Smart Sensors, Measurement and Instrumentation 2

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Octavian Adrian Postolache *Editors*

Pervasive and Mobile Sensing and Computing for Healthcare

Technological and Social Issues

Springer

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2

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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).

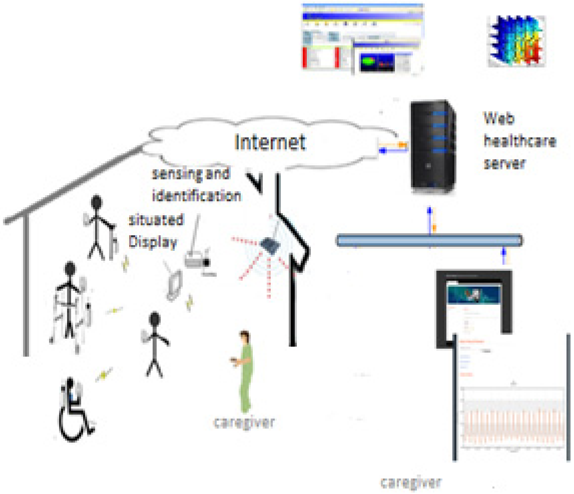


Fig. 1. Diagram of ambient intelligent based on our implemented smart objects

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).

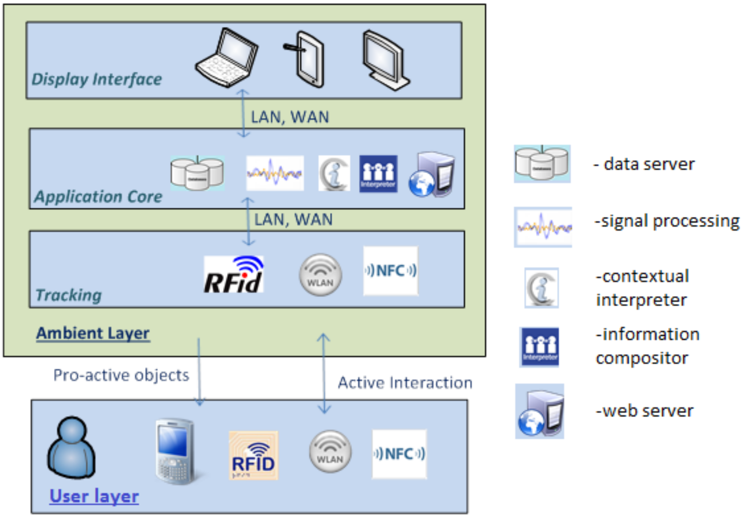


Fig. 2. Software component architecture

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.

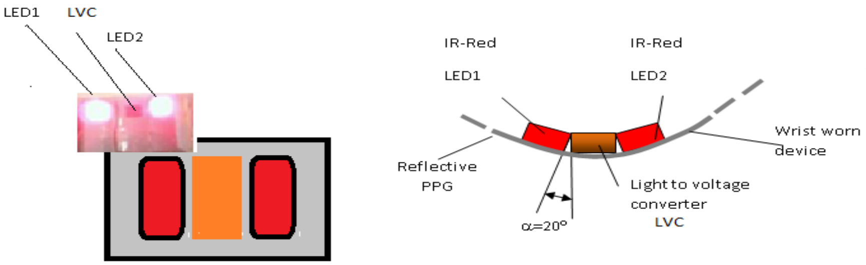


Fig. 3. Reflective photoplethismography sensor

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.

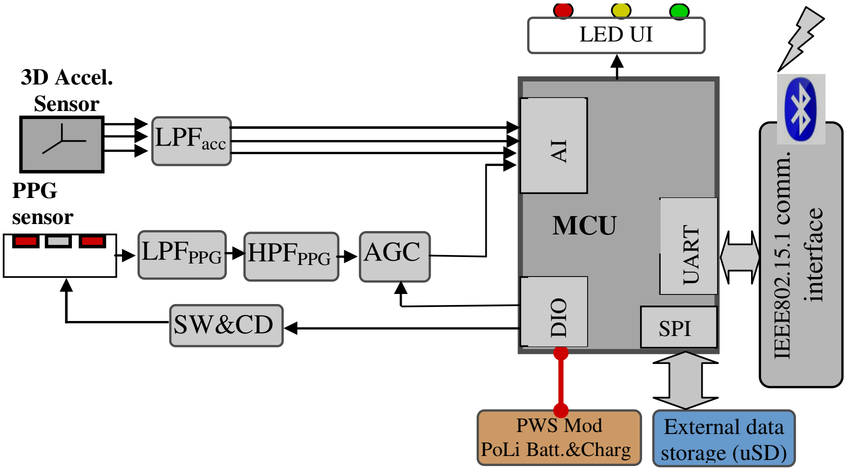


Fig. 4. Smart wrist worn - Microcontroller platform and conditioning circuits block diagram (AI – analog input, MCU-PIC24F microcontroller, SPI – serial peripheral interface, UART – universal asynchronous receive-transmit interface, DIO – digital input output port)

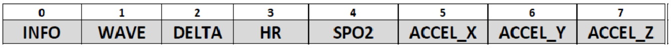
The implemented embedded primary processing software uses the PPG acquired samples to extract the HR value and blood oxygen level (SpO_2 values). An adaptive threshold peak detection algorithm was used to obtain more accurate values of HR. The main steps of the implemented algorithms are:

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.

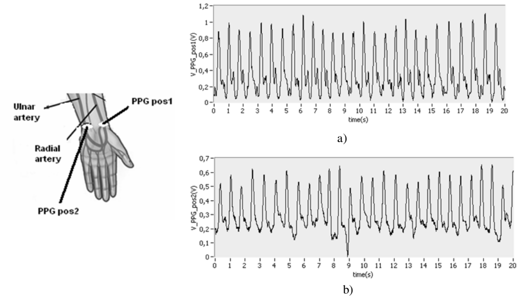


Fig. 6. The PPG signals for two positions of the sensing module on the wrist: a) PPG pos1 b) PPG pos2

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.

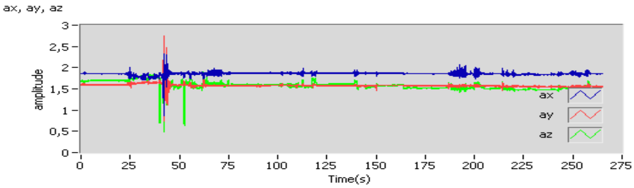


Fig. 7. The evolution of ax, ay, az acceleration during ADL

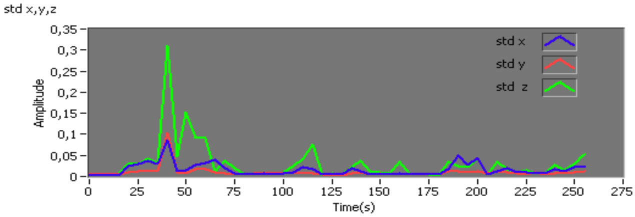


Fig. 8. The evolution of std x, std y, std z standard deviations of the measured accelerations during ADL

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.

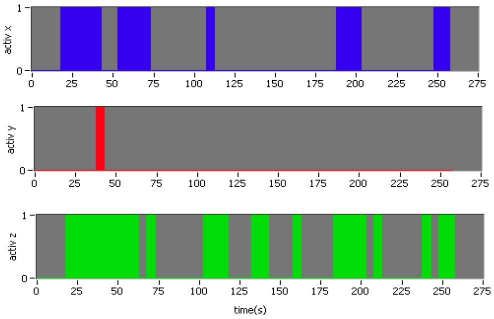


Fig. 9. Activity and non –activity associated with the x, y and z axis expressed by boolean activity indexes

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

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