vital signs such as cardiac activity, blood pressure, respiration, blood oxygen saturation (respiration effectiveness), blood glucose level, etc. Electrical bioimpedance is a technology with a suitable potential for playing a leading role in wearable healthcare systems.

5 Conclusions

In this chapter, we have shown why the successful realization of pervasive eHealth can only become reality through innovative solutions able to remove the critical technological obstacles to implement miniaturised wearable sensor nodes for biomedical applications. Three key challenges have been introduced, namely extreme reliability, small size/weight, and very low power consumption. The merits and performance limitations of electrical bioimpedance (EBI) sensors in the pervasive eHealth context have also been discussed. As a case study, an unobtrusive, ubiquitous wireless EBI sensor for real-time monitoring has been proposed.

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A Universal Wireless Device for Biomedical Signals Recording

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Abstract. The chapter provides a report on the wireless biomedical signal acquisition system that has been developed and applied recently in a hospital. The authors describe a universal wireless device (bioelectric amplifier) with a case study of the wireless communication. Advantages and disadvantages of considered standards have been described. The most important feature of the bioelectric amplifier is the software configuration ability towards specific requirements that occur during the registration of different signals. The study shows examples for ECG (Electrocardiography), EGG (Electrogastrography), EOG (Electro-oculography), EEG (Electroencephalography) with the same wireless device. The portable unit is under clinical trials tests and preliminary evaluation indicates acceptance by medical staff. Additional advantages are the relatively low cost of manufacture and the possibility of application of other wireless transmission standards.

Keywords: wireless networks, ECG, EOG, EEG, EGG.

1 Introduction

Recently the rapidly developing radio-communication systems provide a wide range of possibilities in improving existing medical solutions. This is mainly because of decreasing costs of wireless modules and increasing the speed and reliability of communication. Monitoring of patient health conditions in a hospital, remote monitoring of patients at their homes or monitoring of patient's diets are just few examples of many applications of a pervasive computing. One of the most important aspects during the treatment of patients is a quick response to abnormal vital signs. Remote monitoring systems allow for a direct notification of the patient's problems in the hospital, and for a quick response if the patient is at home. These systems also enable direct contact with a healthcare professional for consultation at any time.

Example applications of wireless networks in medicine are [1]:

1. WBAN (Wireless Body Area Network) – monitoring and acquisition of selected parameters of vital signs.

2. RFID (Radio Frequency Identification) – Hospital can use RFID in order to manage the facilities or patient care. Tags identify the patient and effectively

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prevent medication error. The technology can also be used to control the supply and provision.

3. WPAN (Wireless Personal Area Network) – it has a relatively small range (up to several meters). It utilizes Bluetooth standard. This solution can be used to monitor vital signs of patients. The staff can observe the performance of different patients at the same time, if necessary, may take the appropriate action. WPAN can also be used at home to monitor the basic physiological parameters such as pressure or ECG signal.

4. Sensor networks – networks of multiple sensors deployed in a certain area. They can be placed at the bedside, where they collect data on respiratory rate, heart rate, movement e.g. may indicate if the patient leaves the bed.

5. GPS/UMTS – can be used for home monitoring. Patient can freely perform daily activities and can be under constant medical supervision. The technology can also be applied for telediagnostics.

6. WLAN (Wireless Local Area Network) – This type of data can be used to provide information about patients within the hospital. It also allows remote use of computer-controlled medical equipment.

In the first part of the chapter, we describe selected types of wireless data transmission orientated on medical devices. Then, in section three, some examples of non-invasive methods in the context of medical diagnosis like ECG/EGG/EOG have been presented. Next, a prototype device with a reconfigurable front-end are described. The main part of the device has been built with ADS1298 integrated circuit (IC) which is a dedicated analog front-end for biomedical signal acquisition. This system is characterized by high CMRR (Common Mode Rejection Rate) and is equipped with auxiliary circuits, e.g. electrode-skin contact detection system, active ground circuit, and built-in test redundant part. The device is using a Bluetooth link with a host PC, however, other wireless technologies can be also applied. The communication between the microcontroller and the Bluetooth module is realized with UART, so any module (standards presented in section 2) with UART interface is acceptable. Integration of many functions into a single chip allows for input amplifiers configuration (it reduces size of the analog block) with a low power consumption and a reduction of production costs. First tests of the device on volunteers indicate high performance as well as fulfill medical requirements for signals obtained. The device is also used in the biomedical digital signal processing like ECG detector presented in [2].

2 Wireless Technologies – Selected Issues

The past decade is an enormous growth of wireless communication standards. Many of them are designed for very specific applications like for medical devices. Due to accessibility and mobility requirements wireless is the preferred medium in medical applications. Moreover, the wireless technologies are being developed to provide communication between stand-alone medical machines and make them interact. The paragraph is a brief overview of wireless data communication standards applied in medical devices. Next section is divided into two points, first reports some aspects on mobile phones data transmission, second is focused on ISM (Industrial Scientific Medical) open access standards [1, 3].

2.1 Cellular Network Standards

A cellular network is composed of a number of transceivers called base stations. A single base station offers a radio communication within area depending on operating frequency e.g. for 1800MHz network the area is around 614km^2 (the cell radius is 14km), for 950MHz frequency, the cell radius is 27km and area exceeds 2200km^2. There are several data communication standards like GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for GSM Evolution also called Enhanced GPRS), UMTS (Universal Mobile Telecommunication System), etc. Due to the wide availability of GSM modules, we will discuss the main advantages and disadvantages of the aforementioned standards.

GPRS/EDGE

GPRS is a data transmission service available in the GSM technology (also called 2.5G technology). It is a packet transmission protocol that allows multiple users to send data in packets through shared channels. A dedicated channel is not reserved to subscribers for the duration of the connection, but they are allowed to a transmission at the time of sending and receiving data (full-duplex). This saves power and minimizes costs. This is a paid service to the GSM network operator. Advantages of the standard are: range which is usually wide enough for a user (exactly the same as GSM network), the patient can move and do certain exercises. GPRS wireless transmission protocols is based on the Internet protocols IP, so it can work easily with existing IP protocols in the fixed network [1]. EDGE, in turn, is an improved version of GPRS. It is a packet data transmission system, however, it offers much greater data transfer than GPRS (230kb/s, in practice less than 200kb/s). This is achieved mainly through the use of a new modulation and new ways of coding. GSM/GPRS networks used GMSK modulation while EDGE introduced more efficient 8-PSK modulation. Moreover, both are used for data transmission. The new method of modulation significantly affects the throughput, although the structure of the frame or the packet structure remains unchanged.

The weak points of GPRS/EDGE are: energy consumption by the device which causes shortening the operating time (a few hours) and data transfer limited to 115kb/s or 230kb/s. In practice, the data transmission is much lower and usually is between 30 and 80kb/s. It is paid connection so the data transfer can be expensive. The choice is good if the biomedical signal can be sampled with low frequency so the amount of data is rather small or there is no possibility to apply other standards.

UMTS

Nowadays, UMTS is the most popular standard for mobile telephony. It is characterized by high speed of data transfer, so that network offers the ability to make voice calls, video calls, and to send text messages or data. UMTS radio interface, called a UTRAN is based on the technology of broadband multiple access to the channel in the area code (WCDMA). With the new radio interface, it is possible to make better use of available radio resources and to offer higher data rate. UMTS technology can provide new multimedia services which are absent in the second generation of mobile telephony. Services such as simultaneous transmission of voice and video in real time open up new possibilities for using mobile networks. The maximum throughput in UMTS technology is about 2 Mb/s. Only UMTS enables full usage of multimedia information (including video, audio) for medical consultation purposes [1].

2.2 ISM Networks

The ISM bands are strictly defined and the use of selected frequency depends on e.g. location (USA and EU regulations are different). Generally, the ISM bands are license free if some other requirements are fulfilled, e.g. maximum power dissipation (the communication range for a particular band), however the availability of use is sometimes subjected to local acceptance.

WI-FI

Wi-Fi is the name for technologies that are based on IEEE802.11 standards. Each of the IEEE802.11 specifies a different modulation type and the corresponding data transfer. The concept of the channel has been applied in order to separate each connection. E.g. the 2.4GHz band is divided into 13 channels with a width of 22MHz [4]. The main standards are depicted in tab. 1.

Table 1. Comparison of IEEE802.11 standards

Type	Frequency [GHz]	Modulation type	Data transfer [Mbit/s]	Range (indoor/outdoor) [m]
802.11	2.4	IR/FHSS/DSSS	2	20/100
802.11a	5	OFDM	54	35/120
802.11b	2.4	DSSS	11	38/140
802.11g	2.4	OFDM,DSSS	54	38/140
802.11n	2.4 or 5	OFDN	600	70/250
802.11y	3.7	OFDM	54	-/5000

Thanks to its characteristic, Wi-Fi has found wide application at public access points, building security and control systems and home electronics. Tab. 1 shows good enough data speed and range for the medical remote monitoring systems. Greater range improves comfort because the patient can move around the apartment. IEEE802.11x does not have any limitation on the number of transmitters. There are well known systems for monitoring patient’s breath (20 sensors transmits signal to the receiver). The main weak point for portable Wi-Fi is power consumption which reduces the operating time on a battery (typical time is less than 8 hours).

Bluetooth

Wireless standard for creating secure connection between devices located nearby (depends on substandard). Bluetooth architecture is presented as a layer model [5,6]:

- Physical layer – the radio link layer control is responsible for sending and receiving data packets. Operating frequency range is 2400-2483.5 GHz and is divided into 79 independent channels with a width of 1MHz. Data packets are transmitted at schedule intervals with a length of 625us to cyclically changing frequency. Bluetooth is a full duplex standard.
- Data link layer – its task is to control the operation of the corresponding radio module. Two protocols can be distinguished in this layer: Management Protocol LMP link and L2CAP logical link.
- Higher layers – higher level protocols. It includes protocols such as SDP (Service Discovery Protocol), RFCOMM (Radio Frequency Communications Protocol), TCS (Telephony Control Protocol), OBEX (Object Exchange Protocol) and BNEP (Bluetooth Network Encapsulation Protocol).

There are three classes of the Bluetooth transmitters [5, 6]:

- Class 1 – 100mW, range up to 100m
- Class 2 – 2,5mW, range up to 10m
- Class 3 – 1mW, range up to 1m.

Bluetooth transmitters offer small data transfer, which limits their use in certain applications. On the other hand, these devices have very low power consumption, which encourages implementing such solution in mobile devices. An important advantage is the ease of use because the data link is controlled by Bluetooth stack. Recently, a Bluetooth low energy has been introduced which aim was to increase the transmission speed, low power consumption and fast access to data. With this assumption, the main recipients of such solutions may be medical industry. Devices equipped with the Low Energy standard charge 100 times less energy in comparison to standard Bluetooth solution (see tab. 2).

Table 2. Comparison of the Bluetooth and Bluetooth low energy [5]

	Bluetooth class 2/3	Bluetooth Low Energy
Frequency	2.4 GHz	2.4 GHz
Range	10-100 m	10-100 m
Data Transfer	0.7-2.1 Mbps	305 kbps
Number of devices in network	7	Unlimited
Time response	100+ ms	<6ms
Energy consumption	1(reference)	0.01-0.05
Current consumption/ (life on battery)	40 mA / 5-10 days	10-20 mA / 1 year

3 A Reconfigurable Device for Bioelectric Signal Acquisition

This section presents the concept of building a universal device for recording (acquisition) of bioelectric signals with wireless transmission to a computer. It is shown that by using currently available systems i.e. ADS1298 and Bluetooth module, it is possible to build a device that can be easily adapt to the tasks previously requiring the use of separate devices. Next, bioelectric signals for health diagnosis like ECG, EGG and EOG with the use of our reconfigurable device are discussed. The concept of building reconfigurable device for measuring a variety of diagnostic signals is shown in the fig. 1. The patient's cable defines the configuration of an analog front-end. Full signal with a constant level (direct coupling) is sent to the PC where isolation of a proper component is performed with an appropriate method of filtering. Our solution combines the features of universality and economy and is open for future application because the signal is not prefiltered by the recording equipment.

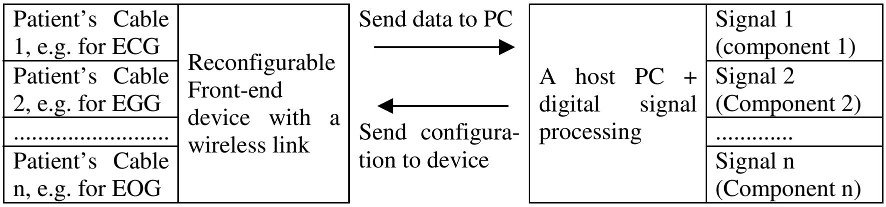

Fig. 1. The idea of a universal wireless device for bioelectric signal recording

3.1 Non-invasive Methods for Assessing the Patient's Health

Non-invasive assessment of the patient's condition lies mainly on the analysis and registration of certain biosignals from the body surface. It is an important feedback that allows assessing not only patient's condition but also treatment effects. Advances in technology create an opportunity for safe application of medical devices both in the hospital and in the natural environment (at home). The best recognized type of patient's evaluation are 24-hour Holter, remote monitoring of cardio disease, the use of external and implantable stimulators, defibrillators and infusion pumps dispensing certain substances (medications). Typical measured values are voltage, impedance, temperature, chemical composition of specific substances and movement or location of the patient. Electrical signals available on the body surface area have small values and are located in the micro- and mili-Volts range [7]. Tab. 3 shows the voltage level of the most popular bioelectric signals.

Table 3. Basic features of bioelectric signals

Signal	Peak to peak amplitude [mV]	Bandwidth [Hz]	Number of channels
ECG	1 – 3	0.05 – 100	1 - 12
EEG	0.05 – 0.3	0.02 – 35 (70)	16 - 256
EOG	< 0.3	0.02 – 17	1 - 2
EGG	< 0.5	0.015 – 0.2	1 - 4

Further processing of the electrical signals must take into account: appropriate signal amplification, selection of useful differential component which occurs in the presence of e.g. energy network (50/60Hz) and which should be suppressed. All these elements are realized through analog front-end of sufficient robustness.

3.2 Wireless Recorder Description

Most measuring devices record the signals on the surface of the patient’s body and send it by a wire or wireless to a system collecting and analyzing data. Rarely, the unit stores the data in memory, still, 24-hour Holter is a good example of such device. Block diagram of a typical wireless recorder is shown in fig. 2. It consists of an input circuit, a microprocessor unit, RF (radio frequency) module and a power supply block.

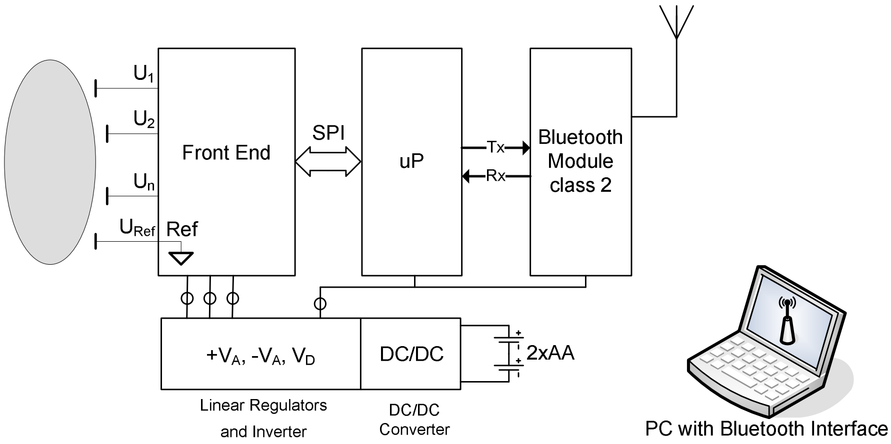

Fig. 2. Block diagram for the wireless recorder of biomedical signals

3.2.1 Signal Acquisition – Analog Front-End

The construction of a good analog front end for biomedical signal acquisition is not a trivial task. Based on the bioelectric signal section, the analog part includes a set of differential amplifiers with high CMRR ratio which allows for signal amplification and removes distorting components. Configuration of input amplifiers depends on the type of evaluation and required links with patient (channels).

Moreover, the amplifier input connected to the patient via electrodes should be protected against static discharge (ESD). The entire device must meet the requirements arising from the standards for medical equipment such as IEC60601 [9]. This is a challenge for designers of medical equipment. The next step in the signal processing diagram is A/D converter. Currently available microcontrollers contain multichannel A/D converters with a resolution of 10 – 12 bits. In many cases it is sufficient to obtain high quality signal data. In order to obtain higher resolution of 14-24 bits other and usually more expensive A/D converters should be introduced.

The authors have decided to use the integrated system ADS1298 recently developed by TI, which allows for simplification of the analog input. Its internal structure is composed of multi-channel bioelectric signals amplifier and set of high resolution A/D converters. The block diagram of the ADS1298 is shown in fig. 3. The most important advantage is the configuration of the input differential amplifiers. The programmable input multiplexer allows for configuration of the amplifier. The chip contains also eight A/D converters with a resolution of 24 bits and the control unit for setting parameters for A/D and amplifiers. The ADS1298 has been configured with the following parameters: sampling frequency 500Hz per channel, gain equals 6 and switched on the electrode-skin contact condition block for monitoring the deterioration of a signal.

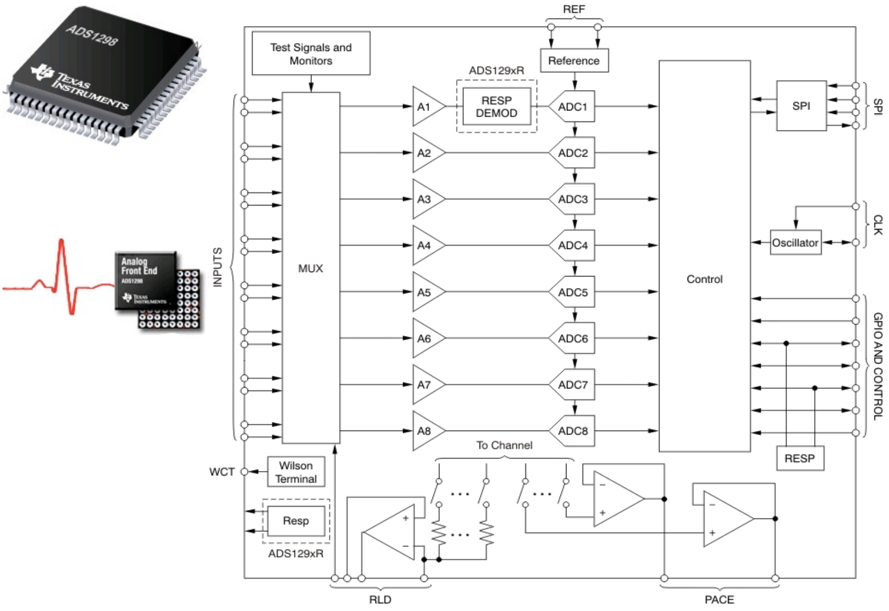

Fig. 3. ADS1298 block diagram [8]

3.2.2 Microprocessor Unit

There are many microcontrollers that can be applied for portable medical devices. Usually, the choice is dictated by the knowledge of the developers. Processor selection is not critical and most 8, 16 and 32-bit single processors can be used. The authors are familiar with Microchip processors and decide to use PIC16F883 [10]. It belongs to 8-bit family and offers low power consumption (approximately 6.5mA) at a sufficient speed. The microcontroller is responsible for ADS1298 system configuration, Bluetooth configuration, reading data from A/D converters (e.g. 8 channels), formatting a frame and sending data to a host via selected standard. General overview of the program together with time required for consequent tasks is presented in the fig. 4. The processor is waiting for a signal 'dataready' in the main loop. Then the system reads data from the ADS1298, create the data frame and sends it to the Bluetooth module. An important added value is sending information about electrode-skin state and battery level which facilitates the operation of the device. The Bluetooth speed has been set at 230.4 kb/s.

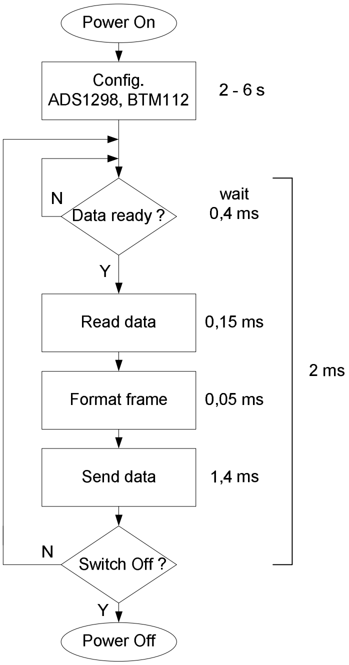

Fig. 4. Simplified block diagram of the hardware program (firmware)

3.2.3 Bluetooth Module Description

The Bluetooth technology has been used for duplex data transmission. The main advantages and disadvantages of the Bluetooth have been described in section 2. As mentioned before, it is a popular standard and many devices like notebooks, PDAs and cell phones. There are a lot of Bluetooth modules from different vendors. An example module class 2 is shown in the fig. 5. The wireless recorder has the BTM112 module which is characterized by a low current consumption and easy to use communication service i.e. SPP (Serial Port Protocol).

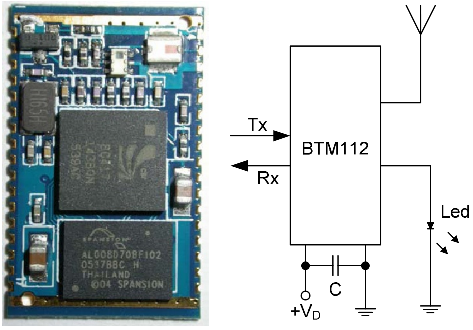

Fig. 5. An exemplary Bluetooth module BTM112 from Rayson [11]

BTM112 is configured with the use of ATA commands for the following parameters: data speed 230.4kb/s, broadcasting disabled (feedback echo off), unique module name with the 4-digit access code. These changes made possible to achieve an appropriate data rate and automatically establish link between our device and PC.

3.2.4 Communication Frame Format

Data from the ADS1298 are collected and standard frame containing 216 bits are created (24 bits of status and 8x24 bits of data from successive channels). The communication between ADS1298 and the microprocessor is realized with the SPI interface [8]. The Bluetooth module (BTM112) is fed via UART interface. The frame consists of: a channel interface, electrode bit status, data field (8x4bytes), synchronization counter state (2 bytes). It includes 34 bytes. The order of bytes is:

Ch0_data	**Ch1_data**	**……**	**Ch7_data**	**Sync. counter**
(4 bytes),	**(4 bytes)**	**……**	**(4 bytes)**	**(2 bytes)**

The synchronization counter is used to capture the lost frames. In the absence of an individual frame, the missing data are obtained by interpolation of neighboring data (it is possible because of the oversampling). The PC application offers reconfiguration of the ADS1298 amplifiers via the microprocessor unit. For this purpose, the processor creates a frame and sends it to an amplifier in the following format: 2 bytes of the header, 1 byte of the ADS register address and 1 byte of the new registry value:

Header (2 bytes)	**Register Address (1 byte)**	**Register Value (1 byte)**

The sequence 0x4F5E, 0x05, 0x05 set: the first channel of ADS1298 on with a gain equals 6 and the test signal in channel input.

3.2.5 Power Supply Module

It has been assumed that the system will be powered by one or two AA size NIMH batteries with a capacity of 2000mAh. It has been applied a common solution that consists of an impulse voltage booster converter (type boost) with high efficiency of 80-90%, a set of linear stabilizers of low drop out voltage and voltage inverting converter in order to obtain negative voltage. Power supply system provides 3.3 V for the digital part and ±2.5V for the analog part. The input battery voltage is monitored to obtain information if the battery is running out and need replacement. Total current consumption does not exceed 90mA, which means one set of batteries allows for working time over 20 hours.

3.2.6 Additional Temperature Sensor

An additional thermistor has been introduced to monitor the frequency of breathing. The thermistor is placed in the front of the mouth or nose and records changes of air temperature. The thermistor is connected to the input of ADS1298 channel via voltage divider circuit. There is a possibility to connect other sensors with digital outputs such as digital thermometers, accelerometers, pressure sensors, etc.

4 Application of the Device

The current section is focused on the device application. It has been decided to apply the device for recording bioelectric signals like ECG, EGG, and EOG. The authors would like to underline the possibility of the firmware reconfiguration and the ability to change parameters of the input amplifier.

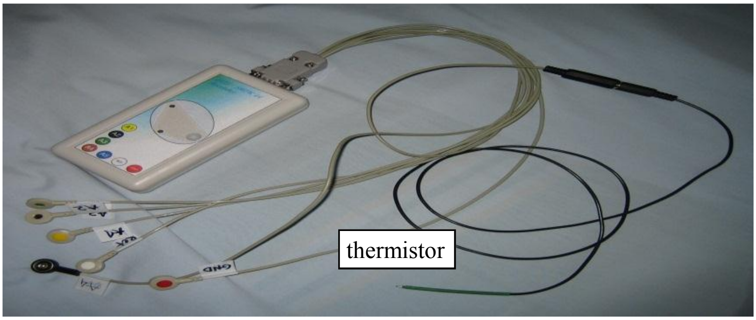

Fig. 6. 4-channel EGG – a prototype device

The last part of this section describes potential benefits that could bring the use of the proposed device. Fig. 6 shows the prototype of four-channel EGG package equipped with thermistor (temperature sensor) as breathing sensor.

4.1 ECG Configuration

ECG recording is one of the most frequently performed tests. Typical ECG system requires 10 connections (cables) with a patient under test [12, 13]. Configuration of the input amplifiers for standard ECG is shown in the fig. 7, i.e. two limb leads (I and II) and six precordial (V1-V6), the other leads are calculated in software. Our device offers this amplifier formation through firmware and ADS1298 reconfiguration.

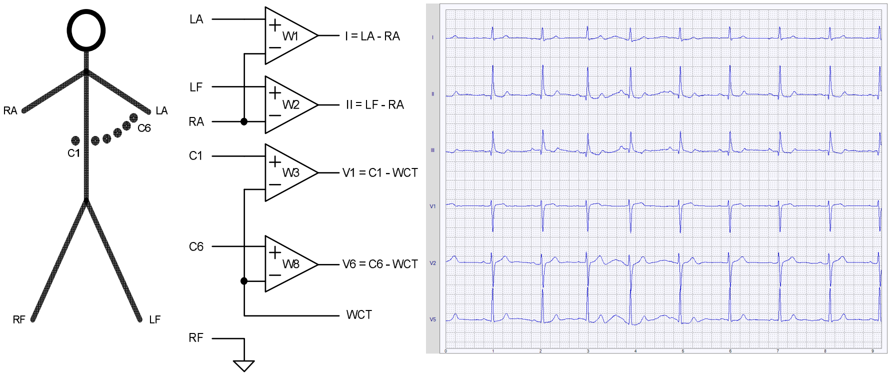

Fig. 7. ECG leads, configuration of the input amplifiers, and ECG signals

4.2 EGG Registration

Electrical activity of the stomach relates gastric contractions and plays an essential role in digestion. The main component of the myoelectric activity of the stomach is so called slow wave with a frequency of 3 cycles per minute (0.05Hz) and therefore requires a long recording time [14].

Typical EGG test takes about 2 hours and consists of three parts:

1. the first part requires usually not longer than 30 minutes and is referred to a stage before a meal (tested person should be fasting),

2. the second part takes between 5 and 15 minutes, during which time the person under test eats a standardized meal (standard depends on the health care center performing the test),

3. the third part usually takes 30-120 minutes after the meal (postprandial).

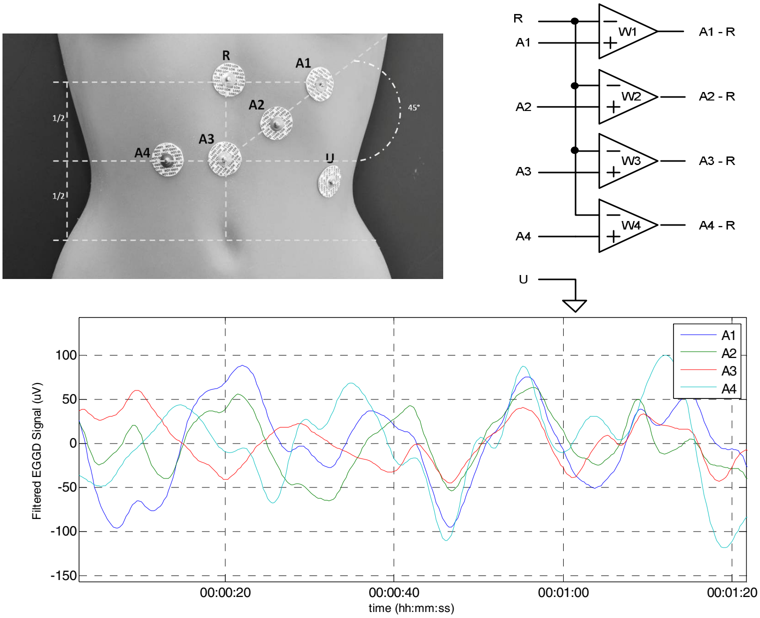

Fig. 8. EGG: electrodes arrangement, amplifiers input configuration and exemplary 80 seconds of EGG signals

The use of wireless technology significantly enhances the research process and increase patient comfort during the EGG test. Four-channel EEG signal is obtained from the electrodes correctly placed on the surface of the patient's stomach as shown in fig. 8.

4.3 EOG Configuration

There is an electric field around the eye which shape is similar to the dipole field due to the potential difference between the cornea and retina. Field vector is associated with the current position of the eyeball. EOG measurement is performed in the horizontal plane (H) and vertical (V) by means of electrodes placed appropriately on the surface of the face (around the eye) [15,16]. The principle of recording the EOG is shown in fig. 9.

The horizontal component (H) of the EOG signal during reading the text is shown in the fig. 10. Fixing the eye on the individual words and turn back of the eye to a new line of text can be noticed. The rising part of the signal corresponds to reading a single line of text and horizontal sections of the signal correspond to reading a single the individual words. The vertical axis shows the rotation angle of the eye in degrees (horizontal plane). The EOG filter parameters are in tab. 4.

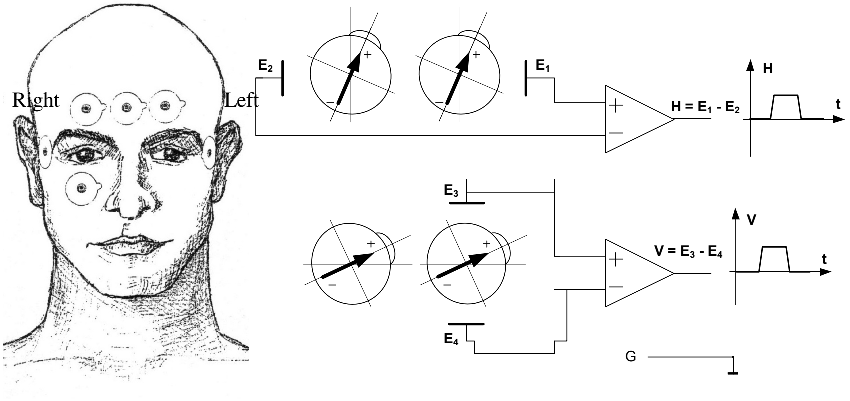

Fig. 9. EOG test: location of electrodes and configuration of the input amplifier [17]

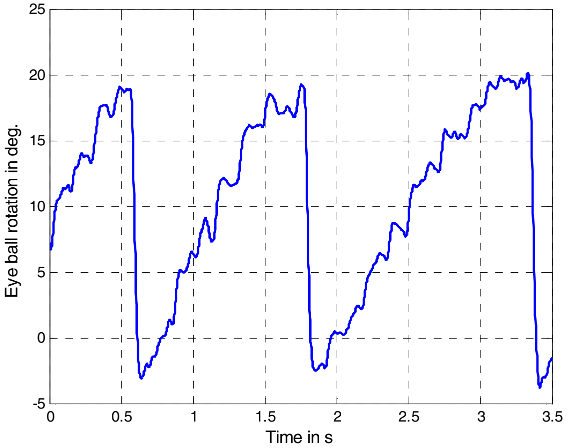

Fig. 10. Horizontal component of the EOG while reading the text

Table 4. EOG filter description

Component	LPF (Low Pass Filter)	HPF (High Pass Filter)
	Corner frequency f0 Filter's coefficients	Corner frequency f0 Filter's coefficients
EOG	f_0=17 Hz **b**= 10^{-3}[0.0999;0.3997;0.5995;0.3997;0.0999] **a**=[1;-3.4423;4.4771;-2.6048;0.5715]	f_0=0.02Hz **b**=[0.9998;-1.9996;0.9998] **a**=[1;-1.9996;0.9996]

Digital filters designed for signal processing, which are presented in this chapter, have the following transmittance:

$$H(z)=\frac{b_0+b_1z^{-1}+b_2z^{-2}+b_3z^{-3}+....}{a_0-a_1z^{-1}-a_2z^{-2}-a_3z^{-3}+....} \quad (1)$$

where **a**=[a_0;a_1;a_2;…] **b**=[b_0;b_1;b_2,…].

4.4 Multi-parameter Bioelectric Signals Registration

ADS1298 IC contains 24-bit A/D converter that can be used for a number of input channels. A small gain of measuring amplifier allows registration of the signal with a constant component and avoids the analog high pass filter construction which is usually required in biomedical devices. Simultaneous recording of complex signals are to be extracted with the use of band pass filters. Example of such an acquisition is shown in the fig. 11, where components: EGG, respiratory, and ECG are isolated from the recorded (complex) signal [18].

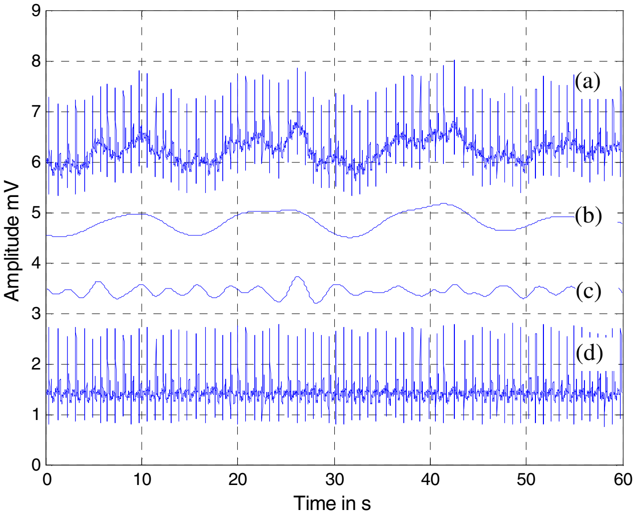

Fig. 11. Example of multi-parameter signal recording (a) and its components: EGG (b), respiratory (c), and ECG (d) signals

As mentioned before, the signal processing is performed in microprocessor on digital signal. A connection of two IIR (Infinite Impulse Response) Butterworth filters has been composed in order to isolate appropriate signals, namely LPF (Low Pass Filter) and HPF (High Pass Filter), as shown in fig. 11. All designed filters are recursive (IIR, Infinite impulse response) Butterworth type but LPF's are of 4th order and HPFs are of 2nd order. Parameters of the corresponding filters are gathered in tab. 5 (The coefficients correspond to formula 1).

Table 5. Filters description for a component isolation from multi-parameter signal

Component	LPF (Low Pass Filter)	HPF (High Pass Filter)
	Corner frequency f_0 Filter's coefficients	Corner frequency f_0 Filter's coefficients
EGG	f_0=0.15 Hz **b**=10^{-11}·[0.0787;0.3148;0.4723;0.3148;0.0787] **a**=[1;-3.9951;5.9852;-3.9852;0.9951]	f_0=0.015Hz **b**=[0.999;-1.9997;0.999] **a**=[1;-1.9997;0.9997]
Respiratory	f_0=0.5 Hz **b**=10^{-9}·[0.0966;0.3865;0.5797;0.3865;0.0966] **a**=[1;-3.9836;5.9509;-3.951;0.9837]	f_0=0.15 Hz **b**=[0.9987;-1.9973;0.9987] **a**=[1;-1.9973;0.9973]
ECG*	f_0=50 Hz **b**=[0.0048 0.0193 0.0289 0.0193 0.0048] **a**=[1;-2.3695;2.314;-1.0547;0.1874]	f_0=0.5 Hz **b**=[0.9918 -3.9673 5.9509 -3.9673 0.9918] **a**=[1;-3.9836;5.9509;-3.951;0.9837]

4.5 Signal Quality Monitoring

Detachment and deterioration of the electrode-skin contact [19] is an important issue during the long term recording test. Hence, monitoring the aforementioned contact improves quality of the test. On the other hand, it ensures valuable diagnostic information. Acquiring a signal with a DC constant component is our solution to the monitoring system. Exemplary change of the constant level for EGG signal during 2-hour test has been shown in the fig. 12. For comparative purposes, the signal from the electrode without preconditioning of the skin is shown (label "RS" in fig. 11). Comparison of RS signal with other EGG leads indicates significantly greater change in DC component. It may carry addition diagnosis information, which requires further investigation.

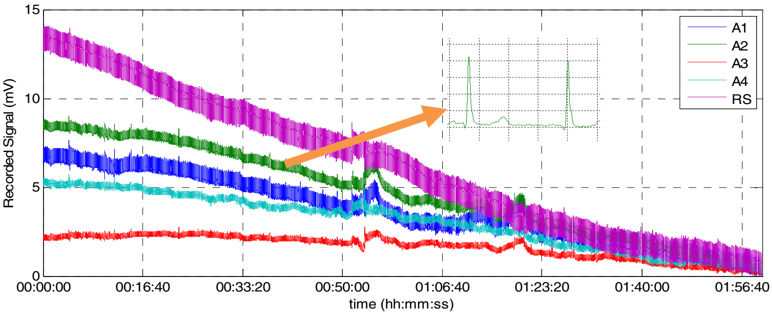

Fig. 12. Example of signals recorded with a DC component

5 Conclusions

The universal wireless device for bioelectric signal acquisition has been presented in this chapter. Using recently developed ADS1298 analog front-end IC significantly simplifies the construction of universal reconfigurable bioelectric signal amplifiers. The communication between the device and host PC has been built with the Bluetooth technology, yet, other standards presented in section 2 can be also applied. The device can be configured off-line and on-line depending on the current requirements and the test: EGG, ECG, EOG.

Thanks to a specific feature of the developed system and ADS1298 IC there is a possibility of acquiring signals with a DC component (unfiltered). It is very important because the designer does not need to construct the analog input filters (usually high pass filters). Digital post filtering can be applied which greatly simplifies the construction of the amplifier and reduces production costs. The A/D 24 bits resolution ensure high quality of the output signal and allows for extracting wide set of artifacts from signal which rises the quality of diagnosis. The use of radio communication simplifies the implementation of the tests and improves patient's comfort during the examination. It also reduces the testing procedure for medical device which is fully separated from electrical network. Note that the largest cost of implementing the device in the real environment (e.g. hospitals) is to obtain certificates of conformity to standards. The production cost of the hardware does not exceed 150USD although it may rise dramatically after obtaining the required certificates.

Currently, we are working on portable device with a GSM and WiFi links. The future of medical portable devices is wireless due to patient's comfort and relatively low cost of electronic circuits. Moreover, the pervasive computing together with such devices makes the whole health care system much more reliable, cheap and above all safer. Patients should welcome these developments with satisfaction because they save their time and effort of visiting medical centers and improve their comfort.

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Wireless Sensing System for Healthcare Monitoring Physiological State and Recognizing Behavior in Daily Life

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Abstract. This paper describes the basic system concept for pervasive healthcare and presents a wireless sensing system for healthcare to monitor physiological state in the living environment. The importance of constantly monitoring, analysing and utilizing human daily information has been growing in the area of healthcare. The introduction of ICT in the areas of medicine and welfare has created new systems and services for healthcare and can help promote disease prevention and health maintenance through wirelessly delivered healthcare and ubiquitous medicine. The availability of information about a person's daily physiological state and activity makes it possible to judge their health condition and behaviors and provide predictive diagnoses and treatment.

The objective of the work is to establish a wearable wireless body area network (BAN) system that is useful in pervasive healthcare. In this work we developed a wireless sensing system to monitor thermal physiological state. Sensors which make up a wireless system are varied depending on the purpose of use of the system. Wearable small-sized and wireless sensors which consume little power have to be developed to measure the desired vital signals or human data. Moreover, reliable wireless communication network is needed to obtain the data of multiple wearable sensors in real time. BAN can realize wireless connectivity among sensors deployed on human body.

The important indicators for monitoring the thermal physiological state are core body temperature, microclimate within clothing, skin temperature, heart rate and movement. To develop the monitoring system, ear-worn temperature sensors, thermo-hygrometers and skin temperature sensors were newly developed. The ear-worn temperature sensor enables a continuous non-invasive measurement of the equivalent of core body temperature in daily life. The thermo-hygrometer can measure microclimate within clothing. These sensors transmit data wirelessly in synchronization with each other. Data can be obtained reliably in daily life without restraining wearers' movements using multiple networked wearable sensors with a reasonable battery life. The level of data loss in wireless communication was low making it possible to estimate physiological state using more than 10 sensors simultaneously, even though both the IEEE 802.15.4 radio and the low power radio coexist.

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The application system for the prevention of heat stroke was evaluated on two situations. One is for the prevention of heat stroke and feeling sick during exercise in conditions of high ambient temperature and humidity. The other is for the prevention of indoor heat stroke among the elderly. It is necessary to recognize individual behaviors to be able to provide appropriate support based on the context. Some activities to be recognized at home were learned and identified using the location data. Experiments showed that the detection of the abnormal level of several kinds of physiological data and their change was effective in judging the physiological state and giving a warning on the health condition in the context of the activities and surroundings. This system will be broadly applicable to healthcare in everyday life such as temperature control for heat stroke prevention and lifestyle management based on the circadian rhythm and health condition.

Keywords: wireless network, wearable sensing, BAN.

1 Introduction

Due to the development of ICT (Information and Communication Technologies) and MEMS (Micro Electro Mechanical Systems) technologies, sensors have become sophisticated. Pervasive healthcare techniques which consist in sensors embedded in environments can provide global health information by continuously monitoring and analyzing people's home activity. The pervasive systems can provide long-term monitoring of users without the burden of wearing sensors. However, their support is still limited to a closed environment and they do not sense vital signals directly. On the other hand, sensors that measure vital signals and human daily movements have also grown in performance and become small enough to be wearable throughout the day. Sensors deployed on human body can obtain biological information, store the information and send it in real time to healthcare administration agencies via networks. The real-time information makes it possible to sense signs of change and sudden changes in the health condition. By monitoring and analyzing the real-time data along with the historical data stored on the server, doctors or experts could detect pathological change in its early stage, provide corresponding healthcare advices to the users, or enforce emergency actions if necessary. It is possible to estimate the everyday health condition, energy expenditure and lifestyle pattern of a person and recommend proper exercise, diet, rest and treatment. Therefore, the importance of regularly monitoring biological information has become recognized and is rising in the area of healthcare.

The human body gives out various bio-signals. Data to be measured is determined depending on each demand and purpose. Heart rate (HR) is often continuously measured to monitor physical and mental condition and exercise intensity. Blood pressure and body temperature are generally measured about once a day for assessing health condition. However, blood pressure and core body temperature vary during the day and over many days reflecting the medical and health condition, the state of activity and the circadian rhythm. There is also a need for measuring them continuously in daily life.

Some previous studies have attempted to monitor thermal physiological state through wired and wireless communication continuously. However, each vital sign such as core body temperature and ECG has been measured using stand-alone devices [1]. The data obtained cannot be easily utilized in real time because the data have to be integrated with other data to put to practical use. As regards core body temperature, it is desirable to measure the level continuously within the context of activity and environment in order to monitor the state of health and disease. In particular, in conditions of high ambient temperature and humidity, the elderly and children are at increased risk of heat stroke, causing increase in core body temperature due to deterioration or underdevelopment of the body's heat regulating mechanism and need to be watched over. It is expected that an integrated system that enables usual and non-invasive measurements of human thermal state will be developed.

We have developed some biological information measurement systems [2]-[4]. The systems consist of a number of wearable wireless sensors, some were ones we developed newly and others were existing ones. When commercial devices are incorporated into a system, some different types of wireless methods, such as ZigBee, Bluetooth, UWB and a low power radio, may have to coexist in the system. When multiple wireless sensors are used simultaneously, it is thought that data loss occurs if there is any interference between the sensors because of collision of transmission time and multipath. As the reliability of data is critical when human vital signals are being monitored, it is important to ensure that the data can be correctly obtained. Moreover, it is required that the necessary information is obtained depending on the intended application. Therefore, systems have to be properly designed to ensure the reliability and availability of the data. In this paper I introduce a wireless sensing system that monitors thermal physiological information in daily life for prevention of heat stroke and feeling sick.

2 Motivation

With the increasing medical expenses resulting from the coming very aged society, it will soon become impossible for the nations to pay huge medical expenses. In Japan the medical expenses for elderly people aged over 65 years old exceed 55% of citizens' medical expenditure in 2009 [5]. In addition, the trend of nuclear families is increasing and many elderly people who live alone need support. In Japan's aging society with a falling birthrate, it has become necessary to work on prevention of disease and health maintenance in order to improve in quality of life (QOL) and reduce medical care expenditure.

The Japanese medical system has been centered on the care in hospitals for ill patients. However, because of the situation, the government is starting to place importance on preventive healthcare and the use of medical care at home. Wireless sensing systems will become helpful tools to establish it. For remote diagnosis and home healthcare, it is required to be able to collect a very large amount of biological information and monitor them efficiently. Daily vital signals can provide useful clues as to health condition. It is possible to provide continuous remote monitoring, consulting and more flexible healthcare by using wearable sensors and the networked system.

In recent years, the number of the victims of heat stroke has been increasing, which has become a social problem. Heat stroke is a physical disorder caused by a sudden rise in body heat due to high environmental temperature and humidity. Even young people suffer heat stroke and are taken to hospitals, in particular during exercise. The guidelines for heat stroke prevention use wet bulb globe temperature (WBGT) as an assessment index of thermal environmental conditions in order to estimate the effect of temperature, humidity, wind speed and solar radiation on humans. This index has become widely accepted for heat stress measurements. However, its use as a model for human response to heat has not been always effective in heat stroke prevention because physiological factors are not taken into account. In addition, the effects of the four environmental factors on the WBGT do not necessarily affect humans under all conditions. It is thought that it becomes possible to take measures to prevent heat stroke by measuring each physiological state. Therefore, we aim at measuring each state of persons in order to prevent from getting out of shape and support daily activities including exercise in thermal environments.

3 Wireless Sensing System

Figure 1 shows the basic system concept for pervasive healthcare. First, wearable sensors which consume little power are needed to measure the desired vital signals. Second, reliable wireless communication network is needed to obtain the data of multiple wearable sensors in real time. Body area network (BAN) can realize wireless connectivity among sensors deployed on human body (Fig.2). The local controller can collect vital signals and environmental information and give feedbacks based on the information covering sensors' data of those who stay at home without carrying a cellular phone (coordinator).

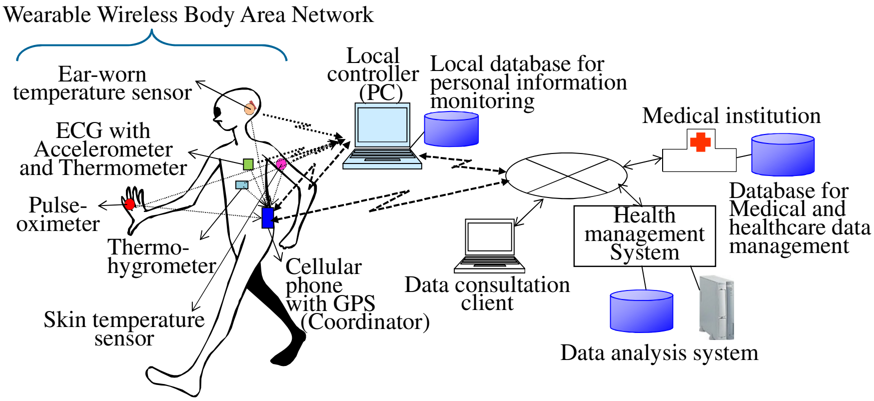

Fig. 1. System concept for pervasive healthcare

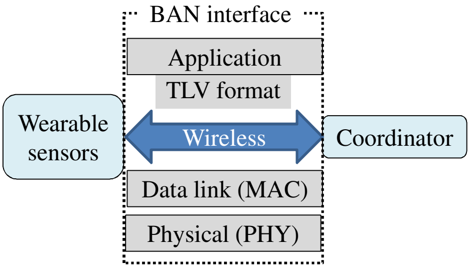

Fig. 2. BAN interface

In this work we developed a wireless sensing system that monitors thermal physiological information in daily life for prevention of heat stroke and feeling sick. The important indicators for monitoring the physiological state of humans under thermal environments are considered to be core body temperature, skin temperature, microclimate within clothing, HR and the amount of activity. Core body temperature is the operating temperature of an organism. It is an important parameter for checking the overall health condition, in particular in hot and humid conditions. HR derived from ECG is one of the indices of heat strain [6]. HR increases to compensate for the decrease in blood flow back to the heart, which is the result of increased blood flow to the skin as it gets hot. The amount of activity can be also calculated by measuring HR and acceleration [2]. The microclimate within clothing and skin temperature are commonly used to assess thermal comfort [7]. The temperature and humidity in the space between clothes and the skin are measured as microclimate within clothing. The skin temperature reflects the amount of heat dissipation, which is a quantitative measure of thermoregulatory responsiveness. The temperature of the surface of the body is not uniform. Therefore, the mean skin temperature is used as the index; it is calculated from the measured temperature at four areas of the body, namely, chest, forearm, thigh and calf based on a simple weighting formula (1) [8].

$$T_{skin}=0.3\times(T_{chest}+T_{forearm}) + 0.2\times(T_{thigh}+T_{calf}) \tag{1}$$

To measure these important indicators, the system developed consists of an ear-worn temperature sensor, two thermo-hygrometers, four skin temperature sensors and an ECG sensor with a tri-axial accelerometer. Additional sensors can be easily installed as up to 32 sensors are supported by this system.

Wireless micro-controller modules (ST Microelectronics, STM32W) were incorporated into ear-worn temperature sensors, thermo-hygrometers and skin temperature sensors. The micro-controller performs the functions of A/D conversion, data processing, and data transmission. It integrates a 32-bit ARM® Cortex™-M3 microprocessor and a 2.4 GHz, IEEE 802.15.4-compliant transceiver. The IEEE 802.15.4 radio has the characteristics of ease of installation, reliable data transfer, short-range operation, low cost and reasonable battery life. The maximum transmission distance is approximately 10m without requiring special antenna.

The sensors transmit data wirelessly in synchronization with each other based on the timer of the coordinator. The 2.4 GHz, IEEE 802.15.4 communication has the beacon mode, in which normally sleeping network sensors wake up periodically to receive a synchronizing beacon from the coordinator. For the sensors with a 2.4 GHz, IEEE 802.15.4-compliant transceiver which has very low duty cycle, a TDMA type contention free protocol in the MAC layer is used to avoid multiple access interference and guaranteed time slots were provided in a scheme. Each data packet is transmitted up to 3 times to compensate for data loss.

To enhance the security and reliability of data transmission, we are also considering the introduction of ultra wideband (UWB) for BAN. UWB has the characteristics of high data transfer rate and low transmission power. Due to the low power spectral density (PSD) in conforming to the FCC specifications and the regulations of each country the probability of intercept is low. In February 2012, the IEEE802.15.6 standardization group has approved a new standard for wireless BAN use, which adopted impulse radio UWB communication. The circuit system of IR-UWB needs less semiconductor chip area due to its simplicity. As a result, the production cost could be reduced compared to other radio systems if it is mass-produced. Establishment of the standard will speed the development of UWB modules that are following the standard. We are now introducing UWB communication to other wireless healthcare systems and have examined them.

The followings are the sensor devices at present.

3.1 Ear-Worn Temperature Sensor

Ear-worn temperature sensors were developed for continuous noninvasive measurement of core body temperature. The temperature of blood in the pulmonary artery (PA) is considered to be the true core body temperature. However, this site is not suitable for monitoring temperature during human daily activities. Temperature readings obtained with a tympanic membrane thermometer are very close to core body temperature [9]. A thermopile is an electronic device that converts thermal energy into electrical energy. The infrared noncontact thermometer using thermopile receives infrared radiation from the tympanic membrane and can measure the temperature.

Figure 3 shows the outside appearance of the ear-worn temperature sensor. The sensor consists of a temperature sensing part, a wireless micro-controller module and a battery. It can transmit data wirelessly at an interval of one second or more. The sensor is powered by a 3.7V rechargeable lithium-ion button battery. The battery life lasts for more than 100 hours of continuous operation when the data is transmitted at an interval of one second. The sensor has a specified accuracy of ±0.2 ºC in the range $32^{\circ}C \leq T \leq 42^{\circ}C$ and resolution performance of 0.02ºC. The size is 38mm in diameter and 13mm thick excluding the sensing part and the part that hangs from the ear. The length and direction of the sensing part can be adjusted to fit into a person's auditory meatus and to receive infrared radiation from the tympanic membrane. It was designed to be similar to an ear-hook type earphone to make it wearable in daily life.

Fig. 3. Ear-worn temperature sensor (left) and its sensing part (right)

3.2 Thermo-hygrometer and Skin Temperature Sensor

Thermo-hygrometers and skin temperature sensors were developed using relative humidity and temperature multi sensor modules from Sensirion AG. Figure 4 shows the outside appearance of the first version of thermo-hygrometer and skin temperature sensor. The sensing part of skin temperature sensor is situated outside the main unit to be in close contact with skin. It is a single chip relative humidity and temperature sensor module incorporating a calibrated digital output. The module includes a capacitive polymer-sensing element to measure the relative humidity and a band-gap temperature sensor. They are seamlessly coupled, to a 14-bit and a 12-bit analog to digital converter respectively, and a serial interface circuit on the same chip. The sensors have the accuracy of about ±0.3ºC, ±1.8%RH and resolution performance of about 0.01 ºC, ±0.03%RH . The first version of the sensors is 45mm×32mm×9.5mm in size including the power source. Using the prototype product of a smaller high-performance button battery, they became less than half the size of the first version.

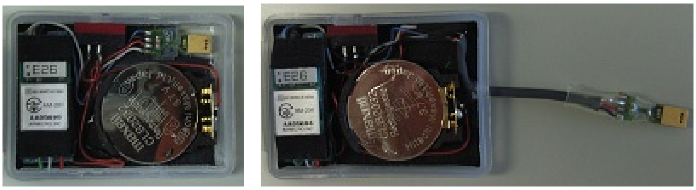

Fig. 4. First version of thermo-hygrometer (left) and skin temperature sensor (right). (The cases are opened.)

3.3 ECG Sensor with Accelerometer and Thermometer

An existing wearable small-sized RF-ECG from Micro Medical Device Inc. was used since its measurement accuracy has been validated [10]. It wirelessly transmits ECG signals, as well as tri-axial acceleration and surface temperature. It utilizes low power radio transmission (2.4GHz). The maximum transmission distance is approximately 20m. The sampling rate is 204 or 100Hz, its size is

40mm×35mm×7.2mm, and its weight is 12g. The power source (a 3V lithium-ion button battery, CR2032) has a life of about 48 hours of continuous operation.

Using these sensors, the system for monitoring thermal physiological information was constructed as shown in Fig.5. Measurements and graphs of core body temperature, skin temperature, temperature and humidity within clothing, ECG, heart rate and accelerations can be monitored in three windows. Figure 6 shows a screen image of the display for monitoring. These sensors could work continuously for more than 24 hours in everyday life.

To examine the rate of data loss, measurement experiments were carried out during desk work in an ordinary office environment and during everyday life in a home environment. The data from an ear-worn temperature sensor, two thermo-hygrometers, four skin temperature sensors and an ECG sensor was continuously measured for 3 hours in each environment. The sampling rate of the ECG sensor was 204Hz and that of the other sensors was 1Hz. The coordinator was placed on the desk in the office and in the middle of the room in the home.

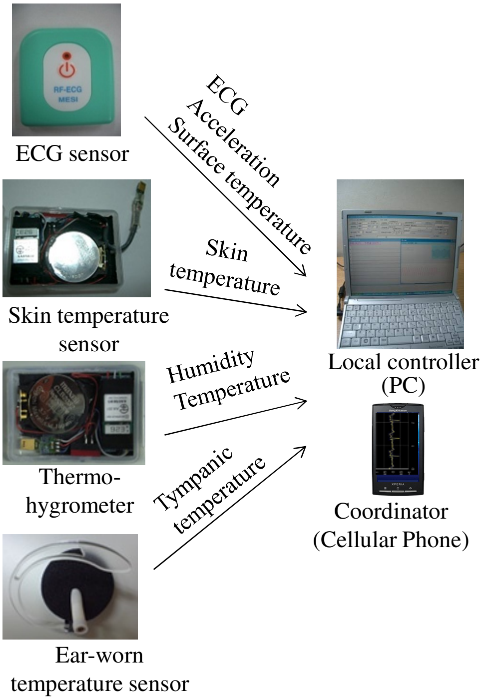

Fig. 5. Basic system configuration

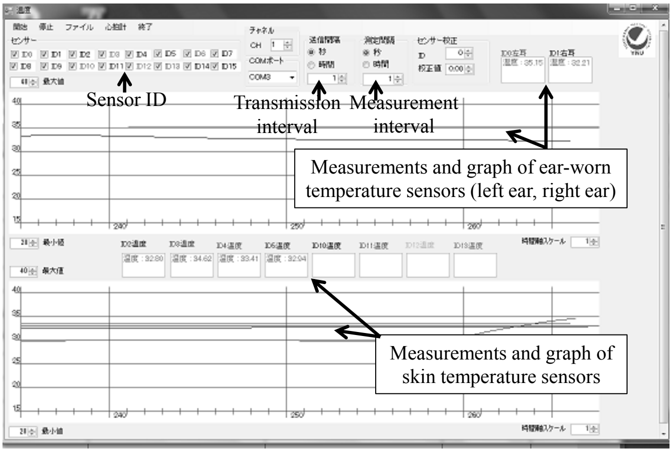

Fig. 6. Screen image of measurement software

The result was that the mean rate of data loss from the sensors apart from the ECG sensor was about 0.01% in the office environment and the data loss was discontinuous. 6.7% of the data was not received correctly from the first transmission, however data loss was almost completely eliminated by retransmitting data once or twice. The data loss rate of the ECG sensor was about 0.42% due to the high data rate and imperfect error control.

We think that there was little interference between the sensors because a TDMA type contention free protocol in the MAC layer was used, however writing errors sometimes occurred. In this situation, the distance from the sensors to the coordinator ranged from 0.2m to 3m. On the other hand, the mean rate of data loss was less than 0.02% in the home environment due to data retransmission, though data loss was 7.1% for the first transmission. There was little continuous data loss. The data loss rate from the ECG sensor was 0.65%. The distance from the sensors to the receiver ranged from 0.3 to 5m.

The data from multiple sensors could be continuously sent and recorded though two different wireless methods of IEEE 802.15.4 radio and low power radio were used. Since changes in temperature are not sharp, we think this level of data loss is acceptable. We also think that the data loss rate of the ECG sensor is acceptable since HR can be calculated using interpolated data due to the high sampling rate.

4 Application of System

An application system was made up for the prevention of heat stroke and feeling sick during exercise. The system comprises sensors which measure important indicators, core body temperature, skin temperature, microclimate within clothing on the chest and back, HR, amount of activity and environmental conditions. The thermo-hygrometer developed can also monitor environmental temperature and humidity to be easily set up into the ambient surrounding. In sunny outdoor environment such as grounds that get a lot of sun, a WBGT measurement system is also expected to be installed in order to take into account the effect of solar radiation. Therefore, the system was configured as shown in Fig.7.

Experiments were performed under two different conditions. In one experiment, the physiological state of a subject (male in his 20's) and the environmental condition were measured while exercise was performed in a room controlled at a temperature of 32°C and at a humidity of 55%. In the other experiment, the physiological states of two subjects (male and female in their 20's) and the environmental condition were measured while exercise was performed in a room controlled at a temperature of 28°C and at a humidity of 65%.

The subjects had a rest for 10 minutes at the beginning, pedaled cycle-ergometer at 20W for 10 minutes of warm-up exercise and then pedaled it at the workload of 50% of maximal exercise stress for 20 minutes. After exercise, they had a rest for 20 minutes of recovery. In the experiments, the subjective assessment of the level of comfort and wetness feeling was also made verbally. The subjects participated in these measurement experiments after providing informed consent for the experimental procedures. This study was conducted in accordance with the Helsinki Declaration of 1975 and was approved by the local Ethics Committee of Yokohama National University (Japan).

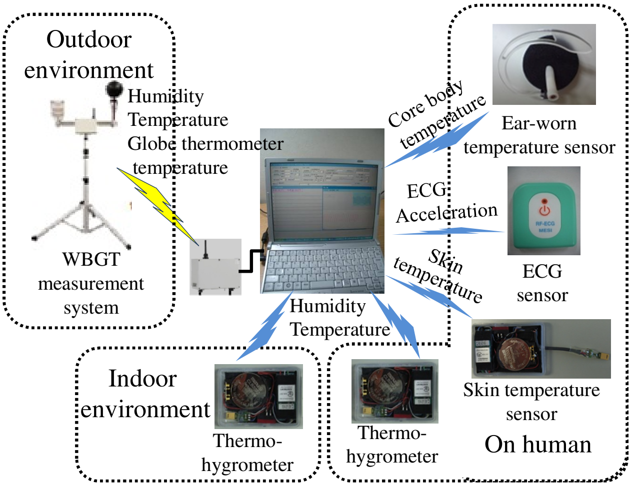

Fig. 7. Total configuration of the monitoring system

One subject's example of the changes in core body temperature, mean skin temperature and microclimate within clothing, the indicators of sympathetic function and parasympathetic function and subjective assessment during exercise is shown in Fig.8 - Fig.10. The indicators of sympathetic function and parasympathetic function are calculated as LF/HF and HF/(HF+LF) from low-frequency (LF, 0.04 - 0.15 Hz) power component (reflecting a mixture of parasympathetic and sympathetic activity) and high-frequency (HF, 0.15-0.4 Hz) power component (reflecting parasympathetic nerve function) in heat rate variability (HRV) obtained from ECG, respectively. Rapid increase in humidity within clothing caused by the increase in exercise intensity and gradual increase in core body temperature, mean skin temperature and temperature within clothing were monitored. As the intensity of exercise was not so high, the core body temperature did not get raised too much compared with mean skin temperature and temperature within clothing. However, the levels of discomfort and wetness feeling in the subjective assessment increased with the increase in humidity within clothing after the intensity of exercise was increased. At the same time, the indicator of sympathetic function (LF/HF) increased and the indicator of parasympathetic function (HF/(HF+LF)) dropped relatively. The results show that there seems to be a correlation among the subjective discomfort level, the indicator of sympathetic function and humidity within clothing. There was not much difference between the results of the experiments under two conditions.

It can be said that the system enabled real-time monitoring and evaluation of the physiological condition during exercise. However, the index and threshold for giving warnings against heat stroke couldn't be found from these experiments. A lot of data need to be collected during exercise performed in conditions of high ambient temperature and humidity to use the values of core body temperature, LF/HF and humidity within clothing as the indicators for a warning against heat stroke.

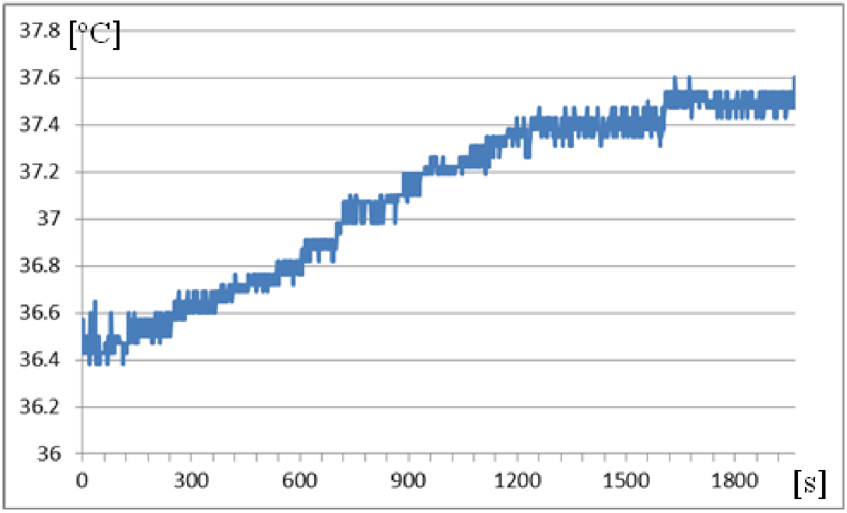

Fig. 8. Example of change in core body temperature

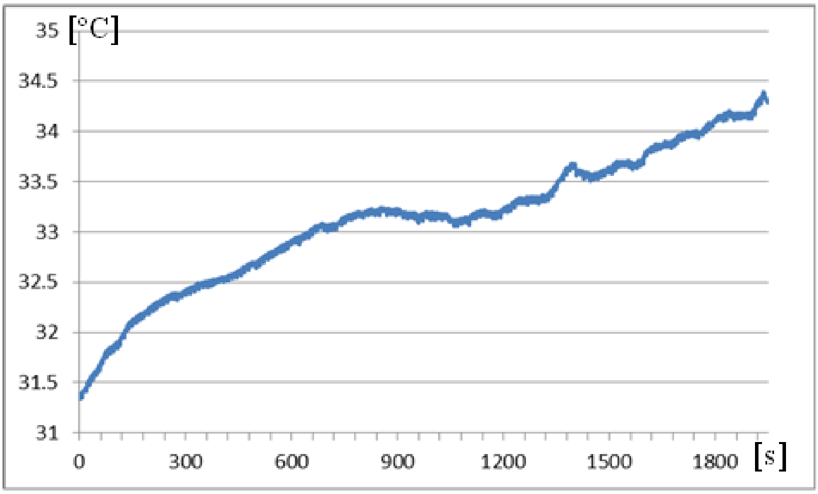

Fig. 9. Example of change in mean skin temperature

Moreover, the system was applied for the prevention of indoor heat stroke among the elderly.

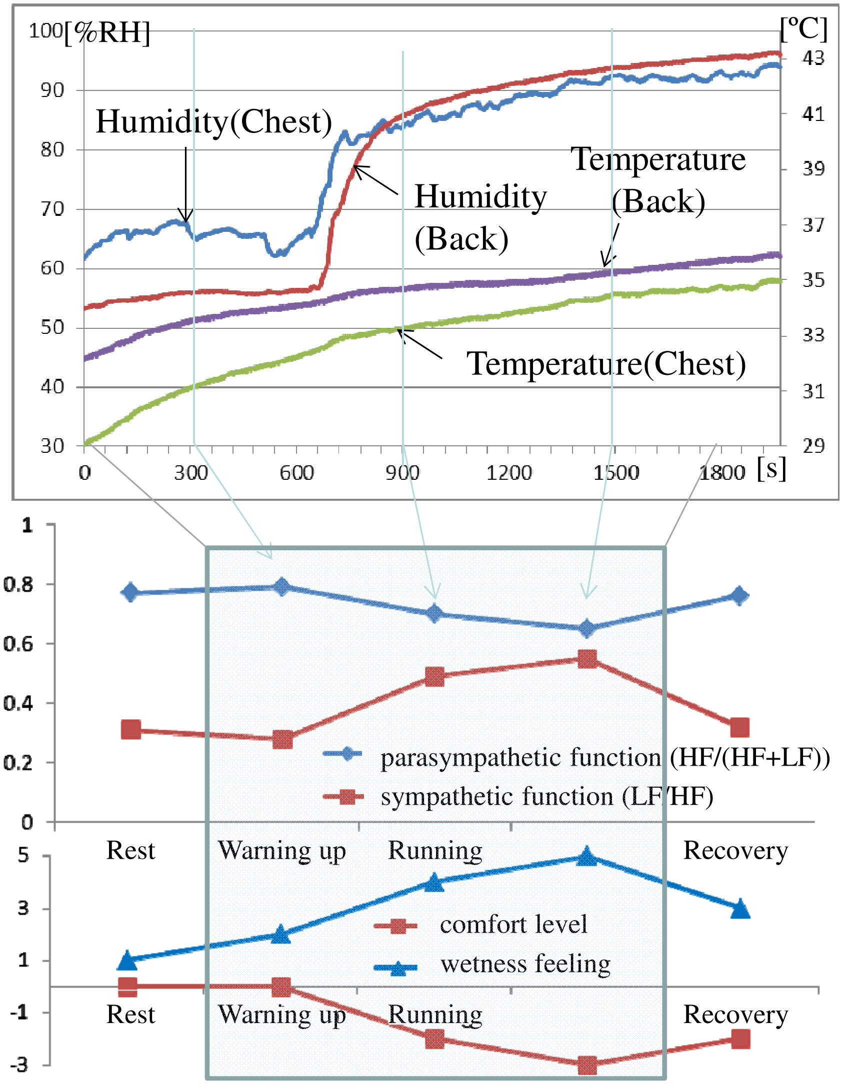

Fig. 10. Example of changes in microclimate within clothing (above) and the indicators of sympathetic function and parasympathetic function and the subjective assessment (bottom)

To prevent indoor heat stroke, it is critical to monitor their physiological data along with the activities. If activities such as food intake, fluid intake, fluid elimination, and going outside are monitored; and if the frequency and occurrence of each activity are recorded from when a person gets up, then warnings such as “Drink enough fluid” or “Rest due to heat” could be given appropriately. Therefore, a prototype system that monitors the thermal physiological state and the ambient temperature and humidity, recognizing the wearer’s behaviors was constructed as shown in Fig.11. As home activities are considered, it is expected that there will be a relation between the activity and the location. To monitor daily activities without hindering mobility, the location data obtained with the impulse radio UWB positioning system was used [11]. The method to recognize individual behaviors is as follows.

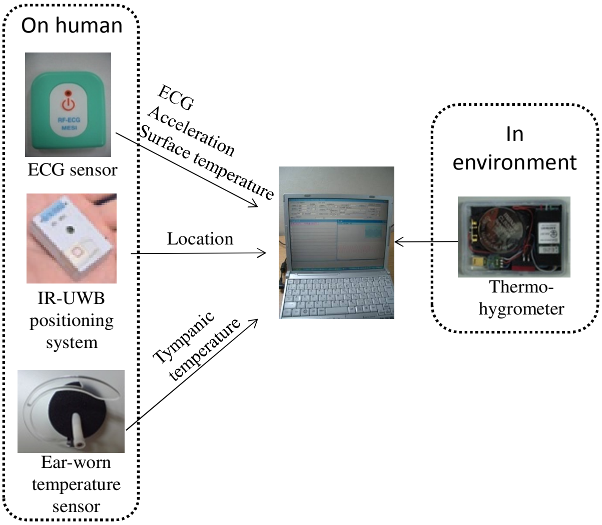

Fig. 11. Prototype system to prevent indoor heat stroke

When the sensor data is obtained, the time-series data is divided into equal time periods for the input time span. It is converted to a sequence of 4-dimensional feature parameters, the location (x-axis, y-axis) and its variation. Next, clustering is applied to the constructed space and the resulting clusters are labeled. Clustering is performed by the k-means algorithm by incrementing the number of clusters by one, starting at one until the variance of each cluster is below the threshold. Then, while the activity is being observed, the obtained feature parameters are projected into the 4-value space and the cluster with the shortest Euclidean distance is determined. By outputting the cluster labels successively, the state is represented as a symbol sequence. Similar symbol sequences are extracted for the same behavioral state. In order to recognize not only a state but also activity expressed by the state sequences, the hidden Markov model (HMM) is used to learn similar states and label them as the same state. The HMM is suitable for learning symbol sequences with large individual differences as in this case, since it is robust to shifts and to contraction or expansion along the time axis. For the recognition of activities using HMM, models are prepared by being trained beforehand using a training set; and then which model the input is most similar to is determined.

In the following algorithm, activities performed in the learning period are classified and the learning process is carried out for each activity. The Baum–Welch algorithm was used for learning.

(Step 1) A HMM is constructed using all observed symbol sequences as the training data.

(Step 2) All symbol sequences of the training data are obtained from the HMM of Step 1. A histogram is constructed by representing the output probabilities of the symbol sequences on the number axis.

(Step 3) Discriminant analysis is applied to the histogram and a minimum is found near the reference value. This value is used as the threshold.

(Step 4) If the output probability is not less than the threshold, a flag is set to one for the symbol sequence. If it is less than the threshold, the flag is set to zero.

(Step 5) For each set of symbol sequences with the same flag, a HMM is constructed using that set as the training data.

(Step 6) Using each of the constructed HMMs, the output probability of each symbol sequence is examined. The symbol sequence is projected into the space with the output probabilities in the HMM as the axis. The base vectors are determined by principal component analysis.

(Step 7) The base vector axes for which the cumulative contribution exceeds the threshold are used. For each axis, the histogram and the threshold are determined by repeating Steps 2 and 3 and the flag for the symbol sequence is determined.

(Step 8) Steps 5 to 7 are repeated until the combinations of symbol sequences to which the same flag is assigned in Step 7 are the same as the combinations obtained in the previous loop.

In this algorithm, the processing classifies all activities observed in the learning period as different kinds of activities. Similarity of output probabilities is used as the index for activity classification since similar state transitions are performed in the HMM when similar symbol sequences are obtained from the HMM. The output probability of the symbol sequence was defined as the symbol output probability derived by the Viterbi algorithm.

To recognize the activities, the symbol sequences of the observed activities are obtained from among all HHMs and symbol sequences are projected into the space made by the base vectors. The flags are determined and the activity whose flag is the same as the stored activity is output as the recognized result.

An experiment for learning and recognizing the activities in a house was conducted. Figure 12 shows the layout of a temporary house used in the experiment. This type of house is common in Japanese facilities for the elderly. It was assumed that the activities that should be recognized are fluid intake, having a meal, fluid elimination and going outside. Eight different activity patterns of fluid intake, an activity pattern of having a meal, six different activity patterns of liquid elimination, two different activity patterns of going out and eight other different activities were considered. Each activity was repeatedly carried out and the data were collected for learning. The relations between the numbers of states of HMM and the recognition rate were investigated changing the number of clusters and the optimal number of clusters was found out. The symbol sequences were learned through the constructed HMMs. Using the HMMs after learning, the symbol sequences for recognition were output.

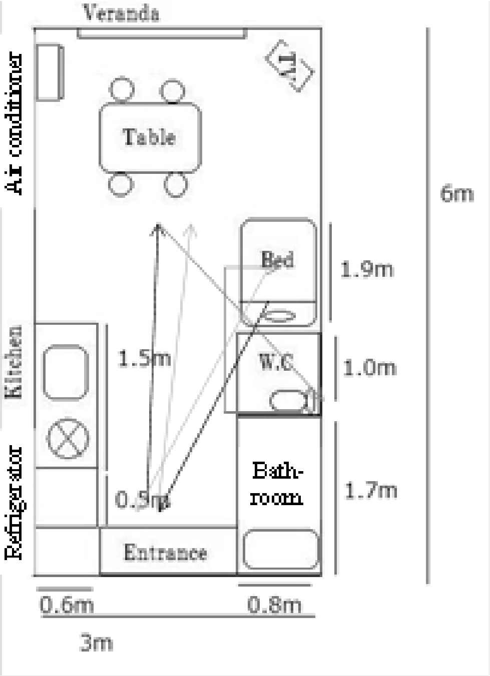

Fig. 12. Layout of one-room house

The recognition rate changes with the number of states corresponding to the number of clusters. The case of drinking is shown in Fig.13.

As the number of clusters increased, the recognition rate was improved. When the number of states got more than 5 in the case of 5 clusters, the recognition rate reached 100%.

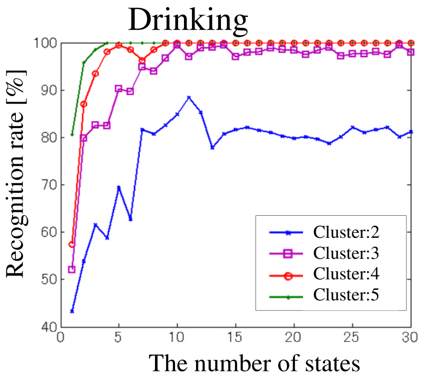

Fig. 13. Recognition rate with changing the number of states (Drinking)

The number of clusters was set to 5 for all of the activities. When the number of states is 5 for having a drink, having a meal and going out and 10 for eliminating, the recognition rate reached 100% as shown in Fig.14. Therefore, the values were adopted to recognize the activities.

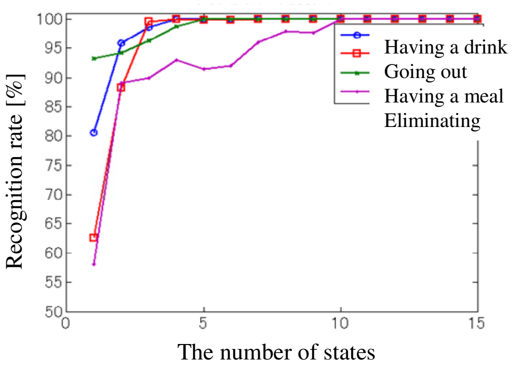

Fig. 14. Recognition rate (The number of cluster is 5)

A prototype system which gives advice for the prevention of heat stroke was developed. Warnings against lack of fluids are given following the rules below if the either core body temperature or HR is more than the threshold under high ambient temperature and humidity above a certain level.

1. When both activities of having a drink and having a meal are not detected for 2 hours,
2. When both activities of having a drink and having a meal are not detected for 10 minutes after eliminating,
3. When coming home.

The system was demonstrated based on a scenario following the schedule (Fig.15). In the room, core body temperature, HR, location, and environmental temperature and humidity were measured at the same time. The system could recognize activities correctly, record the number and interval of occurrence of each activity and give warnings at the appropriate timing. The elderly can get advice based on each thermal physiological state and living situation by using such kind of system when they stay in a room with high temperature and humidity.

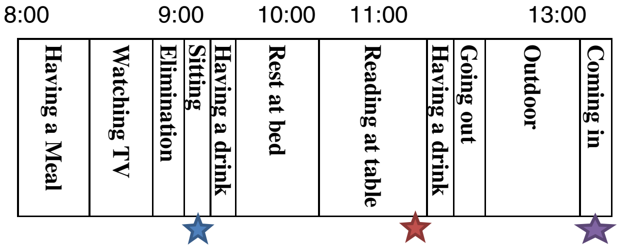

Fig. 15. Scenario's schedule

5 Conclusion

A wireless sensing system for monitoring physiological information in daily life was developed based on a basic system concept for pervasive healthcare. The data of wearable sensors can be continuously measured using wireless BAN in living environments. It makes possible to give remote diagnosis and health management in real time. The system can monitor a person's thermal physiological state. An application system for prevention of heat stroke and feeling sick was designed and the possibility to help prevent heat stroke was shown in the experiments. In the future, we will do longer-term measurements for data accumulation in daily life including during exercise in conditions of high ambient temperature and humidity, improve the algorithm to give a warning against heat stroke using data collected and evaluate the effectiveness.

The spread of Internet of Things (IoT) makes it possible to create a dynamic global network. Physical and virtual things are seamlessly integrated into the information network and come to interact and communicate among themselves and with the environment by exchanging the sensed data. It facilitates creation of services without direct human intervention. When human beings take part in the network by pervasive sensing, a lot more services could be expanded into. Ubiquitous healthcare is one of the services. The infrastructure to realize it is being developed rapidly. Social requirement and economic necessity will encourage the trend. The challenge is how to provide the services. As data sets collected through pervasive sensing grow in size, the big data have to be efficiently processed within tolerable elapsed times. Information security has also become a critical issue. Technologies to analyze the data, predict the possible event and utilize the information are required depending on the kind of services. The business models to provide services are also needed. Pervasive sensing will become accepted through essential services by overcoming these challenges.

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Automatic Sensing of Speech Activity and Correlation with Mood Changes

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Abstract. The association between social relationships and psychological health has been established fairly recently, in the last 30-40 years, relying on survey-based methods to record past activities and the psychological responses in individuals. However, using the self-reporting methods for capturing social behavior exhibits a number of shortcomings including recall bias, memory dependence, and a high end user effort for a continuous long-term monitoring. In contrast, automated sensing techniques for monitoring social activity, and in general, human behavior, has a potential to provide more objective measurements thus to overcome the shortcomings of self-reporting methods. In this paper, we present a privacy preserving approach to detect one component of social interactions - the speech activity, through the use of off-the-shelf accelerometers. Furthermore, we used the accelerometer based speech detection method to investigate the correlation between the amount of speech (which is an aspect that reflects the participation in verbal social interactions) and mood changes. Our pilot study suggested that verbal interactions are an important factor that has an impact on individuals' mood, while the study also demonstrated the potential of automated capturing social activity comparable to the use of gold standard surveys.

Keywords: speech activity detection, wearable computing, emotional response, mood changes.

1 Introduction

Throughout the history, the relationship between social interactions and emotions was an aspect of humanity analyzed by intellectuals from nearly all disciplines, from psychologists and philosophers to artists and poets. For instance, one of the most famous Shakespeare's plays, Othello, portrays characters from different backgrounds whose happiness depends mostly on social interactions. However, scientific evidence on the association between social relationships and psycho-physical health has been established fairly recently – the late 1970s and the 1980s [1]. The methods for collecting interaction data, which were used at that time and that are still prevalent in social and health related sciences, include surveys or human observers who continuously take notes on social behaviour of the

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monitored subjects. Survey-based methods exhibit a number of drawbacks including recall bias, difficulties in recalling activities that have occurred in the past, influence of the current mood [2], and a high end user effort for continuous long-term monitoring. In addition, self-reports correspond poorly to communication behaviour recorded by independent observers [3]. On the other hand, engaging human observers to record communications in groups is inefficient if the size of the group is large or if the interactions occur in various physical locations [4].

The use of automated sensing techniques for capturing social activity has been explored in the past decade, in order to address the limitations of self-reporting and observational methods. Recognizing the occurrence of social interactions in an automatic way is typically based on sensing proximity of subjects and/or on detecting speech activity. Since solely physical proximity does not always provide enough evidence for inferring social interaction [5] (for example, two colleagues sitting across from each other in the office and not interacting), methods for detecting social interactions usually include audio data analysis. This requires the activation of microphone that is either mounted in a monitored area or embedded in a mobile device (the mobile phone [6] or specialized device such as Sociometer [4]). However, in a number of situations (for example, in public spaces or in the case of monitoring patients) audio data cannot be obtained due to legal or ethical issues [7]. Moreover, activating microphone typically raises privacy concerns in subjects, even with methods that do not require continuous voice recording, thus affecting their natural behaviour.

In this work, we present the approach of detecting speech activity using an off-the-shelf accelerometer intended to identify another manifestation of speech different than voice, namely the vibration of vocal chords. The vibrations, caused by phonation, spread from the area of larynx to the chest level, which is a convenient place for attaching a sensor with an elastic band (similarly to attaching respiratory or cardio sensors) minimizing the interference with typical daily routines. We envision that the accelerometer-based speech detection can complement methods for automatic recording of social interactions, as an alternative to audio data analysis through microphones that may raise privacy concerns in subjects thus affecting their natural behaviour.

We used the accelerometer based speech detection method to investigate the correlation between the amount of speech, which is one aspect that reflects the participation in verbal social interactions, and mood changes. The current literature in social psychology reports several studies that examined how the social activity impacts the mood during the day [8] [9] [10] [11] [12], however none relied on the automated methods for collecting data. Despite being a pilot study with 10 subjects, the experimental setting was fully unconstrained yielding results that are consistent with the previous research [10][11][12] that reported positive association between the mood dimension of PA (positive affect) and the amount of speech activity.

2 Detecting Speech Activity with an Accelerometer

2.1 Privacy Issues in Interaction Data Collection

When detecting speech activity and, in general, sensing social interactions, an important issue is regard for subjects' privacy [13]. Capturing natural behavior pertains to recording people as they freely go about their lives, however there is a typically trade-off between the quality of collected data and the level of respecting subjects' privacy [6].

Privacy issues relate to an array of ethical norms that needs to be addressed. All subjects in the study should always know that they are being monitored, moreover they must have the right to authorize the use and the diffusion of the collected data [13]. If monitoring involves audio archives, they can be partially or totally deleted by subjects while recording uninvolved parties without their consent is considered unethical and illegal [6]. Despite addressing all the ethical norms, people are prone to change their behaviour if they have concerns about the way of monitoring, which negatively affects the reliability of the collected data. In the case of old methods such concerns can be raised due to a human observer, while for sensor-based approaches the presence of audio data analysis is critical. When automatically recording social behaviour, protecting privacy often implies discarding useful information [6] which is not always acceptable trade-off thus in some studies even the raw audio data was analyzed [14]. In response to this, several experimental designs included privacy-sensitive recording techniques, however the fact that microphone is activated may still raise concerns thus affecting subjects' natural behaviour. This often depends on the technical education and cultural background of monitored subjects, which can affect the perception of privacy [15] [16].

2.2 Our Approach

As an alternative to microphone-based methods for detecting speech, a few studies aimed to infer speech activity based on mouth movement, fidgeting, or gestures [7] [17] detected using machine vision. However, this limits application scenarios to areas that are covered with the camera system. Therefore, we attempted to avoid audio or visual cues for detecting speech activity, which led us to investigate physiological effects of phonation – vocal chords vibrations.

After the age of 20 the predicted fundamental frequency of vocal chords remains approximately 100Hz for male and 200Hz for female adults [18]. Therefore, identifying vibrations of these fundamental frequencies produced by vocal chords during phonation pertains to speech activity detection. Instead of a purpose-built accelerometer (with an appropriate shape, targeted frequency range and sensitivity), we investigated the use of an off-the-shelf accelerometer thus aiming for an easily applicable and cost effective solution. Since mounting sensors on the neck (close to the larynx area) may be too obtrusive, we selected the chest surface, in particular the central part of the sternum which is the area with the highest displacement amplitude of vocal chords vibrations [19]. This position is also convenient for attaching a sensor with an elastic bend (similarly to attaching respiratory or cardio sensors) minimizing the interference with typical daily routines.

2.3 Data Analysis

In our experiments we used Shimmer accelerometer [20] attached at the chest level to analyze frequency spectrum. The sensor specifications are as follows: the range of ±1.5 and ±6g, sensitivity of 800mV/g at 1.5g and a maximal sampling rate of 512Hz. According to the Nyquist-Shannon sampling theorem, the ceiling boundary frequency component that can be detected using this accelerometer is 256 Hz, which fulfils the requirements for the intended application (since the fundamental frequencies of vocal chords are approximately 100Hz for males and 200Hz for females). To analyze the frequency domain of acceleration time series (square roots of the sum of the values of each axis x, y and z squared), the method relied on Discrete Fourier Transform (DFT) defined for a given sequence xk, k = 0, 1, … N-1 as the sequence Xr, r = 0, 1, … , N-1 [21]:

$$X_r = \sum_{k=0}^{N-1} x_k \, e^{-j2\pi rk/N}$$

Frequency spectrum was analyzed in Matlab applying the Fast Fourier Transform (FFT) to calculate the DTF and then the power spectral density was computed.

As expected, low amplitudes of the chest wall vibration were similar to the noise level thus making it difficult to distinguish accelerometer readings that contained speech from those that contained noise, only by analyzing the frequency spectra. In order to tackle the problem of noise, a simple noise cancelling strategy [22] was applied which consists of summing frequency spectra in time. This strategy is based on the assumption that the signal components are always focused in the same frequency range in contrast to noise that is, in this case, more random. Considering time frames for performing power spectral density analysis, the best accuracy was achieved by analyzing a sum of power spectral densities computed separately for five consecutive 2-second long time series (corresponding to 1024 samples in this case). Hence, each 10-seconds frame was represented with the power spectral density that was a sum of spectral densities computed for each 2 seconds. Therefore, our goal was to recognize the presence of spectral components that correspond to speech with the resolution of 10 seconds. Processing data in 10-second time frames resulted in the highest accuracy regardless of the duration of the speech i.e. whether there was only one word spoken or a continuous talk of 10 seconds. Decreasing the resolution corresponded to lower ratio between speech amplitudes and noise levels while processing data in longer time units was more likely to fail in detecting shorter durations of speech.

We investigated various classification algorithms (namely SVM, Naïve Bayes, Naïve Bayes with kernel density estimation and k-NN) and parameters for characterizing the spectral density (namely mean, maximal, minimal, and integral values regarding different frequency ranges). It turned out that Naïve Bayes with kernel density estimator applied on the two parameters – integral and mean values of the components between 80 Hz and 256 Hz, provided the highest classification accuracy. Note that the classification selection, a choice of signal parameters, frame size for calculating power spectral density and the resolution cannot be generalized since they strongly depend on the accelerometer's characteristics. In the following, we report the accuracy of our approach.

2.4 Results

We created a set of accelerometer data that contained speech activity of 19 subjects, 10 males and 9 females (overall, 2 minutes each subject, that is 38 minutes, divided in 10-second time frames) and accelerometer readings that contained physical movements without voice (approx. 2 hours of accelerometer readings that included sitting, standing and normal speed walking in 10-second data resolution). The voice recognition accuracy was estimated through leave-one-out method of sequentially selecting accelerometer readings that corresponded to one subject/one activity as a test unit while using the rest of the set for building the model (training set for Naïve Bayes with KDE classification). The voice was correctly recognized in 93% of cases while mild physical activities without voice induced false positives in 19% (Table 1a). The same model was used to test accelerometer readings acquired in more intensive activities such as fast walking or running which resulted in 29% rate of false positives (Table 1b).

Table 1. Speech Detection Accuracy

a)	Voice Detected	No Voice Detected
Voice	93%	7%
Mild Activities	19%	81%

b)	Fast Walking or Running
No voice detected (true negatives)	71%
Voice detected (false positives)	29%

Our approach demonstrates that the speech activity can be reliably detected in typical daily situations that include mild activities. More intense activities such as running may result in a higher rate of false positives. However, using different type of accelerometer may mitigate this.

The accelerometer-based approach does not require capturing privacy sensitive information. However, on the other hand, it imposes a sensor worn at the chest level, which may be perceived by subjects as obtrusive, consequently stigmatizing them. This issue, while currently a concern, may be mitigated, since accelerometers are increasingly becoming widely adopted both in research and everyday life. The shape and size of already accepted commercial accelerometer-based solutions can suit also the speech recognition purpose (such as Fitbit [28] – an accelerometer device for tracking wellbeing aspects of individuals' behavior), while the chest area is convenient for attaching a sensor with an elastic band (similarly to attaching respiratory or cardio sensors) minimizing the interference with typical daily routines. Therefore, imposing an accelerometer as an alternative to the use of microphone was a compromise for preventing privacy concerns in subjects while providing a mobile solution for continuous monitoring of speech activity.

In the following section we apply this approach to investigate the correlations between the amount of speech and the mood states.

3 Speech Activity and Mood Changes

The current literature reports several studies that examined how the social activity impacts the mood states during the day [8] [9] [10] [11] [12]. Vittengl et al. [8] and Robbins et al [9] demonstrated that different types of social encounters provoke diverse emotional effects, while there is also an association between the overall amount of social interactions and responses in positive affect [10][11][12]. All the studies were consistent in revealing the positive relation between social events and the mood dimension of positive affect (PA), while negative affect (NA) factors were shown to be correlated either with only certain types of conversations or not associated with social activity at all.

Through a pilot study, we investigated the correlation between self-reported mood changes and the overall amount of speech within a certain interval that reflects participation in verbal social interactions. This study demonstrates the use of low cost sensing technologies for monitoring speech activity as one aspect of social behavior, which according to the previous studies, has an impact on emotional response of individuals.

While we automatically estimate the amount of speech activity, the mood in subjects was measured relying on the standard, questionnaire based method. Despite of an increasing attention that the field of automatic mood recognition has been receiving, the practical use of such methods, as a reliable alternative to standardized questionnaires, has not been demonstrated yet. Therefore, we opted for the method of assessing mood fluctuations during the day based on EMA (Ecological Momentary Assessment) approach in order to compare retrospective and momentary mood data [23]. The EMA approach, which involves asking participants to report their psychological state multiple times a day, reduces the critical issue of retrospective recall of extended time intervals. The retrospective recall is related to cognitive and emotive limitations that bias the recall of autobiographical memory influencing subject's report by most salient events during the recall interval. The questionnaire used in this study was derived from a well-established scale – the Profile of Mood States (POMS) that consists of 65 items in its standard version. However, long and repeated mood questionnaires become a burden on subjects; therefore we derived 8 adjectives from the POMS scale, namely cheerful, sad, tensed, fatigued, energetic, relaxed, annoyed and friendly that were rated on 5-point scale (1-not at all, 2- a little, 3- moderately, 4- quite a bit, 5- extremely). The points were summed across the items related to PA and NA dimensions while the difference in scores between two sequential questionnaires was taken as a measure of relative change of subject's mood states. The questionnaires were administered three times a day, scheduled to best fit with office workers' routines that participated our experiments. Typically, the questionnaires were answered in the morning, after lunch and at the end of working day.

3.1 Study Design

One's mood may depend on a number of different factors, such as circadian rhythms [24], type of environment [25], quality of sleep [26], state of health, private problems or some other factors incomprehensible not only through direct measurement but also difficult for an individual himself/herself to identify. Therefore, it may be impossible to consider all the factors that influence the mood and provide the ultimate conclusion about the exact cause of one's state of mood. For this reason, this study follows relative changes of the mood dimensions of PA/NA rather than focus on an absolute mood state, while assuming that interval between two mood assessments of a couple of hours (in the experimental design) is not sufficient for a significant change in "background" factors. It is hypothesized that these factors, such as private problems for example, are likely to be constantly present during relatively longer periods of time while, the activities within that period have pre-dominant influence on relative changes of mood. The goal of this research is to capture patterns of the amount of speech activity, in most cases, provoke similar responses in individuals' mood.

3.2 Experiments

In order to estimate the amount of speech activity within a certain period, the Shimmer accelerometer [20], attached on the chest, was continuously sampling and storing the data. Applying the model described in the previous section, each 10-second time frame of the acquired data was separately queried and classified according to the presence of speech. Afterwards, for each interval of interest we calculated the number of minutes in which at least one 10-second frame indicated speech status thus providing an aggregated number of minutes in which subjects were speaking. Overall 10 knowledge workers (7 males, 3 females) were recruited during one working week (5 working days). The characteristics of the sample are presented in Table 2.

The paper-based questionnaires were administered at 10:00, 14:00 and 18:00 (or with slight deviations when subjects were temporary unable to fill-out the questionnaire) thus dividing working day in two intervals of interest – one between 10:00 and 14:00 and another between 14:00 and 18:00. The amount of speech activity was expressed as the number of minutes in which speech status was identified, divided by the duration of the monitored interval. In total, 122 questionnaires were collected and the self-reported mood dimensions of PA and NA were analyzed with respect to the amount of speech activity detected in the previous time interval. Overall, 78 such intervals were analyzed, with the duration of 221±37 minutes, in which subjects spent 27.9±12.1% of time (minutes) in speech activity.

Table 2. Characteristics of the sample

Age (years)	33.3±9.4
Marital status	
Married	0%
Single, Divorced	100%
University/post diploma	90%
Work hours/week	39.2±1.7
Duration between two questionnaires (minutes)	221.3±37.0
Morning intervals (minutes)	250.3±37.5
Afternoon intervals (minutes)	192.3±41.2
Number of reported positive mood changes	4.9±1.5
Number of reported negative mood changes	5.4±2.0

Fig. 1 shows the distribution of Spearman correlation between the amount of speech activity as estimated from accelerometer readings and reported mood changes. The mean correlation between the amount of speech activity and PA and NA scores was 0.34±0.27 (min=-0.03, max=0.76) and -0.07±0.33 (min=-0.62, max=0.39) respectively.

The distribution of the correlations between the amount of detected speech and PA scores were significantly greater than 0 (t=4.009, P<0.005) and not significantly skewed. The distribution related to NA scores was not significantly less than 0 (t=-0.721) and was significantly negatively skewed.

The results suggest that the time spent in speech activity (reflecting the participation in verbal social interactions) was positively correlated with changes in reported PA and was not related to the changes in NA scores. On the other hand, the mood score reported at the beginning of monitored interval and the amount of speech activity within that interval showed no significant correlations, 0.153 and 0.225 for PA and NA respectively, indicating that participation in verbal social interactions was not influenced by the initial subjects' mood. This may be due to the fact that working environment typically imposes conversations leaving no options for the one to choose the level of socialization depending on the current state of mood.

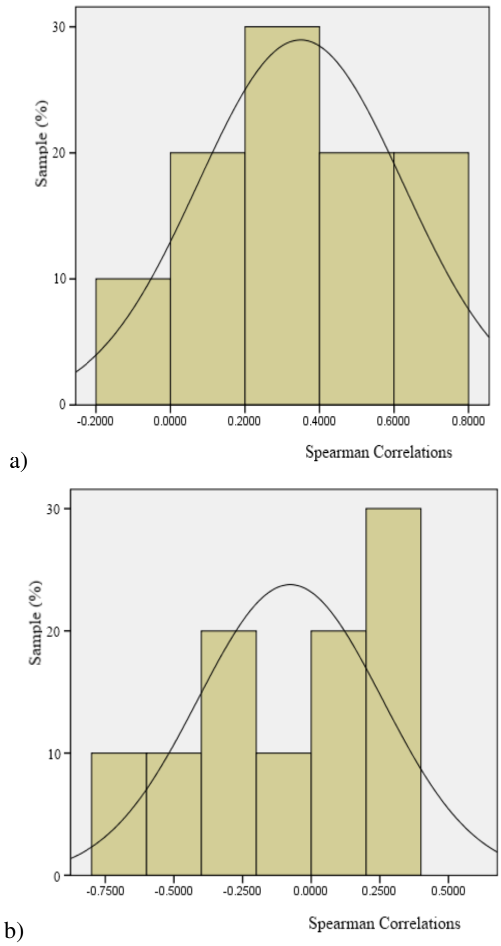

Fig. 1. Distributions of Spearman correlations between an amount of speech activity and a) PA and b) NA

4 Conclusion

In this paper we presented the concept of using an off-the-shelf accelerometer to infer speech activity by detecting vibrations at the chest level. This approach does not require capturing sensitive data, with a trade-off that includes a sensor worn at the chest level, which may be perceived by subjects as obtrusive. However, as an alternative to microphone-based method, the use of an accelerometer was a compromise for preventing privacy concerns in subjects while providing a mobile solution for continuous monitoring of speech activity. Such an approach allows for privacy-preserving collection of a large amount of speech activity data while being an easily applicable and a cost effective solution.

We investigated the correlation between the amount of speech and the mood changes through a pilot study relying on the accelerometer based approach to detect speech activity. The results of our study suggest that the amount of speech, which reflects the engagement in verbal communications, positively relate to the reported PA while no evidenced correlations were found for NA. These results show that verbal interactions are an important factor to be considered when taking into account the overall wellbeing of subjects in general and knowledge workers in particular.

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The Potential of Pervasive Sensors and Computing for Positive Technology: The Interreality Paradigm

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Abstract. Positive Technology is an emerging field that could be defined as the scientific and applied approach to the use of advanced technology for improving the quality of our personal experience. This discipline effectively combines the purposes of Positive Psychology with the enhancements of Information and Communication Technologies to promote individual and social well-being. Here, we suggest that a further advancement for Positive Technology might be offered by a new technological paradigm, namely Interreality. The value of Interreality Paradigm lies in bridging the gap between virtual and real world by integrating different pervasive sensors and computing technologies to create a hybrid, closed-loop empowering experience for the assessment and treatment actually missing in the traditional research and clinical approach of psychological disorders. Interreality Paradigm uses biosensors, activity sensors and mobile devices (PDAs, mobile phones, etc.) to conduct the continuous assessment throughout the virtual and real experiences. It enables tracking of the individuals' general and psychological status over time in several settings. The information collected during the assessment phase is constantly used to monitor individuals' progress and to precisely calibrate their treatment sessions thanks to a decision support system. Finally, Interreality Paradigm uses advanced simulations (virtual experiences) to transform health guidelines and provision in meaningful and engaging experiences. A recently funded European project "INTERSTRESS – Interreality in the management and treatment of stress-related disorders" will offer the right context to test and tune these ideas.

Keywords: positive psychology, positive technology, virtual reality, interreality paradigm.

1 Introduction

Positive Technology is an emerging field that could be defined as the scientific and applied approach to the use of advanced technology for improving the quality of our personal experience [1,2,3]. This discipline effectively combines the

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purposes of Positive Psychology [4,5,6,7,8] with the incredible enhancements of Information and Communication Technologies (ICTs) to foster positive emotions, to support individuals in reaching engaging and self-actualizing experiences, and to improve social integration and/or connectedness between individuals and groups: in sum, to promote well-being. Since ICTs allow the individual to live positive virtual experiences, an open challenge remains unclear: how can these virtual experiences improve the real world of an individual, and how can his/her real experience affect the virtual world? Here, we suggest that a further advancement for Positive Technology might be offered by a new technological paradigm, namely Interreality. The value of Interreality Paradigm lies in bridging the gap between virtual and real world by integrating different pervasive sensors and computing technologies to create a hybrid, closed-loop empowering experience for the assessment and treatment actually missing in the traditional research and clinical protocol of psychological disorders [9,10,11,12,13]. Starting from the socio-economic context that has led to a new definition of well-being, the paradigm of Positive Psychology will be fully explained. Then, the attention will be focused on Positive Technology and its promising applications. Finally, Interreality Paradigm will be introduced and explained in its technological and clinical advantages.

2 A New Definition of Well-Being

Since the mid-1940s, there has been a shift not only in the definition of the disease, but mainly in that of the well-being. Health was first conceived as a physical state of the body when perfectly functioning and with no evidence of disease, then it began to be conceptualized in a more holistic way, integrating also the social, cultural and psychological aspects. In the 1946, the *World Health Organization* (WHO) defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [14]. The WHO's 1986 *Ottawa Charter for Health Promotion* has enriched this definition highlighting the importance of the health promotion in healthcare:

"*Health promotion is the process of enabling people to increase control over, and to improve, their health. To reach a state of complete physical, mental and social well-being, an individual or group must be able to identify and to realize aspirations, to satisfy needs, and to change or cope with the environment. Health is, therefore, seen as a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources, as well as physical capacities. Therefore, health promotion is not just the responsibility of the health sector, but goes beyond healthy life-styles to well-being.*" [15]

The change of cultural paradigm that has led to a multidimensional definition of well-being has also influenced psychology. As underlined by Seligman and Csikszentmihalyi *"the new century challenges psychology to shift more of its intellectual energy to the study of the positive aspects of human experience"* [4]. Before the World War II, indeed, psychology had mainly three missions: curing the mental illness, making individuals more and more productive and identifying high talent [4]. Gradually, it becomes clear that a disease model may limit psychologists' comprehension of typical and optimal human functioning: this trend has resulted in a change in emphasis toward the study of the factors that allow individuals and communities to flourish - the strengths' perspective [16]. Within this framework, Positive Psychology could be defined as “nothing more than the scientific study of ordinary human strengths and virtues”[17].

2.1 Positive Psychology: Three Routes to Well-Being

In 2000, Seligman and Csikszentmihalyi officially announced the birth of Positive Psychology in the first twenty-first century issue of the *American Psychologist* [4]. As suggested also by Gable and Haidt [18], Positive Psychology has a long history starting from the pioneering research on "health mindedness" by William James in 1902, to Maslow's advocacy for the study of individuals’ basic universal needs in 1968, to the Cowan's recent investigation on resilience in children and adolescents (e.g., [19]). Within the humanistic approach, Rogers introduced the concept of full functioning as fulfilment of the healthy and creative traits of the individual in a process of continual personal constructive growth: “*Here in this palm like seaweed was the tenacity of life, the forward thrust of life, the ability to push into an incredibly hostile environment*” [20]. These researches have gradually led to a paradigm shift, in Kuhn's terminology, from a psychology aiming at the reparation of deficits to a psychology focused on human potentiality [8]. The incredible value of Positive Psychology lies in having offered a unifying framework for the scientific study of well-being and in providing evidences to promote well-being [21,22]. On these basis, Positive Psychology is the scientific study of well-being to understand human strength and virtues and to promote them to allow individuals, communities, and societies to thrive [4,5,6,7,8]. So defined, a fundamental interest of Positive Psychology is the scientific study of well-being: what is, which factors allow its attainment and which consequences it leads at individual and social levels. Seligman, the father of Positive Psychology, in his book "Authentic Happiness" identified three constituents of well-being or happiness: a) pleasure or positive emotions; b) engagement; and c) meaning [23]. According to Seligman, there are three routes to well-being:

1. *the pleasant life*: achieved through the presence of pleasure and promoted by activities that increase positive emotions;
2. *the engaged life*: achieved through engagement in empowering activities and utilization of own strengths and virtues;
3. *the meaningful life*: achieved by identifying and connecting with something larger than oneself.

The pleasant life is based on a hedonic definition of well-being, which is rooted in Epicurean equation of happiness with pleasure, comfort and enjoyment. Kahneman and Colleagues [24] defined hedonic psychology, one of the two fundamental approaches of Positive Psychology [6], as the study of *“what makes experiences and life pleasant and unpleasant”* [25]. So defined, hedonic approach poses for itself an ambitious target of research and intervention by maximizing human happiness. Although there are many ways to evaluate the pleasure continuum in human life, most study has used assessment of subjective well-being (SWB) [26], that consists of three components: life satisfaction, the presence of positive mood, and the absence of negative mood. The salience of positive emotions in increasing well-being is recently highlighted by "broaden-and-build model" [27,28]. According to Fredrickson [27], first of all positive emotions provide the organism with undefined action tendencies that may lead to adaptive behaviour: for example, joy is associated to the tendency to explore our surrounding physical and social environment. Secondly, positive emotions could reduce or mitigate the impact of stressful negative emotions: participants who were exposed to "positive films" after the vision of a "negative film" showed more rapid recovery from the cardiovascular activation [29]. Finally, positive emotions have fundamental long-term effects by broadening the thought–action repertoire and by building future physical, psychological, and social resources [28].

The engaged life is based, indeed, on a eudaimonic definition of well-being, that is rooted in Aristotle' ethical doctrine and its advocacy to fully realize our true nature (one's daemon), through the exercise of personal virtues in pursuit of a common good [30]. According to eudaimonic view, the other fundamental approach of Positive Psychology, well-being consists of more than the merely satisfaction of pleasure because it involves instead the actualization of human potential [6]. Ryff & Keyes [31] have introduced the concept of psychological well-being (PWB) that consists of six aspects of human experience: autonomy, personal growth, self-acceptance, life purpose, mastery, and positive relatedness. Self-determination theory [32,33] is an interesting perspective that has embraced the concept of self-realization as a central aspect of well-being specifying what it means to actualize the self and how that can be accomplished. Within eudaimonic approach, Peterson and Seligman [34] identified six universal virtues (wisdom, courage, humanity, justice, temperance, and transcendence) that are favoured by 24 character strengths representing the psychological components of them.

The meaningful life, finally, is based on a more complex definition of well-being that integrates individual well-being to social well-being by serving a purpose larger than oneself to promote connectedness between individuals, groups, and communities [35]. Csikszentmihalyi explained that he had realized the need for a positive psychology in Europe during the World War II:

"As a child, I witnessed the dissolution of the smug world in which I had been comfortably ensconced. I noticed with surprise how many of the adults I had known as successful and self-confident became helpless and dispirited once the war removed their social supports. Without jobs, money, or status, they were reduced to empty shells. Yet there were a few who kept their integrity and purpose despite their surrounding chaos. Their serenity was a beacon that kept others from losing hope. And these were not the men and women one would have expected to emerge unscathed. They were not necessarily the most respected, better educated, or more skilled individuals. This experience set me thinking: What sources of strengths were these people drawing on?"[4]

A Positive Psychology should take positive communities and positive institutions into accounts because individual experiences are necessarily embedded in several social contexts [8]. In this framework, Ryff and Singer have embraced these issues by introducing the concept of interpersonal flourishing, which could be defined as the development of positive relations with other people as a key dimension of well-being [36]. More recently, Biswas-Diener emphasized the shift from individual to collective well-being: the individual flourishing could be achieved by including group-level interventions, policies, and social change broadly [37].

3 Three Routes to Well-Being in Practice: Positive Technology

The progressive union of information and communication in technology has led to the field of Information and Communication Technologies (ICTs). Today, the current Golden Age of ICTs is dramatically changing every aspect of our individual and social lives. On one side, in fact, ICTs are becoming more and more popular in daily life because they are user-friendly and low-cost. On the other side, the technological sophistication has allowed the development of increasingly advanced devices. As underlined by Riva and his Colleagues [1], a significant part of the reflections concerning the use of technology starts with the same question: “What is wrong with technology?”. The incredible progress in ICT sector and its clear influence in everyday life have led technology developers, designers, and psychologist to reflect about another starting question: “What is right about technology?”. In this perspective, Positive Psychology appears to be a promising framework to develop ICTs that foster positive emotions, promote engagement in empowering activities and support connectedness between individuals, groups, and communities. Within this scenario, Positive Technology could be defined as the emerging scientific and applied approach to the use of advanced technology for improving the quality of our personal experience. If Positive Psychology identifies three constituents of well-being, namely positive emotions/pleasure, engagement/actualization and meaning/connectedness, positive technologies could be classified according to their effect in promoting these three features [1]:

1. *Hedonic level*: technologies used to induce and/or enhance positive and pleasant experiences;
2. *Eudaimonic level*: technologies used to support individuals in reaching engaging and self-actualizing experiences;
3. *Social and Interpersonal level*: technologies used to support and improve social integration and/or connectedness between individuals and groups.

For each level, we will try to identify crucial features that could be manipulated to develop different positive technologies (see Fig.1).

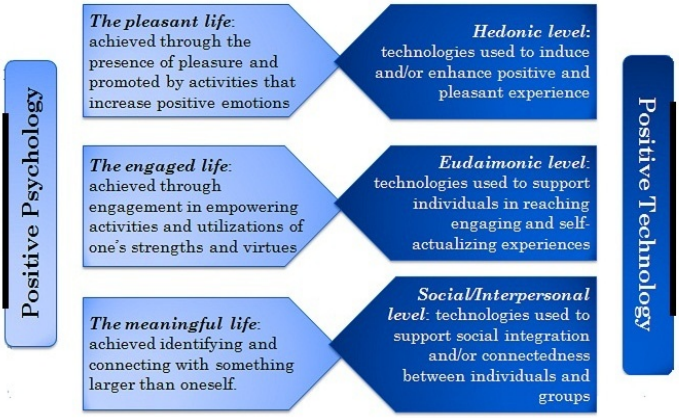


Fig. 1. From Positive Psychology to Positive Technology

3.1 Hedonic Level: Using Technology to Foster Positive Emotions

The first level of Positive Technology concerns how to use technology to foster positive emotions, such as joy and relaxation. There is a long history of researchers trying to induce affective states in experimental and clinical settings. On the basis of Russell's model, it is possible to modify the affective quality of an experience by manipulating the "core affect", a neurophysiological state corresponding to the combination of hedonic valence and arousal that endows individuals with a sort of "core knowledge" about the emotional features of their emotional experience [38]. Several procedures for the induction of mood states have been developed to investigate individuals' emotional responses [39,40,41]. Although it's not particularly recent, an interesting categorization of mood induction procedures (MIPs) is given by Gerrards-Hesse [39]. In that review, the authors proposed to classify them according to the stimuli used to affect participants' states: for example, Velten's mood induction technique [42] used self-referent statement describing positive or negative sensations to be repeated by the participants with the added instruction to get into the advocated mood state. Another category comprises the mood induction procedures built on the exposure of emotion-eliciting materials, such as pictures [43], music [44,45] or films [40,46]. Recent researches showed that Virtual Reality (VR) could be effective to induce positive emotions. The potential advantages of using VR technology in inducing positive emotions are essentially the following:

- *Interactivity*, to motivate participants, including video and auditory feedback;
- *Manipulability*, to allow the therapist and/or the researcher to tailor the sessions focusing on the specificity of individual as well as to increase task complexity as appropriate.

Riva and Colleagues tested the potentiality of Virtual Reality (VR) in inducing specific emotional responses, including positive moods [47]. Results suggested the efficacy of VR as an affective medium: the relaxing virtual environments induced relaxation. Villani and Colleagues compared the efficacy of structured experiences provided through different technologies (video, audio and VR) for inducing relaxing states: results showed a significant reduction of anxiety and a significant improvement in emotional states, assessed through psychological self-report and physiological parameters, but no difference among media conditions [48,49]. Within EMMA Project (Engaging Media for Mental Health Applications), some VR environments (Emotional Parks) were developed to induce positive states [50,51,52]. Emotional Parks combined different Mood Inductions procedures, such as Velten's self-statement [42], affective images from IAPS [53], and music to induce positive mood state within several virtual environments.

More recently, some studies explored the potentiality of emerging mobile devices in inducing positive emotions. Grassi and Colleagues [54] that showed relaxing narratives supported by multimedia mobile phones are effective to enhance relaxation and reduce anxiety in a sample of commuters. Villani and Colleagues [55] demonstrated the efficacy of a stress management protocol supported by the use of mobile phones in reducing anxiety levels in a sample of oncology nurses.

The advantages in using a mobile mood induction procedure could be potentially several both in research and clinical setting: first of all, a mobile platform can be multifunctional, exploiting the possibility of using more complex and combined stimuli (e.g., images, music, mobile application created ad hoc). Secondly, the use of a mobile device increases the ecological validity of the experiment: although the laboratory study maintains its status as the "gold standard" of controlled observation and concise testing of hypotheses, ubiquitous mobile platform offers the possibility to study user's experience in everyday environment.

3.2 Eudaimonic Level: Using Technology to Support Engaging and Self-actualizing Experiences

The second level of Positive Technology investigates how technologies can be used to support individuals in reaching engaging and self-actualizing experiences. This field of investigation includes, in turn, two sublevels:

- technologies that allow individuals to reach the state of flow [56];
- technologies designed to enhance individual self-efficacy [57].

The theory of flow [58] provides a useful framework to define what is an "engaging and self-actualizing experience". Flow, or optimal experience, is a positive state of total involvement of consciousness characterized by a perceived balance between high environmental opportunities for action (challenges) and adequate personal resources in facing them (skills). Additional features are deep concentration, clear rules in and accurate feedback from the task at hand, loss of self-consciousness, control of one's actions and environment, positive affects, and intrinsic motivation. The theory of flow has been deeply used to take into account the user experience with ICTs [59] in order to investigate the factors that influence its occurrence [60] and to study its specific consequences in different computer mediated communication activities (e.g., [61,62,63]).

Recent research showed the potentiality of VR in supporting the emergence of flow state because it offers the immediate opportunity for action, the possibility to create increasingly challenging tasks due to its manipulability, and the opportunity to calibrate the appropriate and multimodal feedback [64,65,66]. In addition, some researchers have draws parallels between the experience of flow and the sense of presence, conceived as the subjective perception of “being there” in a virtual environment [67]. Both experiences, indeed, have been described as absorbing states, marked by a merging of action and awareness, loss of self-consciousness, and high involvement and focused attention in the ongoing activity [68,69]. On these premises, Riva and Colleagues suggested the use of VR for a new class of applications in mental health based on the strategy of the “transformation of flow” [66,70], which could be conceived as an individual’s ability draw upon an optimal experience induced by technology, and use it to promote new and unexpected psychological resources and sources of involvement. For example, Gaggioli and Colleagues [71,72] developed and tested on 9 post-stroke patients the VR Mirror comprising a three computer-enhanced mental practice sessions per week. Results showed a good acceptance of this system by patients, giving support to the introduction of virtual reality technology into mental practice interventions.

The second sublevel regards the use of emerging ICTs in promoting self-efficacy as a crucial key in health promotion [57]. Within this perspective, self-tracking is a fast-growing trend in the field of e-health that consists in the “regular collection of any data that can be measured about the self such as biological, physical, behavioural or environmental information. Additional aspects may include the graphical display of the data and a feedback loop of introspections and self-experimentation” [73]. This approach is enabled by the increasingly convergence between ubiquitous computing and wearable biosensors, which allows personal health data to be collected, aggregated, visualized, collated into reports and shared [74,75]. Self-tracking is rooted into the experience sampling approach, a paper-and-pencil methodology developed by Csikszentmihalyi and Larson [76] that requires participants to fill out multiple brief questionnaires about their current activities and feelings by responding to random alerts throughout the day. As underlined by Ebner-Priemer and Trull [77], several terms have been used to refer to real-time assessment of psychophysiological data: Ambulatory Assessment [78], Ecological Momentary Assessment [79], Experience Sampling Method [80], and Day Reconstruction Method [81]. These assessment methodologies, although arose from different research paradigms, have in common the continuous recording of psychological and physiological data or indices of behavior, cognition or emotions in the daily life of individual. On these basis, Gaggioli and Colleagues developed and tested the use of PsychLog (www.psychlog.com), a mobile experience sampling platform that allows the collection of psychological, physiological and activity information in naturalistic settings [82,83]. PsychLog consists of three main modules: the survey manager module, the sensing/computing module and the visualization module. The survey manager module allows configuring, managing and administering self-report questionnaires to collect participants' feedback on his/her quality of experience in its various cognitive, affective and motivational dimensions randomly during a day.

The sensing/computing module (figure 2) allows continuously monitoring heart rate and activity data acquired from a wireless electrocardiogram (ECG) equipped with a three-axis accelerometer. The wearable sensor platform includes a board that allows the transduction, amplification and pre-processing of raw sensor signals, and a Bluetooth transmitter to wirelessly send the processed data. The PsychLog application extracts QRS peaks through a dedicated algorithm [84] and R-R interval time series.

Finally, the visualization module (figure 3) allows plotting in real time ECG and acceleration graphs on the mobile phone's screen.

In this perspective, mobile self-tracking could be conceived as a persuasive technology [85] that allows individuals to accurately monitor their health and check their progress with encouraging and motivating feedback enhancing self-efficacy [57].

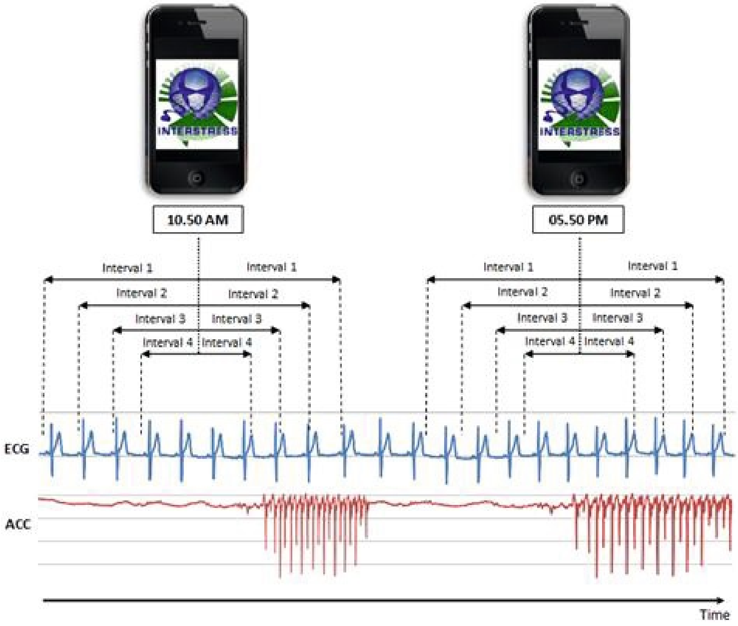


Fig. 2. PsychLog: The sensing/computing module

Fig. 3. PsychLog: The visualization module

3.3 The Social and Interpersonal Level: Using Technology to Promote Social Integration and Connectedness

The third level of Positive Technology regards the use of technologies to support and improve the connectedness between individuals, groups, and communities. The crucial question is to understand how to use ICTs to create a mutual sense of awareness and a strong sense of community at distance. Short and Colleagues defined social presence as the *"degree of salience of the other person in a mediated communication and the consequent salience of their interpersonal interactions"* [86]. The incredible progress of ICTs has allowed to enhance the social presence in several mediated activities, such as online learning [87] and healthcare (eg., [88]). Riva and Colleagues [89] recently suggested that an individual is present within a virtual group if he/she is able to put his/her own intentions (presence) into practice and to understand the intentions of the other group members (social presence). The technology has to provide the virtual group with the possibility of expressing itself and of understanding what each individual member is doing [90]. In this perspective, a virtual group is able to achieve a social optimal experience (networked flow state) in which the actions of the individuals and of the collective are merged and guided by "we-intentions", and the group acts as an autonomous, self-organizing entity [91]. In this perspective, social networking sites and pervasive computing technologies appears to be powerful tools for bringing people with shared interests to support and improve the connectedness between individuals, groups, and communities. As underlined by Swan, in addition to general social networking websites (for example, Facebook or Twitter), more specific purpose-driven social networks are dramatically emerging [73]. Morris developed and tested the use of a technological platform measuring phone calls and visits to derive public displays of social interactions with relatives and friends to reduce feelings of social isolation and depression in elderly individuals [92]. These ambient displays, which reflect data on remote and face-to-face interaction gathered by wireless sensor networks, are intended to increase awareness of social connectedness as a dynamic and controllable aspect of well-being. In the same direction, within the Nostalgia Bits Project (NoBits), Morganti and his Colleagues developed a web-based platform where tangible artefacts (for example, photos, stories, and personal documents) of an elderly person's life can be uploaded and become a significant resource for use by other generations, and a means for connecting the elderly users with members of their own generation [93]. NoBits aims at fostering social interaction between the elderly and their family and increasing cross-generational interactions and mentoring. Another interesting example in this area is PatientsLikeMe (http://www.patientslikeme.com/), a health social network where patients may be able to find and share health information and emotional support [94].

4 Interreality Paradigm: Bridging Real and Virtual World

Currently, positive technologies for improving well-being and promote strengths and resilience in individuals and communities could be classified at three different levels: hedonic level, eudaimonic level and social/interpersonal level. The concept of "personal experience" is what unites these three levels [1]. According to the Merriam Webster Dictionary [95] it is possible to define "personal experience" both as ''a) direct observation of or participation in events as a basis of knowledge'' and ''b) the fact or state of having been affected by or gained knowledge through direct observation or participation.'' These definitions clearly underline the two sides of personal experience: if we can intentionally control the contents of our personal experience, its contents define our future intentions. As underlined by Riva [1], we both shape and are shaped by it. The examples presented showed that emerging technologies could be used to manipulate the quality of our personal experience in three separate, but related ways [1]:

- *by structuring it* using a goal, rules, and a feedback system to provide individuals with a sense of purpose focusing his/her attention and orienting his/her participation in the experience;
- *by augmenting it* to achieve multimodal, mixed and interactive experiences;
- *by replacing it* with a synthetic one using VR system to simulate physical presence in a synthetic world that reacts to the action of the individual as if he/she was really there.

In order to manipulate and enhance the features of our personal experience, Positive Psychology appears to be a promising framework to develop ICT that foster positive emotions, promote engagement in empowering activities and support connectedness between individuals, groups, and communities. Since ICTs allow the individual to live positive virtual experiences, an open challenge remains unclear: how can these virtual experience improve the real world of an individual, and how can his/her real experience affect the virtual world? For instance, Virtual Reality has been widely used to carry out exposure-based treatments for anxiety disorders (e.g., [96,97,98,99]). As suggested by Repetto and Riva [9], although the virtual reality-based therapy has showed good efficacy in the treatment of anxiety disorders, the virtual experience in clinical settings remains separate from emotions and behaviors experienced by the patient in the real life world. The behavior of the patient in VR has no direct consequences on the real-life experience and the emotions and problems experienced by the patient in the real world are not directly addressed in VR exposure. To overcome these limitations, we suggest that a further advancement for Positive Technology might be offered by a new technological paradigm, namely Interreality. Interreality paradigm creates a hybrid environment within a closed-loop empowering experience for improving well-being [9,10,11,12,13]. The incredible value of Interreality Paradigm lies in bridging the gap between virtual and real world by integrating different technologies to develop assessment and treatment protocols actually missing in the traditional research and clinical fields of psychological disorders. The potential advantages offered by Interreality Paradigm will be explained and discussed in the following paragraphs.

4.1 Interreality Paradigm: From the Technology to Clinical Rationale

- From a technological viewpoint, Interreality Paradigm is based on the following integrated devices/platforms:

- *3D individual and/or shared Virtual Reality worlds:* They allow a controlled exposure, an objective psychophysiological assessment, and the provision of motivating and engaging feedbacks;
- *Personal Digital Assistants and/or mobile phones (from the virtual world to the real one):* They allow the possibility to conduct a real-time psychophysiological assessment and to deliver psychological interventions during daily activities;
- *Personal Biomonitoring System (from the real world to the virtual one):* It allows a pervasive psychophysiological assessment through wearable biosensor both in clinical and ecological settings and a decision support system for treatment.

These technological devices are integrated around two subsystems: the *Clinical Platform* (inpatient treatment, fully controlled by the therapist) and the *Personal Mobile Platform* (real world support, available to the patient and continuously connected to the therapist). These two platforms allow:

- *an objective assessment of psychophisiological data using pervasive biosensors and behavioral analysis:* monitoring of the patient's behavior and both his/her general and psychological status, early detection of symptoms and timely activation of feedback in a closed-loop approach;

- *a Decision Support System for treatment planning trough data fusion and detection algorithm:* monitoring of patient's responses to treatment, management of the treatment and the provision of support for clinicians in making therapeutic decisions;
- *the provision of warnings and motivating feedbacks to improve patients' compliance and self-efficacy:* the sense of presence allowed by this approach affords the chance to deliver behavioral, emotional and physiological self-regulation training in engaging and motivating experiences.

Thanks to this powerful integration, Interreality paradigm bridges the gap between real and virtual world in the assessment and treatment of psychological disorders:

- the assessment is conducted continuously throughout the virtual and real experiences. It enables tracking of the individuals general and psychological status over time in several settings;
- the information collected during the assessment phase is constantly used to monitor individuals' progress and to precisely calibrate their treatment sessions thanks to a decision support system.

4.2 Interreality Paradigm in Practice: INTERSTRESS Project

According to Cohen and Colleagues [100] "Psychological Stress" occurs when an individual perceives that environmental demands tax his/her adaptive capacity. In this perspective, stressful daily experiences could be conceptualized as a continuous person-environment transaction in which individual isn't able to effectively cope with a challenge that is perceived to exceed his/her skills [10,101]. Every day, in fact, individuals are continually invited to deal with several situations or circumstances (for example, being fired from work or having trouble with parents or partner) that provoke anxiety and psychological discomfort. The Cochrane Database of Systematic Reviews identified in the Cognitive Behavioral Therapy (CBT) the best-validated approach for stress management [102,103]. CBT aims to influence dysfunctional emotions, behaviors and cognitions through a goal-oriented, systematic procedure to change cognition and to encourage individuals to proactively respond to daily stressors by reducing their negative thoughts and by optimizing his/her use of personal and social resources. Typically, this approach may include both individual and structured group interventions (10 to 15 sessions) interwoven with psychoeducational materials, experiential exercises and out-of-session assignments (practicing relaxation exercises and monitoring stress responses).

Even if CBT is the "gold standard" for the treatment of psychological stress, there is still room for improvement. In particular, there are three major issues to solve:

- the therapist is less relevant than the specific clinical protocol used;
- the protocol is not customized to the specific characteristics and needs of the patient;
- the therapy is more focused on the top-down model of change (from cognition to emotions) than on the bottom-up (from emotions to cognitions).

To overcome the above limitations, within a recently funded European project, "INTERSTRESS – Interreality in the management and treatment of stress-related disorders", we proposed a stress management protocol based on the Interreality paradigm. INTERSTRESS Project aims at helping individuals to effectively manage psychological stress through the acquisition of techniques of relaxation and coping strategies within six weeks treatment supported by advanced pervasive sensors and computing.

INTERSTRESS platform is based on the following technological devices:

1. *3D individual and shared Virtual Reality worlds:*

   Individual 3D Virtual Reality worlds offer the opportunity to deliver controlled and tailored VR-based exposure sessions in clinical setting according to the specific characteristics and needs of the patient (figure 4). These virtual environments are used in clinical setting and are fully controlled by the clinicians. These virtual worlds exploit the sense of presence provided by the engaging virtual experience to practice several stress management exercises: relaxation techniques, VR biofeedback, assertiveness training, time management training, and problem-solving training.

Fig. 4. INTERSTRESS: A VR-based stressful situation

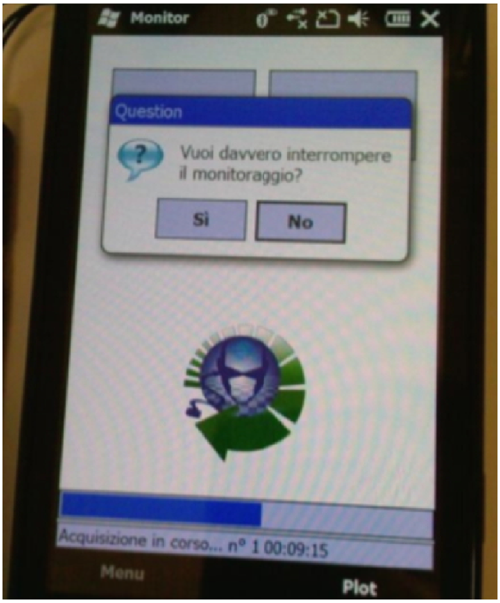
   On the other hand, in order to support connectedness between individuals for health promotion and medical education, shared 3D worlds appears to be promising technological devices. In particular, Second Life (SL) is a virtual three-dimensional platform that has been extensively used for medical education [104]. Within INTERSTRESS Project, Riva and his team developed the Learning Island, a Second Life platform aims at exploiting the motivation and the engagement provided by a shared virtual experience to teach the users about how to improve their stress knowledge and management skills also beyond a clinical setting [105]. In the Learning Island (figure 5), individuals can learn a) what is stress, what is stress; b) which are the fundamental stressors that occur in daily life; c) which problem-focused (e.g. resource optimization and better planning) and emotion-focused (e.g. relaxation training, use of emotional support) coping strategies could be used to cope with stress.

Fig. 5. INTERSTRESS: The Learning Island

2. *Personal Digital Assistants and/or mobile phones (from the virtual world to the real one).*

In INTERSTRESS Project, a patient's activity in the virtual world has a direct link with his/her life through a mobile phone. The mobile phone allows the possibility to deliver real-time psychological experience sampling assessment [76] and psychological interventions during daily activities [106]. On one side, the mobile phone permits to accurately analyze real-time interaction between environmental demands and individual adaptive capacity and to precisely detect stressful events during the daily life situations [82].

This mobile experience sampling approach opens a "window into a daily life" [74] since participants are invited to provide self-reports of their momentary thoughts, feelings and behaviour across a wide range of daily situations in ecological contexts. On the other hand, the mobile phones could became a true Personal Digital Assistant that provide warnings, motivating feedbacks, and psychological interventions during daily activities as a consequence of critical participants' psychophysiological state. In the field of mobile interventions, Riva and his team has recently showed the efficacy of mobile biofeedback in reducing anxiety in a sample of GAD patients [107,108]. Within INTERSTRESS Project, a mobile Heart Rate Variability (HRV) biofeedback will be developed to help participants in managing and coping psychological stress. Recent research, in fact, demonstrated that low HRV is associated with a wide variety of medical and psychological health problems, such as cardiovascular diseases, metabolic syndrome, depression, anxiety and psychological stress [109,110,111].



Vuoi davvero interrompere il monitoraggio?

Acquisizione in corso... n° 1 00:09:15

Fig. 6. INTERSTRESS. Mobile Application.

Tocca il fuoco, fermati e ascolta la narrativa
alla fine

Fig. 7. INTERSTRESS: HRV mobile biofeedback training

The mobile system collects data from a wireless wearable electrocardiogram equipped with a three-axial accelerometer. Then, the mobile application provides a real-time and graphical visualization of user's physiological parameters. For example, by controlling the respiration rate, variations in the HRV indexes control the increase or the decrease of the size of a campfire in a valley or the movement of the waves in a beach.

3. *Personal Biomonitoring System (from the real world to the virtual one):* It allows pervasive psychophysiological assessment through wearable biosensor in clinical and ecological settings and classifications for the decision support system for the treatment.

The Personal Biomonitoring system is a platform composed of an Electrocardiogram (ECG) module equipped with a three-axis accelerometer and integrated into a wearable chest band that collects, fuses and analyzes psychophysiological data. This wireless Biomonitoring system unobtrusively makes a real-time monitoring of heart rate, heart rate variability, breathing rate, activity data as meaningful physiological parameters related to psychological stress (e.g., [112,113,114,115,116]).

Data extracted by the Personal Biomonitoring System are automatically sent to central database (including physiological parameters collected in clinica settings, such as Electroencelography signals, Skin Conductance signals, Facial electromyography Corrugator and Zygomatic responses, and Respiration signals) for advanced analysis and classifications for the decision support system in order to evaluate psychophysiological status of the patient, monitor his/her progress and adapt the progression of the treatment.

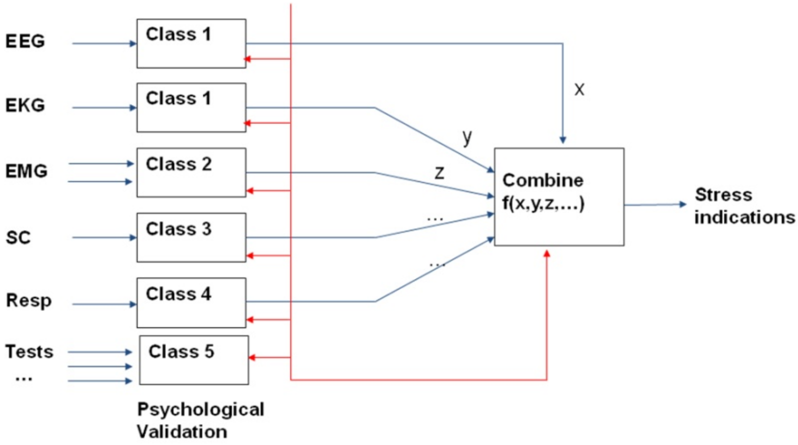


Fig. 8. Signal processing and data fusion for stress detection

4.3 Interreality Paradigm: Challenges and Cost Effectiveness

In a recent review, Riva [117] identified four major issues that may limit the use of the proposed Interrality approach in the assessment and treatment of psychological disorders:

- the lack of standardization in VR hardware and software, and the limited possibility of tailoring virtual environments to the specific requirements of the clinical or experimental setting;
- the low availability of standardized protocols that can be shared by the community of researchers;
- the high costs (up to $200,000) required for designing and testing a clinical VR application;
- expensive technical support or continual maintenance are often required.

To address these challenges, Riva and his team developed NeuroVR (http://www.neurovr.org) in 2007 – a free virtual reality platform based on open-source elements, and the updated version in 2010: NeuroVR 2 [118]. The software allows non-expert users to adapt the content of several pre-designed virtual environments to the specific needs of the clinical or experimental setting. The key features that make NeuroVR suitable as assessment and treatment tool for Interreality paradigm are the possibility to customize the virtual environments according to the characteristics of the patient, the enriched and engaging experiences provided to the patient, and the possibility to wirelessly connect virtual environment to wearable biosensors [118].

On the other side, mobile phones have became more and more popular in everyday life since they have quickly evolved from only voice and text-based devices enabling minimal user-device interaction, to low-cost Personal Digital Assistant, with digital camera, GPS and navigator, MP3 and video player, interactive agenda, advanced 3D graphics, Instant Messaging and Internet Browser equipped with 3G/UMTS and 4G [119].

As suggested by Preziosa [106], the critical advantages that mobile phones may introduce in Interrality paradigm are the following:

- the wide diffusion of mobile platforms reduces the problems of digital divide and offers the possibility of research and treatment access;
- mobile phones guarantee the availability of the contents any time and everywhere: in this sense their portability would be an eligible feature for assessments done in the patient's context;
- the interactive feedback increasing participants' compliance to the treatment and their self-efficacy;
- the high connection speeds offer new opportunities for a quick transfer and management of data for the clinical practice.

As recently suggested by Simpson [120], the evaluation of costs encountered or saved by introducing the use of ICTs must balance technological, training and support costs with factors such as reduced treatment costs, a longer lifetime horizon, improved family and work commitments, costs incurred through time and expense of travel. In this perspective, recent studies suggest that the use of Interreality technologies (virtual reality and mobile phones) may lead to cost savings and improved outcome for both patients and health services [121,122].

5 Conclusion

The incredible value of Interreality Paradigm lies in bridging the gap between virtual and real world by integrating different technologies to develop assessment and treatment protocols actually missing in the traditional research and clinical fields of psychological disorders. Interreality paradigm is based on a closed-loop concept that involves the use of several integrated positive technologies for assessing, adjusting and/or modulating the emotional regulation of the patient, his/her coping skills and appraisal of the environment based upon a comparison of that patient's behavioral and physiological responses with a training or performance criterion. From a technological viewpoint, Interreality is based on the following elements: a) 3D individual and/or shared Virtual Reality worlds; b) Personal Digital Assistants and/or mobile phones (from the virtual world to the real one); c) Personal Biomonitoring system (from the real world to the virtual one). On one side, the patient is continuously assessed in virtual and real worlds by tracking the behavioral and emotional status in the contexts of challenging tasks thanks to pervasive biosensors (*customization of the therapy according to the characteristics of the patient*). On the other hand, feedback is continuously provided to improve both the appraisal and the coping skills of the patient through a conditioned association between effective performance state and task execution behaviors (*improvement of self-efficacy*).

In conclusion, we argue that the potential advantages offered to Positive Technology by the inclusion of pervasive sensors and computing are:

- *a real-time feedback between real and virtual worlds:* Interreality Paradigm uses biosensors, activity sensors and mobile devices (PDAs, mobile phones, etc.) both to track in real-time the behavior and the health status of the user and to provide targeted suggestions and guidelines;
- *an extended sense of community:* Interreality Paradigm uses hybrid social interactions and dynamics of group sessions to provide each users with targeted – but also anonymous, if required – social support in both physical and virtual world;
- *an extended sense of presence:* Interreality Paradigm uses advanced simulaions (virtual experiences) to transforms health guidelines and provision in experience. In Interreality Paradigm, the patient do not receive abstract information, but live meaningful and engaging experiences.

Obviously, any new paradigm requires a lot of effort and time to be assessed and properly used. Without a real clinical trial, the Interreality paradigm will remain an interesting, but untested concept. However, a recently funded European project, “INTERSTRESS – Interreality in the management and treatment of stress-related disorders - will offer the right context to test and tune these ideas.

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Utilizing Social Media, Mobile Devices and Sensors for Consumer Health Communication: A Framework for Categorizing Emerging Technologies and Techniques

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Abstract. While the advent of social media, ubiquitous Internet-connected mobile devices and widespread deployment of sensors are still relatively new phenomena, a rapid penetration of these technologies is being seen and their impact in relation to health-related communications is more recently also being considered. In relation to health in particular, these communications systems can also be considered to gain extended capabilities when used in conjunction with each other in relation to consumer health communication. In this paper we introduce a framework to categorize and analyze the emerging types of consumer health-related interactions and communications enabled by these technologies and consider how the techniques fit within this broader framework for the utilization of emerging communications technologies for applications to healthcare.

Keywords: social media, consumer healthcare applications.

1 Introduction

Online social networks and social media, Internet-connected mobile devices and bio-sensors have a number of important capabilities that support their potential utilization in consumer health communication. Their potential to add novel capabilities to health communication practices arises due to both the technical capabilities and novel usage and behavioural characteristics implied by utilizing these communications technologies.

While these three technology types are not the only possible emerging technology categories to be utilized for novel health communication capabilities, these three are considered within this work as; 1) they do encompass a significant span of the contemporary emerging communications innovations; 2) the range of technologies indicated by each of these categories is broad in itself. That is, mobile devices include the hardware and software technologies enabled by current and emerging mobile and portable devices. This captures a wide range of significant developments both now and within the short-term of the coming five years.

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For example it includes the currently rapidly developing capabilities of smart-phones and their software and communications capabilities such as mobile apps. Sensor technologies also encompass a wide range of individual technologies. These include existing health-related sensors such as blood glucose sensors, ECG, EEG and pulse oximeters to name a few [1-2]; the sensor capabilities being ubiquitously included in smartphones such as accelerometers, microphones, digital cameras, GPS-capabilities; emerging bio-sensors and external sensor devices such as microscopes, environmental sensors and anticipated sensor systems such as "lab on a chip" technologies.

Relevant characteristics of social media include the following:

- One-to-many communication: Unlike a number of the revolutionary electronic communications advents in recent decades, including email, instant messaging, text messaging and others, social media is not focused on a one-to-one model. This means that communications take on more of an information dissemination, group reception-focused nature. While research in relation to this is still in a relatively early stage, an impact on the nature and content of the communication occurring has been seen [3-5].
- Social nature: In part due to the previously listed characteristic, and partly due to the fact that the communication is between those with social and/or professional or other real-world or personal relationships, the communication has a highly social and engaging aspect to it [6] and can support online group discussions.
- Low barrier to communication: While traditional forms of communication such as a letter required both operationally and socially greater barriers to be crossed before communication would take place, electronic communications and most recently social media and social networking are leading to a lower barrier to communication [7]. This is particularly seen with the combining of these communication technologies with the increasingly ubiquitous mobile device technologies such as smart-phones [5]. This has led to a greater frequency of communication with for example the proportion of micro-blogging communications such as those via the Twitter service originating from mobile devices, rapidly increasing [8].
- Geographically correlated: While social media and social networking support a truly global forum of communication, as social network connections are typically between people that are known to the user individually, this typically will involve a higher proportion of contacts from their own community or city [9].

All of the above characteristics have some relevance to the use of social media in health communication as will be described in more detail in this paper.

Relevant characteristics of mobile devices include:

- Continuous connectivity: Emerging mobile and smartphone technologies have created a situation where essentially all members of the population, including increasingly globally, are continuously connected. At the level of feature phones this includes a voice communications capability and limited data via SMS. However as of early 2012 already often half or more of the population in numerous developed countries are smartphone owners [10] and these provide more sophisticated and continuous real-time data connectivity and capabilities.

- Person-centric: Mobile devices are typically carried with or on the person of individuals. This allows for a particularly intimate, context-sensitive and immediate from of data communication, one which has relevant capabilities when utilized for health-related communication.
- Sensor support: Smartphone devices both contain device-internal sensors and also typically support short range communications technologies to allow interfacing with sensors – the smartphone then utilizes such technologies as the cellular network for long range communication to connect to the Internet.

Relevant capabilities of sensors include:

- Health data: Sensors have various capabilities to measure health or physiological aspects in everyday life. As such they are particularly relevant to potential application to consumer health communication.
- Pervasiveness: Sensors have witnessed a rapid decrease in cost and increase in measurement capability [1-2]. This has led to the sensors being far more widely available and deployed in the human world than previously. This new economic feasibility is a capability that can also assist health communication. Noting these sensor capabilities, these are still various challenges to the advancement of affordable, low-maintenance, ubiquitously available health-related sensors.

Areas in which these emerging consumer health communications technologies have notable significant potential for impact on healthcare:

- Chronic disease: Chronic disease accounts for over 70% of health cost and 80% of deaths in the US [11]. Approximately one-fourth of persons living with a chronic illness experience significant limitations in daily activities [12]. As such it is the most significant category of health condition. Chronic disease is however best combated through lifestyle change and this must occur within an individual's daily living and work environments not in a clinical setting. As such mobile devices, social networks, and sensors, as they reach directly to individuals on a daily basis, do prima facie have the potential to provide information or affect behavior in relation to chronic conditions. At the same time it is yet to be determined if, how and how effectively these technologies might be able to be utilized in relation to lifestyle behavior. It might also be considered from an ethical perspective how desirable such impacts might be, notwithstanding the potential improvements to the health of the population.

  Chronic conditions often do not require just clinical interventions but require a long-term dialogue between health professionals and patients. Long-term lifestyle modification is often the best treatment [13].
- Personalized health care: Mobile devices, sensors and social networks provide for fully individualized and personalized communication

notwithstanding the one-to-many communication capability of social networks. Analysis would suggest there is the potential for this to be more personalized and targeted temporally and spatially than even online personal health records. Examples of using Internet resources include taking a face-to-face lifestyle intervention and turning it into an Internet-based intervention [14].

- Emergency detection: The continuous connectivity has the potential to support earlier notification and response to emergency situations. As the telephone and voice-only mobile phone have already much extended these capabilities, emerging smartphone data capabilities can provide for more sophisticated data flows and processing to potentially identify and communicate emergencies.

There are also further technologies that arguably have a longer period expected until they can be utilized in non research-and-development, real-world health communication practices – these include nanotechnology-based techniques and brain-computer interface. These areas however are not considered in this paper.

2 A Framework for Consumer Healthcare Applications of Social Media, Mobile Devices and Sensors

2.1 Categorization of Health Interactions

In this paper we will consider the roles of social media, mobile devices and sensors in relation to health communication, and a framework to categorize these contains five broad categories based on the interacting parties involved:

- Patient-patient interactions
- Clinician-patient interactions
- Public health-consumer interactions
- Researcher-patient interactions
- Corporate-patient interactions

The emphasis of the work will be on the role of social network technologies in health communication in particular given their human-to-human communication focus, but the relevant and additional capabilities of mobile devices and sensors will be discussed. In the social network the nodes are individual people, although some individual nodes may be individuals representing organizations engaging in the system. These categories of social network clearly share nodes and are overlapping and inter-mingled. Mobile devices will typically correspond in their usage to individuals as will health sensors.

A potential sixth category not considered in this work is clinician-clinician interactions. This is an important emerging category that is not considered here as this work focuses on consumer health communications. Emerging sites such as Sermo (www.sermo.com) are examples of how social networking systems can provide forums to support clinicians in their sub-areas of interest and specialization.

2.2 Enabling Technology Platforms for Enhancing Health Communication

Individual people can interact with online social networks via accessing any Internet-connected computing device. However, health social media applications are more closely linked to the physical individual and have greater capabilities through this physical connection. As such, as we consider each of the above categories, we consider each of the the following technology enablers in the context of that category:

- Social media – one-to-many communication and low barrier to communication

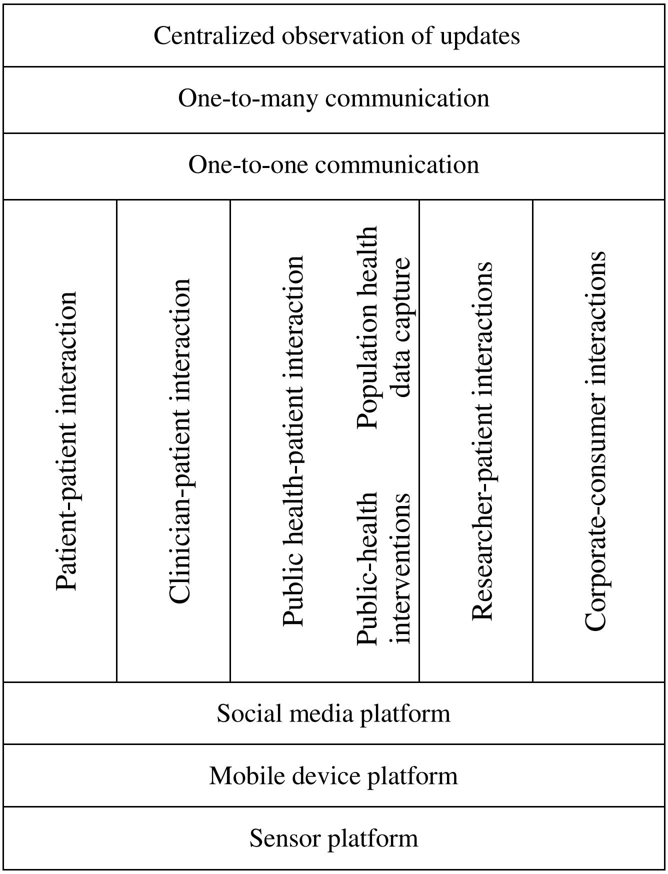

Fig. 1. Framework for healthcare applications of emerging communications technologies

we will then consider how social media capabilities can be enhanced when used in conjunction with:

- Mobile devices – continuous connectedness
- Sensors – enabling linking to the physical and person physiology measures [15].

2.3 Modes of Communication

The nature and modes of technology-enabled communication have a number of characteristics affecting relevance to health communications.

- Centralized observation of updates – due to the public aspects of various forms of social media communication, this provides a valuable source of whole-of-community data which can have implications for some of the categories of interactions indicated in Section 2.1. This can allow public observation of system-wide updates such as via services such as Twitter, or can allow the system operator to observe and analyze updates and communications across the social network system. Mobile operating system platforms and individual apps also may have this capability, although there may be a greater requirement to make users aware of this in such cases.
- One-to-many communication – this effects both patient health communication behavior and modes of interaction involving patients and clinicians. Whether interactions in social network systems are visible or not to larger numbers, or how this can be controlled by a user has fundamental implications for the type of health communication that can take place in a given online social media system.
- One-to-one communication – highly interactive, immediate and personalized health communication enabled. In general, contemporary social media systems, supported by use by mobile devices have an 'always on' functionality, and this means being able to exchange one-to-one messages in real-time. Smartphones and other mobile devices enable much more immediate one-to-one communication than previously.

It should be noted that any given social media platform, and also considered in conjunction with the enabling technologies of mobile computing and sensors, can support a varying number of different modes of communication.

3 Patient-Patient Interactions

In the case of patient-patient interactions, the dominant emerging technology capability is that of social media, of the three considered. We will focus on social media and include in a sub-section of Section 3 a discussion of how mobile device and sensor technologies can enhance this form of communication.

There is substantial work indicating the potential support benefits for patients via social network-based communication between patients [16-18]. Swan [19] suggests that benefits include emotional support and information sharing between patients who have similar conditions. This includes one key value health social networks provide, “the potential to find others in similar health situations and share information about conditions, symptoms and treatments”. Proving the particular benefits of such a characteristic still awaits more detailed demonstration.

Clearly we can consider such health-related communications in the context of larger, all-purpose social networks such as Facebook, LinkedIn or Twitter or we can consider interactions in the context of smaller health-specific social networks. The exact model as to which of these types of social network will be more important is yet to be determined, but it can be seen already that there is some overlap in the groupings, individuals and communications happening between these two types of network.

Web sites such as PatientsLikeMe (www.patientslikeme.com) demonstrate such bringing together into online communities of patients coping with the same type of health condition [20]. This site as one of its core aspects emphasizes patients to have confidential profiles as a way for patients and sufferers to openly share experiences with others while not revealing their ‘real world’ identities. Frost &Massagli [18] identify three themes about the behaviour of patients using such sites as PatientsLikeMe. These are, “asking advice of a user with a particular experience, offering advice to a user with a specific symptom or health problem, and fostering relationships based on shared attributes”.

Specific chronic conditions also have dedicated social networks, such as TuDiabetes (www.tudiabetes.org) for diabetes sufferers. Diabetes management related groups also exist on Facebook [21].

Another project, the Connecting Older Adults project being carried out at The University of Sydney, Australia, explores the potential for online social networks to decrease the isolation of older adults and increase their engagement in the community [22].

Other benefits of social media in patient-patient interactions:

- Rapid dissemination of relevant news to a health condition group. A common activity amongst micro-blogging or professional social networks is the sharing or “re-tweeting” of URLs of recent and relevant articles with one’s online network. It might be considered that there is some competitive or social value in providing very up-to-date story links to one’s network. As such, this can lead to very rapid dissemination of relevant news [23] which can lead in speed, traditional news sites. Social networks support such dissemination of news to linked persons, who will typically share some characteristics, which can include similar health conditions or interests in the case of health social networks as described.
- ‘Competition’ in maintaining good health. Such sites as PatientsLikeMe allow individuals to display graphs of their health data and for some characteristics that are not perceived to be overly private by the patient e.g. weight, cholesterol levels, such competition aspects could benefit an individual’s health progress. However, such benefits are yet to be rigorously measured and so this remains an interesting area of potential future research.

3.1 Mobile Device and Sensor Capabilities

Some companies have already combined health sensor usage with social network capabilities. Company RunKeeper (www.runkeeper.com) has focused on social networking for fitness, on a mobile platform. In this case, GPS and accelerometer sensors detect distances run and running speeds can be used to capture physical activity information and this can be shared with one's network of friends. It particularly supports graphical representation of particular aspects of your health data and allows one to compare this with similar statistics of friends using a functionality they have referred to as a 'Fitness Feed'.

The most prevalent combination of sensing and mobile device capabilities adding to patient-patient social networks at this time is via accelerometers or GPS detecting physical activity, running or walking to allow sharing and comparison with friends via social networks.

Current highly downloaded mobile health apps include Nike+, LoseIt!, RunKeeper, Endomondo and WorkSmart labs and it can be noted that these are typically focused upon fitness data capture and recording.

3.2 Modes of Communication

In relation to the framework introduced, the most significant mode of communication in relation to the patient-patient interactions is one-to-many communication. It is this characteristic that in fact enables the online community, and allows the supportive interaction benefits described above. It is also this mode that enables 'competitive' or supportive social behaviour as it relates to encouraging fitness activities.

A secondary mode is the one-to-one mode. Patients establishing awareness of each other via social media group activities or other means also have the potential to interact in a more private and one-to-one way, where mutual interest has been established.

4 Patient-Clinician Interactions

Prior research has suggested that social media and social networking technologies are fundamentally technologies that can further patient-centered healthcare [19-20]. It is suggested that such technologies can also support physician Q&A and quantified self-tracking.

Also in relation to patient-clinician interaction, there is potential for communicating care plans and using such technologies for more personalized care. Communicating care plans themselves and even allowing interaction in relation to care plan adherence can be achieved to an extent with a traditional Web site-based approach. However mobile device-based approaches in particular, possibly in conjunction with social media, have the potential to more intimately and interactively guide adherence with either a care plan or assist persuasion in terms of healthy lifestyle behavioural choices [24].

An example of clinicians using a mobile technology based-approach to attempt to positively affect the health of diabetic patients is via the 'SMS-Based Health Risk Assessment' initiative being undertaken in 2011, as a collaboration between the Office of the National Coordinator (ONC), American Diabetes Association, two ONC Beacon Communities (New Orleans and Detroit), the CDC and Voxia [25]. Their 'highly scalable public health activation campaign' offers to:

- "Encourage individuals to engage with and manage their health,
- Help individuals assess their diabetes risk levels, and
- Better connect individuals with the wealth of existing wellness and diabetes care resources available today, to help them manage their diabetes more effectively." [25]

Texting based risk assessment is available to anyone with a mobile phone, with the access number available through traditional media. It works as follows:

1. "Through their cell phones, individuals will be asked brief questions that assess their risk for diabetes. The user would answer these questions by sending a text.
2. Based on their responses to this text-based assessment, individuals will be connected with the best possible resources for their needs. This may be an online social forum, a discount for a check-up at a local pharmacy, or the phone number for a local health care provider." [25]

One other aspect to potentially aid conformance with physician care plans is to leverage the social aspects of social media. This can be done by utilizing such characteristics as the 'fun' or competitive aspect that can be associated with social network utilization.

There are also many other ways in which the physician-patient interaction can be changed such as patients accessing physician's blogs, accessing "tweet" updates, making appointments online, re-filling prescriptions and seeing test results online [26, 27]. Another interesting issue for investigation is the potential link between social media and Personal Health Records (PHRs) in communicating with and empowering the patient. Personal Health Records have the ability to be integrated with social media to provide a more engaging communication and reminder capability [28, 29].

4.1 Mobile Devices and Sensor Capabilities

As illustrated by the examples above health communication via a mobile device is seen as a particularly intimate, interactive and engaging way to communicate. Sensor capabilities also have the potential to communicate in emergency situations to physicians and this is seen as highly desirable by potential users [1].

Unlike the case of patient-patient health social network interaction, in the case of clinician-patient interaction, sensors able to capture more private health data, may have an important role to play. In addition to the social media aspects, new sensing capabilities are also key. For example, Telcare's Blood Glucose Meter is the first cellular-enabled glucose meter with embedded 3G technology [30]. At the same time it can be seen that the integration of sensors into social networks in relation to healthcare is still in its early development [31].

While not necessarily integrated with social network systems, the ability of health sensor data to be communicated to an individual's physician or hospital may provide powerful new approaches to monitoring recovery, preventing re-hospitilization or indeed detecting early indicators of potential illness onset. A combination of mobile technologies and sensors, offers particularly relatively beneficial capabilities to enable a ubiquitous computing-based form of telehealth in rural and remote areas [32]; this is due to these techniques requiring relatively low bandwidth, the greater relative difficulties of travelling longer distances and the greater health challenges faced in such areas.

Mobile devices can also provide a platform to deliver reminder messages from clinicians to their patients, or messages to support adherence to treatment.

4.2 *Modes of Communication*

As demonstrated by the above the one-to-one mode of communication is most important in relation to clinician-patient interactions via both social networks or mobile devices. This is because it becomes a mechanism for direct communication and can provide such functionalities as manual or automated reminders. The specific interactions between a patient and clinician are necessarily typically of a private nature.

However the physician Q&A functionality of some online health social networks or support groups does demonstrate the application of the one-to-many mode. Publicly asked questions and publicly displayed physician's answers can provide a useful information source for users of such online health groups.

5 Public Health - Consumer Interactions

Fundamentally social media and social networking have a peer communication aspect where nodes in the network are individual people. However, at the same time a certain number of nodes in social media systems and social networks do either correspond directly to organizations e.g. a university might have a presence in a social network, or individuals in the network may be delivering communications on behalf of organizations. In this way, organizations wishing to disseminate public health messages may also be able to leverage social media technologies for this purpose.

An important novel aspect of such technologies as social media and social networks is the ability to target and even personalize public health message to a greater or lesser extent as part of public health interventions. Recent examples include that of NHS Direct considering using targeted advertising on Facebook and Twitter [33]. A status update such as 'got the flu' might result in receiving a targeted ad such as one directing the user to the NHS's health symptom checkers.

Twitter was seen as potentially highly effective additional communication mode in responding to pandemic events.

Another aspect of public health communications is using social networking message and updates such as those of micro-blogging sites to gain knowledge of the health state of the community at large [33-35]. The mining of the textual updates of social media and micro-blogging is a novel, global and real-time data capability and can once again provide information for public health interventions. This is a novel and powerful public health capability that has not been hitherto available. At the same time it will be important to better understand the methodological limits of such capabilities [33, 36].

There are a number of mechanisms by which public health social media can be targeted and personalized. One possibility is for there to be knowledge of the individual held by or accessible by the organization carrying out the public health messaging. The two primary ways of obtaining such knowledge:

- From electronic health records or personal electronic health records, mining for conditions or updates
- Other forms of timely electronic updates such as Facebook updates or Twitter messages

An alternative for fine-grained public health interventions, is rather than knowing characteristics at an individually identified level, to be able to identify and disseminate electronically to, demographic cohorts that conform to such characteristics as a particular age group, postcode or zip code-based or risk group.

5.1 Mobile Devices and Sensor Capabilities

Mobile devices and sensor capabilities should be significantly considered in both of the areas of public health-consumer interaction mentioned, that is: public health interventions and the gathering of real-time public health status information across a population.

In the first case of public health interventions, mobile devices in particular may provide the ability to bring substantial extra capabilities to personalized public health interventions. In particular, mobile devices allow the delivery of public health messages to an individual in relevant contexts or for example allow the delivery of reminders that will be received in a timely fashion.

For the second case of gathering public health status data, integration of sensor and mobile capabilities does enable, with appropriate privacy protections, a whole new level of public health knowledge [34, 36]. This includes the ability to better understand environmental effects on human health, new research into the human ‘phenome’ and a resource to better understand the links between the human genome and phenome [36]. It should also be noted that such capabilities integrating sensors may have performance implications as they involve potentially large data flows, but that even with meta-data enhanced data the bandwidth requirements are likely to be manageable [37].

5.2 Modes of Communication

The most important modes of interaction here vary depending upon which of the two cases of public health-consumer interaction are considered.

In the case of public health interventions, the one-to-many mode is the most important. This is because this mode allows the dissemination of a targeted public health message to an appropriate sub-population. In general personalized public health messages will not be personalized to the level of an individualized message to an individual. Such communications would be the purview of individualized care that would appropriately take place between a clinician and patient.

It should be noted that the specific functional characteristics of the social network system used would need to be chosen to be appropriate to these forms of interactions. For example in the case of one-to-many public health messaging, it should not be permissible for recipients to be able to see who else is a recipient of such a group message. This would by implication reveal some indication of an individual's health to a broader group, breaching privacy requirements. As such this form of health social media communication requires a social media infrastructure that does not reveal recipients or show individual's receipt or reading of such messages.

In the second case of capturing public health status information across a population or sub-population, the most important mode of communication is the ability to carry out centralized observations of updates. Once again this is a novel characteristic flowing from the more public nature of social network communications and updates. The status information may be gatherable on a fully public basis, but more typically it will be possible for the system operator to gather aggregate data in an anonymized and privacy-preserving way. This latter case applies to the case of specific mobile operating system, software or mobile app systems potentially also including associated sensors.

6 Patient-Researcher Interactions

The formation of online social network groups can also have benefits for clinical trials and research. There are a number of ways in which this may be the case. Firstly, social networks can be seen as closing the feedback loop in relation to clinical trials, allowing direct interaction between patients suffering from a condition and researchers of that condition [19].

Another aspect is that via this closing of the feedback loop, pharmaceutical companies for example could directly assess the demand and market size for particular medications to address particular health conditions. Other novel capabilities could include making available clinical trials information on social networks relevant to the topic of a trial, so that relevant consumers can be more aware of latest research findings in a highly up-to-date way [19]. This could also include making available information on upcoming clinical trials on social networks so as to recruit participants from the relevant condition community.

Another advent is that of 'crowdsourcing' of a research project. For example, [19] mentions the CureTogether migraine community "raising $50,000 in crowd-sourced funding, reviewing and approving applications, open-sourcing the research findings on their website and developing and testing remedies in patient-run clinical trials". How successful or important such a model is will be further determined over time, but there are already numerous examples of crowdsourcing health research studies [38].

Further there is the potential for social networks to facilitate 'long-tail' medicine. Traditionally it was only economical to develop treatments for conditions that were sufficiently widespread in occurrence. However, fine-grained, condition-specific social networks, by reaching to a larger proportion of sufferers of a condition globally, have the potential to bring together a sufficient critical mass of people to make addressing their health condition economically feasible.

There is also the potential of health social networks to help facilitate translational medicine. That is, by achieving the continuous feedback loop between patients and researchers, this will better and more rapidly allow research to be targeted and brought to market as a product for consumers.

A final aspect of research interaction pertains to data mining. This in general does not specifically involve 'researcher-consumer interactions' but the greater capture of population-wide digitized health data, including such data from health social networks enables new scientific approaches utilizing data mining to uncover health-related correlations and possible causations.

6.1 Mobile Devices and Sensor Capabilities

The benefits from the greater integration of health sensors and mobile communications into social networks for research are both potentially transformative and also not as immediately deployable. There are new possible capabilities in relation to clinical trials and public health research [36]. The latter once again has the potential to better understand environmental effects on health and genome-phenome links. At the same time, this is an area that should have further careful deliberation in terms of ethical and privacy issues.

Mobile device and sensor capabilities also have a plethora of applications in capturing more detailed and continuous data from research trial participants. Via automated or semi-automated data capture various limitations of traditional research instruments such as participant surveys may be overcome.

6.2 Modes of Communication

The one-to-many communications mode is the most important to the application to clinical research. In particular, the ability to publicize trials, recruit trial participants and the ability to disseminate the outcomes of the most recent trials. However the centralized observation of updates capability of social media is also pertinent to enabling new research abilities in relation to patient-researcher interactions. This is particularly the case in relation to data mining-based approaches and population-wide research data collection approaches [39].

7 Corporate-Patient Interactions

There are a range of corporate-patient interactions enabled by health social networks. This includes: reaching consumers for advertising purposes and so as to influence their health-related purchasing activities; companies gathering market research information about consumers; review information about companies and their products by and for consumers; and corporate healthcare services utilizing social media as a delivery mechanism.

Companies can use condition-specific, health social networks as forums in which their medicines or other health products can be advertised [40-42]. Once again the public messages allow greater targeted advertizing. For example one area that is relevant to this category of interactions is the marketing of pharmaceuticals. Issues here include the distinction of direct-to-consumer pharmaceutical advertising that while allowed in some countries is illegal in other countries.

In addition another advertizing-related aspect is the consumer rating of health care providers via social networking sites [43-44].

7.1 Mobile Devices and Sensor Capabilities

The extended capability that will occur in relation to the usage of social media from mobile devices include location-based advertizing. This capability also has important potential and application in the health field.

Healthcare sensors and systems are typically manufactured by private companies and this may support a data gathering capability specific to that company. This information may or may not be shareable with clinician information systems to support healthcare. Or it may provide a powerful data tool to be utilized by clinicians.

7.2 Modes of Communication

All of the modes of communication mentioned in the framework may be utilized and be important in this category of interaction. The centralized observation of updates can be utilized to judge market size, demand and trends. One-to-one communication can be utilized for targeted advertizing, based both on particular health condition group membership or based upon public updates made by users.

8 Conclusion

In summary we have presented a framework which categorizes the emerging ways in which social media and social networking, mobile devices and sensors may be utilized in consumer healthcare communication. This framework considers and categorizes these emerging techniques in terms of five categories based on the participants involved in the health-related interactions. In addition, the framework considers the integrated and additional capabilities for each category, available through the use of the technologies in conjunction with each other. The framework also considers the emerging health communication capabilities in terms of three modes of communication inherent to social media. The health communication capabilities of social media and social networking, mobile devices and sensors have the potential for significant impact on numerous aspects of consumer communication in healthcare.

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EHR Ecosystem

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Abstract. This chapter outlines the challenges of providing accurate and timely health information as a way to improving patient outcomes and reducing costs. The last decades experience shows that computerization alone does not improve quality and safety. In order to achieve the expected effectiveness and a positive return on the investment, EHR should be transform in a clinical workflow management system with built in decision support system. These require adoption of business process management technologies that have to be aware of the detailed context of each individual patient.

There are many challenges which diminish the impact of information technology on healthcare, among them, the limited interoperability, technological barrier for most of the elderly people, security, privacy and trust issues. An overview of the methods and tools able to overcome those limitations are presented, including the use of standards for EHR architecture and communication, the progress in terminology and classification systems adoption and the ways to overcome the security threats.

Keywords: EHR, decision support, interoperability, security, privacy.

1 Introduction to Electronic Health Record

Around the world, the healthcare systems know dramatic transformations and unprecedented challenges. The aging population has increased incidence of chronic diseases. The patient's bigger addressability and the diversification of investigation and treatment methods, beyond the positive effect on the quality of care, raise numerous problems including rising costs and the need to manage and share an increasing amount of medical data. Furthermore, the medical errors, associated with greater morbidity and mortality, determine a number of other "secondary" costs.

Computerization is not a solution for all the problems of the healthcare systems, but it is an indispensable tool in healthcare reform and, when properly implemented, can lead to higher quality and lower costs. The main focuses are: accessibility assurance, processes optimization and optimal use of the resources (Chaudhry, 2006).

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The core of any healthcare information system is a structured collection of medical data, accessible by authorized personnel whenever needed and where is needed (Fig. 1).

On a traditional approach, the data is entered the Electronic Health Record (EHR) and is retrieved exclusively by the clinician, the patient being shielded from its own records. The new EHR ecosystem approach breaks this barrier, empowering the patient which is allowed not only to enter new data but also effetely use the recorded data. Therefor the patient is demanding to be part of the healthcare team. The ecosystem facilitates the collaborative work of many clinicians from different specialties and also data exchange with patients and their family.

Fig. 1. EHR Ecosystem

EHR also provides data collection other than those directly related to the health care, such as financial, quality management, various data required for reporting, resource planning and morbidity surveillance (Kenneth, 2007). In order to manage this complex flow of sensitive data, security and confidentiality measures become an essential part of the system and should be based on the most efficient authentication methods.

As many studies report, EHR alone could not improve quality and safety of the healthcare. In order to achieve the expected effectiveness and a positive return on the investment, EHR should be transformed into a clinical workflow management system with built in decision support system. These require adoption of business process management technologies that have to be aware of the detailed context of each patient (Chaudhry, 2006).

2 Building Up a Viable EHR Ecosystem

Medical information systems meet today a variety of models and types. In an attempt to systematize these approaches, three models of patient health information management have been identified (Waegemann, 2004):

- Electronic health record (EHR) group, including Electronic Patient Records (EPR), Electronic Medical Records (EMR) and Computer-based Patient Records (CPR)
- Personal Health Record (PHR)
- Continuity of Care Record (CCR)

All this systems should be linked together by using a unique patient identifier. Electronic health records (EHR) are systems that provide digitized medical information in a structured and fully accessible way. The main clinical information system actually in use is the clinician-controlled, electronic patient record (EPR). EPR is used by a particular healthcare organization (provider, practice, hospital, etc.) though offers limited interoperability but great reliability (Amatayakul, 2007).

Personal Health Record is a system that allows the patient to manage its own health information. A "patient-controlled, patient-owned, and patient-managed" PHR can serve as link among various sources of patient clinical information, but cannot substitute the legal record of any provider (Smolij, 2006).

The reliability of patient-entered data depends on several factors, among them the nature of the information, the patient's health literacy and his motivations to contribute with accurate data. For all these reasons, the data authorship is a limited element which should be taking into consideration at any time when medical decisions are taken.

The CCR is summarized by American Society for Testing and Materials (ASTM) as "a core data set of the most relevant administrative, demographic, and clinical information facts about a patient's health care, covering one or more health care encounters." It is the depiction of patient health information which was completed only by authorized healthcare personnel, what makes it a very reliable source of information.

Besides that variety of record systems, the term EHR is generally accepted as a generic term that covers all concepts. Unless a specific term is used, people use EHR to describe a nondescript concept of paperless or electronic documentation managed into an information system that would cover all types of caregivers, in all settings, including the patient who will want to record personal health status information.

According to ISO definition (ISO/TR 20514:2005), the Integrated Care EHR is "a repository of information regarding the health of a subject of care in computer processable form, stored and transmitted securely, and accessible by multiple authorized users. It has a commonly agreed logical information model which is independent of EHR systems. Its primary purpose is the support of continuing, efficient and quality integrated health care and it contains information which is retrospective, concurrent and prospective".

Building an Integrated EHR System conforming to the ISO definition remains a desiderate at this time. It will require consistent use of standards and medical terminologies in order to guarantee information exchange with other similar systems. The ethical, legal and technical aspects become more pressing with the current debates about the information ownership and the patients' empowerment trends.

2.1 Structural Classification

The complexity of the currently implemented EPR systems varies on a large scale. From structural point of view tree levels of complexity can be defined:

- The “classical” EPR – isolated or integrated on a local network.
- The “Practice Management Systems” including different solutions for collaborative work of physicians like communication software, office automation, online agenda and central administration facilities.
- The “Integrated Management of Healthcare System” with Quality and Chronic Diseases Management. The most sophisticated structures involve, in addition, components like: Prevention and Disease management on the EPR level, a Personal Health Record Portal, a Nurse Health Record, Quality management software - including analytical (statistical) tools on the level of data and processes, and Computerized Knowledgebase for decision support.

2.2 Functional Classification

At the basic level, we can distinguish the following three main functions that any EHR system has to accomplish:

- Collection of the clinical data
- Data integration from multiple sources,
- Support for the medical decision

The functionality of the EHR varies even more than their architecture. Currently, the most used classification (the Gartner Generations Model for CPR Systems) proposes a typology according to their capacity to increase the quality, measured by the errors reduction potential (Ball, 2003):

- Generation I “Collector”: is a comprehensive collection of data, accepting computer-processable data from admitting and registration systems, data from lab, pharmacy, radiology and other clinical or transcription systems.
- Generation II “Documenter”: capable of basic level alerts and reminders; send computer-processable billing data to patient accounting systems and also reports of visits and procedures documented in the systems.
- Generation III “Helper”: support terminologies based encoding and elementary tasks management like medication ordering and tracking or image manipulation by linking it to Picture Archiving and Communication System (PACS) and incoming clinical data.
- Generation IV “Partner”: offering formal workflow management and formal clinical knowledgebase management which allow a contextual decision support.

At the limit between the third and the fourth generation is the break-even for the financial efficiency and usability of the EHR systems.

2.3 EHR Usability

A critical point for the EHR adoption is the ergonomic aspects, because the user's "adoptability" is mainly conditioned by the ergonomics (usability).

According to "State of the EHR" - American Health Information Management Association (AHIMA) report, published in 2004, the first four factors which determine the "success" of an EMR adoption by the physicians are: the speed of encoding, flexibility, decisional support and interoperability.

3 The Long Way to Usability and Interoperability

In order to satisfy the usability and functionality requirements we need a level of semantic congruence between the user and the application that is technologically achievable only by an EHR of fourth generation, which allow a contextual decisional support. Decision support mechanisms have to be made explicit, clearly backing the planned health care providers' activities by referring whenever possible to the generally recognized clinical knowledge according to the current evidence-based state of the art.

The software behavior should reflect the work process of the user, while the software objects should reflect the mental model (clinical concepts) of the user (ontology - terminology) in order to reduce the workflow impedance and the semantic impedance to an acceptable level.

For any given application, in order to represent the semantics of the clinical data, there needs to be a boundary between information model and terminology without gaps or overlaps. Only by integrating terminology models with other structural relationships, including models of context, negation and time, we could formally represent the full meaning of patient medical data, and by this, to achieve the required level of interoperability.

3.1 Interoperability

Considering the message exchange between information systems, three levels of interoperability could be described:

- Basic level - a message from one computer can be received by another, without the ability for the second one to interpret the data.
- Functional level - the format of messages should be defined, allowing the messages between computers to be interpreted at the level of data fields.
- Semantic level – assure transmission of the meaning within the data, providing common interpretability.

In most European Member States, the policies about eHealth interoperability appear to focus nowadays mainly about the basic infrastructure to share electronic "documents" across healthcare facilities. The documents have the advantage to preserve the context of care into a comprehensive information object (referring to the organization and professionals involved, the activities performed, the time of the events, etc.), and to decouple the information from the original legacy systems.

The semantic interoperability is not an all-or-nothing concept. A partial semantic interoperability is acceptable since the full one is not foreseen for the short and medium time. The rapid development of medical ontologies based on a common foundation ontology could be the solution for the near future.

Other strategies are promoting the standards adoption. ISO/TR 20514 identified four prerequisites for EHR semantic interoperability: standardized reference model, standardized service interface models, standardized set of domain-specific concept models and standardized terminologies.

3.1.1 Relevant Standards for EHR Systems

Development standards for the medical field have raised the interest of many organizations worldwide, which is benefic while all these organizations collaborate. Because a general agreement wasn't always achieved, we assist today on dispersion and divergences between the adopted standards for the same topic, most relevant example being the EHR communication standard.

Worldwide, the main organization involved in the development of technical standards is ISO (International Standards Organization). In 1998 was created the Technical Committee TC 215, responsible for standardization in the field of information for health, health information and communications technology.

Other important international Standard Development Organizations in the EHR domain are (Eurorec, 2012):

- IEEE - Institute of Electrical and Electronics Engineers - address wire and wireless communications, light and power systems and develops standards in many industry domains, including Biomedical and Health care.
- IEC - International Electrotechnical Commission- prepares and publishes standards for all electrical, electronic and related technologies.
- IHE - Integrating the Healthcare Enterprise – declare its main goal the improvement of clinical care by stimulating the integration of all kind of clinical information resources.
- OASIS - Organization for the Advancement of Structured Information Standards - drives the adoption of e-business standards.
- IHC - is the OASIS International Health Consortium - provide a forum for the global healthcare community to articulate and coordinate requirements for XML- and Web services-based standards.
- HL7 - Health Level Seven - was founded in 1987 by several vendors of software for the health care industry. Their main goal was to facilitate a better interoperability of Hospital Information Systems (HIS) by developing messages consensual formats.
- DICOM - Digital Imaging and Communications in Medicine Standards Committee – develop standards for medical images transfer and for communication between medical devices.

The European standardization activity is organized within the CEN (Comité Européen de Normalisation), from 1991 has been established a technical committee for medical informatics – TC 251.

The EHR standards cover from more general aspects such as definition and purpose of EHR systems, data types and codification systems, to specifying in the detail computer models for data storage or for documents and procedures needed for medical information exchange.

The most relevant standards for the development of electronic health records could be groped in:

- EHR architecture standards
  - ISO / TC 215 - TS 18308 - describe the requirements for EHR architecture
  - ISO / TC 215 - TR 20514 - EHR: Definition, scope and context
  - CEN/TC251 - prEN 12967 - set of specifications for health information systems architecture (HISA)
  - CEN/TC251 - EN 1828 - describe structural categories for the classification and coding of surgical procedures
  - CEN EN 13940-1:2006 - Health Informatics - System of concepts to support Continuity of care - Part 1: Basic concepts
  - ASTM - E 31.19 defines the content and structure of the EHR

- Standards for EHR communication
  - CEN/TC251 - EN 13606 - European standard in five parts regarding EHR interoperability (reference model, archetypes, reference archetypes and term lists, security requirements and distribution rules, exchange models)
  - HL7 - RIM - describes a reference model for organizing the information, integrating a messaging model based on XML (Clinical Document Architecture)
  - IEEE ISO 11073-20101 defines the communication between medical devices

3.1.2 EHR Architecture

In the context of compliance with standards, EHR architecture must be interpreted as the general framework for organizing and structuring of EHR and not defining a specific format for data collection.

It is important to clearly differentiate between records' architecture and data formats. There are two basic formats for data: typical format for data storage and the format for data interchange (messages / protocols).

A HL7 message, for example, it accurately describe the segments, the data elements, the size of the data fields for each clinical message, just as the storage format describes the data items and the size of the fields from medical records database. The difference between these formats must be understood also in terms of differences between a message and a record. A message serves a definite purpose, is inevitably transitory and is meant to transfer data between the management information systems. On the other hand, a record serves a general purpose, is persistent and is part of a management information system.

Many systems are currently developed based on a "single layer" approach, meaning that all domain-specific concepts are translated directly in the program code and database structure (Connolly, 2001). The medical field is constantly changing so the medical concepts are evolving too, that’s why the software products are up-to-date only at their creation time, thus being highly perishable. The solution comes from a dual approach (Fig. 2), where the semantics of information and the knowledge for a particular domain are modeled in different layers (Beale, 2002).

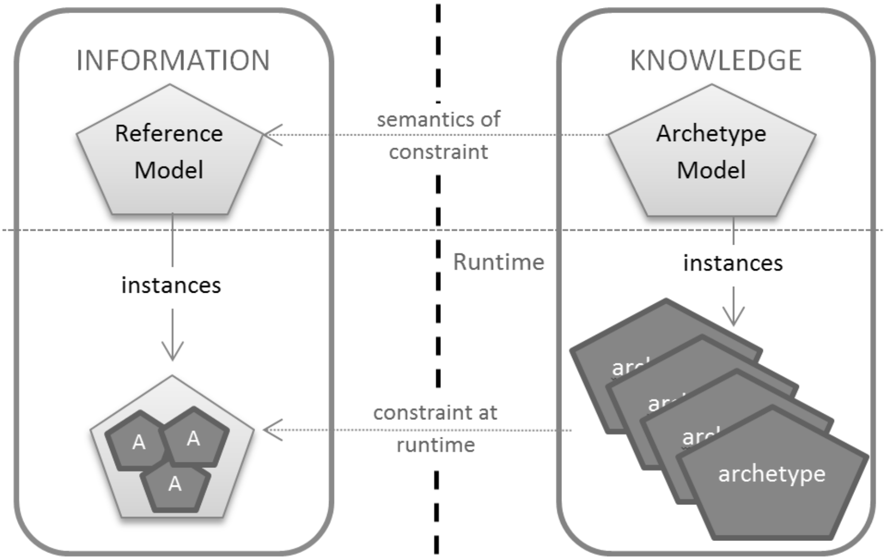

Fig. 2. Relation between Information model and Knowledge model

One layer, named “Reference Model”, is dedicated to information modeling through object-oriented programming formalism and database schemas. It contains only general concepts of the medical field, non-volatile, able to maintain its validity in time.

The second layer, named “Archetype Model”, is dedicated to knowledge, requiring its own formalism and structure. In this plan are modeled the numerous and often transient concepts from different medical specialties (Zeng, 2002).

At runtime, the EHR system checks the compliance of the input data with the constraints dictated by the stored archetype concepts. The computer system maps the input data to the reference model, which means that the stored data structure remains stable even if clinical concepts change over time.

This new paradigm has the origin on the concept models elaborated during the GEHR, Synapses and SynOM projects (Kalra, 2003), and later on the ENV 13606-1 informatics model, respectively openEHR Reference Model. It was adopted as European and ISO communication standard (EN 13606), being meant to ensures the interoperability of EHR systems.

The EN 13606 standard is intended for those situations where some or all information contained in the EHR is accessed or transferred following a request made by an external process. The standard must be implemented as an external interface of an EHR system, which can be expressed in the form of messages or interface objects.

EN 13606 – Part 1 (Reference Model) defines a set of classes that form the structural blocks of the EHR and several attributes associated with these classes. It is presented as a set of diagrams based on UML (Unified Medical Language), together with documentation explaining each construct and its associated cardinality, data types, constants, constraints and the relevant terminology for a particular context.

Each of the structural elements defined in the model must have specified:

- A unique identifier (patient identifier, object identifier),
- The clinical significance of the component,
- Access control - ensure access to the component, based on predefined user‘s roles.

EHR as a whole must contain as attributes the following identifiers:

- patient identifier,
- current record identifier,
- institution identifier.

Records of the medical information have always followed a hierarchical model. Clinical observations, reasons for encounter or medical letters may have a structure more or less complex, but are generally organized in structures with header. Typically, these documents are grouped into folders, a patient having one or more such folders in a medical institution.

An EHR extract (core class - the root of the Reference Model) must follow this hierarchical model, as also is required in other various regulations (particularly in ISO 18308), in order to ensure the preservation of original clinical context and the original meaning of data communicated between heterogeneous EHR systems.

The main builders of this model, arranged in a hierarchical structure and accepting inheritance and aggregation properties are: EHR_Extract, Record_Component, Content and Item.

Structural blocks described in the Reference Model are combined in various ways, depending on the type of organization or medical specialty, based on constraints defined in the associated Archetype. Otherwise stated, an archetype is the formal expression of a concept belonging to a specific domain, expressed as a constraint on the data, the data in this case being seen as instances of a particular Reference Model. Sometimes, the Archetypes are specializations of archetypes belonging to other specialties.

EN 13606 – Part 2 (Archetypes) describes a model for archetypes, needed for the archetypes representation in case of their exchange between or among various collections of archetypes or between services associated to archetypes. It does not impose a specific model for the archetype for a particular clinical area.

Currently, the most important and most systematized source of archetypes belong to OpenEHR Foundation where, besides the actual collection of archetypes, covering the majority of medical specialties, are also available tools for those interested in developing new archetypes and a specialized language for describing those archetypes (ADL - Archetype Description Language).

The "dual approach" model, promoted by EN 13606, is currently the starting point on the efforts to harmonize the EHR architecture, mainly targeting the compatibility with the Reference Information Model (RIM) and Medical Document Architecture (CDA) promoted by HL7. The adoption of EN 13606 as an ISO standard and the memorandum of understanding between CEN/TC251 and HL7 are important steps in an effort to develop a unified EHR architectures, universally recognized.

3.1.3 Terminology and Classification Systems

The "classical" or isolated EHR systems are often accepted input as a free, unstructured text. With the increasing need of information exchange, it becomes more obvious the necessity of using a common language for storage and transmitting the data. Standardized clinical terminologies, coding and classification systems are becoming key components for the development of modern interoperable EHR systems.

Some clarification should be made regarding the concepts related to "terminology".

Vocabularies are often called "Terminologies". A controlled vocabulary is a collection of terms describing some entities plus associated meaningless identifiers ("codes").

UMLS definition for biomedical vocabularies include: "thesauri, classifications, code sets, and lists of controlled terms used in patient care, health services billing, public health statistics, indexing and cataloging biomedical literature, and /or basic, clinical, and health services research".

ISO 1087 definition for Terminology: "Set of terms representing the system of concepts of a particular subject field".

Classification systems organize the entities from a terminology into classes, facilitating the capturing of data and their secondary use (e.g. reporting or analyzing the data).

Terminologies are not just a static repository of terms; some of them evolve by including knowledge about their entities, usually as definitions and relations with other terms (e.g. synonyms). When the knowledge aligns with a percepts of a philosophy that deals with the study of being, the terminology itself is called "ontology".

Ontology (from informatics point of view) was defined as "a logical model of the meanings of the entities about which information is to be expressed for use in computers" (Rector, 2008). Formal ontology are theories that attempt to give precise mathematical formulations of the properties and relations of certain entities (Stanford Encyclopedia of Philosophy), in accord to ontological principles like use of well-defined, unambiguous, and non-idiosyncratic types and relations.

A distinction should be also made between information model and terminology. While clinical information model determine and organize the kinds of entities from the medical domain which carry values in a record, the terminology model determine and organize the kinds of entities which are the values.

There is a large variety of terminologies and classification systems used in current EHR systems, most notable being: UMLS, SNOMED CT®, ICD-10, LOINC®, MeSH® and RxNorm.

UMLS - Unified Medical Language System - is a set of three tools, called the Knowledge Sources, which bring together many health and biomedical vocabularies and standards. The Metathesaurus is a collection of more than 1.5 million biomedical definitions and almost 3 million concept names, aggregated from 130 medical terminologies. Its declared purpose is to link health information, medical terms, drug names, and billing codes across different computer systems, enabling interoperability between those systems.

SNOMED-CT® - Systematized Nomenclature of Pathology-Clinical Terms - is a multilingual, clinical reference terminology, with more than 300000 unique concepts and more than 900000 descriptions. It was designed to index, store and retrieve information about diseases, clinical findings, etiologies, procedures, living organisms and outcomes. It contains concepts that belong to multiple taxonomic hierarchies which are related one with another by various semantic relationships (e.g. *isA*). What differentiating it from other terminologies is its size and complexity. The size of description logic form of SNOMED-CT without all the synonyms, mappings, subsets, etc. is of approximately 248MB.

The International Classification of Diseases and Related Health Problems, 10th revision (ICD-10), was developed by the World Health Organization with the initial goal to serve for reporting the mortality. ICD-10-CM is a US clinical modification of ICD-10 developed by the National Center for Health Statistics to replace the ICD-9-CM diagnostic coding system. It is a morbidity classification system that classifies diagnoses and other reasons for healthcare encounters. The ICD-10 code sets contain more than 155000 alphanumeric codes which group together similar diseases and procedures and organize related entities for easy retrieval. The new version ICD-11 is planned for 2015.

The terminologies and classifications are built for different purpose(s), following different designing principles. Focusing more on the financial issues, most of the current EHR systems include vocabularies and classification systems like ICD10 and ICPC, designated for reporting purpose. Considered "output" rather than "input" systems, they are inappropriate for the primary documentation of clinical care. Due to their lack of granularity, cannot be used as an interface or reference terminology. Being designed for epidemiologic statistics and a posteriori human encoding, these coding systems are more than insufficient to satisfy the clinical information systems requirements in term of functionalities and ergonomics (Bowman, 2005).

A proper diagnosis coding system must preserve forever, in coded form, the most detailed diagnostic information in the original medical record. Such "entity" codes can always be decoded to the exact diagnosis terms used, rather than retrieving the labels of a classification (Slee, 2005). The only terminology satisfying these needs is SNOMED-CT - a hybrid terminology / ontology with elements of classifications. That's why it is considered "input" systems, mainly serving to codify the data captured in an EHR system.

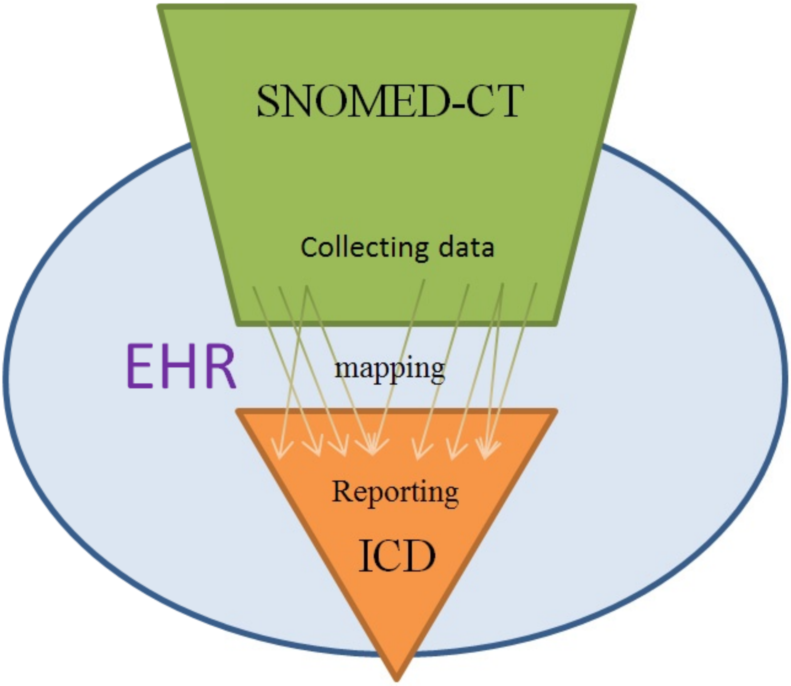

Fig. 3. Input/output dilemma

The "input/output" dilemma could be solved only by mapping a Clinical Terminology to a Classification (Fig. 3). After medical data is recorded using SNOMED-CT, related code(s) in ICD or ICPC should be identified by using the mapping tables. This way the duplication of the data capture could be avoided, and the secondary use of data such as reporting, billing, and statistical analysis are enabled (Stenzhorn, 2009).

4 Security and Privacy

During the long transition of medical data from paper to electronic format there were always debates about the advantages and barriers associated with this new approach, one of the main concerns being related to security, integrity and privacy of the recorded data. Even the problems are not specific to clinical information systems, the increasing accessibility to patient data, aggregation and exchange of a large amount of medical data between remote systems rice new challenges. Consider the case of a paper format, where a security breach could result in destroy or disclosure of one clinical file, a completely different scenario could be imagined in case of the electronic format, when entire medical history of one or more patients may be compromised by a single action.

The patient must be confident that his medical data is in a safe place and it will be used only by authorized medical personnel and only for the purpose for which they were recorded. Losing the patient's trust can seriously affect the quality of care, for example in situations when the patient might be tempted to hide or modify his recorded data.

Secondary use of medical data is likely to increase the healthcare efficiency through the impact on administrative measures or on clinical trials, a key element for this being the medical data de-identification. In other circumstances, the proper identification of the person is essential, for example in case of remotely acquisition of biological signals for diabetic or hypertensive patients monitored at their home. The exact identity of the medical personal, collecting or registering clinical data, as well as the context are also of great importance and must be properly documented.

The medical data ownership was also a subject of long controversy. Basically the patient should be the only one entitled to decide what happens with its own data, having the total liberty to view or to share them. The institution that collects and manages the patient's data should be responsible for their security so it should take all the necessary administrative and technical Safeguards to protect them.

Many types of measures have been implemented in order to guaranty security and confidentiality of medical data, some of them being generic, independent of the nature of records, other being common to any computer system and other, specific to EHR systems. Among them, a series of standards, specifications, reports and regulations designed to ensure the security and privacy in the medical domain (Eurorec, 2012), like:

- ISO 17090: "Public key infrastructure" and ETSI TS 101733: "Electronic Signature Formats" are standards related to infrastructure requirements.
- ASTM E1987-98: "Standard guide for individual rights regarding health information", CEN 13729: "Secure user identification - Strong authentication using microprocessor cards" and ISO/IEC PDTS "Pseudonymisation Practices for the Protection of Personal Health Information and Health Related Services" are related to privacy assurance
- CEN 13694: "CEN Report: Safety and security related software quality standards for healthcare" and ISO/DTS 25238 "Classification of Safety Risks" are standards regarding the safety of the medical records.

- RIDE, "A Roadmap for Interoperability of eHealth Systems in Support of COM 356 with Special Emphasis on Semantic Interoperability", a research project founded by European Commission, addresses the security and privacy issues from the perspective of systems interoperability. The main solutions identified were presented in the final report:

- Access rights to the patient data should be provided only to someone with documented need to know that data.

- Document authenticity should be proved, with the support of digital signature mechanism.
- Peer authentication and encrypted transmission over the network using secure protocols are essential.
- Cryptographic timestamps should be register for any medical or administrative document.
- Audit trail should monitor the editing and access of recorded data.
- Special conditions for emergency access to a core set of data should be established.
- Patient consent for different use scenarios should be properly managed.

• EuroRec Institute addresses the security issues from the perspective of quality assurance. Quality labeling and certification of the EHR systems is seen as a transitional solution in obtaining the interoperability of healthcare systems. It was meant to fill the gap due to the lack of universally accepted architecture standards and still missing of a common medical language. Some of the quality criteria, elaborated during the QREC project, are related to the security and privacy aspects, among them:

- Each health item (and all its versions) should be: uniquely identified, associated with an identified patient and duly time stamped.
- EHR access is only allowed after the user has authenticated himself, by using at least an account (login) and password verification.
- User is able to assign a degree of confidentiality to each version of a health item.
- The system assigns a default level of access to each version of a health item.
- The system allows to audit security related functions and enables audit of security related events.
- Specified de-identified data can be extracted for clinical research.
- There are sufficient system and/or process controls for backup and recovery procedures.
- The system has the ability to create, maintain and apply the roles, and based on that to allow differentiated access permissions.
- Specific measures should be implemented to prevent or mitigate effects of viruses, worms, or other harmful software code.
- Disaster Recovery Procedures should be setup.

• The regulations in many countries already covered most of the measures described above, but in order those to become truly effective, it is crucial that every provider undertake all measures in its power to prevent the data alteration or loss. We finally should not forget that the patient is the only one entitled to decide what happening with its data.

5 Emerging Technologies

High expectations were placed on the effectiveness of EHR systems for healthcare delivery improvement, but the computerization of any clinical process will not be accepted by users unless it optimize that clinical process.

The mechanisms capable to optimize the clinical processes are: tasks automation, specialization in the execution of various types of tasks, automated communication and decisional support. These mechanisms must be apprehended on two axes: the functionality and the ergonomics which are both necessary so that the data-processing tools are acceptable for the user. This supposes an effort of "software engineering" and "knowledge engineering" not often seen by now.

Combining the power of role-based distributed workflow management architecture within a knowledge management platform is the only possible way for obtaining context-related semantically annotated data. The system should allow adaptation of clinical activities for each patient by supporting the combination of predefined processes with ad hoc workflows and flexible management of exceptions.

This activity of innovation and experimentation is not possible without EHR systems of a new generation – defined as Clinical Process Management (CPM) System (Fig. 4).

The conceptual basis for CPM was largely explored and prepared through the clinical guidelines computerization research. Guidelines allow us to specify what should be recorded, when to record it, how to evaluate/make decisions, and what need to be done.

The initial concerns, regarding the efficiency of computerized clinical guidelines, were letting behind once becoming obvious that the medical knowledge is developing much faster than a human can assimilate them. The real challenge of medicine nowadays is to apply what it is already known, and here we can see the real benefit of a knowledgebase clinical information system, integrating Quality Alerts, Safety Alerts, Reminders, Guideline-based Disease Managements Plans, Drugs knowledgebase and Terminologies knowledgebase.

The main problem encountered while integrating clinical guidelines management systems with legacy systems have always been related to syntactic alignments – defining a shared terminology as well as communication protocols - and to the lack of shared semantic between the models underlying different heterogeneous systems. This could be resolved only by developing a single comprehensive semantic meta-model (Unified Semantic Model), able to create semantic data structures for:

- Decoupling meaning from coding and presentation
- Generate post-coordinated concepts through formal logical expressions
- Semantic User Interface Engine
- Natural Language Generation for the EHR notes.

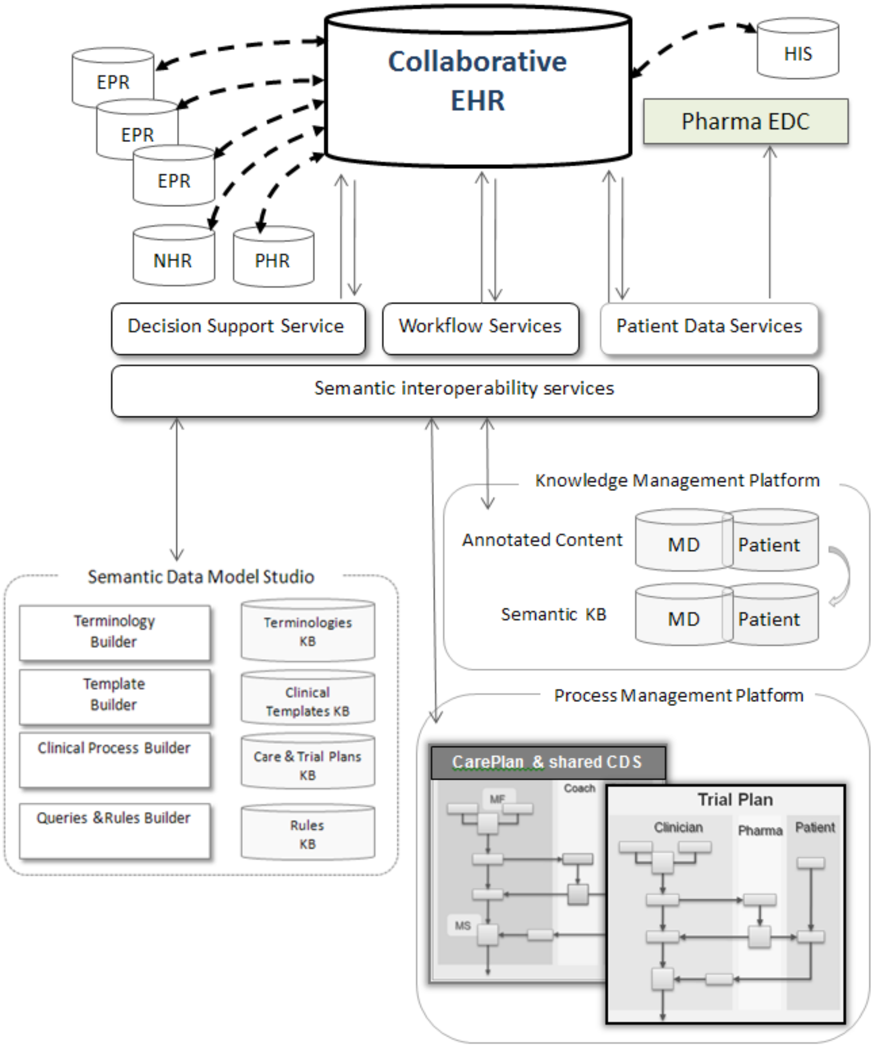

Fig. 4. Integrated EHR systems

6 Conclusion

To fulfill all the expected benefits and actually to contribute to the improvement of the healthcare quality and efficiency, a modern EHR system should combine the following three aspects:

- Coded patient data, managed through a distributed EHR System,
- Medical decision support, through a Guideline Management System,
- Organizational support, through a Workflow Management System.

The development and maintenance efforts should be concentrated more on the medical knowledge base engineering and less on the actual interface like Electronic Patient Record (EPR), Personal Health Record (PHR) or Nursing Health Record (NHR). Mainly it is about development and maintenance of a terminology server, the templates for data collection and data access, adapted to each type of user, to defining the clinical activities and processes and also the set of rules governing the decision supporting systems.

With this kind of architecture, it is feasible to achieve semantic interoperability between EHR / PHR and other systems such as Hospital Information System (HIS) or systems dedicated to clinical trials, through a natural integration of medical data flows and other data flows, such those intended for research or health population surveillance.

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Acquisition and Analysis of Biomedical Signals in Case of Peoples Exposed to Electromagnetic Fields

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Abstract. In this paper we present studies on biological and health effects of electromagnetic fields emphasising the aspects related with measurement of the aggressing electromagnetic fields. A brief review of literature on electromagnetic environment is presented, together with some methods aiming to control and eliminate the electromagnetic interferences on medical instrumentation used in the acquisition of the biological signals (electroencephalography - EEG, electrocardiography - ECG). We performed analysis of electromagnetic fields in order to determine the induced current/field and the specific absorption rate in models of human body and also to correlate the exposure fields with some alterations of the biological signals acquired from a subject laid in various electromagnetic environments. The main goal of this research is to design a method for accurate identification and characterization of the aggressing electromagnetic fields on biological signals and human health.

Keywords: electromagnetic field, specific absorbtion rate, human body.

1 Introduction

The interaction between external electromagnetic (EM) fields and biosystems is known from long time ago and it can have beneficial or harmful effects [1,2,3]. For instance, the electromagnetic fields are used in therapy (hyperthermia treatments, fracture healing), in diagnosis (medical imaging based on magnetic resonance tomography), in biotechnology for the transfer of genetic material between different cells, etc. However, there are epidemiological studies that link EM with etiology of various type of cancer.

There are many concerns related with identification of biological and health effects in the case of people exposed to electromagnetic fields [4,5,6], in order to better characterize potential harmful effects of electromagnetic fields. In this respect, one of the most important challenges is to identify some possible modifications of biological signals in the case of persons who live in different

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electromagnetic environments [7,8,9], mainly on environments where the strength of the electric or magnetic field is relatively high.

For a proper acquisition and analysis of some biologic signals in these specific conditions, it is advisable to act in two directions:

- to eliminate (or at least to reduce) electromagnetic interferences due to external electromagnetic fields of high strength, in the case of acquisition of biological signals, namely the control and exclusion of the field effects on the measurement instrumentation;
- to identify any possible modifications of the signals acquired from exposed persons, due only to the biologic effects of the electromagnetic field.

In this chapter, we present the method to study the effect of electromagnetic field on biologic structure, especially on human being. This approach of identification the biological effects of electromagnetic fields is complex, being based not only on the characterization and control of the electromagnetic environment, but also on the processing and analysis of acquired biological signals.

2 Motivation

The impressive nowadays trend in the development of telecommunications and information technology rises tremendous challenges for the medical environment. On the one side is compulsory to reduce the EM interferences that disturb the processing of the very low level bioelectrical signals. On the other side, the study of the biological effects of the electromagnetic fields becomes mandatory, due to the continuous increasing of their presence in our ambient. In our work, we applied a united approach both to the electromagnetic surveillance and for acquiring biological signals in order to characterize the EM biological effects.

Our interest was focussed on two main (connected) objectives:

- to determine the induced currents and fields in the living organisms by the exterior fields, including the possibility of comparison with natural, biological currents and fields;
- to determine the alterations of various biological signals (ECG, EEG) for the subjects acting in different electromagnetic environments.

Both previously assumed targets are very difficult (e.g. there are various challenges related with separation of the electromagnetic interferences of the exterior EM fields on the medical instrumentation from the influence on the biological structures and functions), but they could have applications in the characterization of some biological or artificial sources of field, based upon their “electromagnetic signature” and in the practice of controlled stimulations in electrotherapy. At large, these researches are devoted to the interaction between (human) beings and electromagnetic field.

3 The Electromagnetic Environment

Besides the natural electromagnetic fields, there are also artificial or man-made electromagnetic fields, created both by intentional emitters - which is used in communications, in treatments of materials or cells (e.g. electrotherapy), and by unintentional ones - every electric or electronic device which has variable current, I, or voltage, U, is a source that produces electromagnetic fields. We generally define the so called „electromagnetic environment" as the integrality of the electric and magnetic fields encountered in the considered area. The wholeness of these „restraints", (also taking into consideration the thermic and mechanic enforcements) represents the environmental factors, influencing all the systems.

In Figure 1 is presented an aggregate overview of a predictable electromagnetic environment, dealing with both natural produced fields (e.g. the biological fields that are useful for medical explorations) and man-made or artificial fields (potentially harmful for human health or for electronic equipments).

The electromagnetic environment is a very dynamic science. Permanently are identified new natural field-sources concurrently with new man-made fields. There are mainly two directions of researches that are entrenched and imposed by evidences:

- the study of the natural fields, produced by living organisms, which may potentiate more information on the functioning of these living systems;
- the study of the protection of both biological systems and technical systems against the artificial electromagnetic stress, taking into consideration the daily increasing diversity of the sources and frequency spectrum.

The challenges in the study of the natural fields are related with their extremely low amplitude and difficulty of genuine extraction from the general electromagnetic background and their adequate processing but this investigation is important in order to characterise the functioning of a specific organ and to correctly establish its "electromagnetic signature". As some modern instrumentation for this domain are magnetoencephalography - MEG (a technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain), the magnetocardiography - MCG (the registration and processing of the detectable magnetic fields associated with cardiac electrical activity) or the thermography (mapping the human body from thermal point of view, by detecting the radiated EM fields, in the infrared or microwave spectrum).

In the study of the protection of both biological systems and technical systems against the artificial electromagnetic stress we have to consider both electromagnetic compatibility (the coexistence without harmful interferences between all the electric equipments normally encountered in the area) and biological compatibility (extremely delicate problems focused on the fields influence on the living organisms, mainly on the human health).

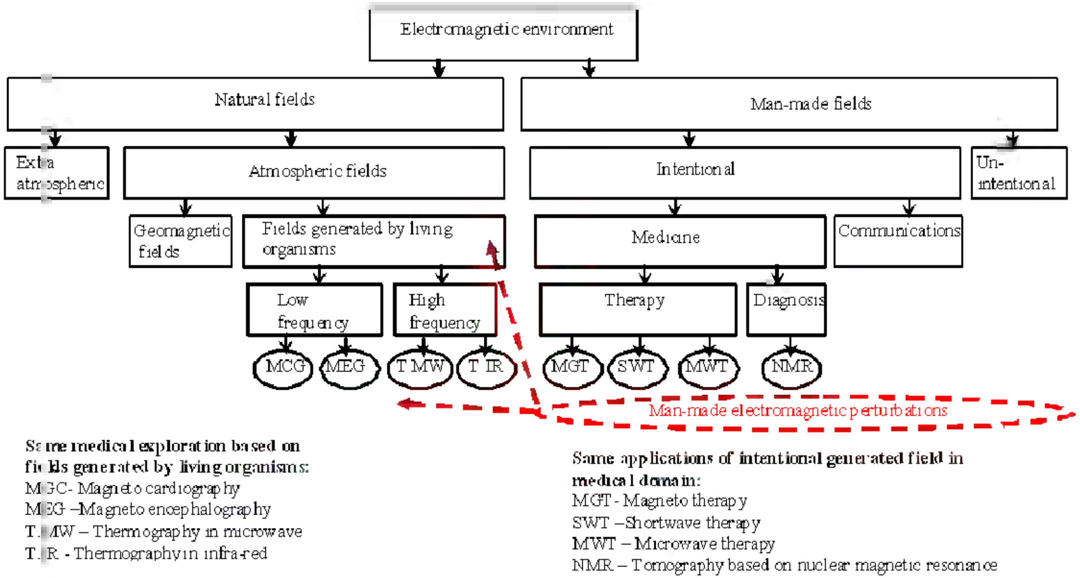


Fig. 1. Electromagnetic Environment

As is well known the electromagnetic waves are very useful both in medical practice – many treatment or exploration methods are fundamentally based on these fields as well as for wireless networks. Some examples of the use of various types of electromagnetic waves in physiotherapy [10, 11] are:

- magneto-therapy using magnetic fields with frequencies, f, under 100 Hz and amplitude of magnetic flux density of hundreds μT (B = 10 ÷ 1000 μT);
- short-wave diathermy with a frequency of 27 MHz and amplitudes of electric field of hundreds of V/m (E = 10 ÷ 2000 V/m);
- microwave electrotherapy with a frequency of 2450 MHz and amplitudes of about a hundred of V/m (E= 10 ÷ 300 V/m).

These are not at all opposite to the general requirement of controlling and even reducing the level of electromagnetic fields in the environment, in order to decrease the electromagnetic interferences and biological and health effects.

The levels of some usually encountered electric and magnetic fields is presented in Table 1.

Table 1. Some field sources with their typical levels

Field source or considered areas	**Field type**	**Electric field - E, and magnetic flux density - B, approximately levels**
Geomagnetic field	Permanent DC magnetic field	B=50 ÷ 70 μT; B_{max} =200 ÷ 500 μT (low uniformity-iron deposits)
	Alternative magnetic field	$B=10^{-3}$ μT; B_{max}= 0.5 μT (magnetic storms), for f< 1 Hz B=10 pT, for f >10 Hz
Atmospheric and lightning discharges	DC field	E=100 V/m at earth level (soil); E=30 V/m at 1 km height
	Broadband electromagnetic pulse	E_{peak}=10 kV/m at less than 100 m; E_{peak}=1÷20 V/m at hundreds-tens km B=1 nT ÷ 500 nT (Hz ÷ hundreds kHz)
Electrostatic discharge	Broadband electromagnetic pulse	E=100 ÷ 140 dBμV/m/MHz (at about 1 m distance)
Near power lines (HV)	Alternative (50/60 Hz and harmonics)	Under the line: B=11 μT (I = 1 kA); E=4 ÷ 16 kV/m (U = 110 ÷750 kV) At 40 m distance: B=2,5 μT (I = 1 kA); E=0,5 ÷ 2 kV/m (U = 110 ÷750 kV) B_{max}=30 ÷ 100 μT
Near power lines (distribution)	Alternative	Under the line: B=0,1 ÷ 2,2 μT (I = 280 A); E=10 ÷ 100 V/m At 40 m distance: B=0,5 μT (280 A); E=1 ÷ 10 V/m

Table 1. (*continued*)

Telecommunications/Broadcasting	Frequencies in 0.3÷3000 MHz	E= 1 V/m÷1000 V/m (near emitters, at distances of cm to hundreds of meters)
Residences, hospitals and offices	Background fields	E_{max}=25 V/m (50 Hz and harmonics); E_{max}=3 V/m (kHz ÷ hundreds kHz); E= 1 mV/m÷100 mV/m (0.3÷3000 MHz) B= 50÷600 nT (50 Hz and harmonics); B= 1÷50 nT(kHz ÷ hundreds kHz)
Some appliances	(50/60 Hz and harmonics)	B=1÷100 µT (distances of cm to meters) E=1÷ 500 V/m
RMN Tomography	Permanent Magnetic Field	B=0,15 ÷ 2 T
	Alternative	B=5 µT (1 ÷ 50 MHz)
Electrotherapy	Low frequency shortwave and microwave fields	E=1 V/m÷1000 V/m, at f=27,12; E=50 V/m÷200 V/m, at f=2450 MHz (distances of cm to meters) B=1 ÷ 700 µT, at f=10÷100 Hz (distances of cm to meters)

In addition, we have to consider the permanent fields generated by the radio - TV broadcasting, without neglecting the transients associated with an electrostatic discharge, involving important time and space changes in the electromagnetic ambient. Obviously, the effects of these fields depend on the distance from the source, and their amplitude and spectrum (narrow or broadband). A general characterization of the environment or of a specific field source could be performed both in frequency or time domain.

4 The Control and Elimination of Fields Effects on the Measurement Instrumentation

In hospital environment, there are both external sources of electromagnetic disturbances (mainly radio - TV transmitters) and internal ones (the general power supply, the electrotherapy and electro-surgery equipment), some of them acting in the near field area, other in the far field.

In figure 2 are shown the two types of coupling between the source (perturbations emitter) and the "victim" (the occasional receiver):

- Coupling through field or *radiation coupling* (electric, represented by a capacitor - C, or magnetic, represented as a mutual inductance - M, or electromagnetic radiation - plane wave).
- Coupling through impedance or *conduction coupling* (dominantly galvanic, capacitive or inductive).

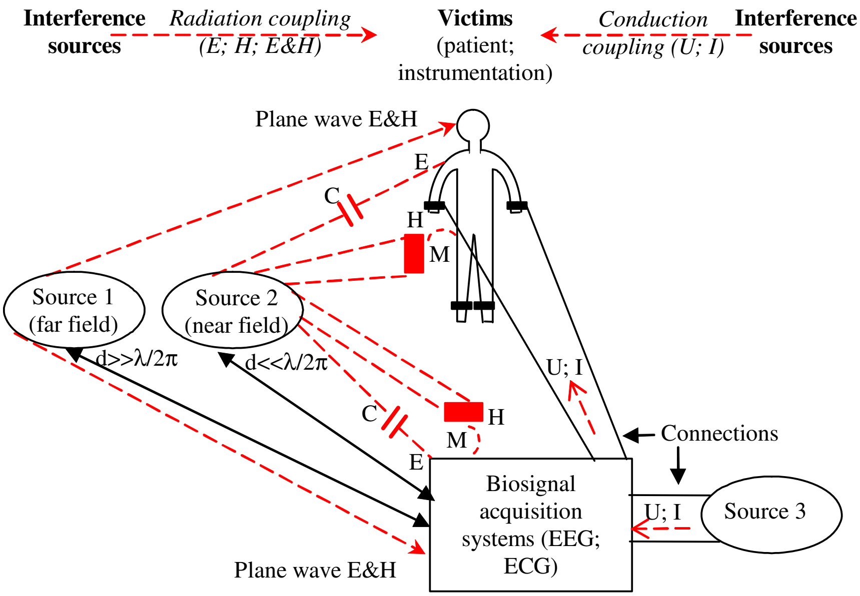


Fig. 2. Electromagnetic interferences to patient and instrumentation

Obviously, the most overspread network is the power supply system (220-230V, 50/60 Hz) and consequently, the associated disturbing fields are significant due to the high currents and voltages involved. The frequency of the power line being in the domain of interest for electrophysiology (e.g. acquiring the ECG - electrocardiography or EEG - electroencephalography signals) is an important reason to carefully think on their influence [12,13].

In Figure 3 we present the most used configuration for acquiring biological signals with three electrodes (electrode 1 on the left hand, electrode 2 on the right hand and the reference-electrode number 3 on the right leg). In the figure are highlighted the disturbing couplings through electric field (capacitive coupling) from the power line to the three main "vulnerabilities": the patient, the connecting path and the amplification module of the measuring device [14]. Also, the interaction of magnetic field, H, generated by power line current, I, in the loop formed by patient electrode 1- wire 1- amplifier, PA – wire 2- patient electrode 2, is represented. This magnetic coupling, which may be reduced by decreasing the loop area, isn't considered in following.

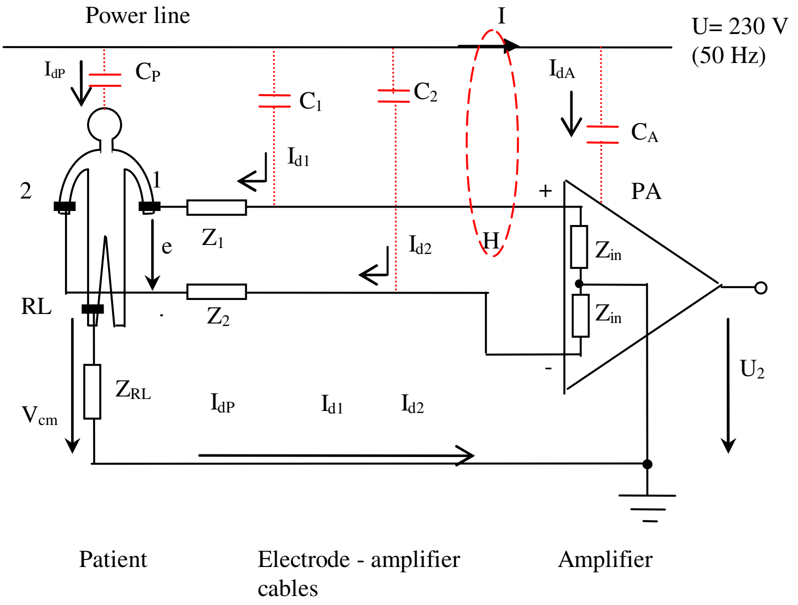


Fig. 3. Power line interference in case of bio-signal acquisition

The acquisition of the bio-electric signals, *e*, (e.g. ECG ou EEG) is accomplished by the active electrodes 1 and 2, connected through the impedance Z_1 and respectively Z_2 and the connecting cable from the electrodes to the input of the differential amplifier. The electrode from the right leg (RL) is connected through the impedance Z_{RL} at the common inlet of the amplifier. Each of the impedances Z_1, Z_2, Z_{RL} contains a resistance for connecting the respective electrode to the amplifier (normally, having the same value) and the impedance of the interface skin-electrode. Here, there are differences from one interface to another, but it is essential to have a quite low level and to be constant with the time passing by.

Due to the high differences in electric potential between the power line and the patient himself, an electric coupling field is developed. In the Figure 3 we have illustrated the network model of this electric field (capacitive) coupling: at patient level through the capacitance C_P and the displacement current I_{dP}, at the level of connecting cable 1 through C_1 şi I_{d1}, at the level of connecting cable 2 through C_2 şi I_{d2} and at the level of the amplifier, through C_A and I_{dA}.

Obviously, all these three impedances (Z_1, Z_2, Z_{RL}) are much lower than the input differential impedance of the amplifier(Z_{in}). The currents I_{dP}, I_{d1}, I_{d2} will go through the patient to the (protection) common, producing a common mode disturbing voltage (we can estimate that its value is the same all over the body).

$$V_{cm} = Z_{RL} \cdot (I_{dP} + I_{d1} + I_{d2}) \qquad (1)$$

If we calculate the voltage at the output of the amplifier U_2, successively considering the effect of the useful voltage e, that appears as a differential mode voltage and the disturbing voltage that acts as a common mode voltage, we obtain:

$$U_2 = A_d \frac{2Z_{in}}{2Z_{in} + Z_1 + Z_2} \cdot e + A_d \cdot V_{cm} \left(\frac{Z_1 - Z_2}{Z_1 + Z_2 + Z_{in} + \frac{Z_1 Z_2}{Z_{in}}} + \frac{1}{CMRR} \right) \qquad (2)$$

A_d is the differential gain of the amplifier and CMRR is its common mode rejection ratio.

The first term is due to the useful signal "*e*" and is affected by the loading effect produced by the acquiring circuit electrodes-cable-amplifier. The decrease of the loading error is accomplished when $2 \cdot Z_{in} >> Z_1$ and $2 \cdot Z_{in} >> Z_2$.

The second term, disturbing in the mass, is due to the finite common mode rejection of the acquisition system and derives from the common mode voltage of the patient body (electromagnetic interferences).

Considering the relation (2), we conclude that there are two main recommendable actions in order to reduce the disturbing effects:

- The acquisition system must be symmetric, meaning that the interfaces electrode-body and the connexions to the amplifier should be identical for both active electrodes ($Z_1 = Z_2$ determines the annulling of the first term inside the brackets).
- The amplifier must have a very high CMRR (instrumentation amplifier), strongly decreasing the second term inside the brackets).

In Figure 4 we are focussed on the main methods for decreasing the disturbances induced by the power line. Firstly, the connections between the electrodes and the electrocardiograph should be double shielded. Secondly, in order to reduce the common mode voltage on the patient, we can establish a feedback, by controlling his right leg ("right leg drive" by the output of the amplifier A_2). The same principle could be implemented for EEG, by connecting this type of feedback not at the right leg, but at the lap of the ear.

We protect the connection cable by screening, with the shield connected to the ground, and consequently, the displacement currents I_{d1} and I_{d2} are branched to the ground (Fig.3) as in case of the amplifier, PA, also protected by a shield.

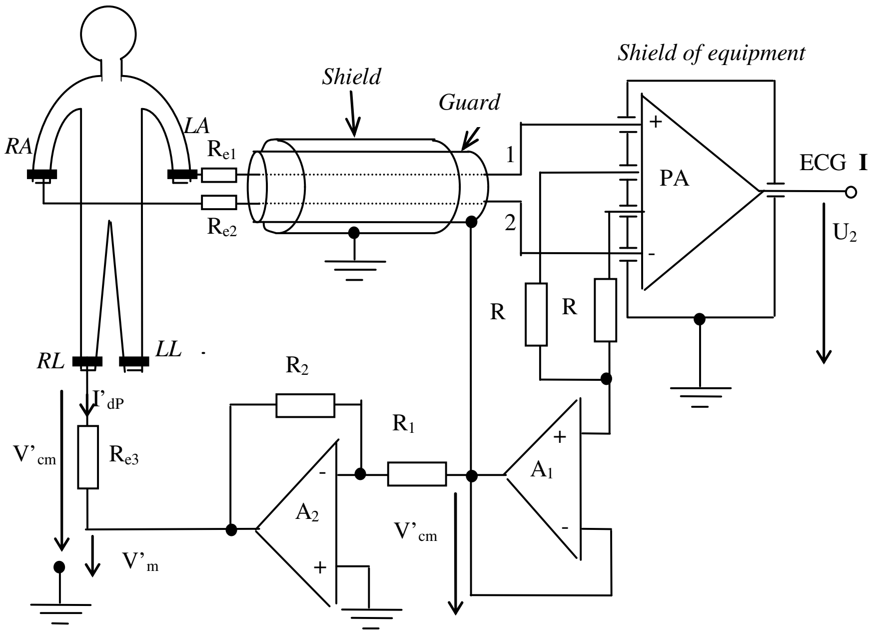


Fig. 4. Power line interference reduction

In addition to the usual shield, it is advisable to use another interior shield, called guard, driven by a simple electronic circuit at the common mode voltage on the patient body, V'_{cm}, namely, at the same potential with the wires 1 and 2 (the bioelectric signal "*e*" appears as differential voltage that must be amplified and is much lower than the common mode disturbing voltage V'_{cm}). Without this "guard", the capacitance that would appear between the two connection wires and the shield could unbalance the input circuit, involving a higher effect of the common mode disturbances.

The pre-amplifier PA is of "instrumentation" type, imposing a high reduction of the influence of the common mode voltages, due to its symmetry. The solution presented in Fig.4 allows a decrease of the common voltage on the patient owing to the feedback "processing system-patient", established through the two resistances R, the buffer A_1, the resistance R_1, the inverting amplifier A_2, the resistance R_2 and the resistance R_{e3}. Consequently, the output voltage V'_m of the inverting amplifier A_2 has the value:

$$V_m^{'} = -\frac{R_2}{R_1} V_{cm}^{'} \tag{3}$$

and the displacement current through the patient I'$_{dP}$ is:

$$I_{dP}^{'} = \frac{V_{cm}^{'} - V_{m}^{'}}{R_{e3}} = \frac{\left(1 + \frac{R_2}{R_1}\right) V_{cm}^{'}}{R_{e3}} \tag{4}$$

Without the improvement supplied by this feedback (the reference electrode from the right leg being connected directly to the common through R$_{e3}$ as it is shown in Fig.3), the common voltage on the patient would had been V$_{cm}$ and the displacement current through the patient I$_{dP}$ may be:

$$I_{dP} = \frac{V_{cm}}{R_{e3}} \tag{5}$$

If we consider that the patient doesn't change his position regarding the source, and his impedance versus the common doesn't significantly change, the displacement currents in these two situations (with or without feedback) will be coequal. Considering this equality we have:

$$V_{cm}^{'} = \frac{V_{cm}}{1 + \frac{R_2}{R_1}} \tag{6}$$

Consequently, by using this feedback, the common voltage on the patient $V^{'}_{cm}$ is reduced in regard to V$_{cm}$ (the situation when the right leg is directly connected to the reference, Fig.3).

We can conclude that, if we want to correctly process the information contained in the low biological signals, it is compulsory to assume special precautions when we design, fix and operate with medical equipment, aiming to reduce the electromagnetic interferences. The most common and affordable items to be treated are:

- the mutual mechanical position and placement of different "actors" of the electromagnetic environment;
- shielding and guarding;
- connections to ground;
- symmetry of the picking-up circuits;
- reduction of the disturbances at the source.

Complementary with the classical methods to improve the electromagnetic compatibility, (that we must apply at any possible level: circuit, board, equipment or even the global structure - e.g. the hospital), various procedures for extracting the useful signal from the noise (amplification, frequency separation, adaptive filtering, average techniques, correlation or inter-correlation techniques) have to be used.

5 Biological and Health Effects of Electromagnetic Fields

The normal sequence for investigating the possible effects of exposing the living organisms to electromagnetic fields imposes the following steps:

- the accurate determination of the incident electric and magnetic fields $E^{inc}$and H^{inc} that aggress the living organisms;
- the determination of the induced electric and magnetic fields, power deposition, energy absorption and the Specific Absorption Rate (SAR);
- the determination of the effects of the induced electric field and of the current density on the biological processes at cell, tissue or whole organism level.

5.1 Determination of Exposure Fields

If we want to determine the electric and magnetic fields disturbing the living organisms, there are two possible approaches:

- the patient under test should carry with him a displaceable measurement device, that registers and records the levels of exposure for one or more days [15];
- performs field area trusted measurements, in various points and time intervals.

A displaceable measurement device could be uncomfortable for the person which is caring it and the limits imposed by weight, volume and price allow only the recording of root mean square (rms) values of the field for 24 hours and the comparison with those accepted by standards.

Although more laborious, the overall measurement of the fields, in various zones or ambient guarantees a better characterization and identification of the sources, also suggesting possibilities for field minimization. It is necessary for that, to consider a large variety of ambient, mainly the professional ones, without neglecting residential or even public areas. The survey of the electromagnetic environment require "in situ" measurements and represents an important part of the electromagnetic and biological compatibility.

We performed measurements on electric and magnetic fields, so providing a survey of the electromagnetic environment in several specific areas:

- close to high-voltage lines or electrical stations (transformer plant);
- in residential areas (in dwellings and laboratories);
- near radio and television transmitters;
- in hospitals.

The results of our measurements has evinced: a great variability of the fields; a great dispersion of the field levels (even in the same place of the same laboratory the field varies a lot both spatially and temporally); the necessity to perform a greater number of measurements which should be processed statistically.

Referring to instrumentation to be used in survey, our research has been directed towards the extension of the field sensor frequency range, time domain measurements, simultaneous electric and magnetic field measurements and isotropic measurements.

In our measurements or survey of electromagnetic environment we tried to be in accordance with the tendencies in the determination of the biological field effects on living organisms, namely:

- the interaction between the weak fields and the biological systems or the long time exposure of humans at low-level fields, involving a higher importance of the accurate evaluation of the electromagnetic environment;
- the biological effects of the electromagnetic transients, also considering the ICNIRP recommendations regarding the human exposure [16].

The consideration of the *long-term electromagnetic field exposure* is very important, especially because the guidelines related with level of EM exposure are based only on *short-term exposure* (immediate health effects) [17]. Taking this into account, we made a one year period survey of the 50 Hz background magnetic fields (magnetic flux density, B) in some dwellings and laboratories [10]. By performing a great number of measurements and a statistical processing of the results we determined the temporal variation of the magnetic field (per day, per week, per month, and in all the year) in these considered residential places.

In Fig.5 are represented the mean values of magnetic flux density - B, with corresponding standard deviation for every day of the week (e.g. mean values for all data per day in the period March 2004 – February 2005) in a laboratory.

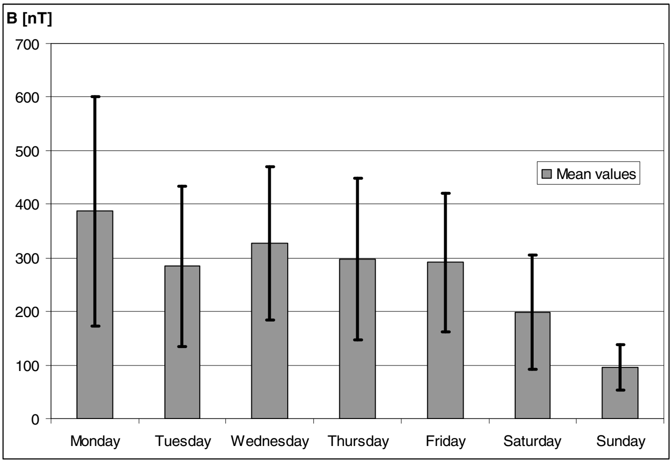


Fig. 5. The mean values of B with plus/minus standard deviation per days of the week for the period March 2004 - February 2005 in a laboratory

The mean values of the magnetic flux density - B, with corresponding plus/minus standard deviation for each month from March 2004 to April 2005 in the surveyed laboratory are shown in Fig. 6.

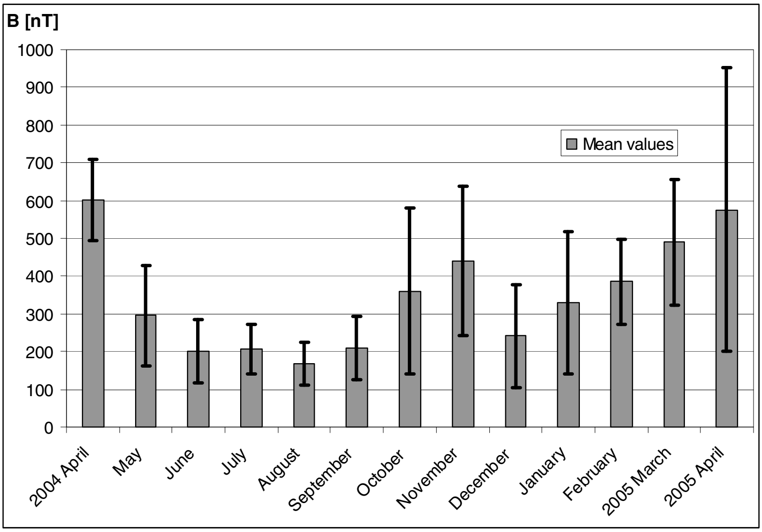


Fig. 6. The mean values of B with standard deviation per months of the year for the period March 2004 - April 2005 in a laboratory

Our results suggests that a great temporal variability of the magnetic field levels may exists in one and the same place, and a great dispersion of the field level in the case of the same type places.

We have also performed measurements of background electromagnetic fields in hospitals, laboratories and dwellings considering 100 kHz ÷ 3 GHz frequency range, namely fields generated by Radio/TV broadcastings and mobile communications/wireless.

In order to characterise low frequency magnetic fields, we designed and implemented a tri-axis magnetic field measurement system [18]. This measurement system, shown in Fig.7, is able to make automate measurements of the magnetic fields and to determine the background magnetic field from residential areas (dwellings and laboratories) or to determine fields generated at different distances by the electrical appliances.

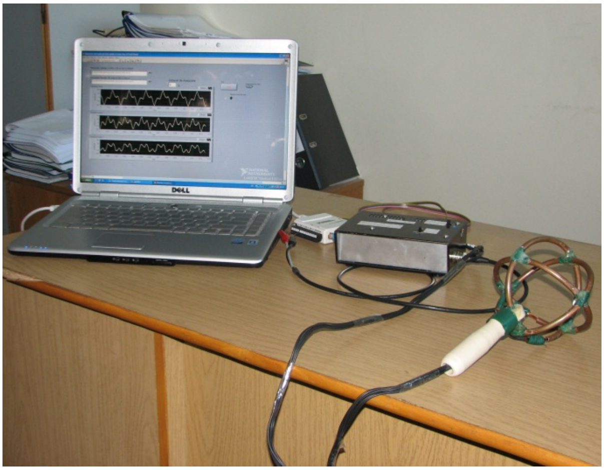


Fig. 7. The proposed tri-axial magnetic field measurement system

Using the proposed measurement system, we have characterised the background low frequency magnetic field due to power line supply. We performed time domain measurements of the three perpendicular magnetic field components, as are shown in Fig. 8.

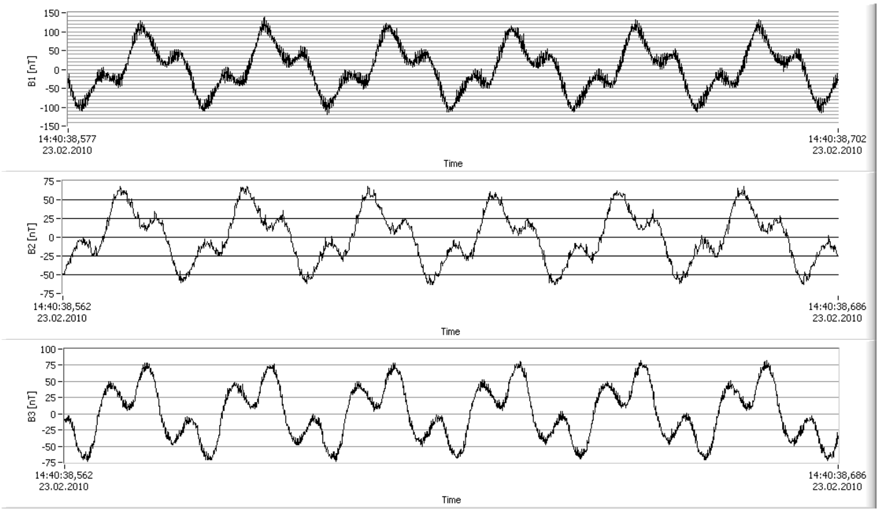


Fig. 8. Time domain representations of the three components of magnetic field vector

In Fig. 9 is shown the frequency domain representation of the three components of the field obtained from the previously stored time domain recordings.

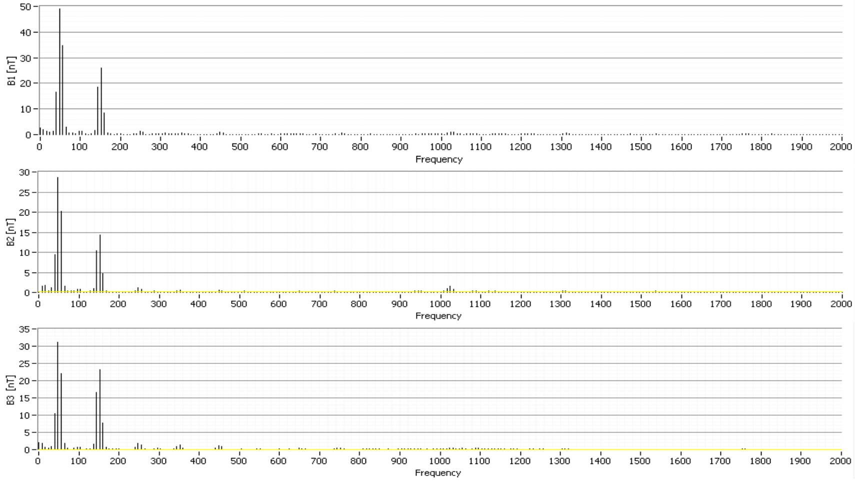


Fig. 9. Frequency domain representations of the three components of the magnetic field vector

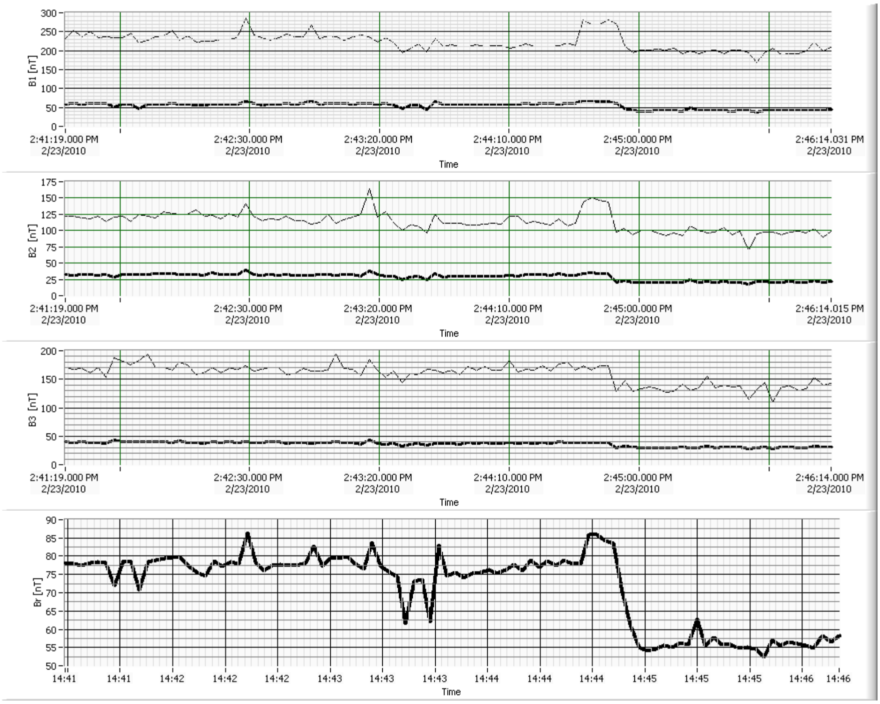


Fig. 10. The r.m.s. values (thick line) and peak to peak values (thin line) of field components and the r.m.s. values of the resultant magnetic field vector for about five minutes survey

Beside the spot measurement of the magnetic fields, it is possible to make long term survey of the magnetic field by storing the time domain representations of the field components and recording the root mean values (r.m.s.) and peak to peak values of the of the components B_1, B_2, B_3 and r.m.s. values of the resultant field vector, B_r .

In Fig.10 are shown the r.m.s. values and peak to peak values of the field components and the r.m.s. values of the resultant magnetic field vector for five minutes survey of the background magnetic fields in an office. A statistical processing of the results for the time period of automate electromagnetic survey is shown in Table 2, (maximum value, the minimum value, the mean value of the resultant magnetic field vector expressed as r.m.s. values, the standard deviation for 94 measurements and the duration from all the survey time when the r.m.s. values of B_r exceed their mean value).

Table 2. Statistical processing of the r.m.s. values for about five minutes survey of B_r.

Survey period	No. of values	Maximum value of B_r [nT]	Minimum value of B_r [nT]	Mean value of B_r [nT]	Standard deviation [nT]	Time when B_r is over mean [%]
14:41–14:46	94	86.38	52.48	71.53	10.28	68.08

The proposed measurement system is adequate to make spot measurement and automatically long term survey and allow a good characterisation of the low frequency magnetic fields, with a view to estimate the human exposure and to identify the magnetic sources based on “electromagnetic signature”.

5.2 Determination of Induced Currents/Fields and SAR

The tissues are materials with good electrical conductivity, about $\sigma \cong 0.5$ S/m, but non-magnetic (with permeability comparable with that of the air - μ_0).

For determination of the exterior electromagnetic fields E^{inc} and H^{inc}, complementary with measuring the induced electric field and currents, we must consider the relationship connecting the wavelength λ, the dimensions of the field generator (the source), the dimensions of the body absorbing the radiation (the receiver) and the distance between the source and the receiver. All these, together with the material constants of the tissues justify the assuming of some approximations.

In order to determine the induced electric field and the induced currents in the organism by the incident exterior fields H^{inc} and E^{inc}, we have to consider the Maxwell’s laws, the limit conditions and the material laws.

For solving these equations and determining the electric field, E, and the current density, J, we use both analytic and computational methods.

The *analytical methods* are well known in the antenna domain and they are workable at regular shapes: sphere, cylinder, ellipsoid.

The more often applied computational method for the determination of the currents and of the induced fields in the body are the finite-difference time domain method, FDTD; finite elements method, FE; finite integration technique, FIT [19,20].

5.2.1 Analytical Methods

The analytical determination of the induced currents and fields in the body is performed in frequency domains.

Following we present a few estimations of the induced currents and fields, by a low frequency incident electric field E^{inc} and an incident magnetic one, B^{inc}.

a) The electric field and the current induced by an incident magnetic field, B^{inc}.

In low frequency domain, in the conditions of neglecting the magnetic field due to the induced currents in comparison with the incident one, we can start from the integral form of Maxwell equation:

$$\oint_{l} \mathbf{E} \cdot d\mathbf{l} = -\int_{a} \frac{\partial \mathbf{B}^{inc}}{\partial t} \cdot d\mathbf{a} \tag{7}$$

If we consider in the organism a circular boundary with radius r and constant B^{inc}, from the equation (7) we obtain:

$$2\pi r E = \pi r^{2} \frac{\partial B^{inc}}{\partial t} \tag{8}$$

Consequently, the values of the induced electric field E and of the induced current density J, along the curve "l", due to the incident magnetic field B^{inc}, normal on the surface bounded by "1" are the following:

$$E = \frac{r}{2} \cdot \frac{\partial B^{inc}}{\partial t} \tag{9}$$

$$J = \sigma \cdot E = \frac{\sigma r}{2} \cdot \frac{\partial B^{inc}}{\partial t} \tag{10}$$

For an incident sinusoidal magnetic field, with frequency "f", we obtain:

$$E = \frac{r}{2} \omega B^{inc} = r\pi f B^{inc} \tag{11}$$

$$J = \sigma r \pi f B^{inc} \tag{12}$$

These formulae allow a simple calculus of the induced electric field and of the current density induced by a low frequency incident magnetic field, B^{inc}. In order to consider the different dielectric properties of various parts of the body, the boundary conditions at the interface must be accomplished.

Therefore, we start from the local form of Maxwell's equations and we arrive at the Laplace equation that must be solved in the region of interest:

$$\nabla \cdot \nabla V = \Delta V = 0 \tag{13}$$

And

$$\mathbf{E} = -\nabla V \tag{14}$$

b) The electric field and the current induced by an incident electric field, E^{inc}

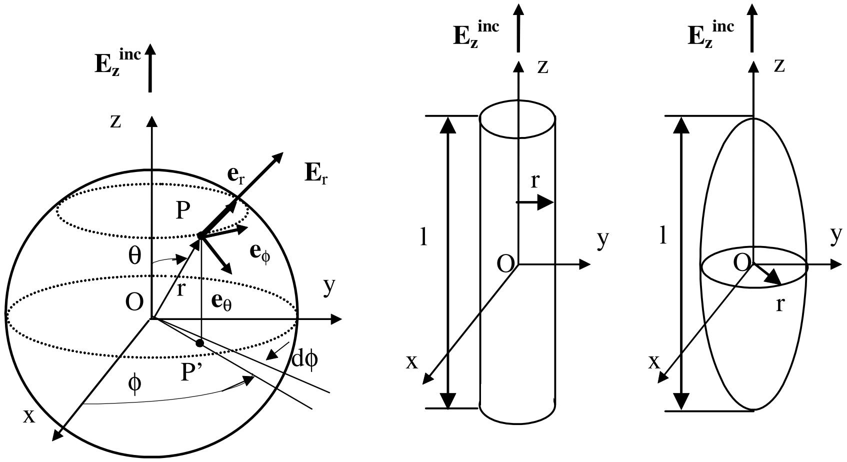
For the analytical calculus of the field and induced current, we model the human body as a sphere, a cylinder or an ellipsoid, like it is presented in Fig.11.

b_1) The determination of the electric field and of the induced currents in the body by a low frequency incident electric field, using the spherical model [21].

The human is modelled like a sphere with radius "r" and the conductivity $\sigma \cong 0{,}5\, {}^{S}\!/_{m}$, see Fig.11a.

The total charge induced inside the angle θ, when ϕ receives values from 0 to 2π is:

$$q(\theta) = \int_0^{\theta} \int_0^{2\pi} \mathbf{DdA} \tag{15}$$



a) b) c)

Fig. 11. Head or/and body models: a) spherical model; b) cylindrical model; c) ellipsoid model

If we calculate the value of the flux according to (15), we obtain for the charge:

$$q(\theta) = 3 \cdot \varepsilon_0 \cdot E_Z^{inc} \cdot r^2 \cdot \pi \sin^2 \theta \tag{16}$$

The induced current is:

$$I_Z(\theta, t) = \frac{dq(\theta, t)}{dt} \tag{17}$$

If it is considered the alternative electric field, having the angular frequency ω, the current through the sphere, crossing the circle at the angle θ is:

$$I_Z(\theta) = j \cdot 3 \cdot \pi \cdot r^2 \cdot \omega \cdot \varepsilon_0 \cdot E_Z^{inc} \cdot \sin^2 \theta \tag{18}$$

The current density and the induced electric field are:

$$J_Z(\theta) = \frac{I_Z(\theta)}{\pi \rho^2} = \frac{I_Z(\theta)}{\pi r^2 \sin^2 \theta} = j \cdot 3 \cdot \omega \cdot \varepsilon_0 \cdot E_Z^{inc} \tag{19}$$

$$E_Z(\theta) = \frac{J_Z(\theta)}{\sigma} = j \cdot 3 \cdot \omega \cdot \varepsilon_0 \cdot E_Z^{inc} \cdot \frac{1}{\sigma} \tag{20}$$

In the situation that $kr << 1$ (the condition of little electric sphere, where k is the propagation constant of the air), the current density and the electric field induced in the sphere are independent from the angle θ and the size of the sphere.

In this way it was established the relationship among the incident electric field E_z^{inc} and the induced current I_z, the current density J_z and the induced electric field E_z.

We can represent the human head like a sphere, but the representation of the human body like a sphere determines errors due to the alterations involved in the induced current by the head, the legs and the hands.

b_2) Obviously, due to the real shape of the human body, the cylindrical model (the human is modelled as a cylinder with radius "r" and length "l") is more adequate than the spherical one. The expressions for induced axial current in the body are different for the cylindrical model, in comparison with the "spherical' approach. In [21] these expressions are deduced in the assumption that the body is "electrically short", ($kr << 1$, where k is the propagation constant and "l" is the height of the subject), condition that is complied for frequencies lower than 5 MHz.

The current, the current density and the electric field in the centre of a "human" having average dimensions (height = 1,75 meters and r = 0,14 meters), placed at a great distance comparing with the earth, are this time proportional to the frequency.

$$J_z = \frac{I_z}{\pi r^2} = 21{,}17 \cdot 10^{-10} \cdot f \cdot E_z^{inc} \tag{21}$$

$$E_z = \frac{J_z}{\sigma_1} = 10.83 \cdot 10^{-10} \cdot f \cdot E_z^{inc} \tag{22}$$

When the frequency $f > 5\,MHz$, the condition for "short electric body" is not fulfilled, the formulae for J_z and E_z are more complex, [22].

As we have already mentioned, due to the complexity and the diversity of biological systems, there are always differences among the results obtained through various methods. More accurate results are obtained when it is possible, "in vitro" as in human or animals models, tissues samples in vitro, etc., by the measurement of the induced fields throughout the intrusion of little dimensioned sensors in the interest area [23]. However, more information and more related to real situations is obtained through the evaluation of the fields and induced currents of "in vivo" exposures both of the cells or the organisms. Moreover, the results could be translated and interpolated between the exposures of different species, from animals to human beings (dimensional scaling).

The models (mathematical or physical) utilised in analytical and experimental determinations are spheroids, ellipsoids, homogeneous cylinders, having the dimensions of the studied beings, but could also be non-homogeneous, having the size and the shape of studied organisms.

5.2.2 Numerical Methods

The previously presented analytical methods are difficult and limited, being applicable to quasi-simple geometrical models: the sphere, the cylinder, the ellipsoid.

The recently developed numerical models are workable on more complicated human models, closer to the reality. Likewise, at the characterization of electromagnetic wave interaction with the human body [24], it must be considered: the excitation source (placed in the near or far field area); the body model with the material constants; the numerical method and the utilized software.

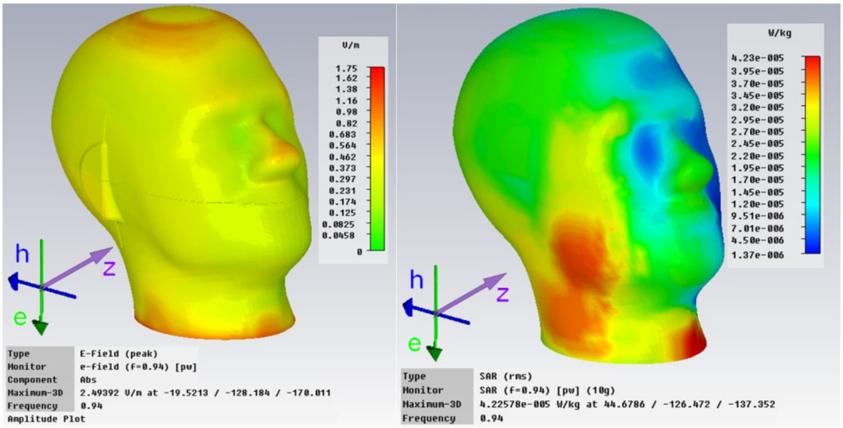
While dealing with the determination of the induced currents/fields and SAR, the convergence verification, the uncertainties estimation and validation are very important for the credibility of the results. The validation is made by comparing results of numerical simulation with results obtained by analytical methods and inter-comparisons between numerical methods [25] or comparisons between numerical methods and measurements results [26].

There are some well spread head models or body models: IEEE head model, models built from clinical tomography data; models obtained from real photography [27]. By using Computer Simulation Technology-CST software and a simple head model (IEEE model), given in software library, which is composed of two kinds of tissue (bone and brain), we have determined SAR distribution in some specific cases of exposure.

The distributions of the induced electric fields and of the SAR in the IEEE head model exposed at a plane wave with E^{inc} = 1V/m and f = 940 MHz are shown in Fig. 12. These values of incident electric field (E ≅ 1 V/m) may be generated at tens of meters from base stations for mobile communications or at about 1 m from a mobile phone in calling stage [28].

Also, we determined the induced fields or currents and the specific absorption rate – SAR, in a virtual human head model obtained by using successive magnetic resonance imaging (MRI) sections.

The numerical simulations were made with CST Microwave Studio software and as incident electric fields, there were considered the levels which we had obtained by surveying different electromagnetic environments.



a) b)

Fig. 12. E distribution (a) and SAR distribution (b) for $E^{inc} = 1$ V/m and f = 940 MHz

5.3 Acquisition of Some Biomedical Signals to Study the Biological Field Effects

The living cells and tissues are extremely complex media, in comparison to inert ones. The living organisms are non-homogenous, non-isotropic, without thermodynamic equilibrium. Consequently, the application of physical laws for describing the interaction field-biotic tissue is very difficult and complex.

Some obvious effects, as tissue heating under the exposure at radiofrequency or microwave fields, could be modelled and elucidated. However, many other biological effects (non-thermal effects) of radiofrequency and microwave fields, the effects of alternative magnetic fields of low magnetic flux density ($B^{inc} < 100\ \mu T$) and low frequency ($f < 100$ Hz), are not still explained away.

In order to elucidate the biological effects of electromagnetic fields, there are performed extended researches and correlation:

- *"in vitro" investigations (studies) on cells and tissues;*
- *epidemiological studies;*
- *studies on animals and humans.*

The investigation aiming to evaluate the electric field and the induced currents is mainly performed "in vitro" on separate cells or on cells in biotic tissues. These currents are influenced by the characteristics of the field, by the mutual placement of the cells, the density and the conductivity of the medium itself. Studies are realized also on little animals (mice or rats). These researches are focussed on the relationship between the electromagnetic fields (incident or induced in the body) and cancer or other disease incidence, being essential to evaluate the carcinogenic effects of the incident electric or magnetic fields having high intensity. There are also epidemiological studies aiming to find statistic relationships between cancer incidence and the civilians' exposure (living or working subjects in specific areas) to electric and magnetic fields. Extended inquiries are focused on the biological effects of the magnetic fields generated by the high voltage lines or the influence of mobile telephony traffic. There are studies on the exposure of *patients and volunteers* (sick or healthy humans; males or females; adults or children and adolescents) to different type of fields [5]. Because of the development of mobile telephony and wireless telecommunications, there are studies made with volunteers, referring physiological effects of the radiofrequency fields generated by these devices (base stations, mobile phone, etc). For instance, the effect GSM radiofrequency radiations on auditory ERPs, or on spontaneous electroencephalography generated during the sleep was presented. Aiming to identify the biological effects of the electromagnetic fields, we have recorded and analysed some biological signals (EEG, ECG):

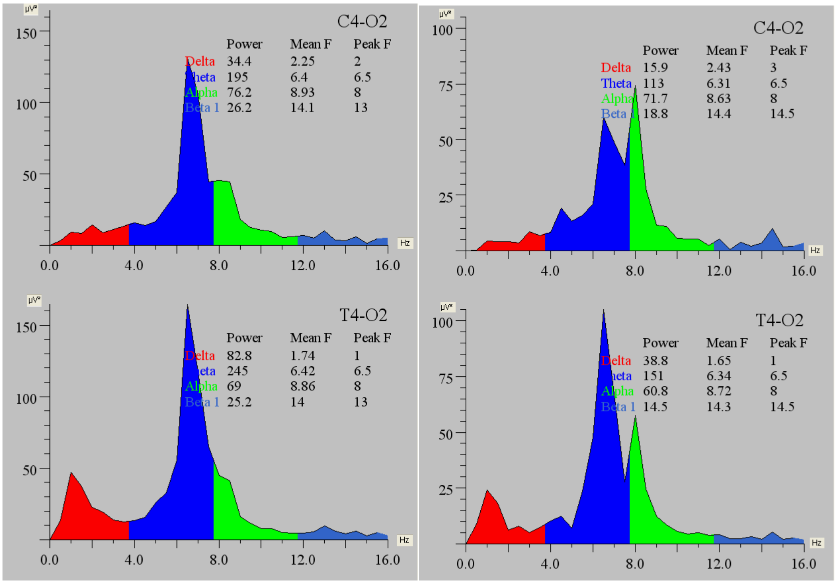
- in different electromagnetic environments;
- in case of patients exposed to electromagnetic fields during physiotherapy;
- in case of the professional exposures (electric and/or magnetic fields generated by power lines).

We recorded the electroencephalographic signal (EEG) of a patient in two different electromagnetic media: a normal room and a shielded room built for biomedical applications [29], placed inside the first one. Although the recordings have been successively performed on the same patient, there were observed some differences [30], as it is shown in Fig.13. In Fig. 13 are represented in frequency domain (Fast Fourier Transforms - FFT) of the EEG from two EEG leads (C4-O2 and T4-O2), done in various electromagnetic media.

It was observed that the electrical potential and the power of the EEG recorded in the shielded room are lower than those recorded in a normal room. Thus, it was observed a significant increasing of the delta and theta wave powers for EEG recorded in media with higher levels of electromagnetic fields.

We have also considered the recording of EEG in this shielded room, when the parasite alternative magnetic induction is reduced by a dynamic control [29].

Another assumed approach for the determination of any possible effects of the exposure to electromagnetic fields was to record biological signals during the physiotherapy: magneto-therapy operating at frequencies less than 100 Hz; short wave diathermy at a frequency of 27.12 MHz; microwave electrotherapy at a frequency of 2450 MHz. Various challenges were associated with the registration of ECG and EEG for the subjects exposed to the fields associated to space for physiotherapy, mainly related with difficulty to acquire the biological signals in the environment with high magnetic and electric fields generated by electrotherapy devices and for the magneto-therapy, where we deal with the same frequency spectrum. We have registered an EEG signal during a magneto-therapy procedure, for lombar affection. The magneto-therapy was performed with the device BTL 5940 and for the registration of the EEG signal we used the portable device Biopac "BSL MP45", connected to a portable computer, as it is presented in Figure 14.



C4-O2

	Power	Mean F	Peak F
Delta	34.4	2.25	2
heta	195	6.4	6.5
Alpha	76.2	8.93	8
Beta 1	26.2	14.1	13

T4-O2

	Power	Mean F	Peak F
Delta	82.8	1.74	1
eta	245	6.42	6.5
Alpha	69	8.86	8
Beta 1	25.2	14	13

C4-O2

	Power	Mean F	Peak F
Delta	15.9	2.43	3
Theta	113	6.31	6.5
Alpha	71.7	8.63	8
Beta 1	18.8	14.4	14.5

T4-O2

	Power	Mean F	Peak F
Delta	38.8	1.65	1
heta	151	6.34	6.5
Alpha	60.8	8.72	8
Beta 1	14.5	14.3	14.5

a) b)

Fig. 13. FFT for two EEG leads recorded in two different electromagnetic media: a) a normal room; b) a shielded room for biomedical applications

Fig. 14. Recording a EEG lead on a patient during a magneto therapy process

In Fig.15 is shown the time domain representation of EEG signal recorded before therapy (two minutes and thirty seconds), during the magneto-therapy (ten minutes) and after the magneto-therapy. It can observe a great influence upon EEG signal during the magneto-therapy.

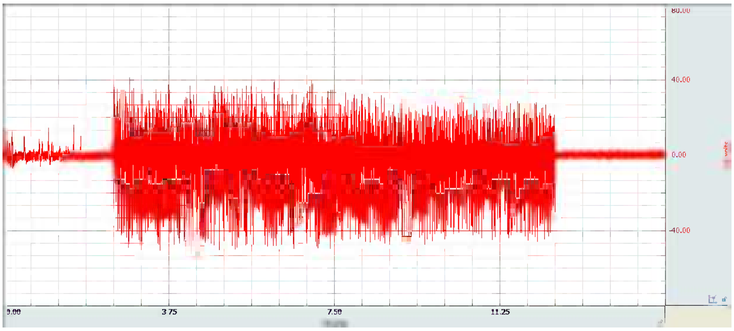


Fig. 15. Time domain representation of EEG before, during and after magneto-therapy

In this specific situation, to isolate and extract the disturbing signal owned to the magnetic field generated by the magneto-therapy device is very difficult, being in the same frequency domain as the EEG signal. Regarding the acquisition, the processing and the analysis of the ECG signal, also considering its higher level and its periodicity, the above presented results suggest that exterior electromagnetic fields may diminish the trusty level of acquisition and identification of EEG or ECG induced by physiological and pathological changes.

In order to optimize the heart rate variability (HRV) quantification we proposed a method to better characterize cardiac cycles extracted from a severe disturbed ECG signal in case of the subjects exposed to significant electromagnetic fields [31]. Furthermore, for the elimination of the influence of exterior electromagnetic fields, we applied at the acquisition of bioelectrical signals, some usual methods for extracting signal from the noise, as the adaptive filtering and coherent averaging.

6 Conclusion

The knowledge on electromagnetic environment for better characterisation of his influence on biological functions and health is important for future of our society when wireless networks and smartphones will become ubiquitous. More researches is necessary in order to developed portable sensors and devices and to improve methods for long time survey of the electromagnetic environment. We presents our investigation on determination of the induced current/field and specific absorption rate where numerical methods are applied on complex human body models, considering real exposure scenarios. Even if currently it is a difficult and cumbersome approach, this investigation may give more insight on influence of electromagnetic fields on biological structure and functions as well as may allow optimization of methods for acquisition and quantification of biological signals (e.g. by reducing the electromagnetic interferences and increasing the signal to noise ratio in EEG and ECG), and discovery of new methods and instruments for diagnosis and therapy.

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Modeling Dependability of IT Services Associated with Social and Economic Infrastructure Including Healthcare

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Abstract. Information technology (IT) services have been applied to mission critical businesses such as financial firms or telecommunication firms. And more applications are expected for IT supporting social and economic infrastructures, particularly those for healthcare in the future. However, defects in IT services will have greater negative impacts on social and economic activities in the future, since the risks of such defects are increasing due to their wider applications and the growth of IT systems' complexity and scale. In this chapter, upon surveying the current state of affairs and seeing that little progress has been made towards understanding and reducing defects in IT services that influence social and economic activities, despite a number of efforts including upgrading software and hardware quality, we propose a new approach to understanding and managing the dependability of IT services by discussing a dependability model. The model consists of not only functions for legacy system dependability but also two types of functions (additional safety and safety operation). Next we evaluate the efficacy of these two types of functions relative to IT dependability, both qualitatively and quantitatively, by using 42 actual cases of IT accidents obtained by the Information-technology Promotion Agency, Japan. Moreover, based on the verification, we examine the ways in which improvement of IT dependability associated with social and economic infrastructure, previously dependent on the skill of individual engineers, is eventually achieved as a result of organizational activities.

Keywords: health information technology, dependability model.

1 Introduction

Defects in information technology (IT) services for mission critical businesses such as financial firms, telecommunication firms or healthcare firms (i.e., IT supporting social and economic infrastructure) often negatively influence social and economic activities.

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For example, there have been mission critical systems such as clinical computing systems, ambulance dispatching systems or the other medical information systems in healthcare firms. And many cases have been reported that defects in IT services provided by such mission critical systems negatively influenced healthcare activities [1,2].

Moreover, new healthcare services, such as patient-centered medical home (PCMH) or personal health record (PHR), are to be developed nowadays and IT plays a significant role in supporting most of such new services [3,4]. Thus it is concerned that IT defects might cause much more negative influences to social and economic activities when IT will be more widely applied to such new services in the future.

In contrast to embedded IT systems such as those that automatically control hardware equipment, the IT systems associated with social and economic infrastructure are enterprise-level systems with the following characteristics:

- They are able to run large-scale applications exceeding several million steps, including complicated on-line and batch processing;
- Frequent interactions with the system are possible, creating the potential for human operation faults;
- Dependability of the IT service is affected by environmental changes (such as a sudden peak of traffic or frequent application updates) caused either directly or indirectly by social and economic activities.

IT services supporting such complicated systems are thought to be highly prone to accidents. We should aim to achieve higher dependability since these types of services are spreading widely throughout society.

In this chapter we discuss enterprise IT services based on papers [5,6] with a focus on the following issues:

1. We survey legacy activities to prevent IT accidents by reviewing the literature and show that legacy models of understanding IT dependability have not been capable of meeting with threats of future IT accidents;
2. We identify functional elements that contribute to IT dependability and systematize these in a model;
3. We verify the qualitative and quantitative relationships between dependability elements and actual cases of IT defects that have been collected by the Information-technology Promotion Agency, Japan.

2 Literature Review

A number of approaches have succeeded in preventing IT accidents. For example, IT system dependability has been improved through the implementation of software development technologies. These include structured software testing and quality assurance technologies [7], higher-reliability hardware solutions such as popular clustering or RAID (Redundant Arrays of Inexpensive Disks) technologies, and continuous improvement of total system development projects such as PMBOK (Project Management Body of Knowledge) [8] for general projects and CMMI (Capability Maturity Model Integration) [9] or *MIERUKA* [10] for IT projects. However, these technologies for improving system dependability are only applicable over a finite period of project development, that of IT implementation.

For during the operation phase after the launch of developed systems, there are ITIL (IT Infrastructure Library) [11,12,13,14,15] and ISO20000 [16]. These include best practices for IT service management and operation and incorporate measures to reduce human operation faults. They assume that necessary functions are developed by the IT development projects and that engineers of service management and operation use these functions as they are. Thus, even when extra functions in a broader sense (including human operations) are needed in IT services where higher dependability is required, we can not find in the ITIL and the ISO20000, any model to define the functions' scope nor any guideline to assign responsibility to determine whether the functions should be developed or not.

Consequently, they seem to expect individual companies to have some suitable model and field engineers in the company to judge whether extra functions should be realized or not.

However, one hesitates to say that we are safe given the number of IT accidents broadcast by the Japanese news media (Figure 1).

We first surveyed the viewpoints of news media firms. According to a summary of 94 recent IT accidents [17] that were covered by the Japanese news media, 49 cases were due to product faults (i.e., reliability problems in a narrow sense including software bugs), 17 cases were due to human errors, and the causes of 28 cases were not specified. Thus, of the 66 cases whose causes were specified, approximately 70% were thought to be due to problems with product quality. This type of news continues to be broadcast because of recognition by the news media firms that there is no way to improve dependability except by improving software quality. However, Japan has been reported to have fewer potential bugs in its finished software than other major software producing countries such as India, European countries, and the United States [18]. Thus, we have doubts about whether this single approach can substantially improve the dependability of IT services associated with social and economic infrastructure.

Approximately 30% of covered IT accidents were thought to be due to human errors. However, since a recent evaluation said that the field operation departments of Japanese IT service operations wield a relatively significant amount of power [19], there seems to be minimal room to improve dependability in this area.

Based on the above discussions, we think that the keys to further improvement of IT dependability lie in the fact that few models have been implemented with a focus on dependability and there has been a lack of clarity in assigning responsibility for developing functional elements involved in each model. That is, we recognized that it is necessary to identify a model which clarifies assignment of responsibility on the assumption that IT accidents actually happen, since there is a high possibility of accidents in complicated IT services supporting social and economic infrastructure.

Upon the above recognition, we next investigated how social organizations understand the overall shape of the dependability in real terms.

We first proceeded to survey public associations of governmental organizations related to IT. The International Standardization Organization [20] and Japan Industrial Standard [21] define the external quality of software using six categories, including functionality and performance, but have not considered the control of faults, including bugs, to be a systematic category. The Ministry of Economy, Trade and Industry (METI) of Japan [22] first introduced the category of controlling faults when they expanded the six categories to 11 categories in focusing on non-functional requirements mainly for enterprise IT services. Furthermore, the category was broken down to two sub-categories, preventing occurrence of faults and preventing the spread of negative effects caused by faults. Despite these steps, the following can be observed:

- Most discussions have focused on preventing the occurrence of faults, with fewer concentrating on mitigating faults' negative outcomes. Moreover, there is no discussion on the importance of countermeasures to prevent the spread of negative effects caused by faults.
- Several checklists are intended to preventing the spread of negative effects caused by faults. However, the checklist items are described at an abstract level, for instance checking for the presence of countermeasures to initial faults after the launch of an IT service. There is neither a systematic explanation of the expansion process by which an initial fault occurrence results in concrete negative outcomes nor suggestions to develop specific countermeasures to cope with the adverse events.

Next, companies that provide actual IT services generally assign causes to IT defects or accidents using categories such as developed application bugs, system infrastructure problems, or maintenance or operation issues. Each individual category corresponds to an accounting department within the company. Consequently, IT dependability is effectively the sum total of each department's efforts to improve its own individual quality measures. However, it is quite unlikely that the overall structure of departmental organizations is derived from a systematic attempt to anatomize the elements that yield optimal IT dependability and then represent these in organizational form. Rather, it seems that these companies have a model of dependability that consists of elements corresponding to individual departments. However, given the number of IT accidents illustrated in Figure 1, there are doubts about the adequacy of such a model.

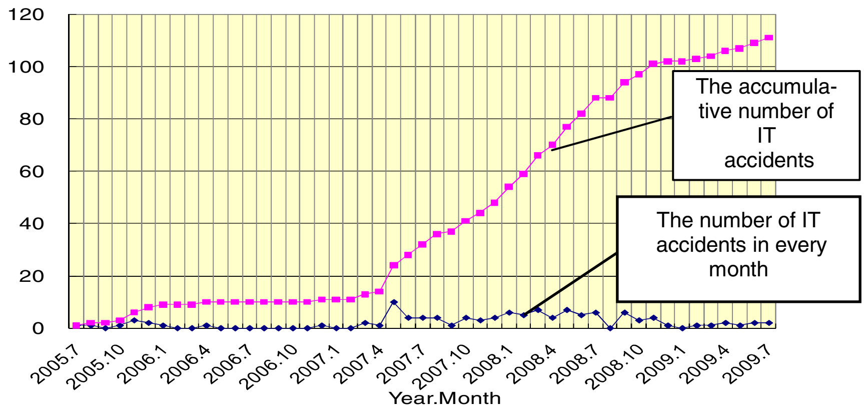


Fig. 1. Trends of the number of IT accidents broadcasted by news media in Japan

3 Systematizing Elements of Dependability

Economically speaking, IT companies benefit most if elements of dependability correspond to existing organizational departments that are hypothetically derived from the point of view of economical rationalism. However, although the idea of this dependability model is reasonable for an IT service provider, it is difficult to say whether third parties can objectively understand the appropriateness of the model.

The reason for this is that the causes of nearly half of the 94 IT accidents mentioned earlier were either not clear or were treated as only human operation faults. Doubt remains as to whether the best way of improving dependability is to divide responsibility among existing departments in the organization.

To deal with this doubt we use modeling to clarify the structure of dependability.

As mentioned before, IT services that support social and economic infrastructure are complicated systems. In order to allow us to model the entire configuration of the complicated systems, we first defined the following three elements to describe the phenomena that occur before the outbreak of IT accidents by using fault-tolerant model [23]:

- Faults: These are root causes that trigger successive events before IT accidents occur. They include, 1) product faults such as software bugs and hardware defects, 2) human operation faults, and 3) environmental changes such as a sudden increase in network traffic or data processing load;
- Service errors: This is a possible status event, which may causes future IT accidents or exacerbate these accidents' negative effects (the service error corresponds to an error in the fault tolerant model);
- Service failures: These are events that negatively influence social and economic activities, for instance terminations of service for a long period of time (IT accidents in the worst case).

By using these elements, we can formulate fault-tolerant functions promoting higher dependability as shown in Figure 2. We define the functions in IT services as follows:

- ■ Safety operation functions: Organizational structures that mitigate actual damage to social and economic activities by responding to service failures, even when faults cannot be fixed.

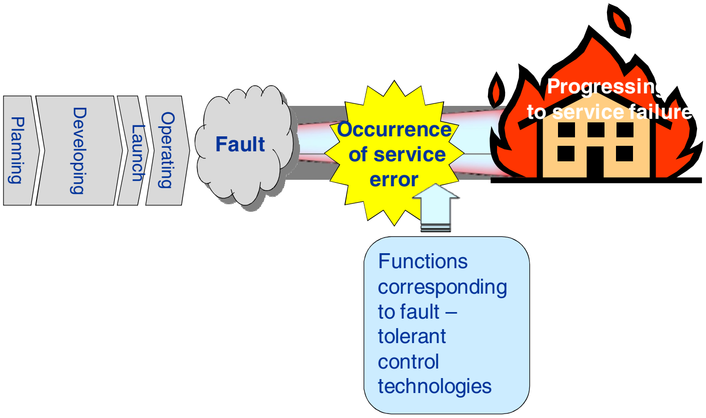


Fig. 2. Legacy fault-tolerant model when applied to existing IT service as it is

Component errors in fault-tolerant devices can be identified relatively more easily by extracting possible production fault cases from design specifications of the devices. However, in IT services related to social and economical infrastructure, there can be a wider range of fault sources, which include not only production faults of all software and hardware devices but also environmental changes and human operation faults by system operation and maintenance engineers. Thus, since the more simple identification methods are not applicable to IT services as they are, we need the following additional functions to cope with service errors caused by a broader range of fault sources.

- ■ Additional safety functions: Functions to identify service errors and decide mechanisms executed in safety operation functions to prevent faults from developing into service failures, or reducing the negative influence of the service failures, even when service errors occur.

The following additional information is necessary as the fourth element to execute such identification and decision in the functions.

- ◆ Early warning sign (EWS): Alert providing notification that service errors caused by faults could progress to service failures.

We call a set of the additional safety functions and the safety operation functions an on-demand safety system.

IT service experts must consider the final scope of the first type of function based on a balance between additional investment and expected total loss, including degradation of social reputation and opportunity loss, since additional development costs other than those necessary for system development are required. Since these functions require decision making regarding contingency plans, the final responsibility for them should rest on IT owners or management executives rather than on field operation and maintenance departments.

In contrast, responsibility for the second type of function is assigned to the field organizations that implement them.

Based on the above discussion, we systematize a bird's-eye view of dependability as shown in Figure 3 by considering the legacy system's dependability, whose responsibility should rest on development departments. According to this viewpoint, overall dependability is composed of the legacy system's dependability, the additional safety functions and the safety operation functions. Since we categorize the tree elements according to the relevant responsibilities, we call this model a manageable dependability model.

Legacy research on improving dependability of enterprise IT services has focused on preventing faults through improving software quality and fault tolerant technology [24] or activities to reduce human operation faults. In contrast, our original approach is to introduce concepts of fault tolerance to the enterprise IT service by taking into account not only service errors but also EWSs.

The outcome of legacy research has included improving software quality to prevent production faults and developing fault-tolerant technologies to increase device dependability. These approaches have been implemented in IT systems facilities as freeze logic and have played a role in system dependability as illustrated in Figure 3.

Problems occur if the additional safety functions and the safety operation functions in Figure 3 always implement the same freeze logic as the system dependability processes, since the additional safety functions have to be developed by considering the following features:

- The final functions to be implemented are decided upon by IT owners or management after limiting and prioritizing candidate functions through a process of obtaining expected probabilities and impacts of each of them;
- Commitment to a function is not a permanent decision. Flexibility is important since the dependability of IT services is contingent on environmental changes. Thus, implementation methods are required to avoid a loss of investment and to realize the maximum scope of functions under a limited budget.

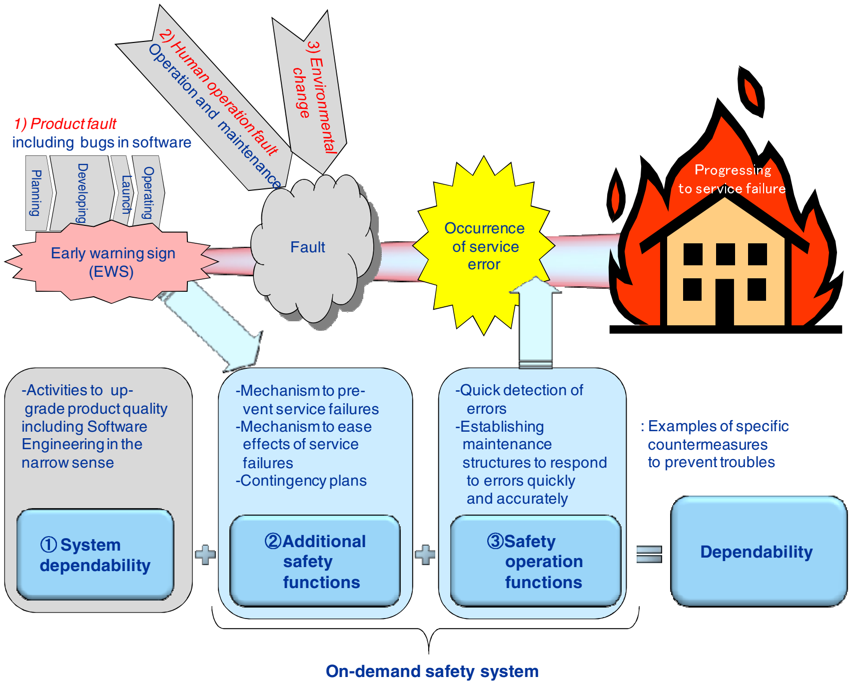


Fig. 3. Systematized model of dependability for IT service (manageable dependability model)

It is probable, then, that the flexibility to change the scope of countermeasures with the aim of higher dependability will lead to a degradation and consequent reduction in the overall scope of available countermeasures if the additional safety functions or the safety operation functions are implemented in facilities that utilize freeze logic.

Therefore, most of the additional safety functions and safety operation functions are thought to lack freeze logic, with a few exceptions, for instance cheap software tools. Implementation of these functions is supposed to follow an approach that requires no extra cost beyond keeping structures of the safety operation functioning normally except during emergencies, during which times costs can be potentially very high. In this sense, we call the combination of additional safety functions and safety operation functions an “on-demand safety system”.

4 Verification of the Model

We next verify whether or not actual IT accidents can be explained using the manageable dependability model illustrated in Figure 3. Specifically, we determine whether existence or absence of the functions in the on-demand safety system affects the dependability of IT services by using actual IT accidents documented at the Software Engineering Center, Information-technology Promotion Agency, Japan (IPA/SEC).

4.1 Qualitative Verification

Case 1

In this case, the response of an on-line service was delayed after the service was started, although a quick and stable response had been observed in the service before the accident. The accident was caused by a batch processing delay in which the process remained active even after the scheduled on-line service start. The delay had been caused by the misexecution of an operator command, which consumed significant server resources while the batch was running.

In this case the fault was the inappropriate running of the command, the service error was batch-processing delay and the service failure was the slow response of the on-line service. An EWS could have prevented this case if by some means such as IT service evaluations the problem had been pointed out before the accident occurred.

The dependability of the service could be improved further if either one of the following functions was implemented:

- An automatic mechanism that starts up on-line applications and gives a higher executing priority to these applications when batch processing is still in progress at the scheduled on-line start time, on the assumption that such service error may happen in reality (additional safety function);
- An organizational structure that, when the automatic mechanism cannot be applicable to the service, more rapidly detects the service error (the batch-processing delay), starts up on-line applications punctually, and gives higher executing priority to the applications without fail (safety operation function).

Since the service error may be caused not only by human operation errors or bugs in batch-processing programs but also by environmental changes such as a sudden increase in data-processing load, it can be concluded that the service lacks the necessary on-demand safety system.

Case 2

In this case, clerks working at computer terminals in shops of customer divisions found that IT services were suddenly unresponsive, although these services were stable and responsive before the accident. Many of the terminals had to be shut down for days since it took a long time to recover service. The reasons for this delay were as follows:

1) Too much time was spent identifying the cause of the abnormal phenomenon.

In this system, a network facility was composed of a dozen high-end network elements that were duplicated to achieve higher system dependability. However, the IT system division had not implemented a mechanism that would detect the abnormal performance of any given network element, since the devices had been very popular and selling well worldwide and development costs had exceeded the budget allowed. Furthermore, the organizational structure necessary to respond to such a case did not exist.

2) Too much time was spent recovering service after detection of the cause.

The cause of the abnormal phenomenon was a bug in the control software whose effects were triggered by changes in telecommunication traffic, i.e., an environmental change. However, even after the cause was detected, there were many ways to avoid the problem, though every option had potential adverse effects. Further complicating the matter was that the bug in the commercial system could not be reproduced in the testing system, while poor cooperation between the systems division and the customer divisions complicated the development of methods to avoid a solution's potential side effects. Thus, methods of trial-and-error were employed so as to avoid the bug's negative influences during the IT service's online service time. This extended the number of days necessary to eventually recover full service.

The fault in this case was caused by an unknown bug in the software product in the network element device, the service error was the delay in identifying the cause of the fault and then recovering service, and the service failure was the extended unavailability of business processes at a large number of terminals. If the risk of this case was somehow pointed out before the IT accident, the alert of the risk would be defined as the EWS.

The dependability of the service could be improved by reducing the duration of terminal downtime through implementation of the following functions:

- Introduction of a mechanism to quickly alert a human operator of the abnormal performance of a network element device's input and output response (additional safety function) and an organizational structure to respond quickly to the abnormal performance (safety operation function);
- Commitment to testing bug reproduction procedures and to verifying side effects of fixing the bug in the commercial system supported by corporate customer divisions after the planned time of window closure, on the assumption that such bugs may actually appear in a complicated system (additional safety function to ease negative influences of service failures), and an organizational structure to execute testing in the commercial system in cooperation with the customer divisions (safety operation function);
- Establishment of contingency plans to continue minimum business processes in the customer divisions even when IT systems are not available (additional safety function) and an organizational structure to execute these plans (safety operation function).

We would encourage management or owners of IT services that support social and economical infrastructure to determine the proper amount of effort to devote to preventing terminations of corporate processes by judging specifically the degree to which they should implement such on-demand safety systems as described in Case 2.

Case 3

If symptoms of the service error are unobservable, there is no way to avoid the negative influences of subsequent service failures, except by eliminating the corresponding causes (faults) of the IT accidents. For example, in this case, test mail was inadvertently sent to actual users because some addresses registered in the test database were equivalent to those of actual users. Engineers failed to detect the problem.

4.2 Quantitative Verification

It is difficult to verify the effectiveness of the manageable dependability model quantitatively, since the broadcasted information of the 94 IT accidents mentioned above contain insufficient information to do so. It was impossible to obtain more detailed information about these cases since this was prohibited by corporate security. We therefore verified effectiveness of the model by collecting as much actual field information on the cases as possible using the approach mentioned below.

4.2.1 Method for Case Specification

We obtained information regarding IT accidents from a sectional meeting named Project *MIERUKA* held at the Software Engineering Center of the Information-technology Promotion Agency, Japan (hereafter, IPA), where strict privacy standards are maintained. The meeting members have 20 to 40 years of experience in developing and maintaining mission critical IT systems for IT vendors or IT users in Japan.

Members recorded information not just about the basic events that transpired during IT accidents but also about outcomes of the events and the countermeasures taken against them. Forty two cases were summarized.

4.2.2 Method for Case Analysis

First, causes of IT accidents were classified into three categories (product fault, human operation fault and environmental change), which are the same as those mentioned in section 2.

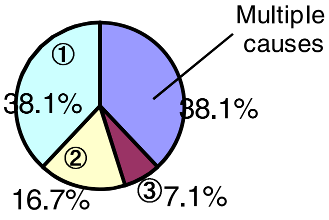
We shared the definition of the system described in Figure 3 and used this to further differentiate whether or not by introducing the on-demand safety system it would have been possible to prevent service failures and ease their negative effects. Moreover, the following procedures were used to avoid biasing the investigation and analysis.

- Members in the sectional meeting of IPA, who were from different companies and offered the cases, performed analysis and evaluation independently without any interference from each other.
- The analysis was summarized after all of the results were reviewed and corrected in the final sectional meeting.

4.2.3 Results of Analysis

Figure 4 shows the results of the analysis of accident causes. Among the 42 cases, approximately 74% were due to product faults, which is nearly the same rate as that seen in the 94 IT accidents mentioned above. This confirmed that activities related to upgrading product quality, which has been focused on thus far, are important.

Causes of IT accidents			
Single cause			Multiple causes
① Production faults	② Environmental changes	③ Human operation faults	
16 cases	3 cases	7 cases	16 cases



①+② : 4.8%(2 cases)
①+③ : 21.4%(9 cases)
②+③ : 2.4%(1 case)
①+②+③: 9.5%(4 cases)

73.9% of IT accidents related to production faults(①).

Fig. 4. Classification of causes of 42 actual IT accidents

We also determined that the ratio of cases where it was possible to have prevented service failures or ease their negative effects if the on-demand safety system had been implemented was 59.5%, as shown in Figure 5.

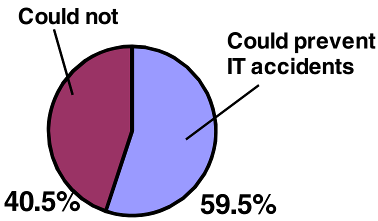
	Total	On-demmand saftey system	
		could not prevent IT accidents	could prevent them
No. of cases	42	17	25
Rate(%)	100.0%		

Fig. 5. Quantitative verification based on actual cases

5 Consideration

Several lessons can be learned from the fact that service failures or their negative effects could have been prevented or eased in approximately 60% of the cases by implementing additional safety functions and safety operation functions.

1) The manageable dependability model, which explicitly introduces additional safety functions and safety operation functions (on-demand safety system in Figure 3) that are distinct from functions utilized in traditional system dependability, is thought to be effective for improving dependability of IT services.
2) Although the additional safety functions and safety operation functions may have been implemented as a result of voluntary efforts of individual field engineers, we are not aware of any systematic and organizational scheme to develop them. We believe that dependability of IT services will be improved by organizational efforts to develop and share among IT services tools to implement the on-demand safety system explicitly demonstrated in the proposed model. Further benefit will be derived from introducing approaches to obtaining feedback from lessons learned while applying these tools to field services and from continually enhancing the tools over the long-term.

6 Conclusion

We clarified the functional elements (the additional safety functions and the safety operation functions derived from a point of view of manageability) of the dependability of IT services underlying social and economic infrastructure and systematized the overall structure of this dependability.

It is difficult to say that the proposed model is clear enough for field persons to practice improving IT dependability in actual. In order to move forward this research to applying to actual works in the fields, it is necessary to promote introducing the model by coping with the following questions.

1) View of developing

It is necessary to show what should be added or changed to the legacy IT service development. It is also required to show overall view of developing the IT dependability including legacy development style.

2) Means

It is necessary to show how to improve the IT dependability as tools for practicing improving the IT dependability.

3) Thread to improvement in the long term.

It is also necessary to show the thread to improve the IT dependability in the long term by using tools of 2) under the new development style mentioned in 1).

In order to cope with these questions from a viewpoint of practices, actual ways for developing IT services and improving the IT dependability [25] are suggested in 7. Annexes.

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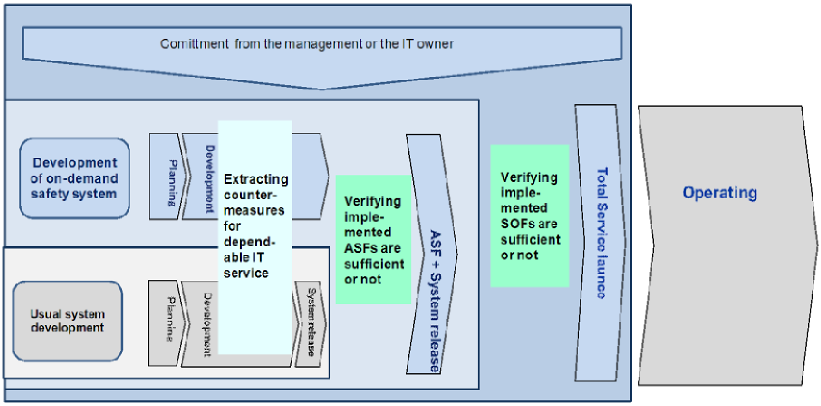
Annexes

An example of implementing the on-demand safety system based on the proposed model is explained below.

In actual practice, additional safety functions and safety operation functions take on various forms such as operation and maintenance documents and organizational structures including not only operation and maintenance engineers but also persons in end-user divisions or contingency plans decided on by management. It is therefore difficult to use existing methods that have been used to develop general IT systems, and instead new methods are required for highly dependable IT services that support social and economic infrastructure.

It should be noted that additional safety functions and safety operation functions require expanding the process for developing an on-demand safety system beyond the usual system development processes illustrated in Figure 6.

Improvement of the dependability of IT services associated with social and economic infrastructure has depended more on the skills of individual engineers working in system development departments or operation and maintenance divisions rather than enterprise organizations or management, as there have been no "managed" models and fewer methods for the higher dependability than those for system development. Thus, there is no assurance that these functions are implemented.



(Note) ASF: Additional safety function
SOF: Safety operation function

Fig. 6. Developing style for implementing additional safety functions and safety operation functions

On the contrary, it become possible to normally implement the on-demand safety system by using the following tools under organizational orders, if the dependability systematized in Figure 3 is commonly recognized.

1) Tools utilized mainly during the planning or development phase

- A bird's-eye view of causal relations;

This is a diagram to extract functions of the on-demand safety system by understanding an overview of causal chains of problematic events, one of whose example is shown in [25].

- A summary of service failure cases

Each case includes concise records of an actual failure event and is composed of facts that include immediate countermeasure taken and lessons learned. An example is shown in [25].

These are used to support practical decision making regarding the implementation scope, since these tools can be used as EWSs to identify service errors and extract necessary functions.

2) Tools used after function development;

- Checklists

These are used for verifying whether IT services can be launched are based on clarifying whether developed functions are sufficient or not (an example is shown in [25]).

Moreover, even after IT accidents occur and are fixed in operation phase, improvement of the dependability of IT services associated has depended more on the skills of individual engineers working in system development departments or operation and maintenance divisions rather than enterprise organizations or management, as there have been no systematized models and fewer methods for the higher dependability than those for system development. Thus, it has been difficult to identify clearly what is improved. On the other hand, as illustrated in Figure 7, it becomes easier to manage that outcomes of improving the IT dependability are actually obtained, since outcomes of feedback from the IT accidents are much more visualized by sharing the above tools. It is also possible to improve the total IT services associated with social and economic infrastructure in the long term, by continuing practicing such improvement cycles.

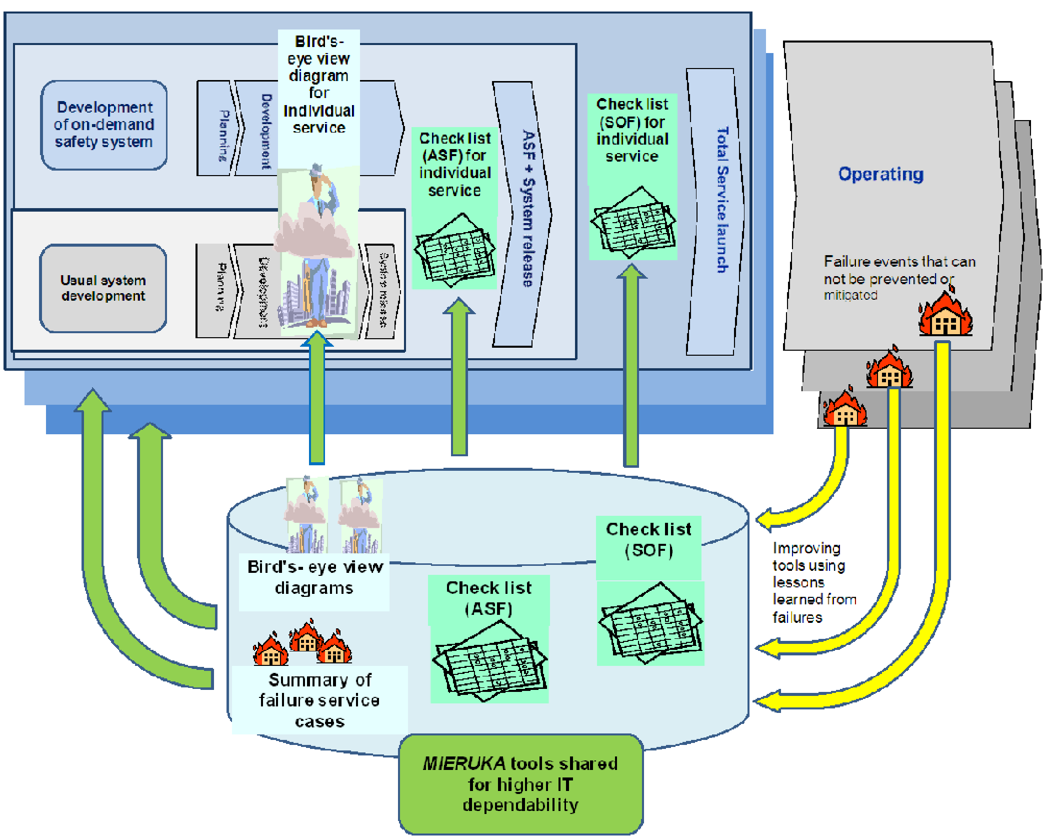


Fig. 7. Continuous improvement of dependability by introducing common tools

Requirements and Barriers to Pervasive Health Adoption

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Abstract. An increasingly significant characteristic that has emerged through the use of eHealth applications is the rise in consumer empowerment. The latest advances in sensor technology, sensors implementation, improved wireless telecommunications capabilities, open networks, continued increases in computing power, improved battery technology, and the emergence of flexible software architecture has led to an increased accessibility to healthcare providers, more efficient tasks and processes, and a higher overall quality of healthcare services. Intelligent infrastructures have provided the layers for contextual information gathering, knowledge processing as well as adaptation and optimization mechanisms. Pervasive health monitoring and care (PHMC) would shift the paradigm of healthcare from the traditional reactive, event-driven model, to one were subjects proactively manage their health in a patient centered healthcare system. The objective of this work was to identify requirements and barriers to adoption of pervasive sensing and computing in healthcare. To do so, the authors systematically reviewed published works on health information technology, eHealth, and pervasive health care, since 2005. We found technological, financial, psychological, logistic and liability issues related with requirements and barriers to PHMC adoption. We identified as potential requirements related with adoption of PHMC: optimization of hardware and software for remote, unobtrusive health monitoring; better evaluation of the implemented systems; better coordination of the involved stakeholders; respect and improvement of existing standards for eHealth or new standards realization; collaboration and team work of all stakeholders that may benefits from pervasive health implementation; training in using new technology; training for searching library and information sciences related with health technology and information communication technology; training in thoughtfully analysis of added value associated with new health technology; promotion of healthier lifestyle using health information technology; analysis of social and organizational change process in order to design flexible, adaptive systems for health monitoring and care; adequate policy support for quality improvement of pervasive health systems; transparency with regard to the goal, business plan and process

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implementation of pervasive healthcare; consideration of patients' perception as well as healthy individuals perception and patient-physician relationship as a core organizational operational system for PHMC; healthcare equity through improved data collection; education for technology literacy; and education for lifestyle management using new technologies. Barriers to implementation are associated with: financial constraints; privacy policy and related issues; poor transparency towards work plans and with regard to the implementation of health information technology; underestimation of complexity of the technological, clinical process and organizational problem; less or even lack of collaboration and team work of all stakeholders - patients, doctors, therapists, sociologists, engineers, computer technicians, etc.; fragmented or lack of responsibility in management of health information system implementation; low effective, persistent and consistent management of system implementation for more closely coordinated forms of health and social care provision; lack of quality audits of health information technology implementation in some healthcare systems; health professionals perception related mainly with less evidences on added value of some implemented eHealth approaches; aspect of culture associated with all stakeholders involved in health information communication technology. For the future it would be desirable to set up a comprehensive method that provides support in implementing PHMC taking into account quantitative measurements of variable identified in this work and potentially supplemented by others standardized surveys.

Keywords: pervasive health monitoring, pervasive healthcare, health information technology adoption.

1 A Short Story. Information Technology in Healthcare

"*I sighed as I flipped again through the paperwork sent with my first admission of the night. All I found was a partially legible discharge summary. The patient, a young man who was ventilator dependent and in a vegetative state since receiving a gunshot injury 6 months previously, had been transferred from a nursing home after a workup revealed a new deep venous thrombosis in his leg. From the limited notes provided by the nursing home, I ascertained that the gunshot had initially caused a subarachnoid hemorrhage. It was my job, as a night-float admitting resident, to determine whether it was safe to start anticoagulation for his thrombosis. I rummaged through his papers again. All I could find regarding his brain hemorrhage was the handwritten statement "Recent head CT stable." I was angry that physicians had sent this patient without adequate documentation. In the corporate world, a business transaction would not be finalized if crucial information were missing, but transfers like this are commonplace in medicine. I called the nursing home and reached a doctor who had never heard of my patient. He agreed to look up the record and call me back. A few minutes later, someone else from the nursing home paged me and said he couldn't find any mention of a previous head CT. I pressed him for more information. After a second perusal of the record, he discovered that a "brain" CT had been performed a few days earlier. My spirits rose as I waited for the report. "Oh," he said, "we don't have a report.*

We're not an acute care facility, so it takes several days for us to receive reports." Defeated, I hung up. Half an hour later, I was wheeling my ventilated patient to the CT scanner for new views of his brain. These days, we can find the answer to almost any question immediately by doing a Google search, but unfathomably, it is still not possible for a physician in Manhattan to obtain a timely report of a study performed in another New York borough. I waited for a corrections officer to open the gates to the prison floor of the hospital so I could see my next admission — a prisoner from Rikers Island who had been sent to a different hospital for stabilization and was being transferred here for treatment. The nurse warned me, "There's not much there," as I looked through the chart. The discharge summary from the transferring hospital was one of the briefest I had ever seen: "Admitted for altered mental status, s/p respiratory distress, and intubated. Treated with broad-spectrum antibiotics, extubated 2 days ago and now stable for transfer." A set of basic laboratory tests from a couple of days earlier was included with the paperwork, but there were no culture reports, no mention of which antibiotics had been used, and no chest radiography reports. A 10-day course of critical care had been summed up in three sentence fragments and one set of lab tests. I spent another 20 minutes drawing labs and cultures and then ran back to the emergency room to see another new admission, still without a clear plan for the patient I had just left. Later that night, I looked over the chart for my sixth admission. A 72-year-old patient with schizophrenia who spoke only Cantonese had been referred from a Chinatown clinic for admission. Because only the words "PPD positive" had been written on the referral sheet, he had been isolated in the emergency room. I wasn't sure whether the tuberculosis positivity was a new finding, and the patient appeared comfortable on the stretcher. He was not coughing, and his lungs were clear. Without any family members present to provide clarification, I tied a mask on him and walked him outside his isolation room to a translator phone. Even through the translator, I could barely get a history. I looked for evidence of a recent skin test on his forearms but found nothing. He was a febrile, and his chest radiograph was normal. I couldn't understand why his primary care doctor had thought he needed to be admitted. Once again, I felt as though I were practicing medicine in the dark" (Litvin CB, 2007).

Litvin [1] story published, in 2007, in The New England Journal of Medicine, the most widely read, cited, and influential general medical periodical in the world, underscores common communication breakdowns among patients, clinical, and administrative staff (e.g., distribution of patient information), related mainly with accessing meaningful data in real time. This is the common perception of healthcare professionals related with eHealth in many countries that currently use eHealth technologies. The term eHealth or e-Health encompasses a range of services or systems that are at the edge of medicine/healthcare, information technology and engineering, including: telemedicine, telerehabilitation, telehealth, telegenetics, electronic health records (EHRs), electronic medical records (EMRs), personal health records (PHRs), patient-centered medical home (PCMH or Medical Home), e-Patient, m-Health, connected health, consumer health informatics, health knowledge management, virtual healthcare teams, medical research using distributed sensors networks, health information system (HIS) or health information technology (HIT), information communication technology (ICT) for healthcare, pervasive health monitoring and pervasive healthcare. In recent years, interest in both eHealth and innovation in pervasive health monitoring and care (PHMC) has grown tremendously, and there has been increasing recognition of the importance of medical devices and other non-pharmaceutical health related technologies to all aspects of healthcare. The World Health Organization (WHO) issued the first global directive on medical devices in 2007, recognizing that, like medicines, many health technologies are indispensable. In Europe, taking into account the financial burdens associated with the ageing of the population and the parallel rise in chronic diseases, the overriding concern of Europe's healthcare sector is to find ways to balance budgets and restrain spending. According to World Bank figures, public expenditure on healthcare in the EU could jump from 8% of GDP in 2000 to 14% in 2030 and continue to grow beyond that date. For Europe, eHealth adoption is one of solution to reduce cost and improve healthcare as was emphasized to the High Level eHealth Conference 2006 in Malaga, Spain: *"Europe can benefit from eHealth that focuses on ensuring better: prevention disease, prediction of disease, personalization of healthcare, participation of Europe's citizens in their own healthcare improvement, increased patient safety throughout all stages of the healthcare process, productivity and performance of Europe's healthcare systems, and of Europe's third healthcare industrial pillar, monitoring of indicators and productions of regular data and reports on health status"* [2]. In many European countries, the health and social-care system is looking at the potential of eHealth to serve as a complementary support structure for quality care that is coordinated, comprehensive, and cost-effective. Moreover, research on pervasive computing technologies for healthcare, which does not aim to replace traditional healthcare, is directed towards paving the way for a pervasive, user-centered, preventive healthcare model [3] at lower cost. PHMC has the potential to significantly improve health outcomes over the long term and thereby reduce direct and indirect costs, given the much greater opportunities for continuous monitoring and adjustment of treatment. The pervasive health monitoring enables to build sensing and computing systems that allow long-term subjects' health assessment and health critical events signaling.

Pervasive healthcare may be defined from two perspectives: i) as the application of pervasive computing technologies for healthcare, and ii) as making healthcare available everywhere, anytime and to anyone [4]. The pervasive healthcare applications include pervasive health monitoring, intelligent emergency management system, pervasive healthcare data access, and ubiquitous mobile telemedicine. Pervasive healthcare is closely related to biomedical engineering (BME), medical informatics (MI), and ubiquitous computing (UbiComp). BME combines engineering skills with medical and biological science to improve diagnostics, treatment, and follow-up. Using technology related MI large sets of medical data are processed to optimize healthcare management. A main objective of UbiComp is physical integration and embedding of computing and communication technology into environments. While BME and MI mostly focus on technology to improve the existing health delivery model, pervasive healthcare in contrast tries to change the health care delivery model: from doctor-centric to patient-centric, from acute reactive to continuous preventive, from sampling to monitoring [5]. Additionally, while the term "pervasive" stands for the tendency to expand or permeate, "ubiquity" is the property of being omnipresent. In this sense, the ultimate goal of pervasive healthcare is to become a mean for achieving ubiquitous health.

Efficient pervasive healthcare architectures, mechanisms and systems could alleviate the problem of supporting and caring for people with a long term condition and less mobility. Some of the problems that initially was thought to be solved by using ICT in healthcare delivery systems were the incorrect recording of diagnoses, unavailability of patient information, delays in accessing the information, space limitations for record-keeping and insufficient personnel for patient monitoring. The paradigm shift in BME and MI has enabled a reduction in these hurdles and a more personalized service to be delivered.

In the last years, worldwide politicians have been supporting greater investments in health information technology and expect it to significantly decrease costs and improve health outcomes. For instance, Barack Obama’s campaign Web site proclaimed that his health plan would *“lower costs through investment in electronic health information technology systems” (Obama 2008)*. An economic stimulus package was passed by the USA Congress including \$19 billion for investments in healthcare ICT (Kaiser Family Foundation 2009), together with the Health Information Technology for Economic and Clinical Health (HITECH) Act, approved in 2009. Under the HITECH Act, every hospital in the United States has been eligible for a minimum of \$2 million — and many millions more for larger hospitals - to buy and use “electronic health records”. Similarly, physicians have been eligible for payments ranging from \$44,000 to \$63,000 to begin to use such health electronic records. And, more critically, the federal government conditions all these investments on the ability of all these electronic health records to be shared, or interoperable, through local, regional, state, and, eventually, a national “health information exchange” [6]. HITECH includes a set of standards that allow senders to push health information securely to known receivers, to market based health information exchange solutions that can be used to create an exchange network. Providers must purchase technology and comply with metrics related to implementation, and that compliance is defined as meaningful use [7]. To achieve the intent and sustainability of meaningful use, technology first needs to show value at the front lines of healthcare delivery [8]. From that perspective, the American policy has made several assumptions as: i. technology is a strategic tool; ii. technology will continuously improve quality; iii. technology will work better if it is comprehensively implemented. The current policy takes a top-down strategy and assumes that there is uniform and solid evidence for use of technology in all types of provider settings, a view that is inconsistent with existing evidence [8]. As Funtowicz and Ravez [9,10] noted, *“The traditional distinction between ‘hard’, objective scientific facts and ‘soft’, subjective value-judgments is now inverted. All too often, we must make hard policy decisions where our only* *scientific inputs are irremediably soft. The requirement for the "sound science" that is frequently invoked as necessary for rational policy decisions may affectively conceal value-loadings that determine research conclusions and policy recommendations. In these new circumstances, invoking 'truth' as the goal of science is a distraction, or even a diversion from real tasks. A more relevant and robust guiding principle is quality, understood as a contextual property of scientific information".* The complex issue of introduction eHealth in our society should be recognized as a *post-normal problem* [11] that can be solved by "bringing 'facts' and 'values' into a unified conception of problem solving in these areas, and by replacing 'truth' by 'quality' as its core evaluative concept" [11]. The idea that quality differences should be measured by accounting for differences in services to the contribution to outcome has increasingly been recommended by some, and some possibilities would in fact exist to account for difference in the marginal benefit for the consumer that result of differences in the quality of the service [12]. Perhaps most prominently, this was shown in one of the recommendations from the Atkinson report from 2005 for strategies to improve price and productivity measurement in the UK: *"An output measure should be adjusted for the attributable incremental contribution of the activity to individual or collective welfare. This should include capturing any change in outcomes which is attributable to the use of the inputs. A basic count of activities does not measure the quality of the output such as change in quality of patient experience or clinical effectiveness. This is a continued weakness of the current method"* [13].

Given the reality of financial crisis in Europe, balancing rising cost pressures against limited resources is a concern across countries. As was emphasized in WHO publications, in 2009 [14]: *"Technological innovation is the most important driver of health care costs, estimated to account for between a half and three quarters of all growth in health care spending* [15,16]. *However, the role played by technological change is complex. New technologies can reduce costs through efficiency gains or through health improvements that reduce the need for further and perhaps more costly care. But they can also lead to higher costs: by increasing utilization; by extending the scope and range of possible treatments available; by extending treatment to a wider set of indications and to more people (expansion); by replacing an existing and cheaper technology (substitution)* [17]; *and, even if not more expensive, by being applied more widely within the relevant patient population than the existing technology (a combination of substitution and expansion)"* [14].

The requirements for adoption of PHMC should be analyzed from a sociotechnical perspective, that combines the social aspects of system development and technical solutions which address how PHMC may enhance the delivery of care.

2 Methodology and Scope of Study

Our objective was to identify requirements and barriers to adoption of pervasive sensing and computing in healthcare. To do so, the authors systematically reviewed guidelines, technical research work, declarations, recommendations, position papers, and social or psychological implication of health information technology published since January 2005 on the clinical and scientific databases: USA NIH repository for peer-reviewed primary research reports in the life sciences PubMed NCBI, Excerpta Medica Database (EMBASE), and IEEE Xplore. IEEE that stands for Institute of Electrical and Electronics Engineers publishes in IEEE Xplore leading journals, transactions and magazines in technology, including electrical engineering, computing, biotechnology, power and energy, telecommunications and dozens of other essential fields. A search of the 'grey' literature, citable material not indexed in NCBI Pub Med, EMBASE or IEEE Xplore, was also conducted. We systematically reviewed English language literature on human research related to the adoption and use of eHealth in the world. To obtain articles on eHealrh implementation and utilization, we required that one or more of the following keywords or phrases appear in the article: eHealth, health information technology, health information technology costs, electronic health records, electronic medical records, personal health records, patient-centered home medical records. All of the abstracts were examined manually to identify whether the publications should be retrieved in full text for further review. We excluded from our analysis the specific field of medical therapeutic research. This research allowed us to select 82 articles with issues relevant for description of requirements and barriers to pervasive healthcare adoption. We limited our analysis to papers related with technical research work on health information technology and pervasive healthcare, guidelines and position papers related with factors that facilitate or barriers to adoption of information communication technology. The scope of our review encompassed the benefits and associated barriers of eHealth for description of presently state of pervasive healthcare implementation and to call for future research on effective implementation and adoption.

3 Hand Fan Model – Framework for Analysis of Determinants for PHMC Adoption

Medical informatics research units began to appear during the 1970s mainly in USA and Poland [18]. Since then, despite the interest and significant investments in promoting medical informatics and health information technology solutions, there remains a major gap between the promise and reality of delivery. The NHS Future Forum [19] recognized that: *"There has been too much focus on different parts of the system - GPs, hospitals, public health - and insufficient attention to how they all join up to provide the integrated care that patients need"*.

In many countries, the information technology systems associated with social and economic infrastructure are enterprise-level systems with the following characteristics [20]: - they are able to run large-scale applications exceeding several million steps, including complicated on-line and batch processing; - frequent interactions with the system are possible, creating the potential for human operation faults; - dependability of the IT service is affected by environmental changes (such as a sudden peak of traffic). Defects in information technology services may have greater negative impacts on social and economic activities in the future, since the risks of such defects are increasing due to their wider applications and the growth of information technology systems' complexity and scale [20]. A meta-analysis of the impact of HIT implementation (i.e., CPOE - computerized physician order entry, EHRs - electronic medical records) across hospitals and ambulatory care organizations in seven countries identified implementation risk factors that included: implementation, and opportunity costs; staff anxiety and resistance to changing long-established processes; concerns about affecting provider - patient relationships; training [21,22]. Costs represent a significant barrier to HIT implementation for both small and large health care organizations [21,22,23,24,25]. The expenditures include acquisition costs (i.e., upfront capital required for purchase), ongoing maintenance costs (i.e. staff training, software upgrades), and infrastructure costs (i.e., cost on system implementation or maintenance; cost of computer upgrades or networking) [26,27].

From a sociotechnical perspective, the adoption of HIT implementation needs to combine the social aspects of system development (i.e., recognizing the skills and work of health care professionals) with technical system functioning (i.e., technology and tasks) to address how health IT fits within the organizational, operational, and cultural processes to enhance the delivery of care [28]. Furthermore, increased implementation and use of electronic records will require changes to workflows, increased emphasis on preventive care, retraining or hiring staff, and increased financial incentives to report and improve performance [29].

Based on the above discussions, we think that the key to further development and improvement in PHMC is *Post-Normal Scientific* analysis and management [11] of complexity of the factors that facilitate or limit PHMC implementation. We identified technological, financial, psychological, logistic and liability issues related with requirements and barriers to PHMC adoption (see Table 1). All these factors are interrelated and focus on one or several issues can improve adoption. However, sustainable health care using pervasive sensing and computing should be achieved by adopting a strategy in which the role of each variable is appreciated in its full context of complexity and uncertainty, taking into account the relevance of human commitments and values.

In the last decades, in problem solving, outline/framework design or for structural/ relationship representations, the graphical representations of relationships between ideas, words, tasks or other items in personal, familiar, educational or business context, the Mindmap is used. Mindmaps are used to generate, visualize, structure, and classify ideas, and as an aid to studying and organizing information, solving problems, making decisions, and writing. We choose to use a hand fan representation (see Figure 1) of interrelation between issues related with requirements and barriers to PHMC adoption for three reasons. First, history of use of hand fan is chronologically and socially correlated with history of using instruments in medicine. The oldest evidence of the use of instruments in medicine is from the Edwin Smith Papyrus, a textbook on surgery, that give details on anatomical observations, and the "examination, diagnosis, treatment, and prognosis" of numerous ailments. It was probably written around 1600 BC, but is regarded as a copy of several earlier texts. Medical information in it dates from as early as 3000 BC [30]. The earliest hand held fan, originated in Egypt in 3000 BC [31]. Ancient Egyptians used hand fans for cooling themselves, winnowing, or for

Table 1. Requirements and Barriers associated with PHMC adoption

	Requirements	Reference	Barriers	Reference
Technological	Sensors and Actuators	45,47,48,49,50	Sensors and Actuators	55,77
	Power management	51	Power Management	51
	Communication Network	45,47,52	Communication network	47,52, 77
	Autonomic Decision Making System	45,47,48,52, 53,54,55,56,57, 58	Interface with the User	95
	Security	46	Security	46,55
	Interoperability	55, 58	Interoperability	55,77
			Defects Management	20,27
Financial	Incentive	49,59,60	Costs	55,78,97, 98
Logistic	Quality Audit	27,69,70,71	Quality Audit	27,69,70 71
	Coordination	27,49,72,	Coordination	27,49,72
	Standard	55,59	Maintenance	48
	Team based care	56,74,75,76	Team based care	49
	Training	76,77,78,79	Training	76,77,96
	Lifestyle incentive management	45,50	Productivity	77
Liability	Policy	49,77,82	Policy	49,59,77, 87
	Transparency	49	Transparency	49,69,71
Psychological	Perception	59,83,84	Perception	73,77, 85,86,87, 99
	Culture	100,102,103	Culture	49,77,99, 100,102, 103
	Education	102,103	Education	99,102, 103

religious ceremonies. Elaborate hand fans symbolized power, royalty and status in the society. We used this graphical representation because we think that it may symbolize PHMC as a tool or instrument to maintain physiological and psychological health. Nowadays, one of the goals of PHMC, as in early beginning of the use of fans, is to be an instrument to maintain health, strengthening users' ability to manage their own care. Moreover, the currently technology related with PHMC is mainly afforded by countries with better socio-economic development and higher income population. Continuing the history, the Chinese made some innovations on the long shafted Egyptian hand fans by mounting it on a much shorter handle, which allowed the user to carry it around. They also popularized the half-moon shape hand fan by using bamboo, wood, ivory and silk. The artistic ability and creativity of the Chinese were displayed as the surface of their hand fans were ornamented with feathers or hand painted with various Chinese designs. Aside from being used to cool people, swat insects, and as a kung fu weapon, the hand fan symbolized various things including beauty, feminism, royalty, and social status. Japan made another innovation on the hand fan by coming up with the first folding fan in the 8th century BC. Like the Chinese and Egyptians, the Japanese recognized that hand fans symbolized prestige, royalty and other social standings. Soon after, hand fans gradually spread to Europe and other western countries [31]. What was happening with medicine in that time? The most ancient Chines medical text, *Huangdi Neijing* also known as *The Inner Canon of Huangdi* or *Yellow Emperor's Inner Canon*, discusses the use of needles for therapy (acupuncture) [32]. Are presented, in this text, concepts which have been developed in China from more than 2000 years, including various forms of herbal medicine, acupuncture, massage (Tui na), exercise (qigong), and dietary therapy. According to the *Huangdi Neijing*, the forces of universe can be understood via rational means and man can stay in balance or return to balance and health by understanding the laws of these natural forces. Man is a microcosm that mirrors the larger macrocosm and the reason of disease development is natural effects of diet, lifestyle, emotions, age and environment [32]. Ancient Chinese thought recognized also that *chaos* and *order* are related. Ying and Yang, emerged from chaos and retain the qualities of chaos. *Too much of either brings back chaos.* As we known, nowadays a significant part of research work on engineering and informatics adopts the new and exciting field of scientific inquiry – the *chaos theory* – to better understand transient changes in economics (Benoit Mandelbrot), communication of information through telephone line (Cantor Set), fractal presented in turbulence, blood vessels, lung, etc. The new *chaos*-based understanding of nature requires a new notion of the appropriate form of scientific practice. This new practice of science is called "*post-normal*" science. The *Post-Normal Science* (PNS) is a new conception of the management of complex science-related issues. It focuses on aspects of problem solving that tend to be neglected in traditional accounts of scientific practice: uncertainty, value loading, and a plurality of legitimate perspectives [11]. *"In pre-chaos days, it was assumed that values were irrelevant to scientific inference, and that all uncertainties could be tamed. That was the "normal science" in which almost all research, engineering and monitoring was done. Of course, there was always a special class of "professional consultants" who used science, but who confronted special uncertainties and value-choices in their work. Such would be senior surgeons and engineers, for whom every case was unique, and whose skill was crucial for the welfare (or even lives) of their clients*" [10]. We observed this tendency of thought on involved stakeholders in the implementation of e-Patient, eHealth Collaborative telehealth, mHealth, electronic health records (EHRs), electronic medical records (EMRs), personal health records (PHRs), patient-centered medical home (PCMH).

e-Patient (Also known as Internet patient), is a health consumer who uses the Internet to gather information about a medical condition of particular interest to him, and who uses electronic communication tools (including Web 2.0 tools) in coping with medical conditions. The term encompasses both those who seek online guidance for their own ailments and the friends and family members (e-Caregivers) who go online on their behalf. e-Patients report two effects of their online health research: "*better health information and services, and different (but not always better) relationships with their doctors*." As the use of the term e-Patient has evolved, there has been less emphasis on Internet access and technology, and a contention that the "e" in "e-patient" stands for "*empowered, engaged, equipped, enabled*" [33];

mHealth or m-Health: Includes the use of mobile devices in collecting aggregate and patient level health data, providing healthcare information to practitioners, researchers, and patients, real-time monitoring of patient vital signs, and direct provision of care, via mobile telemedicine [34];

EHRs: An electronic record of health-related information on an individual that conforms to nationally recognized interoperability standards and that can be created, managed, and consulted by authorized clinicians and staff across more than one healthcare organization [35]. While EHRs are a critical aspect of health IT, the term embodies a much wider array of technologies, including PHRs, m-Health, telehealth (including telemedicine), and the use of technology for physical fitness (e.g., Kinect, Nintendo's Wii Fit), as well as cognitive stimulation (e.g., online Solitaire or memory games). In Hong Kong, a computerized patient record system called the Clinical Management System (CMS) has been developed by the Hospital Authority since 1994. This system has been deployed at all the sites of the Authority (40 hospitals and 120 clinics), and is used by all 30,000 clinical staff on a daily basis, with a daily transaction of up to 2 million. The comprehensive records of 7 million patients are available on-line in the Electronic Patient Record (ePR), with data integrated from all sites. Since 2004, radiology image viewing has been added to the ePR, with radiography images from any HA site being available as part of the ePR [36]. The countries with higher adoption of health information technology (more than 90%), particularly EHRs, are Netherlands, New Zeeland, Norway, United Kingdom, Austria, Sweden, and Italia [see 37]. Nearly all primary care physician in Denmark have EHRs with full clinical functionality [38];

EMRs: An electronic record of health-related information on an individual that can be created, gathered, managed, and consulted by authorized clinicians and staff within one health care organization. The main difference between EHRs and EMRs is that EMRs are used by and within a single organization (such as an ambulatory practice), and EHR applies when it contains data from or is accessed by multiple organizations [35];

PHRs: Health records where health data and information related to the care of a patient is maintained by the patient. This stands in contrast with the more widely used EHRs or EMRs, which are operated by institutions (such as a hospital) and contains data entered by clinicians or billing data to support insurance claims [39]. PHRs can be broadly described as a set of electronic tools that allow consumers to access, coordinate, and control appropriate parts of their health information. PHRs combine not only data, but knowledge and software tools, which motivate patients to become more involved in their healthcare [40,41]. A PHR should typically present a comprehensive and precise review of the health and medical history of the individual patient through the collection of information from a variety of sources. Since it is retained, maintained and controlled by the consumer, the PHR positions the consumer at the core of the healthcare process, potentially fostering personal empowerment and facilitating self-management, shared decision making and better clinical outcomes [40,41]. The health data on PHRs might include patient-reported outcome data, lab results, data from devices such as wireless electronic weighing scales or collected passively from a smartphone. PHRs intersect with connected health in that they attempt to increase the involvement of consumers in their care. PHRs, whether through patient portals, electronic downloads onto a personal USB drive, or through a company sponsored Web site (e.g. MyAlert, Microsof HealthVault), allow patients timely access to their medical information.

PCMH or Medical Home: A team of people embedded in the community who seek to improve the health and healing of the people in that community. They work to optimize the fundamental attributes of primary care combined with evolving new ideas about organizing and developing practice and changing the larger health care and reimbursement systems [42]. Unlike more narrowly focused ways of organizing the delivery of commodities of healthcare, the PCMH aims to personalize, prioritize and integrate care to improve the health of whole people, families, communities and populations. Thus, the PCMH consists of the following: 1) the fundamental tenets of primary care: access, comprehensiveness, integration and relationship; 2) new ways of organizing practice; 3) development of practices' internal capabilities; 4) health care system and reimbursement changes. The PCMH concept links new approaches to health care organization with the well-established primary care function for improving the health of people and populations [42].

The above comparison of history of hand held fans and the use of instruments in medicine underscores our first reason for hand fan symbolic representation of determinants to PHMC adoption. The second reason for choosing the hand fan model in the representation of variables associated with PHMC adoption is its architecture and functionality. The number of pieces that commonly are part of a folding fan, in our model are the determinants (variable associated with requirements and barriers) of PHMC. Links between fan pieces can be associated in our models with statistical correlation between different variable encompassed by PHMC adoption. Low correlation between the determinants that undermine and the determinants that facilitate PHMC may be represented in the open top part of hand fan where may be possible to better observe and analyze the complexity of the factors associated with PHMC adoption, while in the bottom part of the fan, more rigid, less flexible and not much useful for cooling, may be represented in our models the variables with high correlation between barriers and facilitators that reduce the possibility of adoption of PHMC, because of the high risk and lower probability for implementation and functioning.

Fig. 1. Hand fan model of determinants in pervasive healthcare adoption

The third reason for adopting the hand fan model of PHMC is that hand fan is an example of human created instruments where the processes and results are all time different in comparison with the instruments created by other instruments (e.g. machine created objects). When designing PHMC, this model may suggest that it is necessary to analyze the complexity of human perception, thinking, behavior, human relationship with objects and society. For instance, amidst the advent of countless technologies, hand fans by their functionality, usability and associated human values did not become obsolete. Hand fans persisted to exude their value. They are still a useful instrument in our society. Aside from being functional, hand fans have being used for various purposes: gifts or wedding favors during weddings; home decor or office decor; promotional products [31]. Hand fan graphical representation as a model for the determinants to PHMC adoption may symbolize also the potential changes along the time in fabrication, use and perception of the PHMC technology in society - pervasive (ubiquitous) computing "*the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives"* [43]. Ultimately, computers would "vanish into the background" *weaving "themselves into the fabric of everyday life until they are indistinguishable from it*" [43].

Today's health information systems are far from perfect and an attitude of openness and willingness to help to improve the health system is crucial. There is a need for a decision support tool for PHMC implementation that asks the 'right' questions, but does not restrict answers to a pre-defined, context-free set. Responses to questions may serve to identify information needs (including value assumptions), the expertise required and appropriate criteria to be used. Processes incorporating multiple opportunities for stakeholders' involvement at multiple points, and transparent, explicit approaches that incorporate social values or equity arguments into decisions on the development, implementation and funding of pervasive health monitoring and pervasive healthcare, should be considered in the framework of PHMC technologies. The framework should be considered as a checklist of the necessary elements for improving the acceptability of processes and, in turn, decisions.

4 Requirements for PHMC Adoption

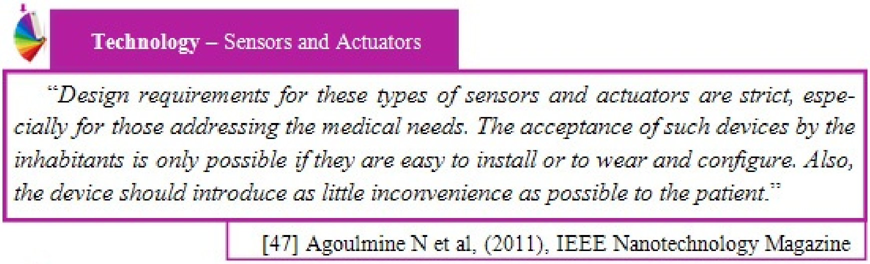
Pervasive technology has been identified as a strong asset for achieving the vision of user-centered preventive healthcare. In order to make this vision a reality, new strategies for design, development and evaluation of technology have to find a common denominator and consequently interoperate [3]. As Kreps and Neuhauser [44] so elegantly stated: *"eHealth information that is interactive, interoperable, personally engaging, contextually tailored, with the ability to be delivered to mass audiences can really make a difference in enhancing the quality of healthcare and health promotion efforts. It can reach diverse audiences with information that matches their health needs and communication orientations. Health information can be easily updated and adapted to changing health conditions. It can foster greater participation between interdependent healthcare providers and consumers and insure that all crucial stakeholders in the healthcare enterprise have access to timely and accurate information to guide their decisions".*

Requirements with regard to the technology of pervasive monitoring systems point foremost to the use of sensors that are: non-wearable; unobtrusive (embedded sensors networks, nanosensors, etc.); compact; lightweight; with long battery life; simple to operate - that is, intuitive and thus requiring little training; relatively easy to customize for different approaches; feasible devices supporting teleassistance. Moreover, monitoring should be ubiquitous. The interface with the user should be not very complex but also not very simple, clinically intuitive with all the features necessary to allow clinicians to deliver high-quality care or to be used for self-management of therapeutic processes. The comprehensive information on the important technological requirements for pervasive healthcare aplications and various solutions for optimization of usability of existing technology for pervasive sensing and pervasive health was presented by Varshney [45].

Many important issues are currently related with sensors and actuators for unobtrusive health monitoring (e.g. improve reliability of non-contact electrocardiogram, ballistocardiogram, unobtrusive plethysmogram or unobtrusive motor activity monitoring) as well as software architecture aiming to provide means for applications running on pervasive sensing devices to make use of a wide range of mobile devices, short-range and long-range wireless communication. In a pervasive health context, the system should integrate heterogeneous devices, to support a multimodal interaction and user interface migration, and also to manage context information. The user should have access to expert fuzzy systems which may provide a "prognosis" in the form of predicted outcomes - with each outcome presented as a curve that is a function of time, and the possibility to explore different intervention plans. In addition to decision support, tools that provide motivation and assist with compliance with treatment or instructions for healthier lifestyle should be available. Virtual reality and augmented reality may contribute to increase accessibility to more comprehensive and efficient health care. For instance, "mediated immersion" (pervasive experiences within a digitally enhanced context) may allow that a patient consult remotely, in real time a physician, and that consultation and diagnosis may be based on using a 3D functional model of patient body or body part, by accessing data from sensors that monitor physiological and biochemical changes in the patient, as well as patient health database (comorbidity, allergy, treatments, etc.).

There are now open issues and technological challenges in pervasive health monitoring related with access to health information, power management, lack of comprehensive coverage of wireless and mobile networks, reliability of wireless infrastructure, privacy and security, representation of data, autonomic decision making, and interoperability. Although several technologies are developed to improve security and privacy (see [46]), more work is needed in order to ensure the integrity and confidentiality of the information, mainly transmitted through wireless and mobile networks where security is still seen as insufficient. We list several references related with important requirements and barriers for pervasive health care. Although the selected literature mainly discusses issues related with HIT, architecture for sensor-enhanced health information systems and for information communication technology for effective PHMC could be design by thoughtful analysis of selected papers.

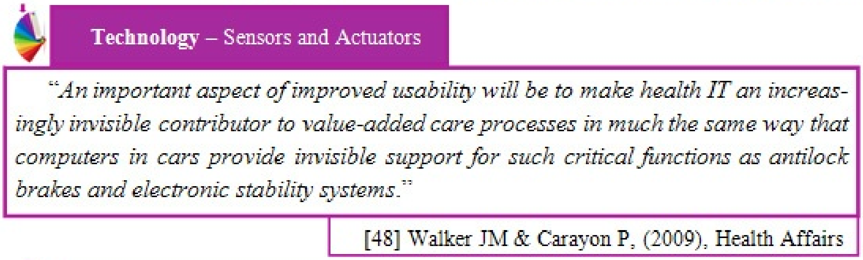
Requirements – Technology



Technology – Sensors and Actuators

“Design requirements for these types of sensors and actuators are strict, especially for those addressing the medical needs. The acceptance of such devices by the inhabitants is only possible if they are easy to install or to wear and configure. Also, the device should introduce as little inconvenience as possible to the patient.”

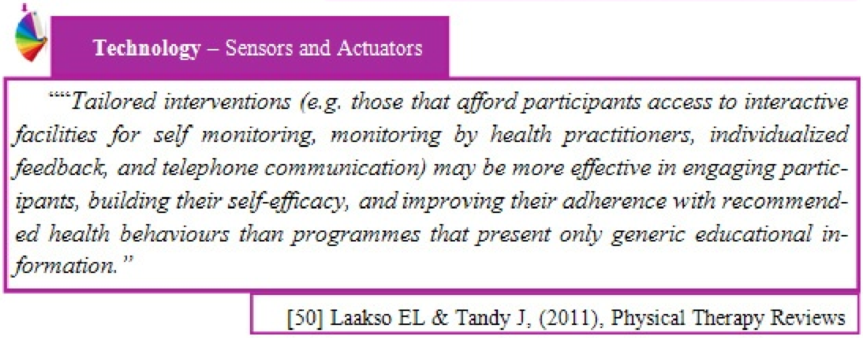
[47] Agoulmine N et al, (2011), IEEE Nanotechnology Magazine



Technology – Sensors and Actuators

“An important aspect of improved usability will be to make health IT an increasingly invisible contributor to value-added care processes in much the same way that computers in cars provide invisible support for such critical functions as antilock brakes and electronic stability systems.”

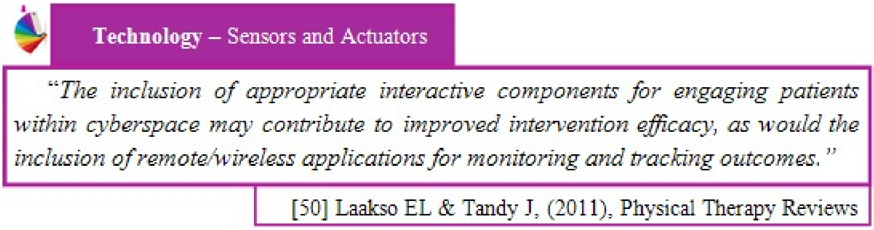
[48] Walker JM & Carayon P, (2009), Health Affairs



Technology – Sensors and Actuators

““Tailored interventions (e.g. those that afford participants access to interactive facilities for self monitoring, monitoring by health practitioners, individualized feedback, and telephone communication) may be more effective in engaging participants, building their self-efficacy, and improving their adherence with recommended health behaviours than programmes that present only generic educational information.”

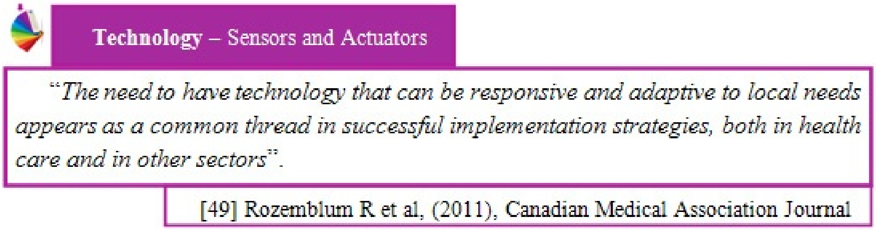
[50] Laakso EL & Tandy J, (2011), Physical Therapy Reviews



Technology – Sensors and Actuators

“The inclusion of appropriate interactive components for engaging patients within cyberspace may contribute to improved intervention efficacy, as would the inclusion of remote/wireless applications for monitoring and tracking outcomes.”

[50] Laakso EL & Tandy J, (2011), Physical Therapy Reviews

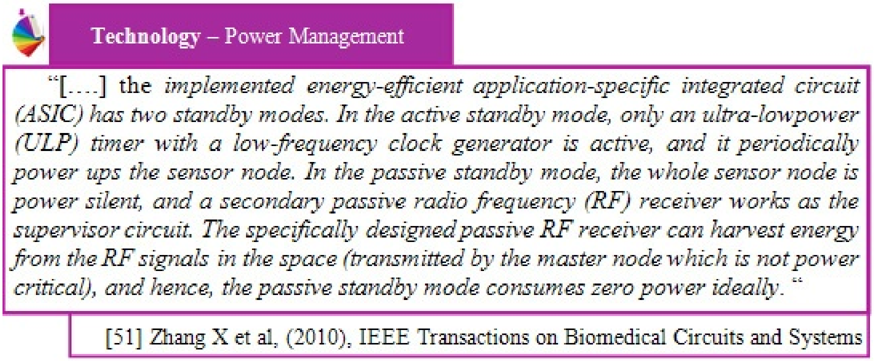


Technology – Sensors and Actuators

“The need to have technology that can be responsive and adaptive to local needs appears as a common thread in successful implementation strategies, both in health care and in other sectors”.

[49] Rozemblum R et al, (2011), Canadian Medical Association Journal

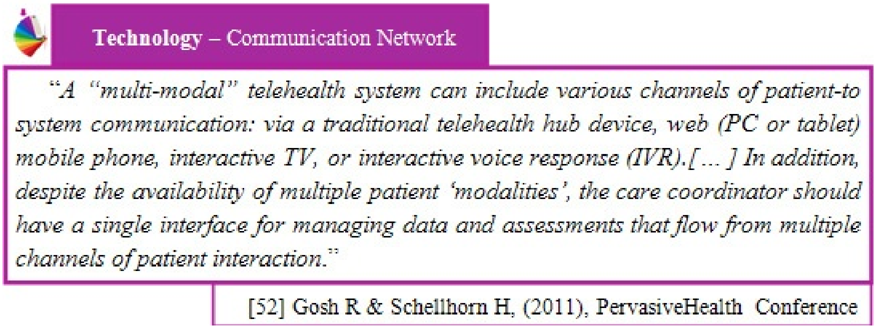
Requirements – Technology



Technology – Power Management

“[….] the *implemented energy-efficient application-specific integrated circuit (ASIC) has two standby modes. In the active standby mode, only an ultra-lowpower (ULP) timer with a low-frequency clock generator is active, and it periodically power ups the sensor node. In the passive standby mode, the whole sensor node is power silent, and a secondary passive radio frequency (RF) receiver works as the supervisor circuit. The specifically designed passive RF receiver can harvest energy from the RF signals in the space (transmitted by the master node which is not power critical), and hence, the passive standby mode consumes zero power ideally.* “

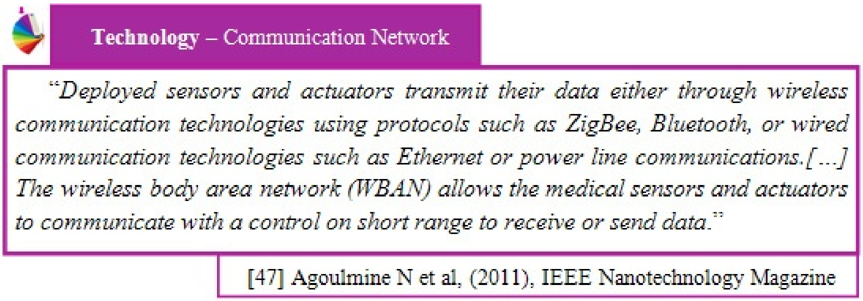
[51] Zhang X et al, (2010), IEEE Transactions on Biomedical Circuits and Systems



Technology – Communication Network

“A “multi-modal” telehealth system can include various channels of patient-to system communication: via a traditional telehealth hub device, web (PC or tablet) mobile phone, interactive TV, or interactive voice response (IVR).[…] In addition, despite the availability of multiple patient ‘modalities’, the care coordinator should have a single interface for managing data and assessments that flow from multiple channels of patient interaction.”

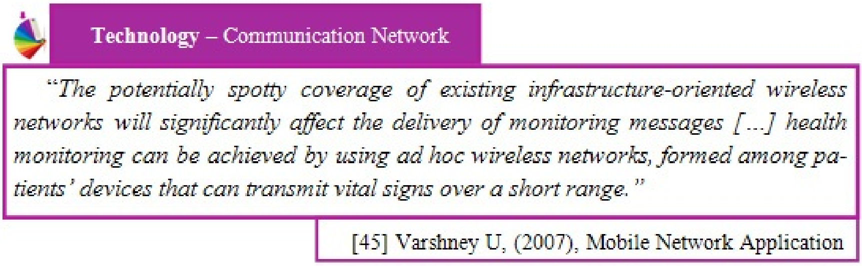
[52] Gosh R & Schellhorn H, (2011), PervasiveHealth Conference



Technology – Communication Network

“Deployed sensors and actuators transmit their data either through wireless communication technologies using protocols such as ZigBee, Bluetooth, or wired communication technologies such as Ethernet or power line communications.[…] The wireless body area network (WBAN) allows the medical sensors and actuators to communicate with a control on short range to receive or send data.”

[47] Agoulmine N et al, (2011), IEEE Nanotechnology Magazine



Technology – Communication Network

“The potentially spotty coverage of existing infrastructure-oriented wireless networks will significantly affect the delivery of monitoring messages […] health monitoring can be achieved by using ad hoc wireless networks, formed among patients’ devices that can transmit vital signs over a short range.”

[45] Varshney U, (2007), Mobile Network Application

Requirements – Technology

Technology – Autonomic Decision Making System

“Some intelligence in the form of context awareness can be built in pervasive services to avoid “False-positive” alerts.”

[45] Varshney U, (2007), Mobile Network Application

Technology – Autonomic Decision Making System

“The ADMS collects, filters, and analyzes the data and then saves it in a local database. The goal of ADMS is to build a model of the inabitant’s environment and maintain their medical profile. All the received data is transformed into knowledge to feed the embedded decision system. Based on the generated knowledge and as a set of predefined policy rules, ADMS may be able to understand the situation of the inhabitant and make appropriate decisions about his/her safety and health care in an autonomic manner. These decision can be either new knowledge in the system, actions to enforce in the smart home components (e.g., switching on a light and opening a window), or actions on the medical sensors (e.g. delivering a drug and changing the sampling frequency). ADMS is also responsible for keeping the third party medical and safety institutions (e.g., hospital and police) fully appraised of the situation of the inhabitant.”

[47] Agoulmine N et al, (2011), IEEE Nanotechnology Magazine

Technology – Autonomic Decision Making System

“Context can consist of both implicit and explicit information and can even be further divided among low level (such as time, temperature, and bandwitdth) and high level contexts (complex user activity). The primary context types are location, identity, time, and activity. In healthcare environment, the context types may also include current medications, handicaps, and current environment and may relate with person’s identity and/or location, but likely to change with time.”

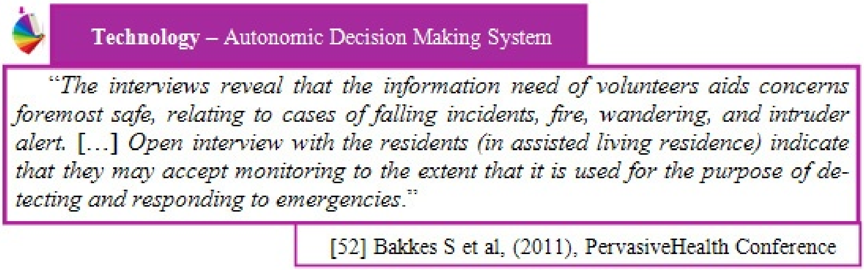
[45] Varshney U, (2007), Mobile Network Applications

Technology – Autonomic Decision Making System

“Simply providing patients with access to their information online and enabling them to share it with others is inadequate; useful technologies for patients need to be ‘integrated into the patient’s…existing health and psychosocial support infrastructure’”

[48] Walker JM & Carayon P, (2009), Health Affairs

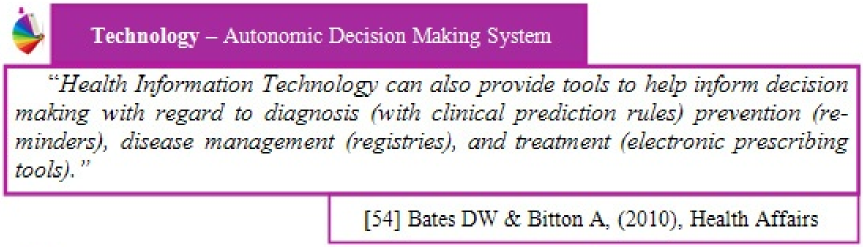
Requirements – Technology



Technology – Autonomic Decision Making System

“The interviews reveal that the information need of volunteers aids concerns foremost safe, relating to cases of falling incidents, fire, wandering, and intruder alert. [...] *Open interview with the residents (in assisted living residence) indicate that they may accept monitoring to the extent that it is used for the purpose of detecting and responding to emergencies.”*

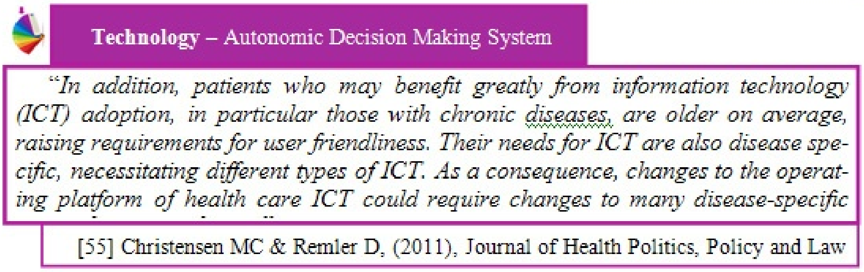
[52] Bakkes S et al, (2011), PervasiveHealth Conference



Technology – Autonomic Decision Making System

“Health Information Technology can also provide tools to help inform decision making with regard to diagnosis (with clinical prediction rules) prevention (reminders), disease management (registries), and treatment (electronic prescribing tools).”

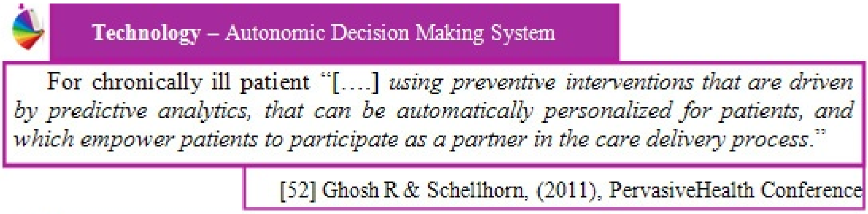
[54] Bates DW & Bitton A, (2010), Health Affairs



Technology – Autonomic Decision Making System

“In addition, patients who may benefit greatly from information technology (ICT) adoption, in particular those with chronic diseases, are older on average, raising requirements for user friendliness. Their needs for ICT are also disease specific, necessitating different types of ICT. As a consequence, changes to the operating platform of health care ICT could require changes to many disease-specific

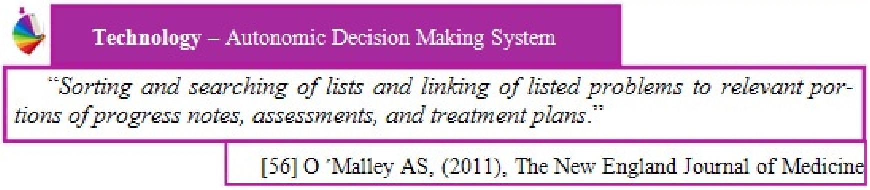
[55] Christensen MC & Remler D, (2011), Journal of Health Politics, Policy and Law



Technology – Autonomic Decision Making System

For chronically ill patient “[….] *using preventive interventions that are driven by predictive analytics, that can be automatically personalized for patients, and which empower patients to participate as a partner in the care delivery process.”*

[52] Ghosh R & Schellhorn, (2011), PervasiveHealth Conference

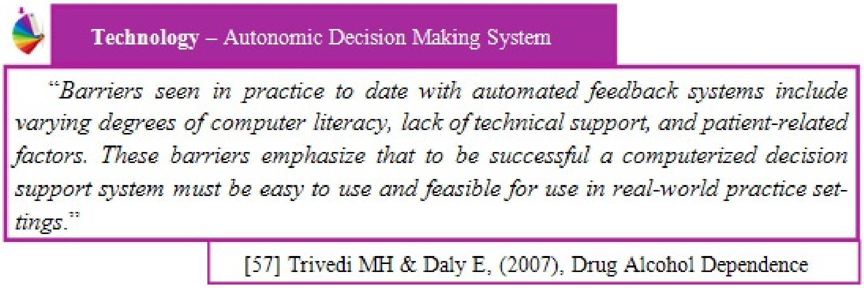


Technology – Autonomic Decision Making System

“Sorting and searching of lists and linking of listed problems to relevant portions of progress notes, assessments, and treatment plans.”

[56] O ´Malley AS, (2011), The New England Journal of Medicine

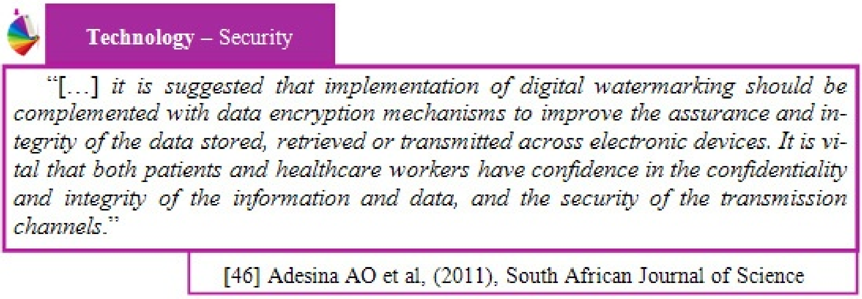
Requirements – Technology



Technology – Autonomic Decision Making System

"Barriers seen in practice to date with automated feedback systems include varying degrees of computer literacy, lack of technical support, and patient-related factors. These barriers emphasize that to be successful a computerized decision support system must be easy to use and feasible for use in real-world practice settings."

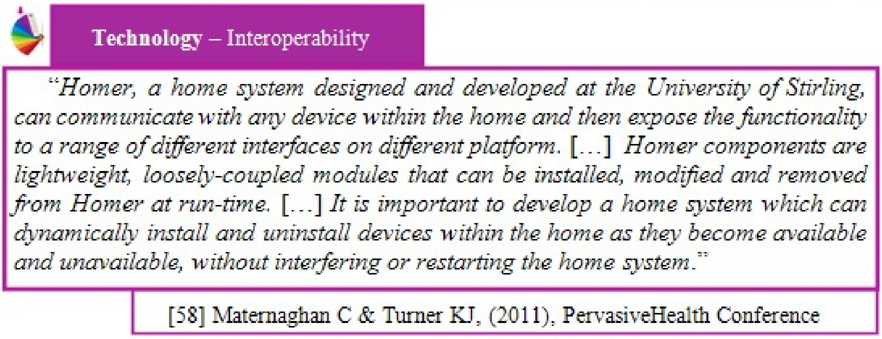
[57] Trivedi MH & Daly E, (2007), Drug Alcohol Dependence



Technology – Security

"[…] *it is suggested that implementation of digital watermarking should be complemented with data encryption mechanisms to improve the assurance and integrity of the data stored, retrieved or transmitted across electronic devices. It is vital that both patients and healthcare workers have confidence in the confidentiality and integrity of the information and data, and the security of the transmission channels."*

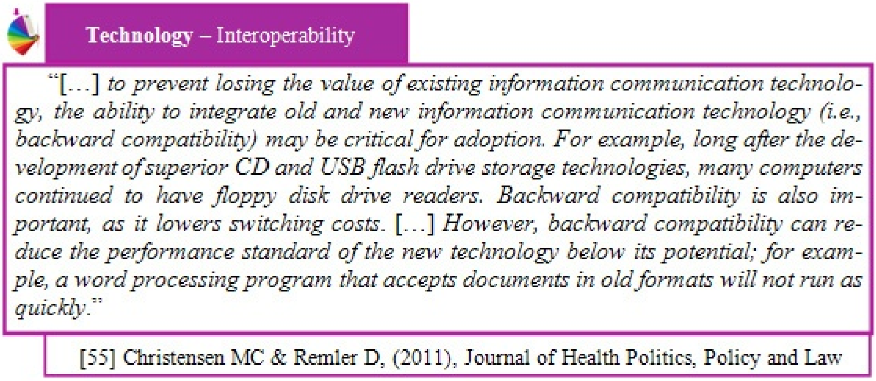
[46] Adesina AO et al, (2011), South African Journal of Science



Technology – Interoperability

"Homer, a home system designed and developed at the University of Stirling, can communicate with any device within the home and then expose the functionality to a range of different interfaces on different platform. […] *Homer components are lightweight, loosely-coupled modules that can be installed, modified and removed from Homer at run-time.* […] *It is important to develop a home system which can dynamically install and uninstall devices within the home as they become available and unavailable, without interfering or restarting the home system."*

[58] Maternaghan C & Turner KJ, (2011), PervasiveHealth Conference



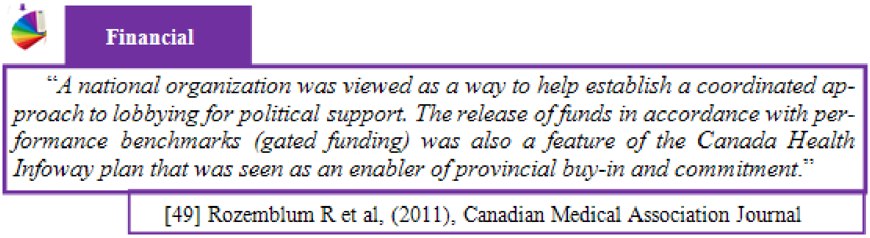
Technology – Interoperability

"[…] *to prevent losing the value of existing information communication technology, the ability to integrate old and new information communication technology (i.e., backward compatibility) may be critical for adoption. For example, long after the development of superior CD and USB flash drive storage technologies, many computers continued to have floppy disk drive readers. Backward compatibility is also important, as it lowers switching costs.* […] *However, backward compatibility can reduce the performance standard of the new technology below its potential; for example, a word processing program that accepts documents in old formats will not run as quickly."*

[55] Christensen MC & Remler D, (2011), Journal of Health Politics, Policy and Law

Incentive for adopting pervasive health monitoring and coverage of some services may support development of health delivery models that are more efficient and of a higher quality, with reduced healthcare labor and at a low-cost healthcare platform for patients and healthcare professionals.

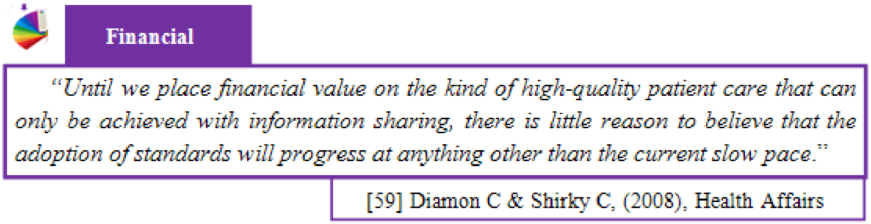
Requirements – Financial



Financial

"A national organization was viewed as a way to help establish a coordinated approach to lobbying for political support. The release of funds in accordance with performance benchmarks (gated funding) was also a feature of the Canada Health Infoway plan that was seen as an enabler of provincial buy-in and commitment."

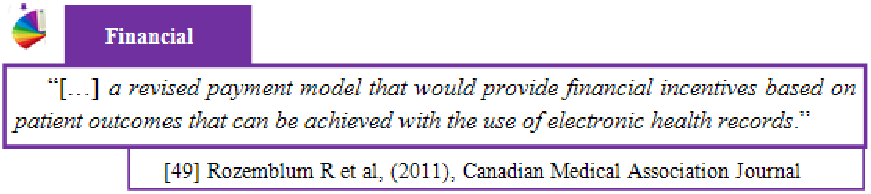
[49] Rozemblum R et al, (2011), Canadian Medical Association Journal



Financial

"Until we place financial value on the kind of high-quality patient care that can only be achieved with information sharing, there is little reason to believe that the adoption of standards will progress at anything other than the current slow pace."

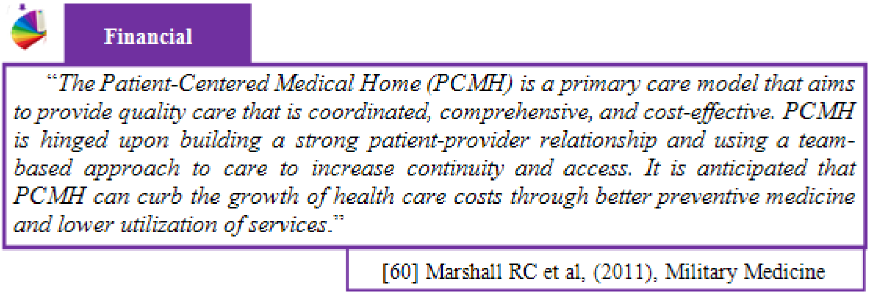
[59] Diamon C & Shirky C, (2008), Health Affairs



Financial

"[…] *a revised payment model that would provide financial incentives based on patient outcomes that can be achieved with the use of electronic health records."*

[49] Rozemblum R et al, (2011), Canadian Medical Association Journal



Financial

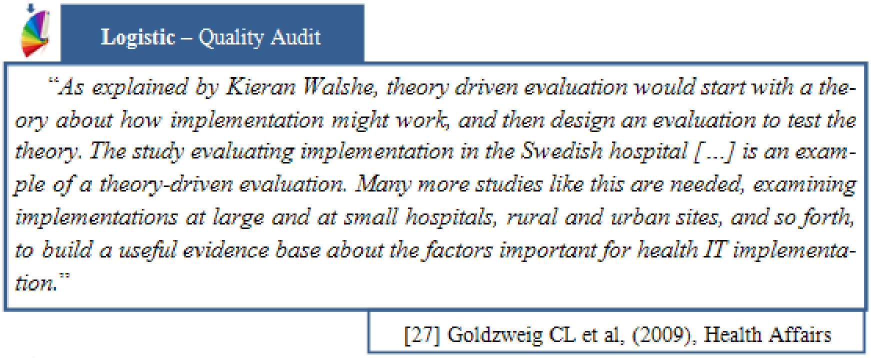
"The Patient-Centered Medical Home (PCMH) is a primary care model that aims to provide quality care that is coordinated, comprehensive, and cost-effective. PCMH is hinged upon building a strong patient-provider relationship and using a team-based approach to care to increase continuity and access. It is anticipated that PCMH can curb the growth of health care costs through better preventive medicine and lower utilization of services."

[60] Marshall RC et al, (2011), Military Medicine

In the study of Coye at al [62] is underscored that remote health monitoring should reduce health expenditure by: (1) early intervention - to detect deterioration and intervene before unscheduled and preventable services are needed; (2) integration of care - exchange of data and communication across multiple comorbidities, multiple providers, and complex disease states; (3) coaching - motivational interviewing and other techniques to encourage patient behavioral change and self-care; (4) increased trust - patients' satisfaction and feelings of "connectedness" with providers; (5) workforce changes - shifts to lower-cost and more plentiful health care workers, including medical assistants, community health workers, and social workers; and (6) increased productivity - decreased home visit travel time and automated documentation. In Europe, Denmark and Netherlands are the countries with higher adoption of health information technology [61,62,63]. In 2006, 98% of the Danish GPs, all 73 hospital and all 331 pharmacies shared data over the network, and about 80% of the totally exchanged healthcare information was sent electronically [60]. The Danish Centre for Health Telematics rates as significant factors for EHRs implementation: a) national, regional and local commitment, b) the cost-effectiveness of the program, c) close cooperation between clinicians and developers, efficient project management, c) testing and certification of software solutions and operators, and f) an intensive information and promotion policy. In our analysis, we find that in addition to optimization hardware and software for remote, unobtrusive health monitoring, more work should be done in order to allow PHMC adoption: 1) better evaluation of the implemented system; 2) better coordination of involved stakeholders; 3) respect and improvement of existing eHealth standards, or introduction of new standards for various aspects of PHMC; 4) collaboration and team work of all stakeholders that might benefit from pervasive health implementation; 5) training in using new technologies; 6) training for searching library and information sciences related with health technology and information communication technology; 7) training in thoughtfully analysis of added value associated with new health technology; 8) promotion of healthier lifestyle; 9) analysis of social organizational change process when is designed PHMC; 10) adequate policy support for quality improvement of pervasive health systems; 11) transparency with regard to the goal, business plan and process implementation of pervasive healthcare; 12) consideration of perception of patients, as well as perception of healthy individuals and patient - health professional relationship as a core organizational operational system for pervasive health monitoring; 13) healthcare equity through improved data collection; 14) education for technology literacy, and 15) education for lifestyle management using new technologies.

A number of publications cite the importance of involving the expertise and knowledge of healthcare professionals to ensure that emerging technologies are appropriate for clinical use [64,65]. Physicians, doctors, nurses, occupational therapists, nutritionists, physiotherapists must be involved in pervasive healthcare, they providing important skills and knowledge for promoting healthier lifestyle and for lowering negative impact of chronic diseases on patients and healthcare expenditure. Stevens [66] suggested that nurse involvement in system's design can yield positive results because they understand the context in which the system will be used and can link it with issues such as patient safety and user acceptance. Huryk [67] reported that nurses are more likely to be satisfied with a system if they have been involved in its design. Excluding healthcare professionals from the development of pervasive health monitoring systems is likely to be detrimental to their design.

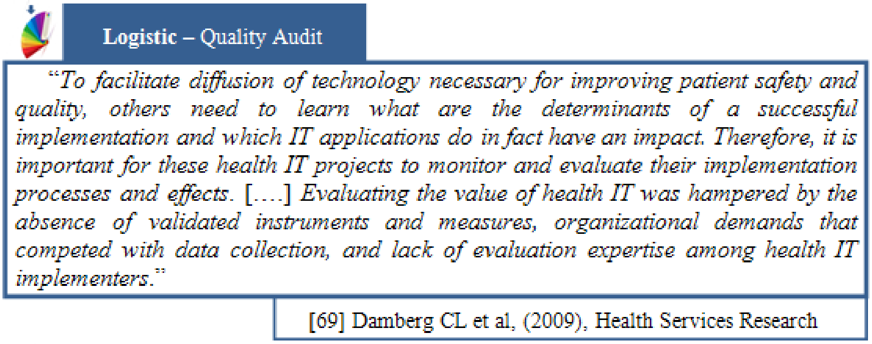
Requirements – Logistic



Logistic – Quality Audit

"As explained by Kieran Walshe, theory driven evaluation would start with a theory about how implementation might work, and then design an evaluation to test the theory. The study evaluating implementation in the Swedish hospital [...] is an example of a theory-driven evaluation. Many more studies like this are needed, examining implementations at large and at small hospitals, rural and urban sites, and so forth, to build a useful evidence base about the factors important for health IT implementation."

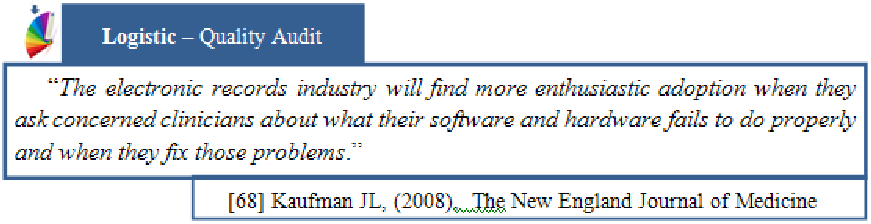
[27] Goldzweig CL et al, (2009), Health Affairs



Logistic – Quality Audit

"To facilitate diffusion of technology necessary for improving patient safety and quality, others need to learn what are the determinants of a successful implementation and which IT applications do in fact have an impact. Therefore, it is important for these health IT projects to monitor and evaluate their implementation processes and effects. [....] *Evaluating the value of health IT was hampered by the absence of validated instruments and measures, organizational demands that competed with data collection, and lack of evaluation expertise among health IT implementers."*

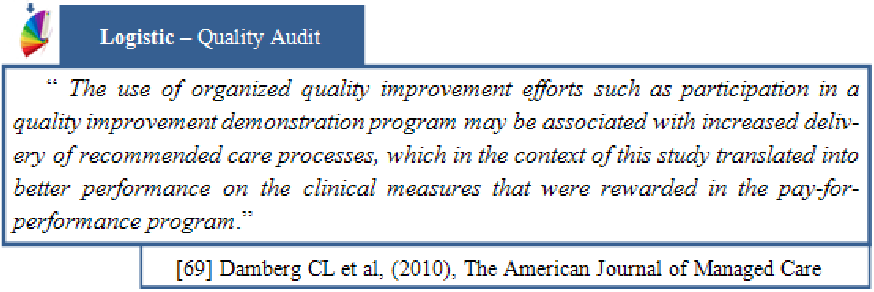
[69] Damberg CL et al, (2009), Health Services Research



Logistic – Quality Audit

"The electronic records industry will find more enthusiastic adoption when they ask concerned clinicians about what their software and hardware fails to do properly and when they fix those problems."

[68] Kaufman JL, (2008), The New England Journal of Medicine

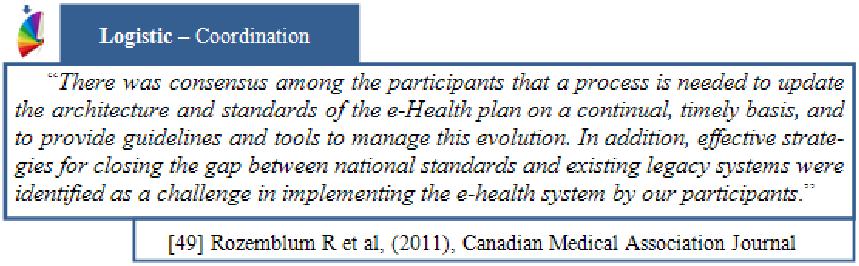


Logistic – Quality Audit

" The use of organized quality improvement efforts such as participation in a quality improvement demonstration program may be associated with increased delivery of recommended care processes, which in the context of this study translated into better performance on the clinical measures that were rewarded in the pay-for-performance program."

[69] Damberg CL et al, (2010), The American Journal of Managed Care

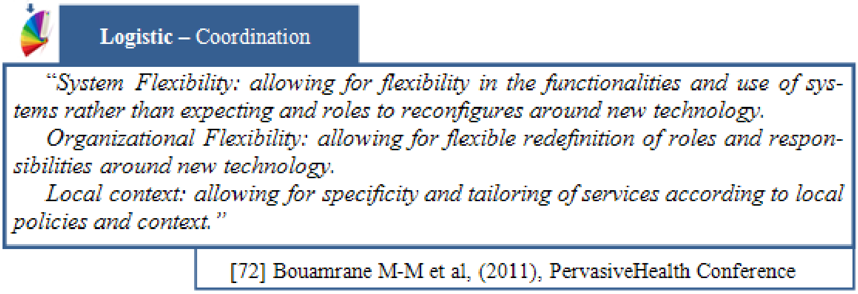
Requirements – Logistic



Logistic – Coordination

"There was consensus among the participants that a process is needed to update the architecture and standards of the e-Health plan on a continual, timely basis, and to provide guidelines and tools to manage this evolution. In addition, effective strategies for closing the gap between national standards and existing legacy systems were identified as a challenge in implementing the e-health system by our participants."

[49] Rozemblum R et al, (2011), Canadian Medical Association Journal



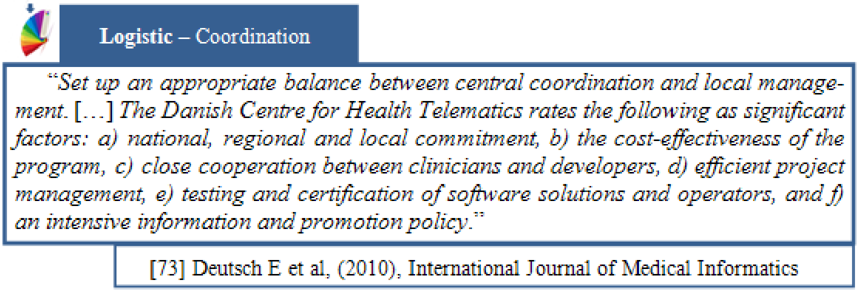
Logistic – Coordination

"System Flexibility: allowing for flexibility in the functionalities and use of systems rather than expecting and roles to reconfigures around new technology.

Organizational Flexibility: allowing for flexible redefinition of roles and responsibilities around new technology.

Local context: allowing for specificity and tailoring of services according to local policies and context."

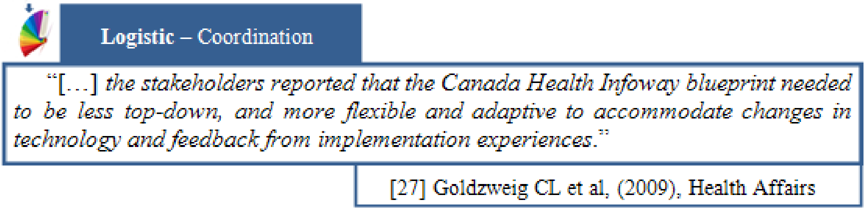
[72] Bouamrane M-M et al, (2011), PervasiveHealth Conference



Logistic – Coordination

"Set up an appropriate balance between central coordination and local management. [...] *The Danish Centre for Health Telematics rates the following as significant factors: a) national, regional and local commitment, b) the cost-effectiveness of the program, c) close cooperation between clinicians and developers, d) efficient project management, e) testing and certification of software solutions and operators, and f) an intensive information and promotion policy."*

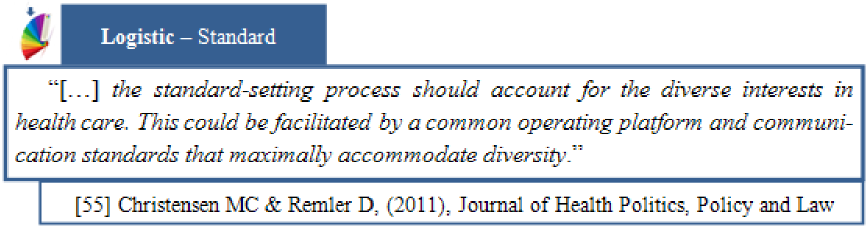
[73] Deutsch E et al, (2010), International Journal of Medical Informatics



Logistic – Coordination

"[...] *the stakeholders reported that the Canada Health Infoway blueprint needed to be less top-down, and more flexible and adaptive to accommodate changes in technology and feedback from implementation experiences."*

[27] Goldzweig CL et al, (2009), Health Affairs



Logistic – Standard

"[...] *the standard-setting process should account for the diverse interests in health care. This could be facilitated by a common operating platform and communication standards that maximally accommodate diversity."*

[55] Christensen MC & Remler D, (2011), Journal of Health Politics, Policy and Law

Requirements – Logistic

Logistic – Standard

> "[…] *standards for moving data across the network are more important than standards expressing the content of that data. Put another way, it is better to share important but uncodified information between Doctor A and Doctor B so that an informed clinical decision can be made, than to have perfectly formatted data that never leaves Doctor A's office.*"

[59] Diamond C & Shirky C, (2008), Health Affairs

Logistic – Team based care

> "*Impairments is individual and varied and as such what works for one person does not work for another, therefore it is even more crucial that people with special needs be consulted in what enables their independence in their home.*"

[74] Jarrold D & Boumrane N, (2011), PervasiveHealth Conference

Logistic – Team based care

> "*Ideally, there needs to be a set of clinicians, managers, and informaticians looking constantly at ways questions can be asked of the data in order to improve care quality, outcomes, and work processes from the perspectives of all key stakeholders.*"

[77] Detmer DE, (2009), Information Knowledge and Systems Management

Logistic – Team based care

> "*HIT can support team-based care with tools enabling team members to identify patient care goals and document and monitor progress using a shared care plan.*"

[56] O´Malley AS, (2011), The New England Journal of Medicine

Logistic – Team based care

> "*It is important to see health information technology less as an alternative means of documentation and more as a new information system that offers clinicians an opportunity to transform the way in which they deliver.*"

[74] Maxson E et al, (2010), Annals of Internal Medicine

Requirements – Logistic

Logistic – Training

"[...] *organizations successful in utilizing e-prescribing software reported greater familiarity with the capabilities and purpose of the system.*"

[77] Police RL et al, (2011), Informatics in Primary Care

Logistic – Training

"The experts will use their experience with EHR implementations and the subject matter to help physicians and administrators select an EHR system that meets their needs."

[76] Maxson E et al, (2010), Annals of Internal of Medicine

Logistic – Training

"Other facilitators of adoption included the availability of technical support for the implementation of information technology (47%) and objective third-party evaluations of electronic health record products (35%)."

[78] Jha AK et al, (2009), The New England Journal of Medicine

Logistic – Training

"Education for health information professionals must be based upon a solid founda-tion of the changing paradigms and trends in health care and health information, as well as technological advances, to produce a well-prepared information workforce to meet the demands of health-related environments. Educational programs should begin with the core principles of library and information sciences and expand in interdisciplinary collaborations."

[79] Cleveland AD, (2011), Journal of Medical Library Association

Logistic – Life Style Incentive Management

"Micro-payment to a user device every time the user exercises or eats healthy food. This mobile money can then be used for paying wireless monthly charges, for donating to a charity of user's choice, or for paying healthcare expenses."

[45] Varshney U, (2007), Mobile Network Application

Requirements – Logistic

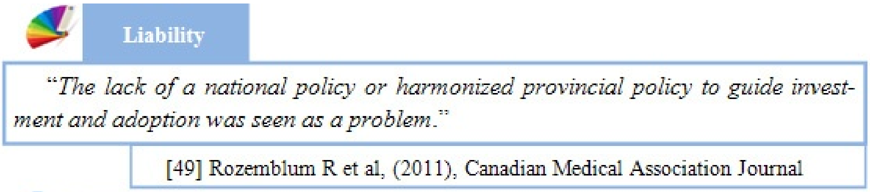
Logiic – Life Style Incentive Management

> *"Computer-based interventions that afford patients timely access to educational and interactive tools are indicated for use with behaviours that require regular input to elicit and maintain selfregulation such as dietary and physical activity."*

[50] Laakso EL & Tandy J, (2011), Physical Therapy Reviews

The liability issue is very important for future adoption of PHMC. Lack of clear regulation and fair penalty related with the cost of lawsuit abuse and fraudulent lawsuits undermine the use and large scale adoption of IT in health care. For instance, the contract for realization of Romanian national health information system - the SIUI (Sistemul Informatic Unic Integrat), was assigned without compliance with requirements of policy related to the type of the contract and without written responsibility of providers for not respecting deadlines and for losses produced by errors in the system. After 6 years and more than 120 million euros for deployment and optimization, the system was blocked in January 2011 because of "some errors in software". A prejudice of 1, 400 000 euro was made by the "errors" of SIUI. The evidences on the value of prejudice and those associated with errors in SIUI were not followed by any criminal responsibility.

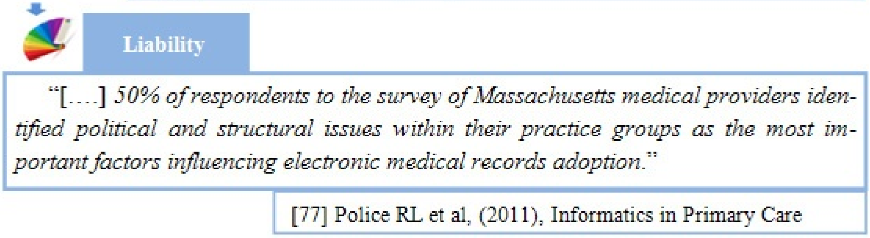
Requirements – Liability



Liability

> *"The lack of a national policy or harmonized provincial policy to guide investment and adoption was seen as a problem."*

[49] Rozemblum R et al, (2011), Canadian Medical Association Journal

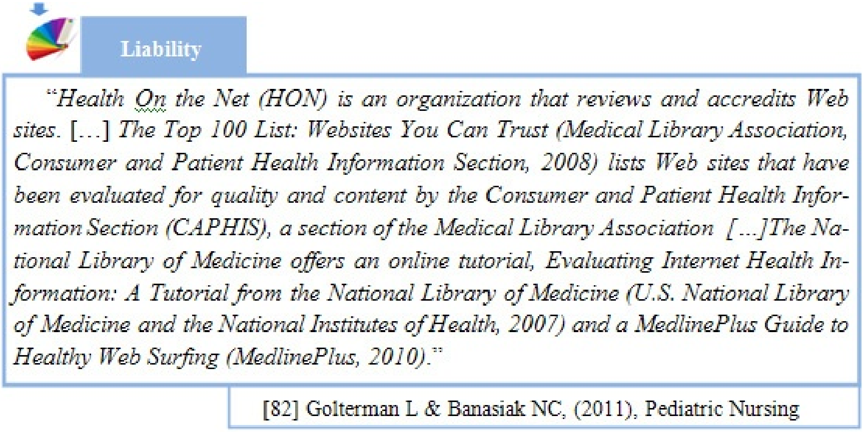


Liability

> "[….] *50% of respondents to the survey of Massachusetts medical providers identified political and structural issues within their practice groups as the most important factors influencing electronic medical records adoption."*

[77] Police RL et al, (2011), Informatics in Primary Care

Requirements – Liability



Liability

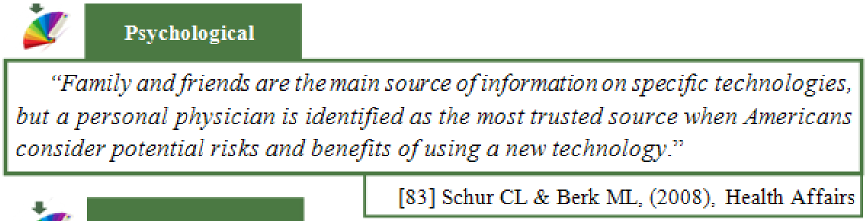
"Health On the Net (HON) is an organization that reviews and accredits Web sites. […] The Top 100 List: Websites You Can Trust (Medical Library Association, Consumer and Patient Health Information Section, 2008) lists Web sites that have been evaluated for quality and content by the Consumer and Patient Health Information Section (CAPHIS), a section of the Medical Library Association […]The National Library of Medicine offers an online tutorial, Evaluating Internet Health Information: A Tutorial from the National Library of Medicine (U.S. National Library of Medicine and the National Institutes of Health, 2007) and a MedlinePlus Guide to Healthy Web Surfing (MedlinePlus, 2010)."

[82] Golterman L & Banasiak NC, (2011), Pediatric Nursing

Well-designed electronic medical records based on pervasive sensing and computing should ensure that providers have appropriate client information at the right time and in the right format to make decisions about client care before, during, and after clinical encounters. Patients' empowerment may contribute greatly to acceptance, and by their implication in the design of the system, an increase in the effectiveness in practice of pervasive health systems may also be achieved.

Pervasive healthcare require changes to workflows, increased emphasis on preventive care, retraining or hiring staff, and increased financial incentives to report and improve performance. The key to maintain partnerships between stakeholders should be honest, open, with frequent communication that builds trust, understanding of other partners' priorities, grasping organizational and operational environments and constraints.

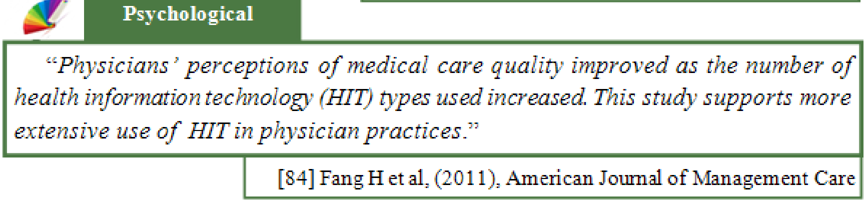
Requirements – Psychological



Psychological

"Family and friends are the main source of information on specific technologies, but a personal physician is identified as the most trusted source when Americans consider potential risks and benefits of using a new technology."

[83] Schur CL & Berk ML, (2008), Health Affairs

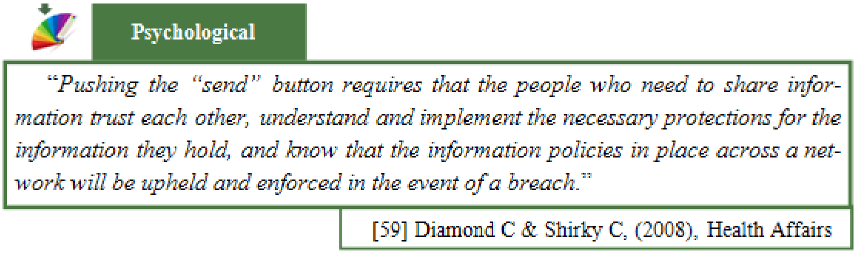


Psychological

"Physicians' perceptions of medical care quality improved as the number of health information technology (HIT) types used increased. This study supports more extensive use of HIT in physician practices."

[84] Fang H et al, (2011), American Journal of Management Care

Requirements – Psychological



Psychological

> *"Pushing the "send" button requires that the people who need to share information trust each other, understand and implement the necessary protections for the information they hold, and know that the information policies in place across a network will be upheld and enforced in the event of a breach."*

[59] Diamond C & Shirky C, (2008), Health Affairs

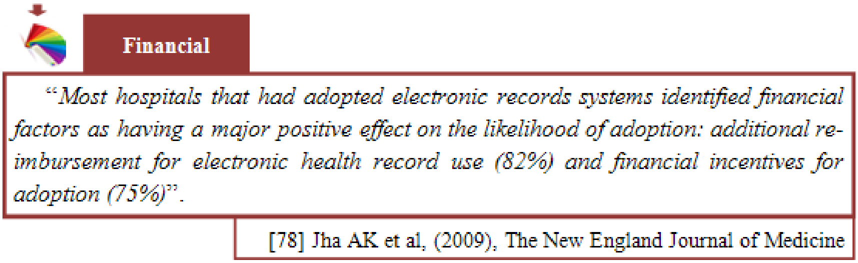
Motivation, greater availability of reliable devices for self-monitoring, measurements for the practitioner between appointments, and a better selection of treatments based on individual response, are all aspects that contribute to the more frequent use and popularity of self-monitoring [80,81,103]. Web based software that may enhance motivation for healthier lifestyle increases compliance with the treatment. Moreover, personalized health monitoring and personalized care may enhance adoption of pervasive health systems. Already, there are many health information applications based on the Internet. However, in 2002, a systematic review [68] has shown that quality of health information available to consumers via the Internet is problematic. A total of 79 studies were included in the review, which assessed 5,941 health related websites, 1,329 web pages and 408 evaluation results for 86 distinct quality criteria. The authors reported that 70% of the studies found that the quality of information on the Internet was problematic, 22% of studies remained impartial, and only 9% of studies achieved a positive assessment regarding quality. In our opinion, more meaningful information related with health may be obtained through the Internet by reinforcing the patient-health professional relationship in the designing of mobile technology and Web 2.0. based systems. This opinion is based on evidences that health professionals are identified by patients as the most trusted sources of information on the potential risks and benefits of using a new technology [103].

5 Barriers to Adoption of PHMC

Deutsh et al [71] analyzing the problem documented during implementation of EHRs in five countries – Denmark, England, Germany, Canada and Australia – have suggest that equal attention needs to be devoted to acceptance, change management, health-policy related goals and implementation strategy, basic legal conditions, data protection as well as technological aspect.

In our analysis, local and regional funding [60] was identified as important problems in the implementation of eHealth. Initial start-up challenges for implementation of PHMC encompass constraints on funding but these costs may be diminished by adapting, where is possible, the existing PHRs, PCMH, EHRs, EMRs to ubiquity and unobtrusiveness in health monitoring. An open issue remains identifying how, when, and by whom this technology and services will be funded. The pertinent issues also involve questions about willingness to pay more for health care on a collective basis and the value and distribution of the benefits gained from higher spending on health care [14]. The decision to fund should take into consideration the implications, the extent to which the transformation will cause shifts in the quality of the process of care, and cost-effectiveness of the pervasive health monitoring implementation, by using social management models and financial results. To deliver better health care at a lower cost, health technology should be redesigned to support improved, patient-centered care and not the isolated tasks of physicians and clinicians [46]. If policy-makers are able to take a more discerning approach to reducing coverage, with a focus on enhancing value and avoiding harmful effects on equity, they may be more successful in alleviating pressure on the public budget. This in turn would contribute to achieving a higher level of attainment of health system goals (or at least prevent them from being further undermined) [14].

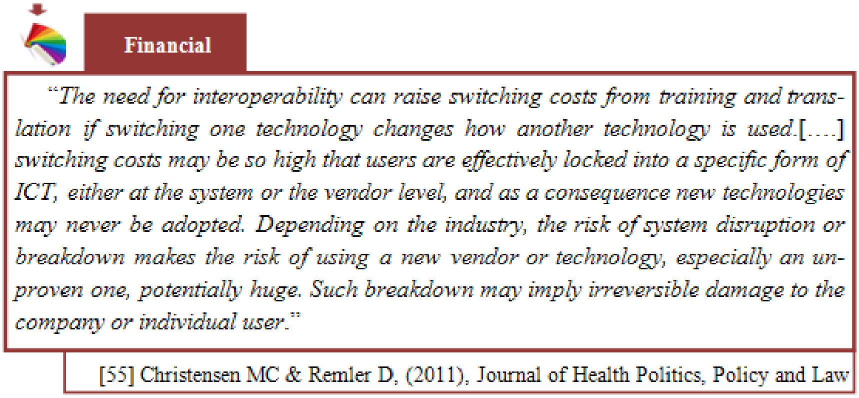
Barriers – Financial



Financial

"Most hospitals that had adopted electronic records systems identified financial factors as having a major positive effect on the likelihood of adoption: additional reimbursement for electronic health record use (82%) and financial incentives for adoption (75%)".

[78] Jha AK et al, (2009), The New England Journal of Medicine

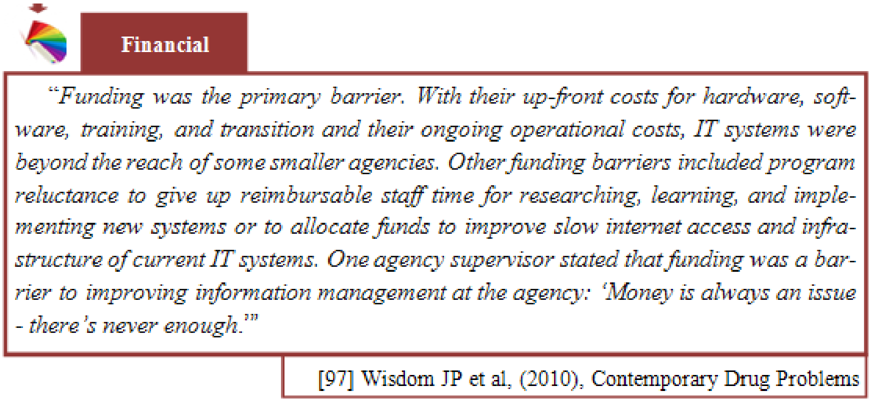


Financial

"The need for interoperability can raise switching costs from training and translation if switching one technology changes how another technology is used.[….] switching costs may be so high that users are effectively locked into a specific form of ICT, either at the system or the vendor level, and as a consequence new technologies may never be adopted. Depending on the industry, the risk of system disruption or breakdown makes the risk of using a new vendor or technology, especially an unproven one, potentially huge. Such breakdown may imply irreversible damage to the company or individual user."

[55] Christensen MC & Remler D, (2011), Journal of Health Politics, Policy and Law

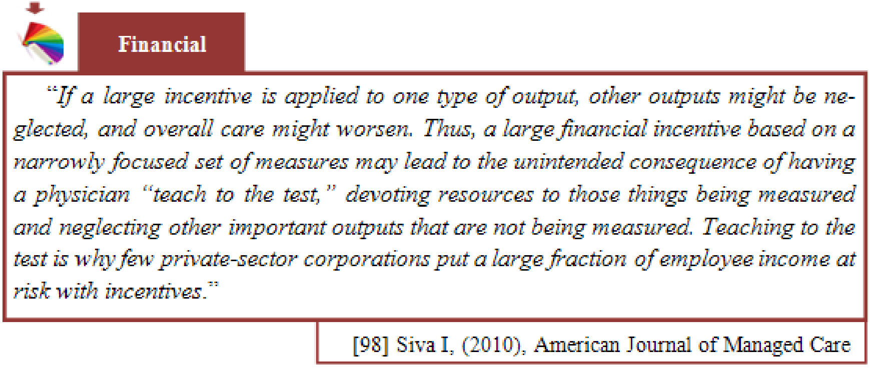
Barriers – Financial



Financial

"Funding was the primary barrier. With their up-front costs for hardware, software, training, and transition and their ongoing operational costs, IT systems were beyond the reach of some smaller agencies. Other funding barriers included program reluctance to give up reimbursable staff time for researching, learning, and implementing new systems or to allocate funds to improve slow internet access and infrastructure of current IT systems. One agency supervisor stated that funding was a barrier to improving information management at the agency: 'Money is always an issue - there's never enough.'"

[97] Wisdom JP et al, (2010), Contemporary Drug Problems



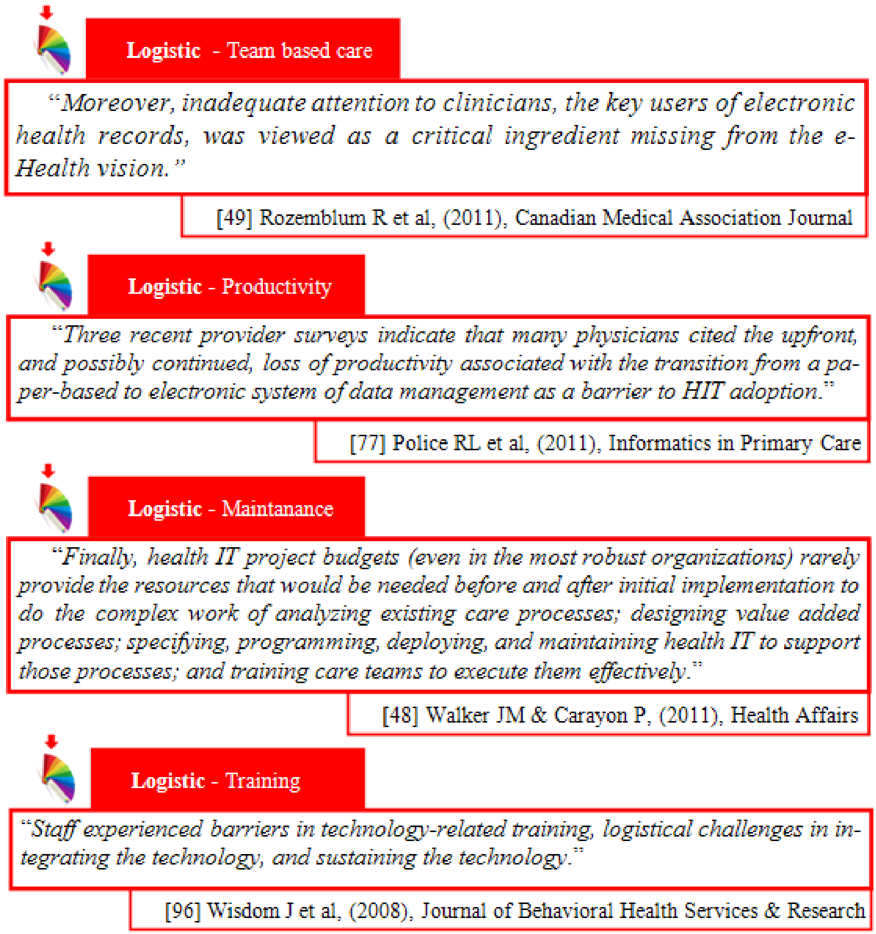
Financial

"If a large incentive is applied to one type of output, other outputs might be neglected, and overall care might worsen. Thus, a large financial incentive based on a narrowly focused set of measures may lead to the unintended consequence of having a physician "teach to the test," devoting resources to those things being measured and neglecting other important outputs that are not being measured. Teaching to the test is why few private-sector corporations put a large fraction of employee income at risk with incentives."

[98] Siva I, (2010), American Journal of Managed Care

We found out that less successful implementation of health information technology is associated with financial constraints but also with : privacy policy and related issues; poor transparency towards work plans and with regard to the business project for HIT implementation; underestimation of complexity of the technological, clinical process and organizational problem; fragmented or lack of responsibility in management of health information system implementation; low effective, persistent and consistent management of system implementation for more closely coordinated forms of health and social care provision; lack of quality audit of the implemented health information technology in some healthcare systems; health professionals perception related mainly with less evidences on added value of some implemented eHealth approaches; less or even lack of collaboration and team work of all stakeholders - patients, doctors, therapists, sociologists, engineers, computer technicians, etc.; aspects of psychological perception and culture associated with all stakeholders involved in health information communication technology.

Barriers – Logistic



Logistic - Team based care

"*Moreover, inadequate attention to clinicians, the key users of electronic health records, was viewed as a critical ingredient missing from the e-Health vision.*"

[49] Rozemblum R et al, (2011), Canadian Medical Association Journal

Logistic - Productivity

"*Three recent provider surveys indicate that many physicians cited the upfront, and possibly continued, loss of productivity associated with the transition from a paper-based to electronic system of data management as a barrier to HIT adoption.*"

[77] Police RL et al, (2011), Informatics in Primary Care

Logistic - Maintanance

"*Finally, health IT project budgets (even in the most robust organizations) rarely provide the resources that would be needed before and after initial implementation to do the complex work of analyzing existing care processes; designing value added processes; specifying, programming, deploying, and maintaining health IT to support those processes; and training care teams to execute them effectively.*"

[48] Walker JM & Carayon P, (2011), Health Affairs

Logistic - Training

"*Staff experienced barriers in technology-related training, logistical challenges in integrating the technology, and sustaining the technology.*"

[96] Wisdom J et al, (2008), Journal of Behavioral Health Services & Research

Standards can improve but can also be a barrier for pervasive health monitoring and care adoption. There are a lot of important standards for sensors development, biosignal acquisition and processing, wireless communication, data networking, eHealth (i.e. HL7). However, as was shown for EHRs [27], many of the applications do not respect these standards. Furthermore, the history of failed standards efforts is filled with vendor approved standards that never passed the crucial test, which is clear utility for the user. Many very well-designed data-networking standards, whether designed by individual vendors or international consortia, were largely unable to compete on a global scale with the Internet's simple but evolving standards [27]. Diamond and Shirky [59] discussed the issue associated with standards in eHealth. They suggest that health information technology should use a minimal set of standards at first, mainly focusing on standard for sharing information, standards guided by a clear policy framework

Barriers – Technology

Technology

"Some authors have speculated that the significant variability in HIT adoption across practice specialties may stem from the fact that existing EMRsystems do not meet the clinical needs of certain physician organizations."

[77] Police RL et al, (2011), Informatics in Primary Care

Technology

"Clinicians frequently comment that "I work for my EHR instead of my HER working for me." Poor usability can result in errors that threaten patient safety, loss of productivity, and the failure to realize the quality and efficiency benefits of health information technology."

[95] Blumenthal D et al, (2011),The New England Journal of Medicine

Technology

"The EMR is currently considered an immature technology which staff have described as 'clunky' and which currently interfaces poorly with other ICT systems. Many staff have given up using it 'until it works better'. [...] *An annual software upgrade in the Veterans Association in August of 2008 resulted in faulty displays of medical records and consequently incorrect doses of drugs, unimplemented treatment cessations, and delays in treatments (Associated Press 2009)."*

[55] Christensen MC & Remler D, (2011), Journal of Health Politics, Policy and Law

Technology

"The types of phone the (elderly) participants have are older phones with very limited screen, as the phone seem to be passed on to them by their children."

[55] Christensen MC & Remler D, (2011), Journal of Health Politics, Policy and Law

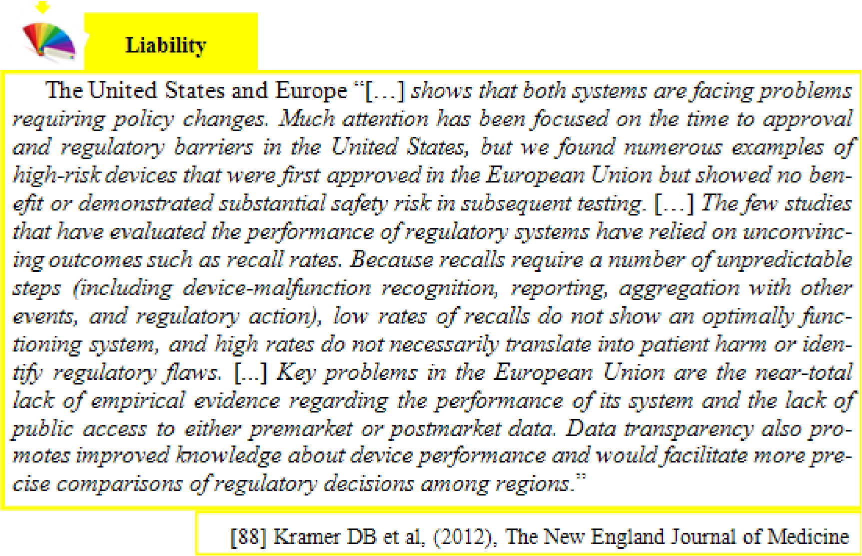
Technology

"Connectivity and interoperability problems were cited as barriers to effective utilization in two recent studies. A cross-sectional survey of primary care providers reported that 52% of physicians had connectivity issues with their EMR during patient visits. Although it is optimal for HIT systems to be able to directly exchange information, true system interoperability has yet to be achieved."

[77] Police RL et al, (2011), Informatics in Primary Care

Furthermore, the pattern of a high degree of technical design but a low degree of trust or incentive to share describes a number of prominent failures [89] in health information technology. Considering that, in many cases health care practitioners fail to assist and/or oversee the nature and content of HIT, creating opportunities for the development of imprecise, dangerous or erroneous medical information [90,91]. For instance, Hardey [92] describes incidents where unidentified online sources have inadvertently or advertently become creators of untrustworthy health information and unregulated distributors of healthcare. Scheidt [93] underlines this fact, stating that technology has a nested context and needs to be considered in relation to such contextual community factors as place, systems, re-structuring strategies, and socio-economic patterns. Failing to account for the variety of ways in which information communication technology is embedded in practice settings, compromises our overall understanding of how people perceive and choose to engage with technology [94].

Barriers – Liability



Liability

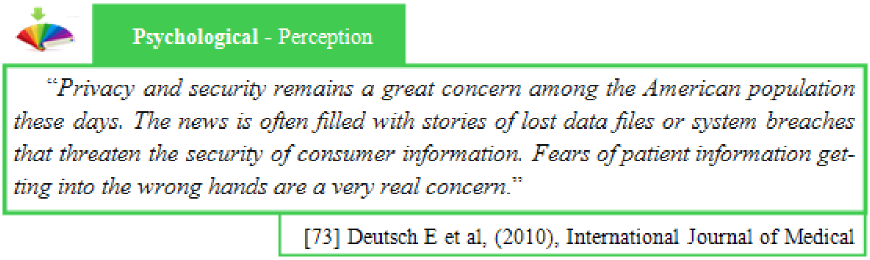
The United States and Europe "[…] *shows that both systems are facing problems requiring policy changes. Much attention has been focused on the time to approval and regulatory barriers in the United States, but we found numerous examples of high-risk devices that were first approved in the European Union but showed no benefit or demonstrated substantial safety risk in subsequent testing.* […] *The few studies that have evaluated the performance of regulatory systems have relied on unconvincing outcomes such as recall rates. Because recalls require a number of unpredictable steps (including device-malfunction recognition, reporting, aggregation with other events, and regulatory action), low rates of recalls do not show an optimally functioning system, and high rates do not necessarily translate into patient harm or identify regulatory flaws.* […] *Key problems in the European Union are the near-total lack of empirical evidence regarding the performance of its system and the lack of public access to either premarket or postmarket data. Data transparency also promotes improved knowledge about device performance and would facilitate more precise comparisons of regulatory decisions among regions.*"

[88] Kramer DB et al, (2012), The New England Journal of Medicine

Moreover, an overly "top-down" approach and insufficient engagement of clinicians were aspects considered to lower the adoption rates of EHRs in Canada [49]. The study suggests that although a "top-down, technical, architecture-first" approach may eventually lead to the same outcome as a "bottom-up, clinical needs-first" approach, the "top-down approach" could be too slow, expensive and inefficient.

Privacy and security are the great concern among physicians and patients. The news are often filled with stories of lost data files or system breaches that threaten the security of consumer information. The PHMC implementation should establish a level of confidence in the data communication in order to avoid disclosure to those to whom it should not be, whether the disclosure is accidental or malicious. Protection of the data should take into account integrity of data - ensure that the recorded information is correct and is not in any way corrupted. A corrupted patient record is a serious problem and could lead to errors in medications, treatment and even to the death of a patient.

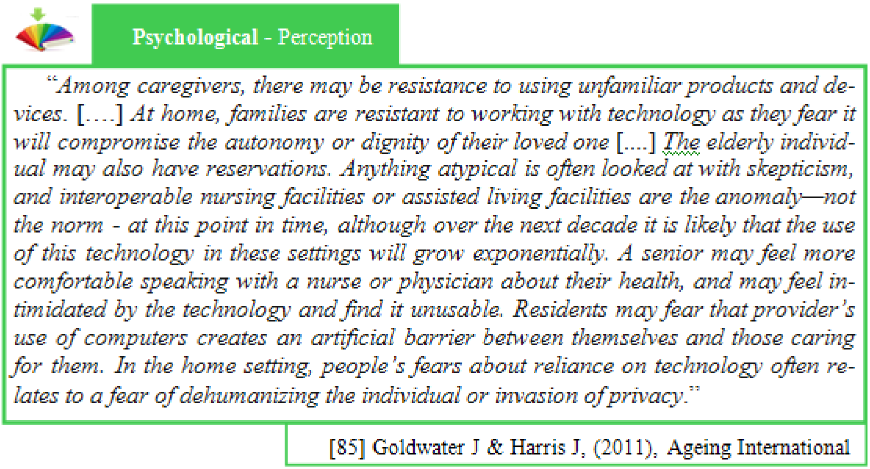
Barriers – Psychological



Psychological - Perception

“Privacy and security remains a great concern among the American population these days. The news is often filled with stories of lost data files or system breaches that threaten the security of consumer information. Fears of patient information getting into the wrong hands are a very real concern.”

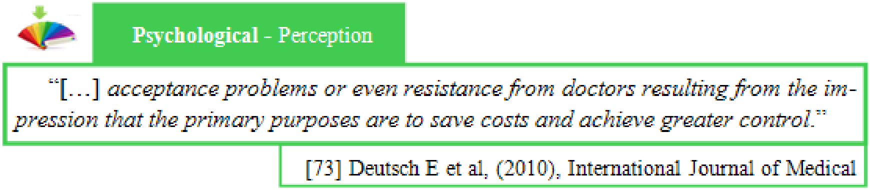
[73] Deutsch E et al, (2010), International Journal of Medical



Psychological - Perception

“Among caregivers, there may be resistance to using unfamiliar products and devices. [....] *At home, families are resistant to working with technology as they fear it will compromise the autonomy or dignity of their loved one* [....] *The elderly individual may also have reservations. Anything atypical is often looked at with skepticism, and interoperable nursing facilities or assisted living facilities are the anomaly—not the norm - at this point in time, although over the next decade it is likely that the use of this technology in these settings will grow exponentially. A senior may feel more comfortable speaking with a nurse or physician about their health, and may feel intimidated by the technology and find it unusable. Residents may fear that provider's use of computers creates an artificial barrier between themselves and those caring for them. In the home setting, people's fears about reliance on technology often relates to a fear of dehumanizing the individual or invasion of privacy.”*

[85] Goldwater J & Harris J, (2011), Ageing International

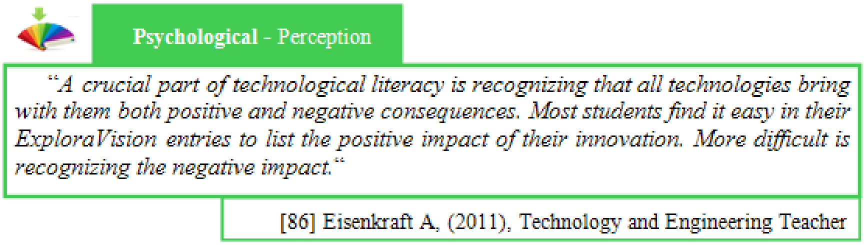


Psychological - Perception

“[...] *acceptance problems or even resistance from doctors resulting from the impression that the primary purposes are to save costs and achieve greater control.”*

[73] Deutsch E et al, (2010), International Journal of Medical

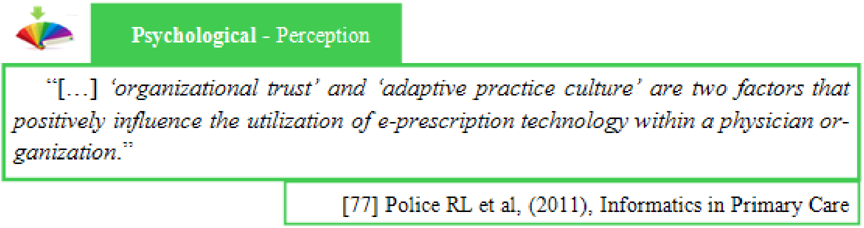
Barriers – Psychological



Psychological - Perception

"A crucial part of technological literacy is recognizing that all technologies bring with them both positive and negative consequences. Most students find it easy in their ExploraVision entries to list the positive impact of their innovation. More difficult is recognizing the negative impact."

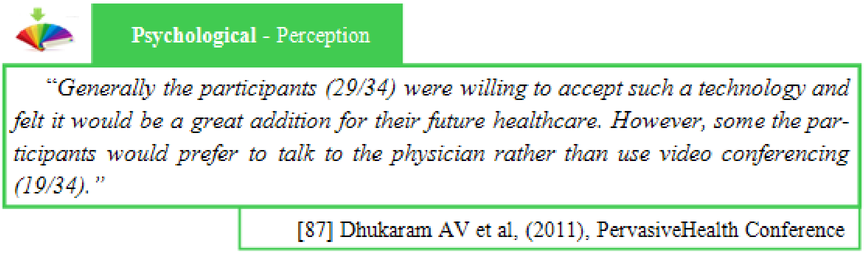
[86] Eisenkraft A, (2011), Technology and Engineering Teacher



Psychological - Perception

"[…] *'organizational trust' and 'adaptive practice culture' are two factors that positively influence the utilization of e-prescription technology within a physician organization."*

[77] Police RL et al, (2011), Informatics in Primary Care



Psychological - Perception

"Generally the participants (29/34) were willing to accept such a technology and felt it would be a great addition for their future healthcare. However, some the participants would prefer to talk to the physician rather than use video conferencing (19/34)."

[87] Dhukaram AV et al, (2011), PervasiveHealth Conference

Pervasive health monitoring and care may be beneficial by improving the health system ability to effectively coordinate care between multiple providers from different health disciplines, in order to assure better access to healthcare for patients located in a wide geographic area. However, presently there are few solutions on interconnectivity/interoperability that allow monitoring and computing everywhere, any time through mobile network, cloud computing, etc. Moreover, a paucity of studies exists with evidences on the added values that PHMC may bring to healthcare systems and to clinician-patient relation. These may reinforce entrenched psychological and cultural barriers related with pervasive health monitoring and care implementation (e.g. perception that healthcare professionals and patients are less prepared to learn to use information technology; resistance to change of the relationship between healthcare professionals and patients; less perception of many engineers and computer technicians on their limited knowledge on bioethics, standards use in healthcare and biomedical measurements; ethnical and racial disparities in access to health care in some countries; communication proficiency between providers and patients; culture, in some countries, that prevent mandatory of quality audits, etc.). For efficient PHMC implementation researches and evidences on healthcare provider differences in communication proficiency, including varied listening skills and different views from their patients of symptoms and treatment effectiveness [99] may be carried out. In the design of PHMC systems should be address also factors influencing patient centeredness and provider-patient communication that include: language barriers; racial and ethnic concordance between the patient and provider; effects of disabilities on patients' health care experiences; providers' cultural competency [100]. Efforts to remove these possible impediments to patient centeredness are carried out in many countries. For instance, in the USA, the Office of Minority Health has developed a set of Cultural Competency Curriculum Modules that aim to equip providers with cultural and linguistic competencies to help promote patient-centered care [101]. These modules are based on the National Standards on Culturally and Linguistically Appropriate Services. The standards are directed at healthcare organizations and aim to improve the patient centeredness of care for people with *Limited English Proficiency* (LEP). Another example, which is being administered by the Health Resources and Services Administration, is *Unified Health Communication*, a Web-based course for providers that integrates concepts related to health literacy with cultural competency and LEP [100].

Health literacy and health information technology literacy are important barriers to adoption of pervasive health monitoring and care. Patients with limited health literacy are more likely to have difficulty understanding instructions and taking medication properly [100], incur higher medical costs and are more likely to have an inefficient mix of service use compared with those with adequate health literacy [102]. They may also experience many difficulties, including: less frequent preventive care; poorer understanding of their conditions and care; higher use of emergency and inpatient services and higher rates of rehospitalization; lower adherence to medication schedules; less participation in medical decision making [100].

It is understood today that there are many good reasons to believe that healthcare professionals education on HIT, that includes content on knowledge, skills, and attitude related to public HIT processing will improve healthcare quality. In addition, training in public health and biomedicine standards and ethics is needed for computer technicians and engineers involved in the development of HIT in order to foster the development of PHMC.

Furthermore, policy measures need to ensure that consumers and service providers are discerning and critical in their use of eHealth services. Such policies should also highlight the necessity to educate consumers. Policy initiatives will need to provide a comprehensive framework, which will ensure that broad-ranging consumer eHealth services can be effectively, efficiently, and safely accessed [103].

6 Conclusions

At the present pace of innovation in technology, medicine practice will change profoundly in the next decades. An increasingly significant characteristic that has emerged through the use of eHealth applications is the rise in consumer empowerment. The patients will not only take a more active and self-managing role, but will be also able to manage parts of their healthcare remotely.

In this work we present our analysis on requirements and barriers to PHMC development and adoption. More work are necessary to be carried out on: optimization of hardware and software for remote, unobtrusive health monitoring; better evaluation of the implemented systems; better coordination of the involved stakeholders; respect and improvement of existing standards and introduction of new standards for various aspects of eHealth system; collaboration and team work of all stakeholders benefiting from pervasive health implementation; training in using new technologies; training for searching library and information sciences related with health technology and information communication technology; training in thoughtfully analysis of the added value associated with new health technologies; promotion of healthier lifestyle using health information technologies; more attention and analysis on social and organizational change process when designing PHMC; adequate policy support for quality improvement of pervasive health systems; transparency with regard to the goal, business plan and process implementation of pervasive health care; perception of patients, healthy individuals and patient-physician relationship as a core organizational operational system for PHMC; healthcare equity through improved data collection; education for technology literacy; and education for lifestyle management using the new technologies.

Barriers to implementation are associated with: financial constraints; privacy policy and related issues; poor transparency towards work plans and with regard to the implementation of health information technology; underestimation of the complexity of the technological, clinical process and organizational problem; low effective, persistent and consistent management of health information technology implementation in health care systems; less or even lack of collaboration and team work of all stakeholders; fragmented or lack of responsibility related with defects and failure in some implemented projects of health information technology; lack, in many countries, of quality audits of eHealth implemented systems; perception and culture associated with all stakeholders involved in health information communication technology.

As a future step, the results of our analysis may be crosschecked and used to mathematically model the cost effectiveness of implementation and adoption of PHMC using quantitative measurement of factors identified in our work and potentially supplemented by others standardized surveys. The new knowledge acquired using these type of evaluation may allow to find solutions for building a sustainable health care system through a flexible environment that adaptively responds to all instability and all unpredictability in the next future, where our life and all business are extremely interconnected in chaotic patterns.

We imagine a world where embedded sensors in our houses or work environment (furniture, wall, floor, toilet, etc.) or inside our body (nanosensors, smart nanorobots, etc.) may send, on demand, reports on health changes during the last hours, or during a day, a month or a year. The reports may be based on measured physiological parameters (heart rate, blood pressure, physiological stress reactivity, weight, temperature, glycemia, cholesterolemia, metabolic equivalent for task, etc.) or on psychological and behavioral data (e.g. meaningful analysis of speech, mood, gesture, muscle force, daily motor activity, etc.). The reports may also suggest personalized healthier lifestyle instructions. We imagine a world where using virtual reality, or “mediated immersion” or augmented reality, we can consult, sitting in our house or in our work place, a health professional that we can choose by consulting data associated with their performance on quality of care measurements. We imagine a world where the quality of life for people with chronic diseases is improved by real time monitoring of health parameters, medication, treatments, etc., through cognitive sensors network that should constantly self-adapt based on the dynamic context of the environment, individual stakeholders, and even more, compelling the interactions and relations between them.

Think about it. The present survey shows that there are people working to build such a world.

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