UNIVERSIDADE DA BEIRA INTERIOR
Faculdade de Engenharia
Departamento de Informática

An Ambient Assisted Living Solution for Mobile Environments

Edgar Tavares da Horta

Submitted to the University of Beira Interior in applying for the Degree of Master of Science in Informatics Engineering

Supervised by Prof. Dr. Joel José Puga Coelho Rodrigues

Departamento de Informática
University of Beira Interior
Covilhã, Portugal
http://www.di.ubi.pt

This work has been partially supported by *Instituto de Telecomunicações*, Next Generation Networks and Applications Group (NetGNA), by Plux Biosensor Engineering, Portugal, by National Funding from the FCT – *Fundação para a Ciência e Tecnologia* through the Pest-OE/EEI/LA0008/2013, and by the AAL4ALL (Ambient Assisted Living for All), project co-financed by the European Community Fund FEDER through COMPETE – *Programa Operacional Factores de Competitividade*.

Acknowledgements

First of all, I wish to thank Professor Joel José Puga Coelho Rodrigues for giving me the chance to join the Next Generation Networks and Applications Research Group (NetGNA), for their advice and continuous support and encouragement throughout the process of supervising my Master's thesis.

I am most grateful to the University of Beira Interior, *Instituto de Telecomunicações*, Next Generation Networks and Applications Group (NetGNA), Covilhã Delegation, Portugal, in the framework by the AAL4ALL (Ambient Assisted Living for All), project, by the multiple kinds of support available that allowed me to perform this Master's thesis.

I am also thankful to PLUX Biosensor Engineering Portugal Staff, for their help and technical support.

Many thanks to all the members of NetGNA, particularly to Ivo Lopes, Bruno Silva, João Caldeira, Orlando Pereira, Fábio Canelo, João Dias, Joel Fernandes, Pedro Rosa and João Isento.

I would like to express gratitude to my friend Sérgio Chambel for the encouragement and to all other friends not mentioned here.

My eternal gratitude to my parents José Horta, Isabel Tavares, to my grandmother Maria José Antunes, also to my girlfriend, Marina Ramos and to my other closest family for all constant encouragement, patient and support.

Finally, this work is dedicated to my grandfather Luciano Ramos and to my grandmother Ana Maria Rocha. They will always be remembered.

Abstract

An Ambient Assisted Living (AAL) mobile health application solution with biofeedback based on body sensors is very useful to perform a data collection for diagnosis in patients whose clinical conditions are not favourable. This system allows comfort, mobility, and efficiency in all the process of data collection providing more confidence and operability. A physical fall may be considered something natural in the life span of a human being from birth to death. In a perfect scenario it would be possible to predict when a fall will occur in order to avoid it. Falls represent a high risk for senior people health. Those falls can cause fractures or injuries causing great dependence and debilitation to the elderly and even death in extreme cases. Falls can be detected by the accelerometer included in most of the available mobile phones or portable digital assistants (PDAs). To reverse this tendency, it can be obtained more accurate data for patients monitoring from the body sensors attached to the human body (such as, electrocardiogram (ECG), electromyography (EMG), blood volume pulse (BVP), electro dermal activity (EDA), and galvanic skin response (GSR)). Then, this dissertation reviews the related literature on this topic and introduces a mobile solution for falls prevention, detection, and biofeedback monitoring. The proposed system collects sensed data that is sent to a smartphone or tablet through Bluetooth. Mobile devices are used to process and display information graphically to users. The falls prevention system uses collected data from sensors in order to control and advice the patient or even to give instructions to treat an abnormal condition to reduce the falls risk. In cases of symptoms that last more time it can even detect a possible disease. The signal processing algorithms plays a key role in the fall prevention system. These algorithms in real time, through the capture of biofeedback data, are needed to extract relevant information from the signals detected to warn the patient. Monitoring and processing data from sensors is realized by a smartphone or tablet that will send warnings to users. All the process is performed in real time. These mobile devices are also used as a gateway to send the collected data to a Web service, which subsequently allows data storage and consultation. The proposed system is evaluated, demonstrated, and validated through a prototype and it is ready for use.

Keywords

Mobile Health, Biofeedback Monitoring, m-Health, Mobile computing, Body Sensor Networks, Healthcare Application, Falls Detection, Falls prevention.

Contents

List of Figures

List of Tables

Acronyms

A	:	Ampere
AAL	:	*Ambient Assisted Living*
ADT	:	Android Developer Tools
API	:	Application Programming Interface
ADC	:	Analog-to-Digital Converter
BAN	:	Body Area Network
BS	:	Body Sensor
BSN	:	Body Sensor Network
BVP	:	Blood Volume Pressure
Bit	:	Binary Digit
CPU	:	Central Processing Unit
DAC	:	Digital-to-Analog Converter
ECG	:	Electrocardiography
EMG	:	Electromyography
EDA	:	Electro Dermal Activity
GSR	:	Galvanic Skin Response
GPS	:	Global Position System
GUI	:	Graphical User Interface
Hz	:	Hertz (International Unit of Frequency)
HTTP	:	Hypertext Transfer Protocol
IDE	:	Integrated Development Environment
IT	:	Information Technology
JDK7	:	Java SE Development Kit 7
LAN	:	Local Area Network

MAN	:	Metropolitan Area Network
NetGNA	:	Next Generation Networks and Applications Group
OS	:	Operating System
PC	:	Personal Computer
PERS	:	Personal Emergency Response System
PLUX	:	Enterprise PLUX Wireless Biosignals S.A.
REST	:	Representational State Transfer
RF	:	Radio Frequency
SHIMMER	:	Sensing Health with Intelligence Modularity, Mobility and Experimental Reusability
SDK	:	Software Development Kit
SD Card	:	Secure Digital Card
UML	:	Unified Modelling Language
USB	:	Universal Serial Bus
UI	:	User Interface
V	:	Volt (International Unit of electric potential)
WAN	:	Wireless Area Network
WLAN	:	Wireless Local Area Network
WS	:	Web Service
XML	:	eXtended Markup Language

1. Introduction

This first chapter describes the work made in order to contextualize concepts of all the rigorous processes, including goals and motivations that are the main focus in Section 1.1 of this work. The problem definition presented in Section 1.2 serves to clarify the purpose of the AAL mobile solution. To achieve the objectives of study mentioned in Section 1.3, there were applied concepts in order to distribute the tasks in limited space. Section 1.4 enumerates the main contributions for the state of the art. These contributions appeared naturally and are included in scientific papers. This dissertation is organised in seven chapters briefly summarized in Section 1.5.

1.1. Focus

Advances in technologies for healthcare along with the increasing of elderly people around the world, make new challenges arise for better quality of life focusing on this population [1]. It is observed that elderly people live longer with the best quality of life as possible. The continuous biofeedback monitoring has encouraged the development of technology associated with sensors and systems for biosignal acquisition, increasingly miniaturized and maintaining a high quality of signal, enough for the information extraction with the minimum discomfort.

In this context, Ambient Assisted Living (AAL) is emerging as an ecosystem that aims to describe and identify resources and services, which enable through the use of technology, to facilitate and improve lives of the disabled, elderly, and chronically ill people [2]. This technology appears as an asset in the current context for integration into a patient monitoring system aiming to improve the quality of life. To identify accidents or high-risk situations in which it is possible to act in order to detect them so as to reduce the time response to these critical events is a major concern [3]. For patients treatment, diagnoses and monitoring, more accurate and rigorous techniques adapted should take into account the dynamic character of the mHealth solution intrinsic to the physiologic parameters analysed [4]. It is vital to analyse these parameters acquired continuously, in real time, to conduct a useful praxis of these signals containing substantial information in detail prepared to medical or automatic analyses [5]. Mobile applications appear as a Personal Emergency Response System (PERS) that contributes to AAL solutions, improved with the use of electronic Body Sensors (BS). These sensors can be placed in a patient body and communicate with mobile devices (such as, smartphones or tablets) through short-range communications, like Bluetooth or larger-range using Wi-Fi and Zigbee [6]. The emergence of Mobile Health (mHealth) is triggered with the greater use of tablets, smartphones, and integration of sensors in mobile devices. The information and communication technologies for the next-generation patient physiological mobile solutions, offer excellent conditions to create innovative solutions and techniques for remote and real-time people monitoring with mobility support [7]. These systems can collect sensed data from patient in real time. Mobile devices can store and process incoming data and also send them to storage systems in real time, including the Internet [8], [9]. Furthermore, the patient can also have information that can be useful to him/her, allowing a detailed and on time information that can be extremely relevant for diagnosis and treatment adjustments for people from healthcare systems (physicians, nurses, and paramedics) [10]. The historical record of physiological sensed data is very useful for diagnosing further problems as the causes of falls and habits that may increase the patient risk. Thus, trying to increase patients' independence, offering a good AAL solution with mobility support, the fall detection system combined with a biofeedback monitoring, and data processing, using body sensors is essential for development up in Health Systems Technology Areas. Through a detailed analysis of the conjuncture of these physical signs it is possible to control chronic diseases, cardiovascular diseases (e.g. hypertension) and others, helping to identify risk factors normally associated with severe pathologies [11]. With this proposal it was embedded on a mobile device, such as a smartphone or a tablet, with a complement of body sensors, and the accelerometer already included in the mobile device. Its possible prepares proposals of a fall detection solution and a biofeedback monitoring activity in real time with mobility support. Figure 1 illustrates typical mobile health systems and services, containing one or more monitoring and/or surveillance resources and devices, such as mobile devices and wearable sensors. They should be connected to the Internet to allow information sending, data storage and retrieval.

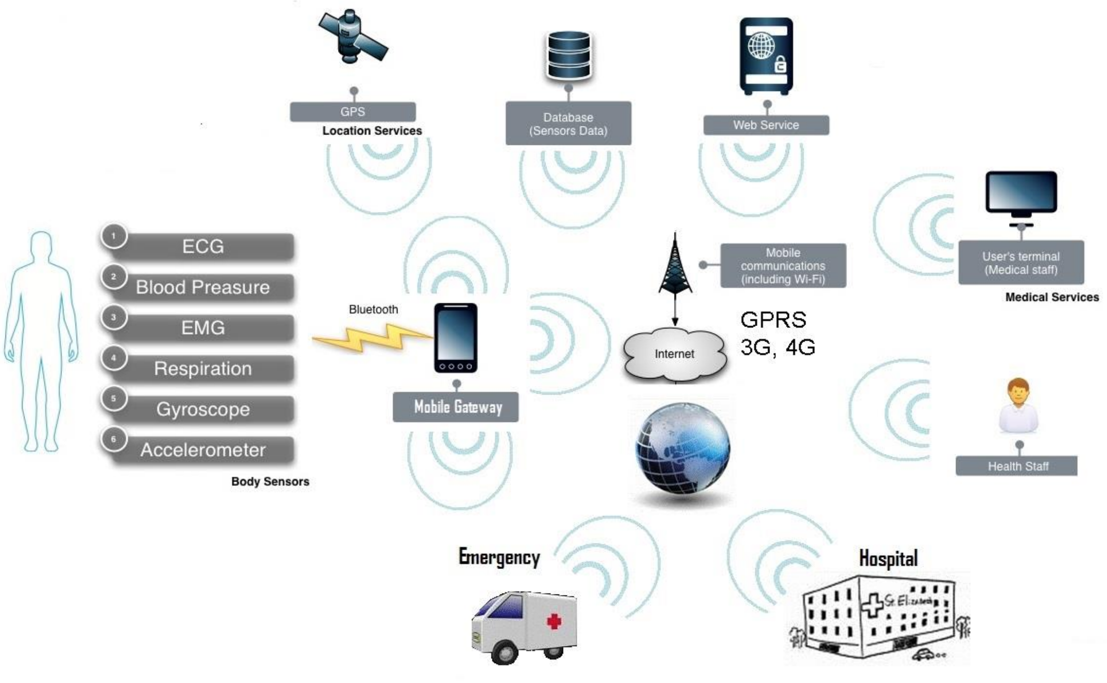


Figure 1 – Illustration of general mHealth systems and services.

In a perfect scenario it would be possible to predict when a fall is going to occur and try to avoid it. Based on this fact, the proposed solution tries to detect situations where fall risk is eminent and then warn the patient in order to prevent it. The patient receives the notice and can try to avoid a fall [12]. The warning messages can be sent through a smartphone or tablet. Biofeedback sensors are carried by the user to send raw data through a Bluetooth connection to a smartphone or a tablet in order to measure the patient biosignal parameters. A BSN attached to a human body can obtain more accurate data from patients monitoring signals (such as, electro cardiogram, electromyography, blood volume pressure, electro dermal activity, and galvanic skin response). This real time collected data from sensors is handled through an automatic algorithm, which is a critical piece for falls prevention [13], [14]. For falls detection, a kinematic sensor accelerometer, included in most of the available mobile devices through an algorithm, provides this benefit [15]. This mobile health tool monitors the body sensors using a real time communication through Bluetooth with a mobile device. A device (smartphone or tablet) uses its computational power to perform a fall detection algorithm, analysing biosignals received at the smartphone [16]. If an abnormal behaviour is detected the patient is notified immediately. Furthermore, the patient caretaker and/or physician can also be notified if needed. With the purpose of distributing information, the sensors send data to the mobile gateway. Subsequently the gateway sends these data received to Web storage (server) and it allows subsequent queries. Figure 2 shows the basic process of distributed information systems implemented for the AAL.

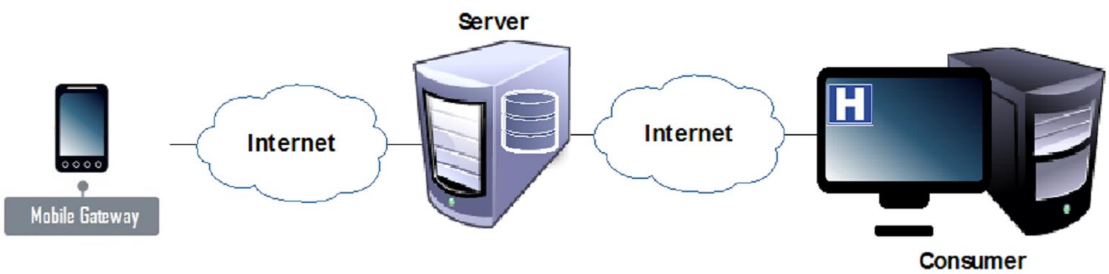


Figure 2 – Illustration of a mobile gateway for AAL mobile solutions.

The proposed AAL solution allows the development of systems that monitor activities and vital signs of lonely elderly people in order to detect emergency situations or deviations from desirable medical patterns [17], [18].

This system aims to be fully focused on patient. In this sense, a methodology for falls prevention is included considering biofeedback monitoring, data processing, and presentation using data collected by body sensors. This solution is embedded on a mobile device and tries to perform user biofeedback activity, fall detection, and it will broadcast to the patient distress signals to prevent fall occurrences.

1.2. Problem Definition

Falling is something natural in the life of a human being from birth to death. A fall may have multiple origins, some of them can be avoided but others not. In elderly people the consequences of a fall increase with age. With the increase of elderly people around the world, new challenges arise to give greater quality of life for these senior citizens. So they can live longer and with the best quality of life as possible.

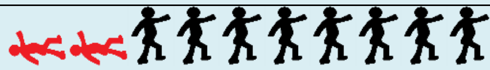
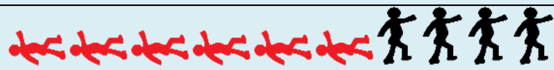
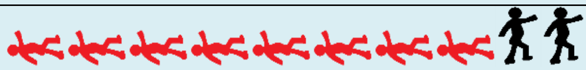
In 2013, a statistical study applied in institutionalized Portuguese older adults, with 65 years old or older, being 32 males and 81 females in a total of 113 elderly. The Table 1 shows falls average of this sample [19].

Table 1. Number of falls by sex and average from a statistical study applied in institutionalized Portuguese older adults, in 2013.

Last 2 years Falls		
Gender	***Number***	***Average(%)***
Male	8	7,1
Female	28	24,8
Total	**36**	**31,9**

Another statistical study performed in United States associates health problems directly with greater chances of falling. Sixteen percent of all Emergency Department visits and almost seven percent of all hospitalizations are for fall-related injuries. Table 2 shows a number of health problems per chance of falling estimation.

Table 2. Health problems per chance of falling estimation statistical study performed in United States.

Number of health problems	*Chance of falling*
0	
1	
2	
3	
4 or more	

In Table 2, in general one elder out of ten will have the risk of fall. If the number of health problems known is one, the chance of falling will be two elder out of ten and these critical numbers enlarge so on. Because of these statistical evidences, if a patient presents health problems it will significantly increase the chances of falling [20].

This real problem in modern society is common in developed countries and the statistical facts presented before demonstrate the seriousness of the problem. Therefore, mHealth solutions attached to health sensors may prevent or even avoid falls reducing the death rates.

1.3. Objectives

The main objective of this dissertation is the design, construction, deployment and performance evaluation of an AAL solution for remote monitoring and falls prevention for mobile environments. This solution considers a mobile application for Android mobile platform with falls detection, falls prevention and biofeedback monitoring, in real time, for elderly and debilitated users. A key aspect of this proposal is the implementation of a consistent and robust solution for mHealth environments, system usability and adaptive proposal. The system will provide network connection to send biofeedback information through Web services to an external clinical database. It also features audio notifications to users and outside alerts, by sending a short message service (SMS) or electronic mail (email) to a caretaker with a brief description of the health problem and GPS coordinates of the user location.

To accomplish this main objective, the following intermediate objectives were identified:

- Study of the state-of-the-art in mHealth solutions, approaches and its challenges, as well as the study of biofeedback acquisition data, falls detection techniques and falls prevention methodologies;

- Research by leading mobile biofeedback devices available on the market and comparison among them;

- Detailed analysis of the system requirements in order to fetch all the system necessities;

- Proposal and deployment of an AAL solution for mobile environments, including a mobile APP on Android OS based on requirement analysis;

- System demonstration on several mobile devices and with multiple sensor systems;

- Performance evaluation and validation of the proposed mobile solution using a real prototype;

This work of research and engineering is expected to produce the desire APP, but it will also provide the opportunity to disseminate knowledge making significant contributions to international scientific entities.

1.4. Main Contributions

This section is devoted to the scientific contributions of this dissertation to the state-of-the-art to the AAL services and on mHealth solutions.

The first contribution aims to present a robust and adaptive solution that enriches the knowledge of bio-signals before, after, and during a fall and also the identification of fall characteristics collection for fall prevention strategies through biofeedback monitoring. A paper with this contribution entitled "A Mobile Health Application for Falls Detection and Biofeedback Monitoring", was presented at the International Workshop on Service Science for eHealth (SSH 2013), co-located with the IEEE HEALTHCOM 2013, Lisbon, Portugal, October 9–12, 2013.

Second contribution of this dissertation is the proposal of a new and enhanced mobile solution for falls prevention that tries to avoid them. A paper with this contribution entitled "Real Time Falls Prevention and Detection with Biofeedback Monitoring Solution for mobile Environments", was published at the 15^{th} International Conference on eHealth Networking, Application & Services in IEEE HEALTHCOM 2013, Lisbon, Portugal, October 9-12, 2013.

Third contribution of this work was describes ubiquitous mHealth methodologies and techniques for falls prevention and detection. It is included in a book chapter named "Ubiquitous mHealth Approach to Biofeedback Monitoring with Falls Detection Techniques and Falls Prevention Methodologies" submitted to a book titled: "Mobile Health (mHealth): The Technology Road Map". The chapter proposal was accepted at June $4^{th,}$ 2013. The full version was submitted by September 1^{st}, 2013 and it is under review.

1.5. Dissertation Structure

This dissertation is organized in seven chapters, subdivided into multiple topics.

This **chapter 1 - Introduction:** first, it starts with focus on the dissertation, focusing on the topic under study. It identifies the research problem, defines the objectives, and presents main contributions as well as the dissertation structure itself.

Chapter 2 - Related Work: it addresses the state-of-the-art, approaching the literature on AAL, mHealth and eHealth, including a brief review about mHealth systems, focusing on health sensors and the importance of biofeedback signal acquisition and processing. Then the most related and relevant work describing falls' detection techniques and falls prevention methodologies.

Chapter 3 – Requirement Analysis: it approaches the requirements analysis in order to fetch all the system necessities, UML diagrams (behavioural, interaction and structural diagrams) and used technologies.

Chapter 4 - Devices Used on the Prototype: it introduces and discusses all the devices used on the prototype and their associated technologies. Photographs of equipment used in the prototypes are shown, which includes technical specifications and a short comparison among them.

Chapter 5 – AAL Mobile Solution Demonstration: it addresses the considered AAL solution for mobile environments APP. The mobile application is introduced and all the features are discussed, the system architecture of the proposed approaches for biofeedback monitoring, falls detection and prevention with outside network communications.

Chapter 6 - Performance Evaluation and System Validation: it presents the results of the mHealth application used on the experiments, describes the used scenario, and focuses on the performance evaluation and validation of the AAL mobile solution.

Finally, **Chapter 7 – Conclusions and Future Work:** it summarizes in a critical way, all the work performed along dissertation, considering the main conclusions of this work, suggestions and challenges for future work.

2. Related Work

In order to focus on the range of this dissertation, it is important to present some related work about the topic. An important note on this type of subject is the existence of broad information about several subjects, often almost obsolete, because progress is so quick in this field. However this gives an excellent point of departure to development of new techniques and solutions. From the basics health care systems to the next level modern mHealth is an important start on the road to implementing this mobile solution.

This chapter presents the related literature to AAL in Section 2.1, approaching the different ways and challenges of this global program. In Section 2.2 it is presented a theoretical analysis in Healthcare technologies regarding eHealth and mHealth aspects. Section 2.3 briefly presents some health sensors systems, enumerating and describing the most used. Section 2.4 discusses about some approaches based on tools and techniques for falls detection, prevention and biofeedback monitoring found in the literature. Finally, this chapter is summarized in the Section 2.5.

2.1. Ambient Assisted Living challenges

The AAL aims to create a better condition of life for the older adults strengthen industrial opportunities in Europe, through the use of technology, information and communication. AAL can gather enormous contributions to healthcare that offer mobile services and solutions for the patients and elderly people [21].

It can develop advanced products, services and systems for ageing well at home, in the community, and at work, increasing the quality of life, autonomy of elderly people, and reducing the costs of health and social care [22]. Considering these circumstances and assuming that evolution follows the increase in people with major physical limitations, it is evident that the topic is a problem, not only in a social level, but also at the level of medical treatment.

The main AAL concept refers thus to the expansion and research of intelligent systems to support better quality of life requirement, providing safer conditions every day in users environment [23]. The new AAL approaches, products or services connect and improve new technologies at home and in social environment. In general, the main challenge of AAL is the technological development that allows users to live independently for a longer period of time, increasing their autonomy and confidence in performing daily tasks. The growth achieved in this subject can improve and help elderly people preserving their quality of life, to stay healthy and continue to have an active participation in society.

Several works related to AAL solutions are available with different approaches, but with the same purpose. These works make often use of wireless sensor networks, machine learning, artificial intelligence algorithms and other techniques. A frame presents methods that support technical development to facilitate programming AAL systems [24]. To provide a full cycle of processes, including processing of sensors data with proper system architecture to an ambient intelligence pervasive infrastructure with a large number of distributed devices that communicate between themselves with centralized services had a significant input to design broad system architecture [25].

In terms of prevention, AAL systems can be considered for different situations, such as falls, physical immobility, monitoring of activities of daily routine, occupying spaces at home, behaviour analysis, and other possibilities. All improvements on each of these scenarios are an important step towards the development of more effective and secure solutions enabling the further development of new mechanisms, products and even services [26].

It is possible detect multiple direct advantages exemplified next: when a person gets older, he or she may find that taking care of himself/herself can become more and more difficult due to chronic health conditions or other problems. The AAL purpose sometimes makes possible to live in his/her own house with the necessary cares and not necessarily in a nursing home or hospital. This allows instant money saver in health care, greater independence and more comfort for the elderly.

Friends and family can help many seniors with several activities of daily life, while they live at home.

It enables older people to have more independence in activities of daily life such as bathing, dressing, eating, mobility and the use of the bathroom, keeping elderly more active. Assistance in administering medications at certain hours is also very important. Help in the management of daily life, remote access to healthcare system, do daily exercise, remote wellness programs and equipment. Socializing with family and inclusive with elderly neighbours belongs to this system [27].

As disadvantages we have several critical situations identified: the assisted living solution may not be the best choice for every senior. Many seniors prefer to live in nursing homes. They may have lived in the house since childhood and find their current living situation comfortable and friendly in nursing homes. They can find difficult to navigate in unknown environments, fear parting with most of his possessions, fear further isolation from family and friends, and look at an establishment as a first step for independence.

AAL offers an alternative to nursing facilities for people who need help with activities of daily living, but not a high level of care. Overloading the elderly and those who are helping with various and too many responsibilities is also a disadvantage.

Another major disadvantage is the difficulty for elder people to interact with new technologies. Technological learning in these cases can be a long and lengthy process [27].

2.2. Theoretical Analysis in Healthcare Technologies

The technologies can improve the efficiency, quality and cost in healthcare services. The mobile computing technologies features have the potential to change health cares. Mobile Health technology enables caretakers to remotely monitor patients' health and also allows individuals to manage their own health more easily and with privacy [28]. This technologies and applications also provide to the patients medical information management and more easily with Electronic health record [29].

This section describes the importance of technologies to bring more benefits in Healthcare systems.

2.2.1. Electronic Health (eHealth) Data Exchange

The eHealth term has appeared since 1999 with internet proliferation. This healthcare practice is supported by electronic and digital processes and communications [44]. The communication of patient data among different healthcare systems, caretakers and other specialists is carried by eHealth records. It enables faster and more convenient access.

An eHealth Record uses a structured representation of health information in an electronic format [45]. A typical system is based on a well-structured and organized archive regarding the patient medical history in an electronic digital form [46].

This methodology presents several advantages regarding health information structuration, namely the capacity to improve health providers efficiency, reducing costs or even increasing treatments effectiveness [47].

Moreover, it allows medical staff or patients to access easily to that information in an electronic or digital way providing to the medical staff enhanced abilities to take improved decisions about possible health treatments or analysis of the patients' health information [48]. Figure 3 presents an illustration of a typical eHealth data exchange system architecture [49].

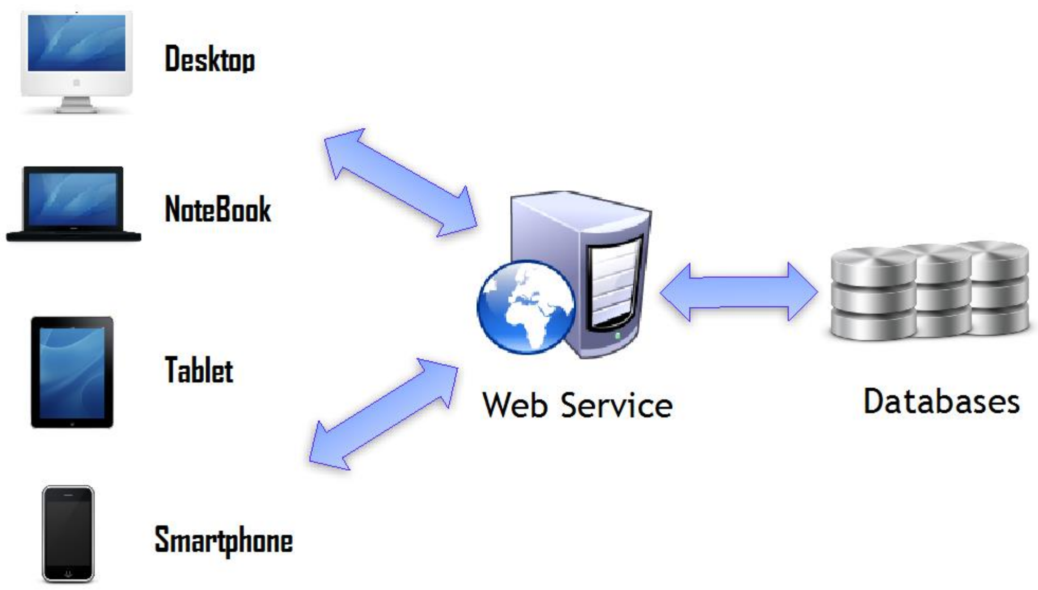


Figure 3 - Illustration of a typical eHealth data exchange system architecture.

The eHealth Data Exchange based on mobile applications are currently gaining popularity due to the fact that users access their health records through the Web, not being constrained to spatial and temporal barriers, although it is necessary a reliable Internet connection in order to support these services [50]. Mobile eHealth records systems rely on the utilization of Web Services that enable the access to data from any personal computer, tablet, or smartphone with Internet connection [51].

2.2.2. Mobile Health (mHealth) systems

As mobile health applications evolve, more sophisticated and advanced health applications emerge, raising concerns about mobility, facility to access anywhere and in extreme conditions [30].

To respond AAL needs focused to Elderly population affected by isolation and displacement incapacities. The mobile health is presented as an excellent solution full of potential and opportunities. These people often underestimate diseases like hypertension and oversights that may cause several damage if not properly monitored for prevention and treatment awareness [31]. Through mobile health, data can be collected from patient's mobile devices (e.g. smartphones, tablets or wearable sensors) and sent to healthcare providers, enabling a remote and fast analysis avoiding patient's displacement.

Mobile technology has been registered as a progressive evolution due to the growing ubiquity of those devices in contrast to desktop computing for it can occur using any device, in any location in any format. Over the years, several definitions of ubiquitous computing have been proposed since 2002 [32]. Its goal is to provide users services available anytime and anywhere in a transparent manner, focusing on the information perceived by the user instead of the technology behind responsible for its operation [33], [34]. Sadly, mobile devices suffer from certain restrictions, namely their processing and storing capacities, turning them inefficient to run heavy or poorly conceived algorithms with many processing tasks [35]. Hence, the development of ubiquitous Web-based systems has come to handle these limitations, releasing the mobile devices from running these heavy tasks, providing them access to remote services and content, regardless the time and place in a transparent manner. Ubiquitous computing may be present whether on client side (e.g. in mobile devices) or even in server side (e.g. Web Service). It offers invisible mechanisms and underlying technologies to support internet, other networks, advanced middleware, operating systems, mobile code, sundry sensors, mobile protocols, location and position. All the interactions with mobile software and/or hardware happen without being noticed by the end-user [36].

Nowadays the mobile devices available on the market mainly Smartphones have already a higher processing and storage capacity but still have many limitations. In the spotlight Samsung S4 and Iphone 5 which have multi-colours processor and high storage capacity. Due to mobile devices proliferation [37] several health applications have been developed and available to the public through online markets [38]. They offer to users the possibility of monitoring their own health state, by creating and maintaining their own health records, treatments alerts, falls' detection, health goals and many others. All these types of applications are present in most popular mobile platforms, such as Google Android OS [39] and iOS [40], with their respective applications stores, such as the Google Play [41] and App Store [42] both online available. Android OS is one of the preferred targets in what health applications is concerned, with several hundred applications available some free and others paid.

The challenges and limitations on m-Health systems are presented, namely the lack of standards regarding the standardization to link telemedicine services, due to difficult operational compatibilities between mobile devices and telecommunications services. Moreover, it is stated that due to systems overly complex and with privacy problems, user acceptance tends to grow up slowly [43].

2.3. Health Sensor Systems

Many biological processes in a patient can be measured. The measurement of this process produces a biosignal that gives an idea of what is happening in a precise moment of time. For biofeedback monitoring system, biosensors and inertial sensors to extract precious information from patient's body are presented.

This section will focus on a briefly description of health sensors properties.

2.3.1. Electrocardiography (ECG)

ECG monitors attach up to three sensors to the body. Each sensor consists of an electrode which records the electrical activity in a different section of the heart. The ECG signal is characterized by five peaks labelled with successive letters of the alphabet P, Q, R, S, T, and U as shown in figure 2 [52]. To understand how and what an ECG records, it is important to have a basic knowledge of how the heart works.

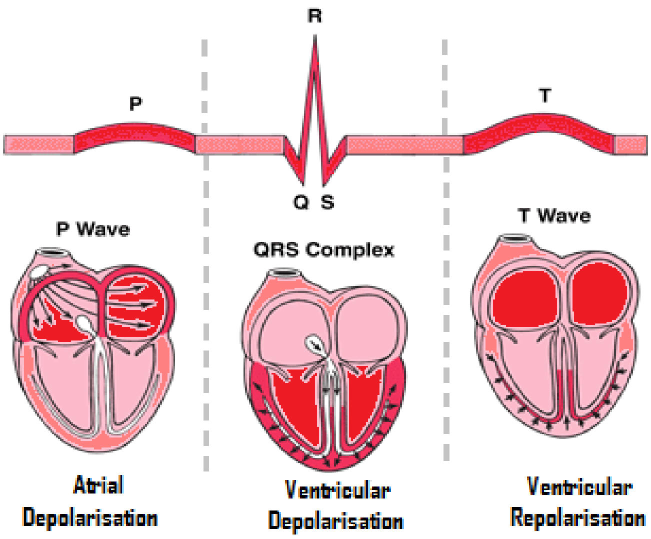


Figure 4 - Illustration of the heart state in ECG signal detection.

The ECG signal is essentially a picture of the electrical activity of the heart over time, captured via external electrodes in different states of electrical polarisation. The potential change, which occurs during depolarization and repolarisation, is exactly what can be measured at the skin surface by electrodes. This recorded electrical activity can then be displayed in a two dimensional graph known as electrocardiogram.

The ECG signals analyses are important to note if changes in electrode placement will ultimately affect in the picture obtained. So it is extremely important that the electrodes are placed correctly [53]. The three lead ECG are based on the most basic form of electrodes placement, known as Einthoven's triangle [54].

When it comes to the interpretation of an ECG signal, the attention turns to the segment and gaps, also illustrated in Figure 4. Several detection algorithms allow us to find heart diseases and other interrelated problems [55], [56]. The ECG beat detection is essential to identify heartbeat morphologies and also detect R wave events in the ECG signal [57].

2.3.2. Electromyography (EMG)

EMG is the technique to evaluate the recording of electrical activity produced by skeletal muscle cells, when electrically or neurologically activated. The electromyography is used in applications to diagnose of neuromuscular diseases and also to control muscular activities among others [58].

The tibialis anterior and gastrocnemius muscles figure 5 were chosen to AAL mobile system to falls prevention and detection.

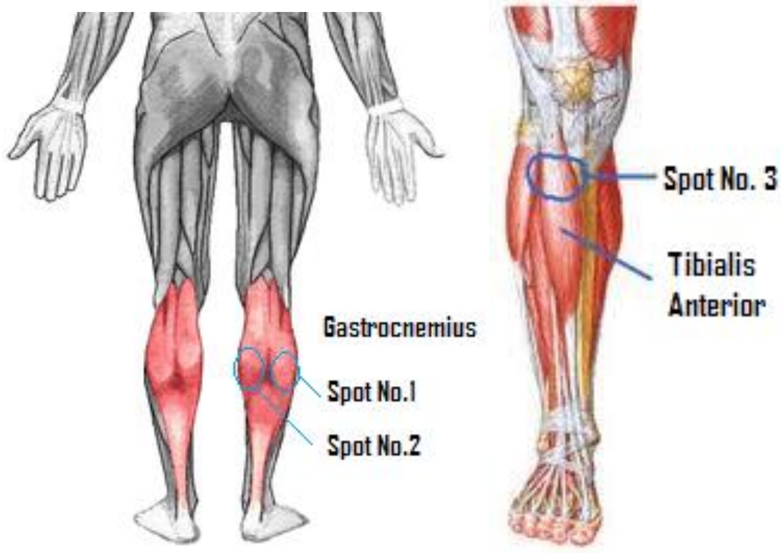


Figure 5 – Illustration in a Human leg the possible spots to EMG electrodes locations.

These muscles are used by their importance in maintaining equilibrium during movement and posture. They are also particularly suitable for surface electromyography because they are rather isolated from other muscles and can be reached easily during daily events [59]. Based on the EMG signal records and the patterns of the segments and gaps in an EMG waveform, muscular activity abnormalities and neuromuscular disorders connected with balance problems can be detected and a diagnose can be given [60], [61].

2.3.3. Blood Volume Pulse (BVP)

BVP sensor uses photoplethysmography to detect the difference in pigmentation of skin colour using extremities such as the fingertips to show the heartbeat and the level of oxygen in blood. The procedure is using a light source to measure the light reflected from the skin using a receiver photosensor.

According to scientific literature, the interaction between light and human tissues can cause photochemical, thermal and electromechanical effects, depending on irradiance of light exposure time [62].

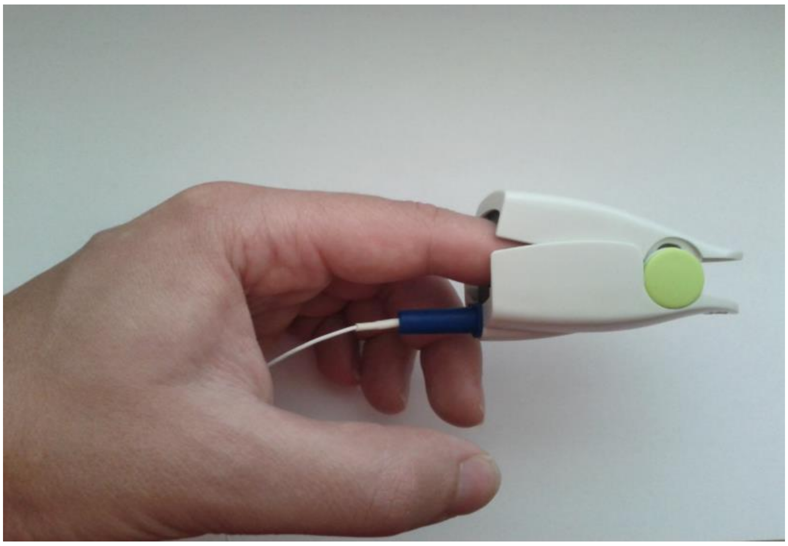


Figure 6 – Photography of the BVP sensor in the fingertip.

Through algorithms it is possible to detect different states with a BVP signal analysing. It allows us to detect Blood volume oxygen, about the maxim and minimum through analysis photoplethysmography reaction.

BVP digital signal processing approaches designed to reflect the BVP waveform change through a single parameter, which could be obtained automatically from the analog to digitized BVP signal [63].

2.3.4. Electro Dermal Activity (EDA) or Galvanic Skin Response (GSR)

EDA or GSR is a sensitive index of sympathetic nervous system activity. This sensor is used to measure the electrical conductivity of the skin of a patient at a given period of time. This electrical conductance in a person's skin is correlated directly to their emotional state. Therefore the excited state of a person can be observed to detect psychological situations less favourable to the patient welfare and health [64].

Figure 7 – Photography of EDA or GSR sensor on the hand palm.

This sensor monitors skin resistance between two reusable electrodes attached in certain cases in fingers of one hand or other in palm of the hand. In response to a stimulus, the sweat glands become more active, increasing moisture on the skin and allowing the current to flow more readily by changing the balance of positive and negative ions in the secreted fluid [65].

2.3.5. Respiration Sensor

The respiration sensor consists of a synthetic tissue band which is placed on the chest area, through the elasticity it allows detection when the lungs are filled with air or voids by the abdomen zone contraction and expansion.

Figure 8 – Photography of a respiration sensor band.

This sensor allows verifying if a person is tired and even nervous when respiration rate decreases or increases [66].

2.3.6. Accelerometer

It is presented today in numerous devices, and it is common in devices with Android OS and IOS system: this small sensor is able to measure the absolute acceleration exerted on him at every moment of time. When the device is in free fall to the ground, the measured acceleration in three axes will be close to zero with the disposal of reading errors. Figure 9 presents a three axes accelerometer module.

Figure 9 – Photography of an accelerometer sensor.

The measure unit for the output value is given in G's, that comes from the values at each instant for the three Cartesian axes presented in accelerometer, X, Y and Z. When the Z axis is pointing towards the soil, a force acts on it. It is the gravity acceleration force of 1G approximately 9.8 m/s^2 on this axis. The most common use of this sensor in devices is to enable identification of the relative position to the ground to rotate the screen. This system uses the capabilities of the accelerometer to identify situations of potential fall of a patient [67].

2.4. Falls Detection and Prevention Approaches

Several approaches based on tools and techniques for falls detection can be found in the literature. Generally, they are mainly concerned with health of elderly and incapacitated people, using techniques based on accelerometers movement data collection and a fall detection algorithm. Considering the contributions available in the [68], [69], approaches, the differences between them come from the fact that one uses a smartphone and the other is based on an embedded accelerometer, GPS receiver, microcontroller sensor solution with Zigbee technology transceiver. Many solutions of monitoring biofeedback are also reported but all of them have in common an explanation of the importance of data acquisition in healthcare systems for surveillance of patient's physiological signals [70]. A more static and no adaptive system showing a biofeedback monitor to handle a specific type of health problem is presented in [71]. A relatively large amount of scientific work has been performed on this topic and there is a considerable convergence among all of them, mentioning that biosignal data is vital for the treatment, monitoring, and prevention of various diseases. Many of these works are quite recent as these systems should be computationally powerful to collect and process large amounts of data in a short time range. However, accidental falls represent the sixth cause of death among elderly people [72] although old still relatively actual. It is estimated that one out of three people aged over 65 years old is at risk of falling and have also higher probability of suffering from health problems not knowing this fact. The concept of fall detection and the context of biofeedback monitor are not new and these technologies have been suffering more significantly technological advancement from the year 2000. Biofeedback evaluation partly contributed to the advancement of health diagnoses like stress assessments, inattention, heart rate, anxiety disorders, depression, and chronic diseases. They contribute significantly and turn possible the development of new treatments and ways to diseases combat. Monitoring physiological parameters is an established topic and is used in diverse areas of medicine and sports. Such technologies are commercially available and, in order to encourage their usability, it is important to demystify the technology turning available what it is, how it works and what quality of information can be expected from it [73].

The capture and processing of biofeedback signals with sensors to a smartphone became possible and increasingly used due to the development and generalized use of these devices for personal use. Several approaches for falls prevention, detection, and biofeedback monitoring may be found in the related literature, using different techniques, tools, and devices [74]. Fall detection is a topic with abundant information where algorithms use sophisticated methods to detect falls, but it is also closely related to describe motion and movements by the patient body. This detection is performed by kinematic sensors such as accelerometers and gyroscopes coupled to most of the mobile devices available in the market. In [12], a quantitative falls risk position using the kinematic sensor was presented to identify an association with different types of falls risk. In [14], a wearable fall detection system with use of accelerometry techniques and a fall detection algorithm is proposed. Both are mainly concerned with the health of elderly and incapacitated people. In order to develop a fall prevention system, a collection of fall characteristics to determinate and train fall events that use strategies with existing resources were reviewed [75]. A detailed methodology for electro cardiogram (ECG) sensor was included in [76]. It uses ECG beat detection and treats their data waves to heart beat recognition, R-wave detection procedure or peak detection to make diagnoses of heart diseases and prevent possible problems. An electromyography (EMG) analysis was performed to investigate the changes that occur in the parameters of the patients electrical signals by increased risk of falling and balance disorders [77]. The galvanic skin response (GSR) was a simple method to detect arousal and analyse physical stimulus in a patient to thereby check if patient has or not imminent risk of falling [78].

There was an extensive range of healthcare applications with biofeedback monitoring from critical monitoring of physiology scenarios of terminal illness up to the own patient make diagnoses of himself. The proposed solution gathers contributions from related work available in the literature. All these systems and techniques above described offered important contributions to the solution proposed in this work.

2.5. Summary

This chapter presented the literature review concerning a state of art in Ambient Assisted Living, a theoretical analysis in healthcare technologies, health sensors systems and covered works in falls detection and prevention. Thus, after a brief introduction, Section 2.1 presented the AAL review along with advantages and disadvantages. Section 2.2 reviews mHealth regarding mobile systems, mobile devices and applications for common users and also the e-Health transmission data among different entities. Section 2.3 briefly introduced some health sensors systems available, presenting the most used in this mobile application. Finally, section 2.4 presented a general scope in falls detection, prevention and biofeedback monitoring works.

3. Requirement Analysis

Software development must always contain a detailed analysis of the requirements and all specifications of the created system. Therefore, requirement analysis is an essential part and its existence is vital to fully identify all system features and behaviours.

The most used modelling specification is Unified Modelling Language (UML) managed by the Object Management Group (OMG). It provides suitable standard methods to model applications and data structure as well as its behaviour, architecture and business process [79]. Although UML is not a software methodology or a programming language, it is a language with semantic notation that allows developers to view, specify, build and document the objects oriented of a system that turns it possible to design conceptual models, which consists of a setup diagrams with textual description of the main actions and procedures.

The requirement analysis is an essential process for product development, because in there is defined precisely the objectives to development. When it comes to software developing, it is extremely important for all the analysis, system features and behaviours will be addressed in this chapter UML diagrams in order to demonstrate behaviours, interactions and the system structures.

Section 3.1 will approach the system essential requirements, Sections 3.2 to 3.4 will present behavioural interaction and structural diagrams to design mobile solution, Section 3.5 will address used technologies, and Section 3.6 will shortly present the Android Platform. At last, Section 3.7 summarizes the chapter.

3.1. Essential modelling Requirements

One of the most relevant steps in requirement analysis is to determine essential requirements. They can be features or constraints, where the requirements that should be presented in the future system are established. Defining essential requirements can be a difficult task due to the need of having a global and complete vision of the future system to fully define these requirements. Hence, the following essential requirements were defined:

- Android API level should be equal or above 15 (i.e., Google Version equal or above 4.0 ICS), which represents 61,2% of the active Android devices across the globe [80];
- Bluetooth hardware should be present to carry sink node with mobile health sensors;
- Wi-Fi or Edge/3.5G/4G modules are required to perform the Mobile Gateway;
- A pervasive Web Service is required in order to provide database repository, external access and data management;
- The system must be self-sufficient to manage resources;
- Every task should work completely invisible and transparent to the end user;

In order to create and integrate the mobile solution specific mechanism, the above-defined essential requirements are required.

3.2. Behavioural Diagrams

Behavioural diagrams are used to represent system functionalities, i.e., it shows what must occur in the modelled system and it comprises use case and activity diagrams. Table 3 shows the main factors that affect the system.

Table 3. Actors, traits and requirements that the system must implement

Actors	*Process traits*
Patient	▪ Access to mobile platform with proper images ▪ Easy and intuitive navigation menus ▪ Registration with several fields to create profile ▪ Enter in platform privacy zones with login and password ▪ Visualise health sensors values in charts ▪ Get notifications from falls prevention and detection ▪ Falls detection and GPS location ▪ Push button to automatically alert patient caretaker or Urgent care with SMS and E-mail
mHealth System	▪ Validate patient data login ▪ Turn on Bluetooth, Wi-Fi and GPS ▪ Establish sink with health sensors stations ▪ Manage data from health sensors ▪ Monitor biofeedback data ▪ Patient motion detection ▪ Display health sensors values in charts ▪ Show notifications from falls prevention and detection ▪ Send automatic alert to patient caretaker or Urgent care with SMS and E-mail ▪ Send Health data to Web Service
Health sensor	▪ Establish sink with mobile devices ▪ Send physiological data from sensors to mobile device
Web Service	▪ Storing received data in a Database ▪ Provide charts visualization and querying through Web site

The main requirements of the mobile solution are here presented. The process traits were divided by various actors to simplify and make a feasible implementation.

3.2.1. Use Case Diagrams

Use case diagrams can be used to describe global system functionalities, by describing a set of actions (use cases) that the actors (subjects system interrelated) should or can perform. The general use case diagram for the m-Health application is presented at Figure 10.

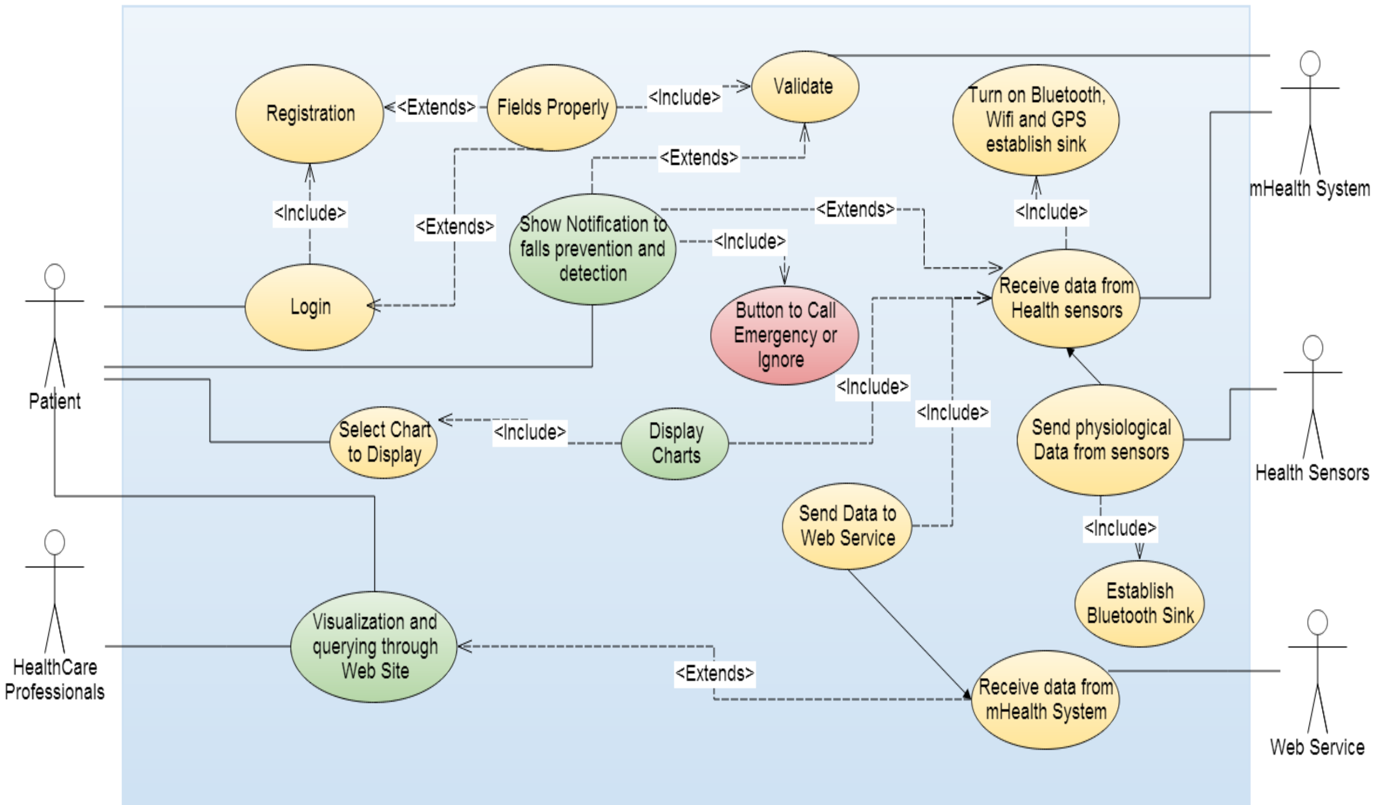


Figure 10 - Application use case diagram.

In the use case diagram actors and their associations with the most significant use cases actions are presented. The actors are drawn as a stick figure, and they can be a person, organization or external system. The ellipses represent specific use case actions and the colours help to understand it.

3.2.2. Activity Diagrams

Activity diagrams are widely used to provide a visualization of the system workflow. Three activity diagrams are defined regarding falls detection algorithm, falls Prevention with Notification Alerts, processing and information visualisation from sensors.

In each specific case, the different Android activities with different sensors reading should be considered simultaneously. Each Android activity is presented as a thread. So threads can be launched in a cooperative state beyond the primary that is created automatically by the system and everything is handled synchronously.

3.2.2.1. Falls detection

The fall detection process was deployed using paradigms of multi-threading to make possible the simultaneous combination of several tasks and several sensors readings.

In Figure 11, it is presented the activity diagram of falls detection system, which represents the sequence of the application and its data flow.

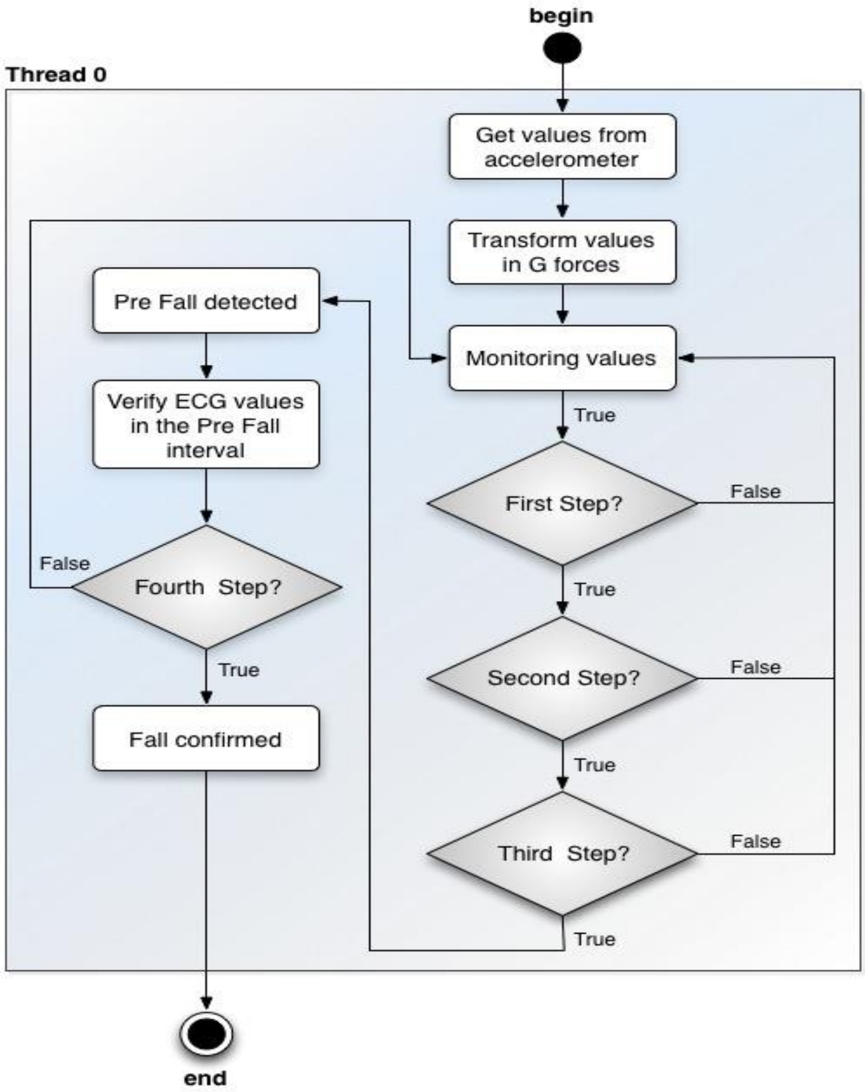


Figure 11 – Falls Detection activity diagram.

Figure 11 presents the workflow of the first thread (called Thread 0). The process starts from getting the acceleration values from the accelerometer and then transforms the values of axes *X*, *Y*, and *Z* received from accelerometer in *G force*, using the Equation 1.

$$G = \frac{\sqrt{x^2 \times y^2 \times z^2}}{9{,}8} \qquad (1)$$

The thread will always be active and monitor the user activity. In the first step, if *G force* is lower than 0.5, the process advances to a second step. In the second step, if *G force* is greater than 2.5, it will go to the third step. In the third step, if the first and second steps present a flag as True, it will start counting 10 seconds, if in the time interval some movement occurs, it is declared as false alarm. In the other case, if there is no activity and the verifying data from sensors (e.g. the ECG values) are too weak comparing to normal values using a threshold value or have irregularities, it is possible the user to be unconscious or immobilized and need help. Then, the system will trigger the fall alert, the time interval in milliseconds, and data from sensors are saved on the database to compare the values at the same time.

3.2.2.2. Processing and information visualisation from sensors

New threads are created for other activities, with the remaining sensors and visualization, launched simultaneously and synchronized in Figure 12.

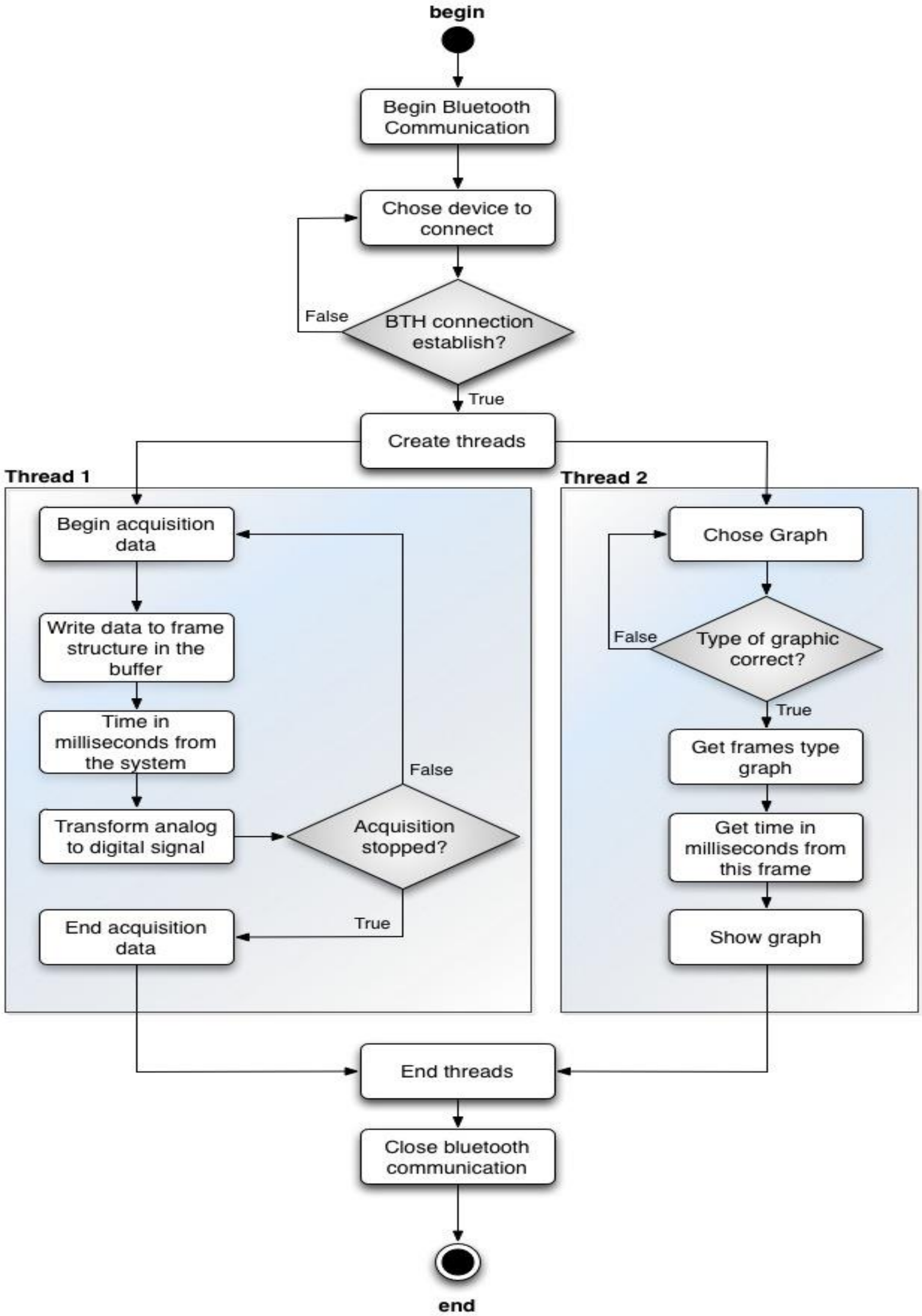


Figure 12 – Bluetooth Connection, Receive, Store and processing data (Thread 1), other Show Charts (Thread 2) activity diagram.

The workflow of the Figure 3 starts with the Bluetooth communication and verification, displaying Bluetooth devices that are in range of the base-station. After a successful connection, the system will create two threads for each sensor, one for the data acquisition and another for the visualization of the values in a graph. When a connection is established, Thread 1 will start acquiring data from the connected sensors and the device starts to receive data frames that are placed on the buffer and saves it on the database. In order to convert the analogue signal output $V_{outAnalog}$ collected, a 12-bit integer, which is given a sampling frequency in Hertz, to a digital signal $V_{outDigital}$ (in volts), the Equation 2 was used.

$$VoutDigital = \frac{VoutAnalog * Vrange}{4095} \quad (2)$$

The Voltage V_{range} value ranges from 0 to 5, specifically for each type of sensor. At the same time, Thread 2 starts drawing the graphs according to the values from the sensor. If the acquisition stops, the acquisition mode will finish and will close the Bluetooth socket communication.

Thread 2 displays charts using the Android library for chart graphs (named Achartengine). In the proposed application it is possible to choose the type of graph to be presented, which may be the Accelerometer, Blood Volume Pulse (BVP), Electro-cardiogram (ECG), Electromyography (EMG), Electro Dermal Activity (EDA), and the Respiration. It is also possible to display several charts simultaneously.

3.2.2.3. Falls Prevention

The diagram shown in Figure 13 presents the sequence of the application and its data flow. The modules health sensors and movement sensors are launched in a cooperative state and the Android activities are handled synchronously.

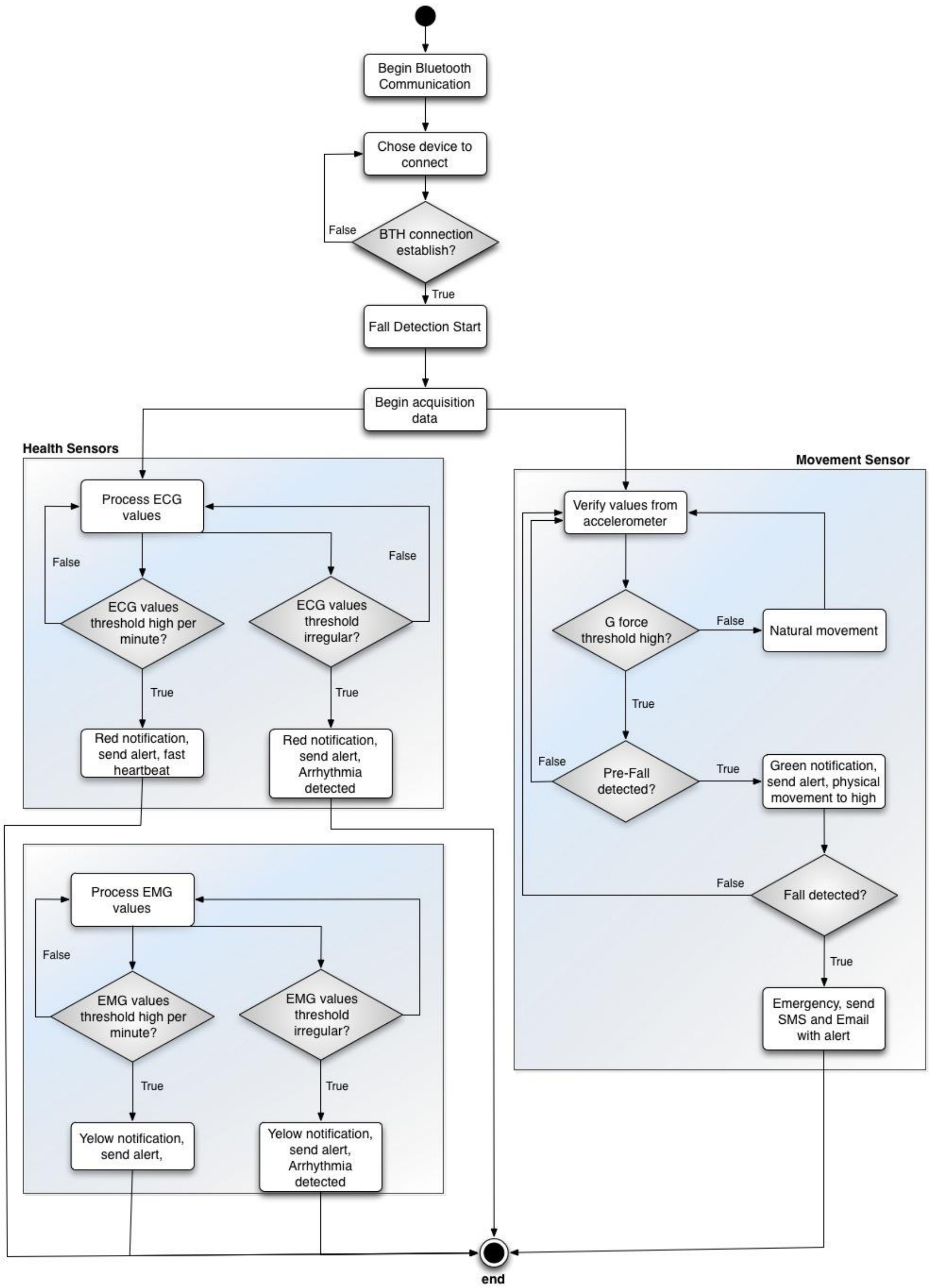


Figure 13 – Falls Prevention with Notification Alerts activity diagram.

By the predefined threshold values and the times, it is possible to detect real life disturbances (in real time) using body sensors (electro cardiology, electromyography, galvanic skin response, and electro dermal activity). With Android notifications it is possible to alert users about disorders, which endanger their wellbeing. A notification is displayed for each type of sensor according to the severity of the detected problem. It shows different suggestions according to the detected issue. Then, the user becomes aware and tries to solve the situation by himself/herself to prevent a further even worse situation.

3.3. Interaction Diagrams

Interaction diagrams are used to describe interactions among elements in the system. The sequence and collaboration diagrams are the two existing and most used interaction diagrams.

3.3.1. Sequence Diagrams

Sequence diagrams are useful to model the logic flow within a system perspective. They are focused on identifying the system behaviour. In this work the system flow was divided in two relevant diagrams. The first one illustrated at Figure 11, presents the Biofeedback monitoring from health sensor, the falls detection and prevention system and patient interaction with Mobile Application sequence diagram.

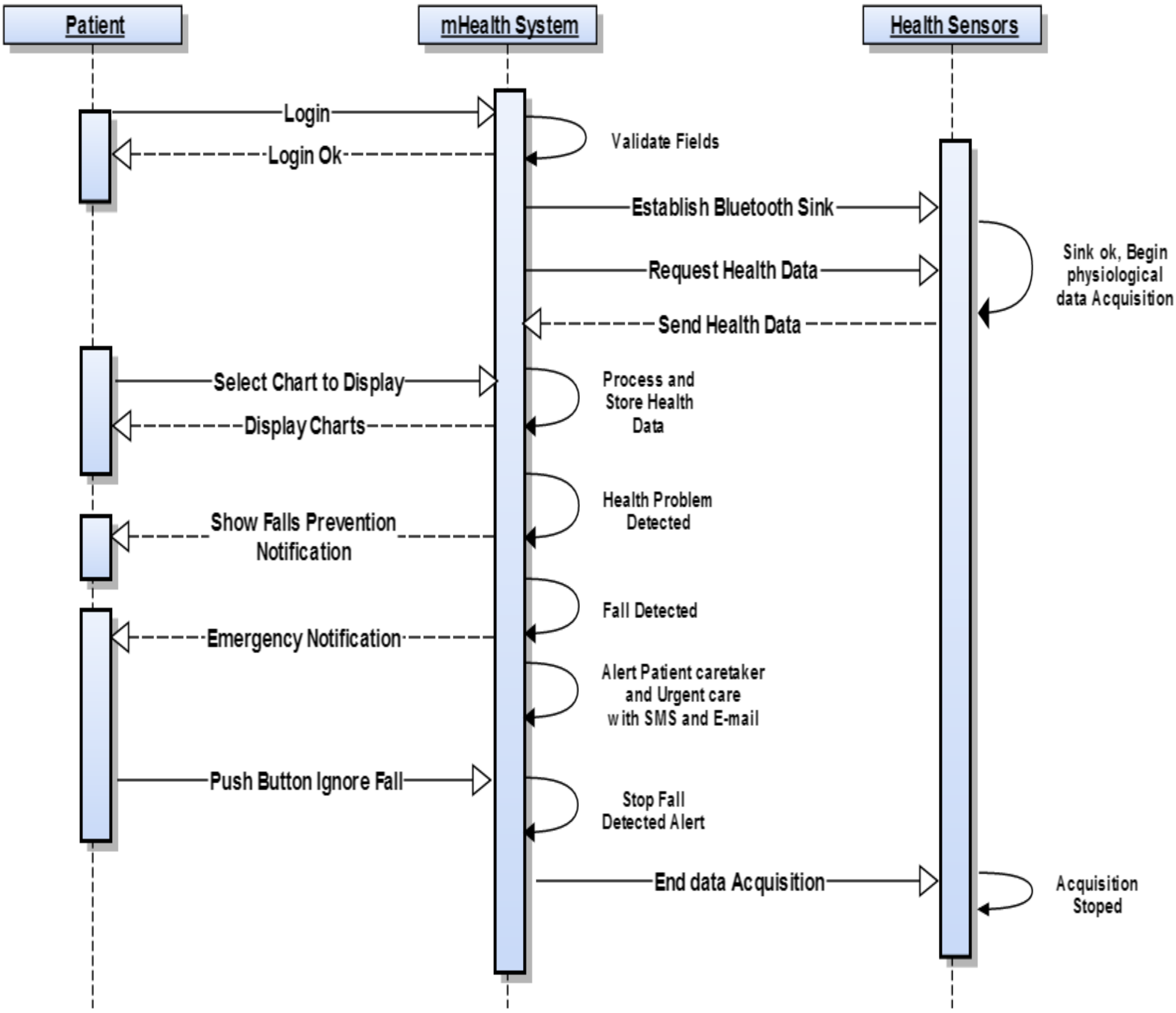


Figure 14 – Interaction among Patient, System and Health Sensors sequence diagram.

The next sequence diagram, presented in Figure 15, represents mHealth Mobile Solution connection with Web Service for external database storage session, so data can be accessed by HealthCare Professional (user's terminal) available from outside for possible data query through the Web browser.

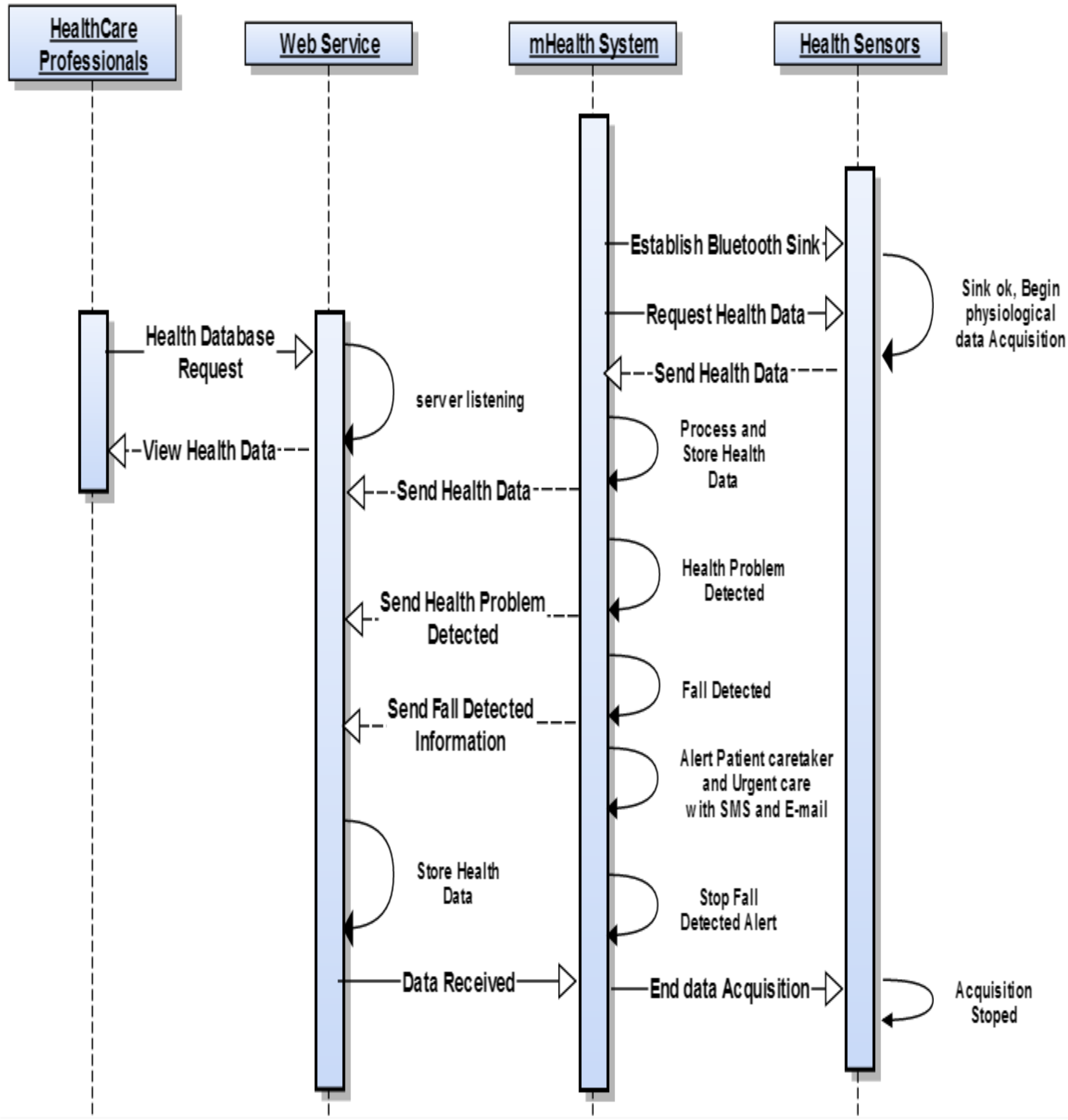


Figure 15 - Interaction among mHealth system, Web Service and Data View sequence diagram.

3.4. Structural Diagrams

Structural diagrams represent the oriented object elements of a system regardless the time. The most used structural diagram is the class diagram. Here is also presented the Database Relational Model structure.

3.4.1. Class Diagrams

Class diagram shows statically the collection of the model elements such as classes, their types, and their relationships. That serves as a model for objects creation. Figure 16 presents a class diagram with proper attributes and methods.

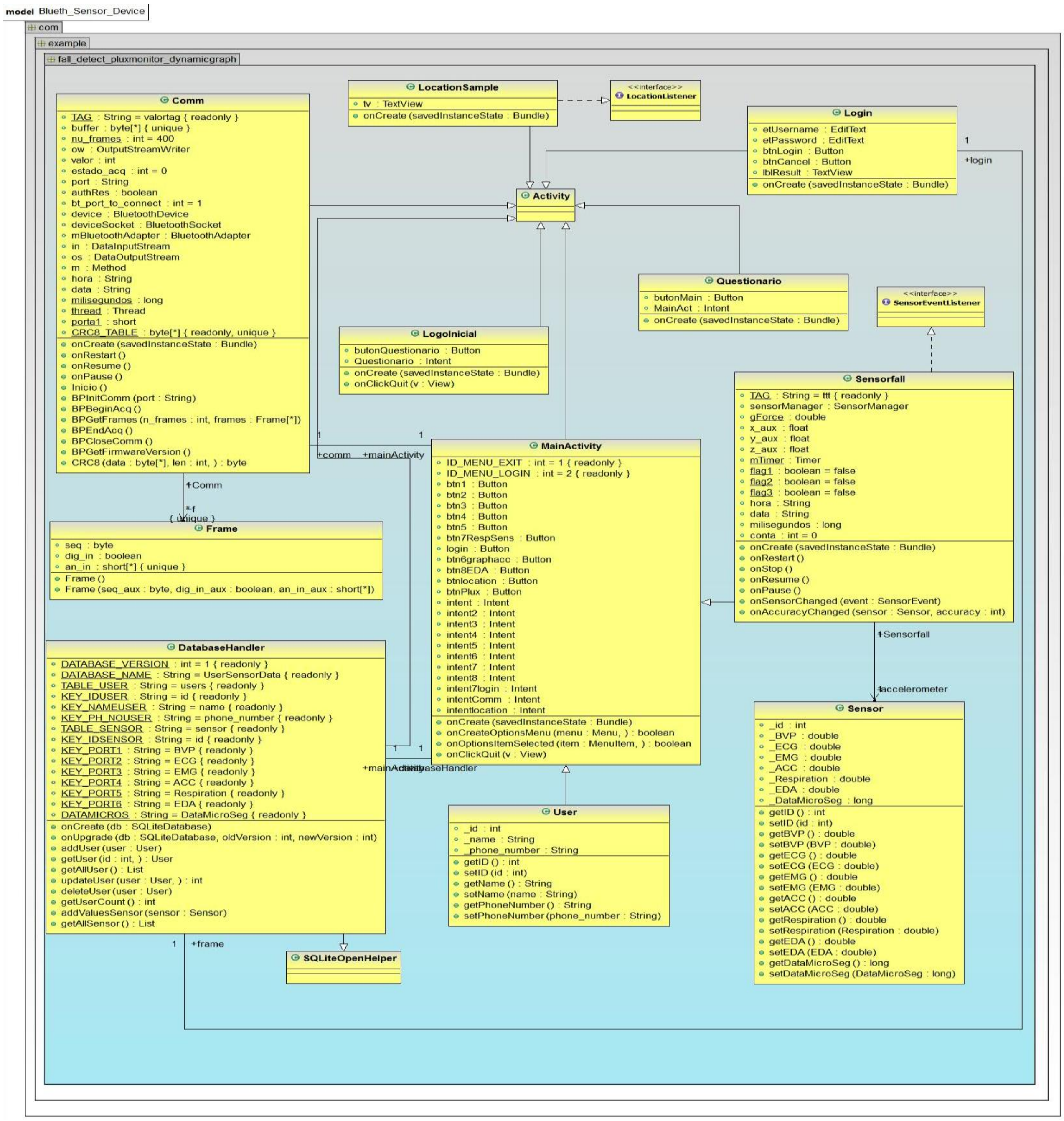


Figure 16 - Class diagram with Bluetooth connection to health sensors, Falls Detection and Prevention, GPS location and Database Handler classes.

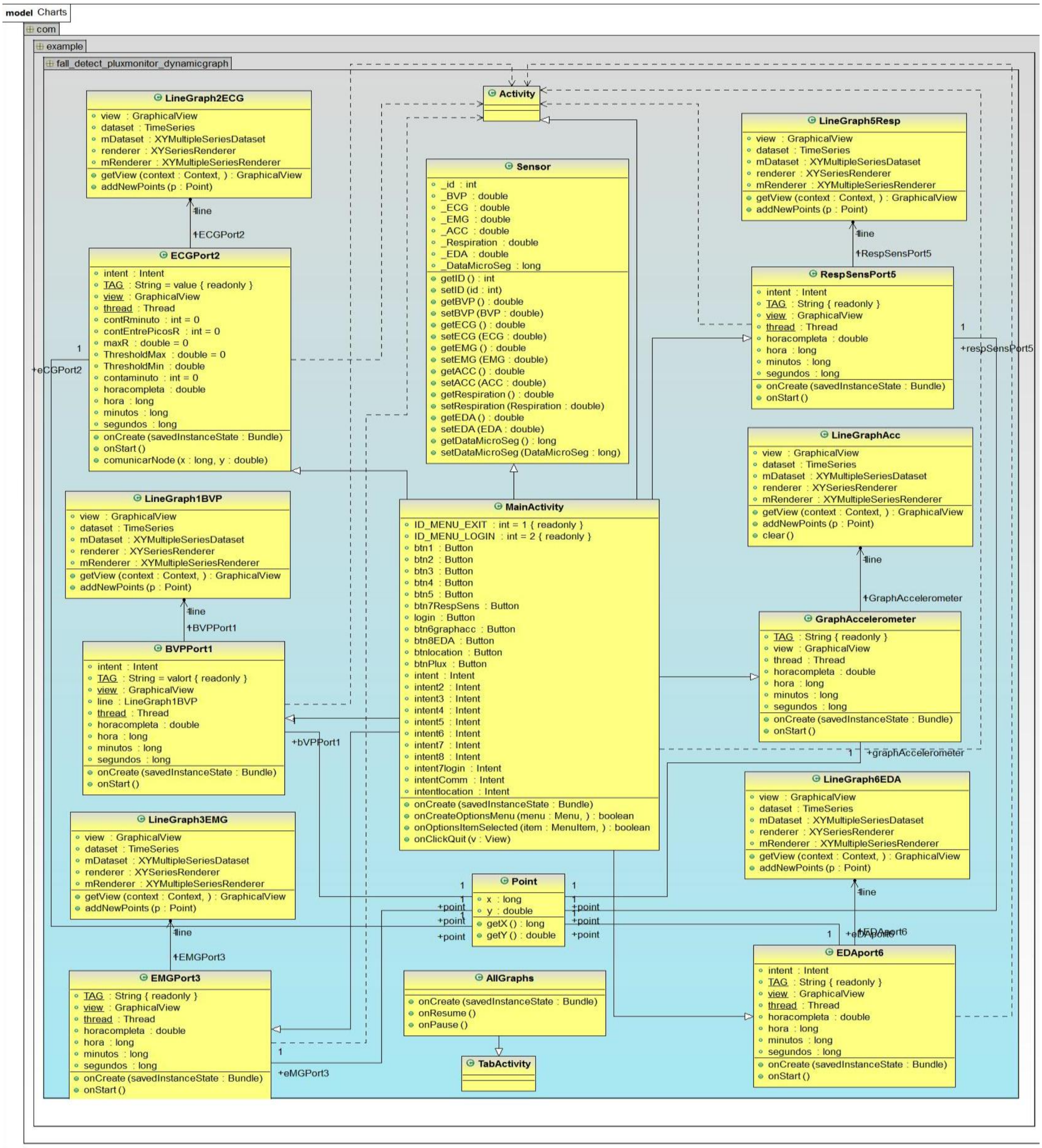


Figure 17 – Class diagram to display health data charts.

In figures 16, 17 the hierarchical representation of classes' dependencies are presented. The classes presented are programmed in Android System and classes are dependent of a main class called activity.

Next section would describe the Android Mobile system and its specific properties.

3.4.2. Database Relational Model

The Relational model is a way to represent and unify the relational entities. This model is used to describe entity needs and information type to be stored in a database.

Figure 18 shows the Relational model diagram based on the notation of the database developed and implemented in MySQL.

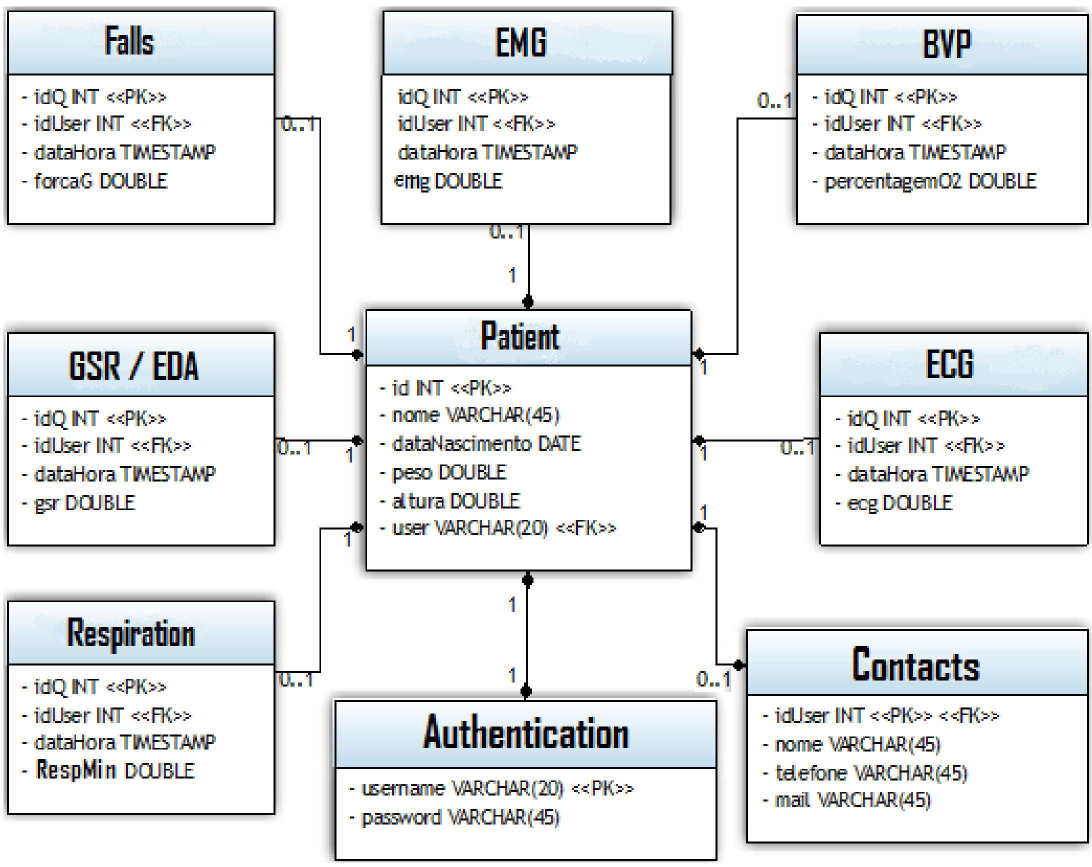


Figure 18 - Database Relational Model Diagram.

The database contains the patient personal data, the data acquired from health sensors and a patient falls' register. All this users' data was saved in mobile devices and in external Web storage by Web services.

3.5. Used Technologies

The AAL mobile solutions aims mobile devices running Google Android operating system, shortly described in the end of this chapter. However, the proposed strategies could also be applied to other mobile operating systems, such as iOS or Windows Phone. Hence in order to be possible apply mechanisms for develop the system, Android Software Development Kit (SDK) [81] was used, which provides the necessary tools and a set of APIs to develop android applications using the Java programming language. The development tool used to develop the different proposed approaches was the Eclipse integration development environment (IDE) in combination with the Android development tools (ADT) plugin, designed to extend Eclipse capabilities, providing debugging options or even test emulators.

As is known all Android devices provide networks connection through Wi-Fi and Bluetooth, a core requirement for the proper functioning of the system. The mobile device receives data directly from the mobile phone accelerometer and from the base station (sink node) of body sensors through Bluetooth. Through mobile gateway all the collected data is sent to a remote database through the hypertext transfer protocol (HTTP) protocol using REST Web services [82].

For local data storage in the smartphone or table about patients, a MySQL database was required. To create database and for query processing it was used the MySQL Workbench toll [83]. The insert and remove data process is performed through a Java script database handler.

3.6. Android Platform

Google Android is a software stack for mobile devices that includes an operating system, middleware and key applications. The Android SDK provides the necessary and required tools and APIs to be able to develop applications for the Android platform, using the Java programming language.

3.6.1. Android architecture

It's essential to have a reasonable knowledge of the Android architecture in order to be possible to design and develop robust and consistent solutions towards Android OS. The following Figure 19 shows the main system components of the Android OS.

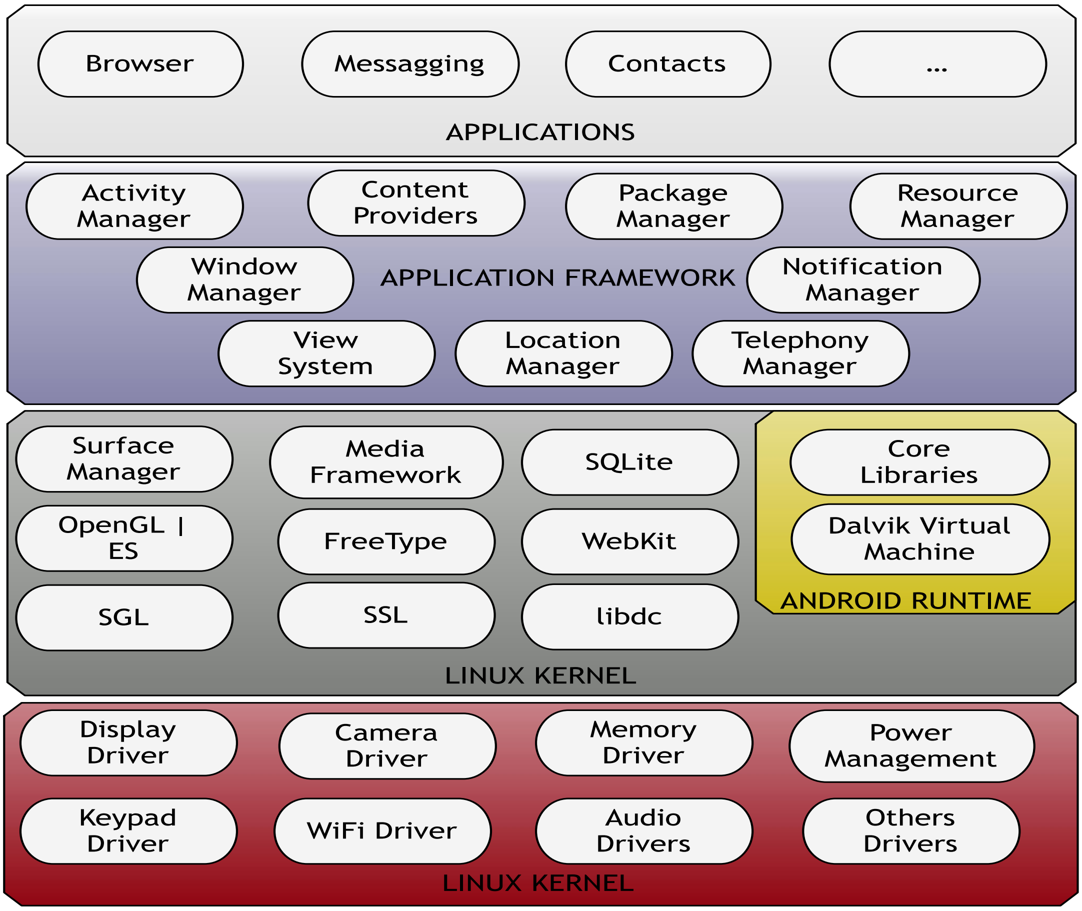


Figure 19 - Android OS architecture.

Components shown in Figure19 may be summarized in four principal layers as follows. **Applications** layer provides by default a set of core applications and allows installation of other ones. Through the **Application Framework** it is possible to access to device hardware management options and other embedded android features.

A set of **Libraries** used by several components of the OS, as well as the **Android Runtime** that comprises core libraries and the Dalvik Virtual Machine (DVM). Finally, **Linux Kernel** handles core system services such as memory and process management, working as an abstract layer between the hardware and the software stack [86].

3.6.2. Android Activity Lifetime

Android possesses an activity stack that manages the different activities that an application may have. In the system, activities are managed as a task stack. Every time a new activity is created, it is placed on the top of the stack and becomes the running activity. The previous activity remains below, in the stack, and it does not come to foreground again until the newest activity appears. The activity has four main states (active, paused, stopped, and dropped). If an activity is on screen foreground, it is active and if it lost focus but is still visible, it is paused. If an activity is completely obscured by another activity, it is stopped, and, finally, if an activity is paused or stopped, it can be dropped from the system memory.

There are seven methods used to loop and control the entire lifetime of all Android activities. Figure 19 represents the activities lifecycle and all used methods to control the lifetime of the mobile application.

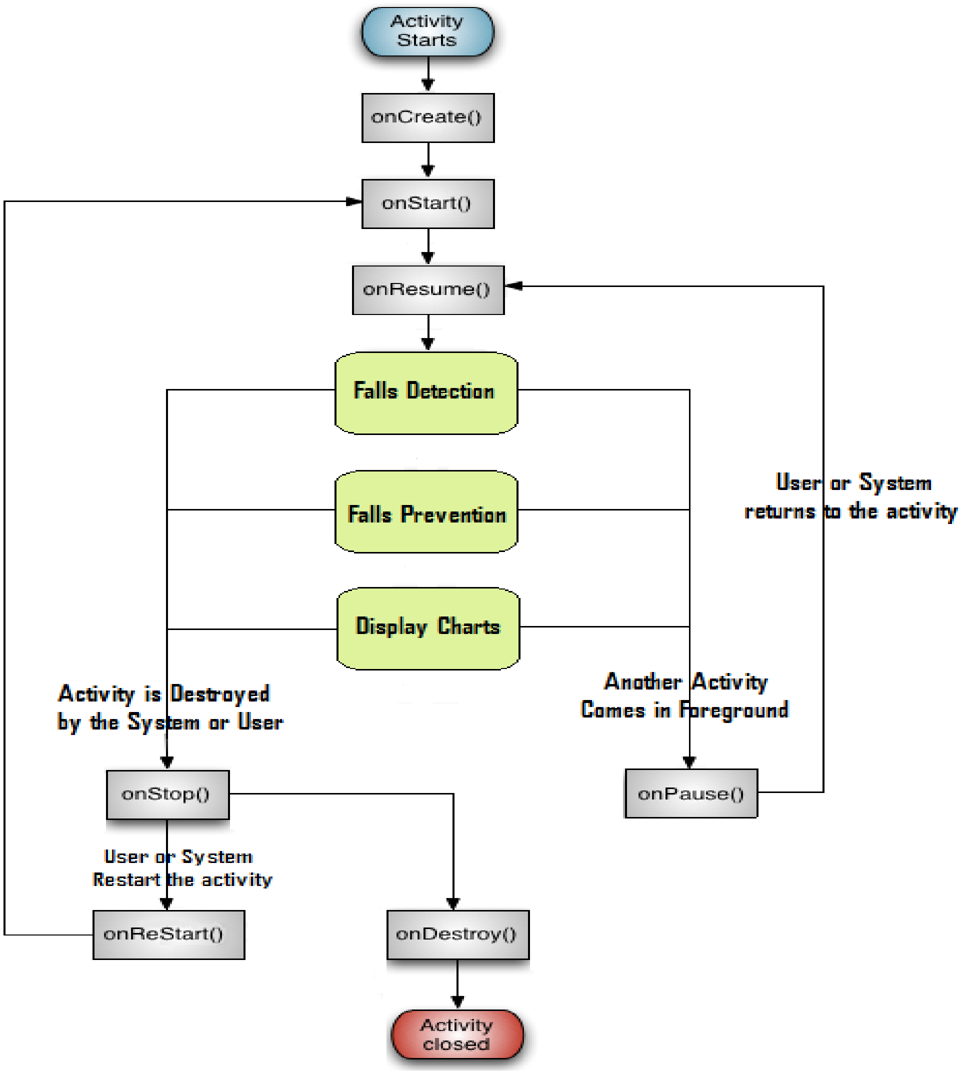


Figure 20 - Illustration of AAL Mobile System Android Activities Lifecycle.

The mobile application possesses three activities and each activity can contain Threads to perform multiple tasks. It is called the *onCreate()* method when the activity is first created. This is where all of your normal static set up is created: views, bind and data to lists. This method is always followed by *onStart()* and this is called so when the activity is becoming visible to the user. It is followed by *onResume()* if the activity comes to the foreground, or *onStop()* if it becomes hidden. *OnResume()* method serves when the activity will start interacting with the user. At this point your activity is at the top of the activity stack, with user input going to it. It is always followed by *onPause()* method when an activity is going into the background. The counterpart is *onResume()*. For example if Falls Prevention activity is launched in front of Falls Detection activity this call back will be invoked *onPause()* method and Falls Prevention activity does its work in background. The *onStop()* method is called when the activity is no longer visible to the user. It will next receive either *onRestart()* or *onDestroy()*. The final call is *onDestroy()* method which is used to destroy activities [87].

3.7. Summary

In this chapter the requirement analysis were approached in order to address all system behaviours and necessary features to the system. Thus, Section 3.1 presented the system essential requirements, Section 3.2 discussed used technologies, Sections 3.3 to 3.5 presented behavioural, interaction and structural diagrams to design mobile solution and in Section 3.6 it was shortly presented the Android Platform. Finally, this Section summarizes the chapter.

4. Devices used on the Prototype

This chapter will focus on the experimental setup of devices used in the prototype. Three proposed mobile health sensors solutions suitable to do research and one designed especially for the AAL mobile solution regarding the main specifications to the AAL mobile environment. The mobile health devices used in the prototype aim the AAL mobile applications to Biofeedback monitoring with falls detection and prevention mechanisms. Those will be shortly introduced and described by the proposed health mobile solutions prototype, in Section 4.1 the Bioplux Research system and in Section 4.2 the Shimmer Research solution. These solutions for biofeedback monitoring have one inertial sensor and five biosignal sensors to extract precious information from patient's body.

Then, in Section 4.3, an AAL specific mobile solution is proposed to enhance the functional requirements in comparison between the previous solutions called AAL Plux chest strap, two biosignal sensors and one accelerometer.

Finally Section 4.4 refers to the available Android devices to perform the mobile application.

Nevertheless, the AAL mobile solution can also be adapted to other available sensor systems and mobile devices smartphones or tablets available in the market.

4.1. Bioplux Research

The Bioplux research system offers flexibility, a big range of health sensors, adaptively, and a great capacity for portability and autonomy. The Bioplux Research system, shown in Figure 21, is a device that collects signals from the sensors, transmitting them via Bluetooth to other devices, where the signals are shown in real time.

Figure 21 – Bioplux Research Body Sensors Kit

For monitoring, the system is based on three principles: connect, acquire, process and visualize data in form of graphic charts on desktops, laptops, smartphones or tablets. This body sensors kit has a base station which is a sink of body sensors (BS), with smart sensor nodes. It also carries a digital port for direct output and input data, and a connector for the transformer to recharge the internal battery providing, more or less, about 12 hours of autonomy. The sensors chosen for this study and owned in this body sensors kit are the following: the accelerometer, the Electrocardiogram (ECG) characterized by six crests and troughs, the Electromyography (EMG), the Blood Volume Pulse (BVP), the Electro Dermal Activity (EDA), and the Respiration sensor. This sensors system was the most deployed to the AAL mobile solution validation because it offers the described excellent conditions.

4.1.1. Arrangement of the Sensors in Patients Body

A good arrangement of BSs in the patient's body is essential for proper readings. In Figure 22 the sensors are placed on the proper local and the base station is synchronized with a smartphone for data acquisition.

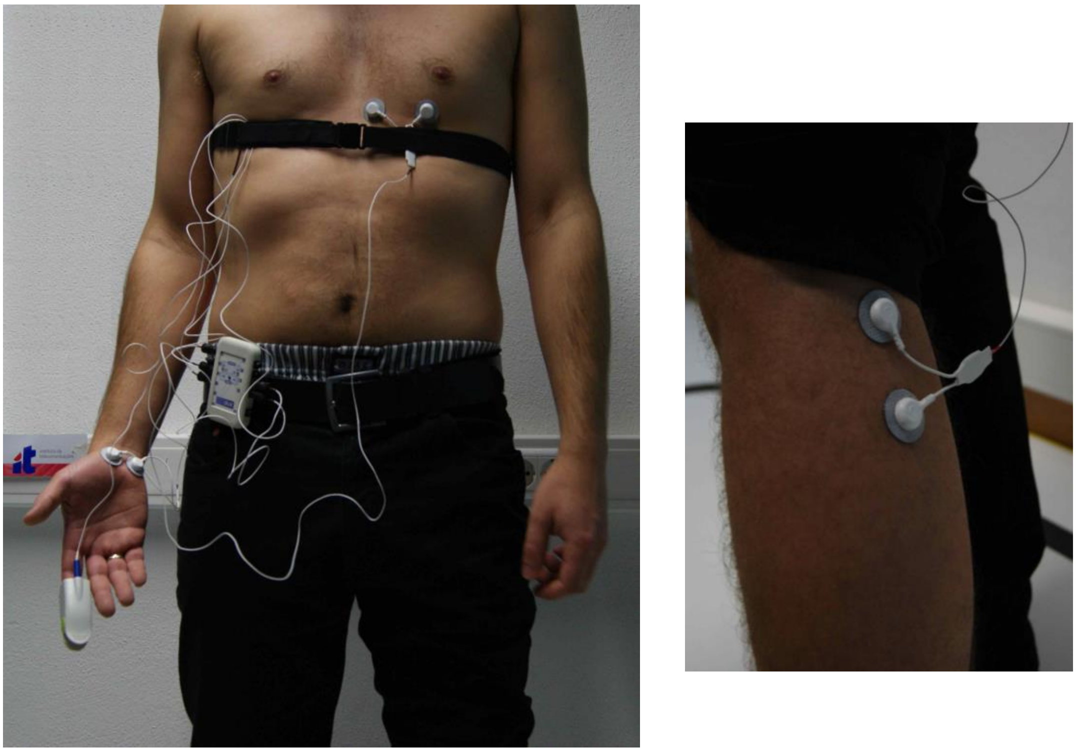


Figure 22 – Placement of the Sensors in the Human Body

Sensors are placed on the patient body with the procedure of Figure 22, in a specific area of the human body. The ECG and Respiration sensors were placed on the chest (heart area), the EDA was positioned on the palm of the hand and the BVP was placed on the fingertips while the EMG was placed on the tibialis anterior and gastrocnemius muscles on the leg.

Modelling a BSN in a human body to be prepared for fall detection is not particularly easy. Sensor readings will have to be performed in ideal conditions of data acquisition or it can become unviable. The flexibility and robustness of the hardware used are taken into account to allow system reliability [88].

4.1.2. Health Sensors Sink Node

The mobile device (smartphone or tablet) used on the prototype will have a communication range with the sink node or sensor base station, shown in Figure 23 approximately 10 meters in ideal conditions and without other equipment which will cause interference within this operating range.

Figure 23 – Bioplux Base Station (Sink Node)

The health sensors readings will be transmitted from base station (sink node) to the patient's mobile device, smartphone or table. This base station is an analogical converter of 12 bits and the first six channels with 1000 Hz sampling and the lasts two with 125 Hz. In data acquisition mode the sample is carried out at the rate of 1000 Hz per second and this means that each sample value is captured at intervals of 0.001 seconds.

The dimensionless values of the amplitude of the signal varies from 0 to 4095 (digital values), for the eight sensor channels available in the Bioplux research device.

4.2. Shimmer Research Platinum

The Shimmer Research Platinum solution system, review 2R.d shown in Figure 24, offers flexibility and Bluetooth connection, a great capacity for portability and autonomy. Shimmer equipment was also used to perform this study.

Figure 24 – Shimmer Research Platinum Kit

The sensors present in the kit for the experiments are the following: an accelerometer, a 3 lead electrocardiogram (ECG), an electromyography (EMG) and the Galvanic Skin Response (GSR) sensor. The important and unique aspects of the setup provide the Bluetooth connection to send data to mobile devices, smartphones or tablets.

Shimmer is a small sensor platform, shown in Figure 25 well suited for wearable application. It provides motion capture, long term data acquisition, and real-time monitoring.

Figure 25 – Basic Shimmer module

Each basic module has power supply and built-in three-axis accelerometer, while additional types of health sensors need to be coupled. A module includes a MicroSD slot supporting up to 2 GB of Flash memory. This allows sensors to store significant amounts of data.

Shimmer provides an Android API [89], to reduce the development time on the Android operating system.

This sensor modules use TinyOS, one mini operating system specified at events designed especially for platforms with memory resources and processing restricted.

Shimmer provides all software for each sensor module with a complete documentation. The software includes installation of the software on the sensor modules carting the whole process of initialization, connection, acquisition and process sensor values.

4.3. AAL4ALL Chest Strap

AAL4ALL Chest Strap performs biometric and medical applications where body monitoring is needed by using 3 different sensors: the ECG, Respiration and Accelerometer. This information can be used to monitor in real time the state of a patient or to get sensitive data in order to be subsequently analysed for medical diagnosis. Figure 26 shows the chest strap to put in the patient for proper health readings.

Figure 26 – AAL4ALL Plux Chest Strap

The bioPlux Research Section 4.1 and the Chest Strap use the same specifications. The protocol is a binary communication protocol between the Plux device and the mobile devices (host). The protocol is typically implemented over a Bluetooth virtual serial port, but it can be implemented over any other binary communication medium. The protocol consists in the commands from the host to the Plux device, to start data communications from the Plux device to the host.

The Chest Strap is the most lightly and easy to carry a solution in comparison between Bioplux and Shimmer sensors kits.

The three electrodes of the ECG, the respiration sensor and the accelerometer sensors are embedded in the Chest Strap without needing to attach electrodes in the plug.

To monitor the system it is based on three principles: connect, acquire and process the raw data to allow visualize data in a form of graphical charts. The first step, connect, the devices wait for a connection through Bluetooth, so the protocol connection is satisfied and the host send to the sink node a string command expressed in ASCII characters to start, stop and control the acquisition mode.

The second, acquisition mode, one frame of data is received every millisecond which is specified in the acquisition command (e. g. sampling rate of 1000 Hz) using 12-bit resolution of the specified channels 1 to 4. An array with the signal sample value at the selected analog channel, from channel 1 to channel 4, as unsigned integers. For 12-bit samples, each value spans from 0 to 4095. For 8-bit samples, each value spans from 0 to 255.

While the receiving process in the sink node is on the run, the process and visualization is done on host (mobile devices) to provide visualization on screen.

4.4. Android Devices

Today, mobile devices networks that power smartphones have become so pervasive and so powerful that mobile Internet usage is ready to surpass desktop usage. With smartphones and other mobile devices connecting wirelessly to almost anything digital, an explosion of mobile-capable devices is rapidly emerging and Android platform is the most successful.

Google has announced on March 13, 2013, there are 750 million Android activations and this number tends to raise for the huge success and the vast range of devices that platform support [90].

Bluetooth and Wi-Fi connection are the most important requirements to support this system on a mobile device. On the market, the majority of smartphones and tablets include these technologies. In this scenario, various versions of Android system are supported, from version 1.6 to the current 4.2. The low cost, wide variety and versatility are direct benefits for users. This application was developed for Android 4.2.2 Jelly Bean but also experimented on other previous Android versions.

The AAL mobile solution was deployed and tested on the following devices, tablet Nexus 7 (Android 4.2.2 version), tablet Samsung Galaxy Tab (Android 2.3.3 version), nexus S (Android 4.1.2 version), Asus Padphone (Android 4.0.3 version).

4.5. Summary

In this chapter, it was shortly presented the devices used to perform the AAL mobile solution prototype. Section 4.1 the health sensors kit Bioplux Research was presented. In Section 4.2 another health sensors kit from other company the Shimmer Research Platinum Kit was presented and in Section 4.3 was described an AAL specific mobile solution called AAL Plux chest strap. Section 4.4 referred to Android mobile devices where the application was deployed and tested.

5. AAL Mobile Solution Demonstration

In this chapter it will be focused on the proposed AAL mobile solution, regarding the main aspects and features of the mobile application embed in the mobile environment. The system Architecture will be shortly introduced and described in Section 5.1 presenting all system modules for falls detection, prevention and biofeedback monitoring. All these modules will be demonstrated in this chapter. Then, in Section 5.2, will be presented the graphical interface appropriated for elderly people. Section 5.3 will perform and explain the biofeedback monitoring tools. Section 5.4 will refer to the falls detection techniques with outside alerts in emergency situations. Section 5.5 will discuss falls prevention methodologies with users' notifications trying to avoid dangerous health circumstances. Section 5.6 will show the Web service from the client side (mobile gateway), server side (Web service) and the health care service (medical terminal).

5.1. System Architecture

This section presents the system architecture based on a body sensors solution and a fall detection and prevention system. Figure 27 illustrates the fall prevention and detection scenario to explain the proposed system architecture with main actions defined for communications process with the mobile application and the healthcare system.

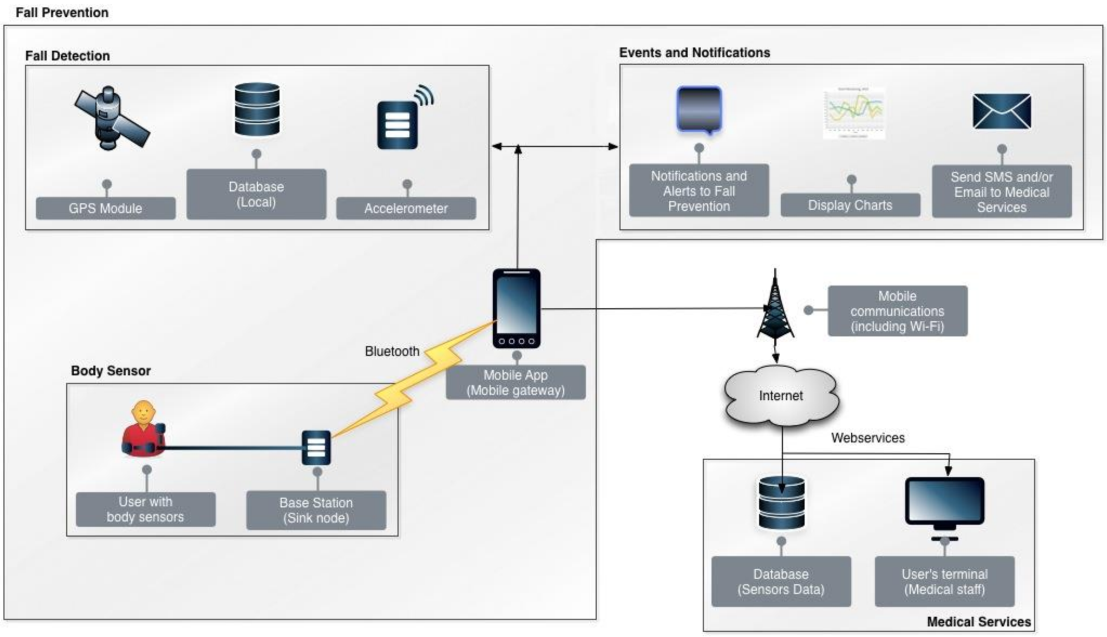


Figure 27 - Illustration of System Architecture with all features and interactions.

The proposed system architecture considers the following four modules: the fall detection, the body sensors, medical services and fall prevention extended system with events and notifications. The fall detection module is responsible for detecting the accelerations caused from the user daily movements and interprets the values in order to detect user falls and even patient motion recognition. Also in this module the mobile gateway receives data directly from the GPS navigation system to provide user location. The body sensors module are responsible for collecting body parameters from the sensors placed along the user body in order to obtain the vital parameters and extra information to perform falls detection system. The base station (sink node) sends the body sensors data through Bluetooth. Events and notifications module is the main responsible for the falls prevention system, this advises the user in real time for health problems detected. In Web services module, all the collected data is sent to a remote database through the hypertext transfer protocol (HTTP) using REST Web services. These data are also available to be consulted by user or medical staff in a browser.

The accomplishment of the system architecture begins with the user needs as well as how it fits in a real context. The mobile gateway is the key point in the architecture that depends on selected technologies that are leading and proven. It provides a system asset, user interface, and important aspects in processing and sharing information securely and effectively. It also offers a flexible integration solution for new sensors, if needed.

5.2. Graphical Interface

This section focuses on demonstrating the solution in a real scenario. The AAL mobile solution user's interface is simple and appropriated for elderly people. The application uses large buttons, intuitive menus and elucidative images. The system controls the patient physiological data, even running in background and alerting the user whenever necessary. Figure 28 shows the splash screen window and Figure 29, a proposed questionnaire only displayed if it is the first time that the application is used in a mobile device.

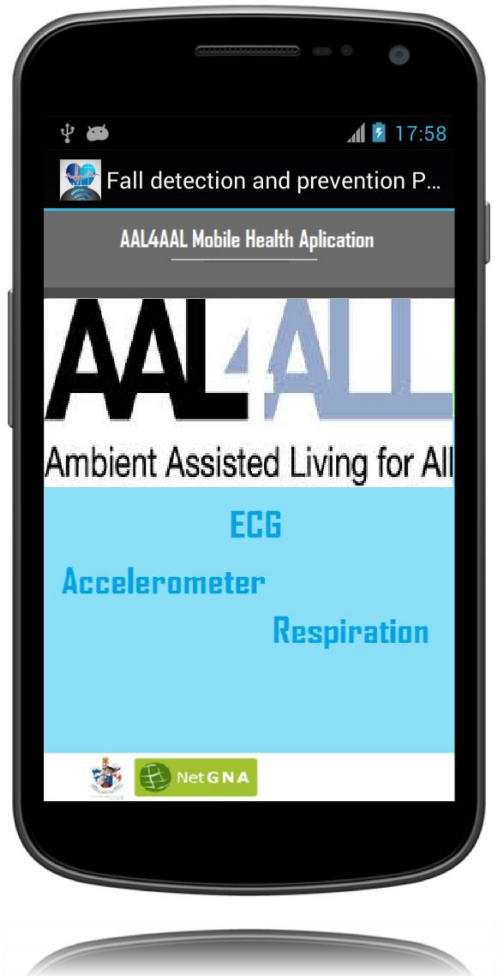


Figure 28 - Splash Screen Presentation.

Figure 29 - First Use Questionnaire.

Figure 30 presents the principal page of the application where the user accesses to all available features. In Figure 31 the login window is presented, the user will enter using his/her Username and the corresponding password.

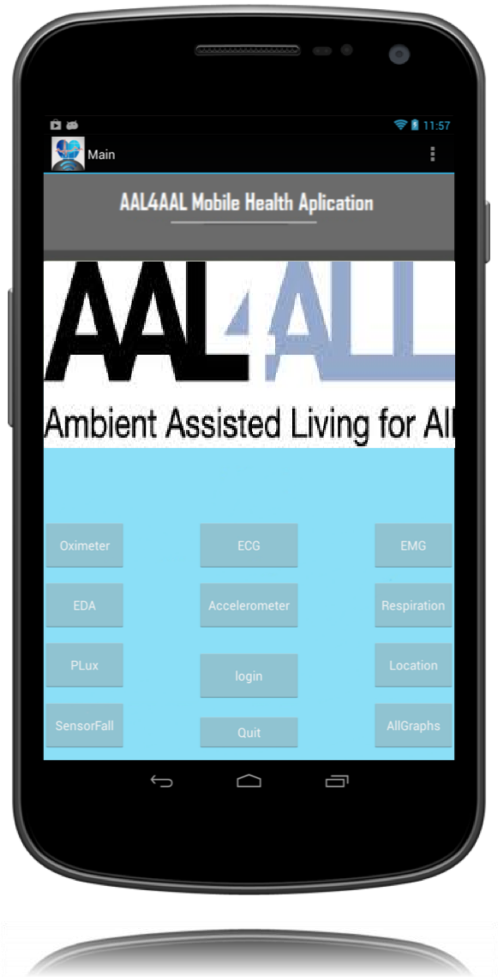


Figure 30 - AAL Mobile Application Main Page.

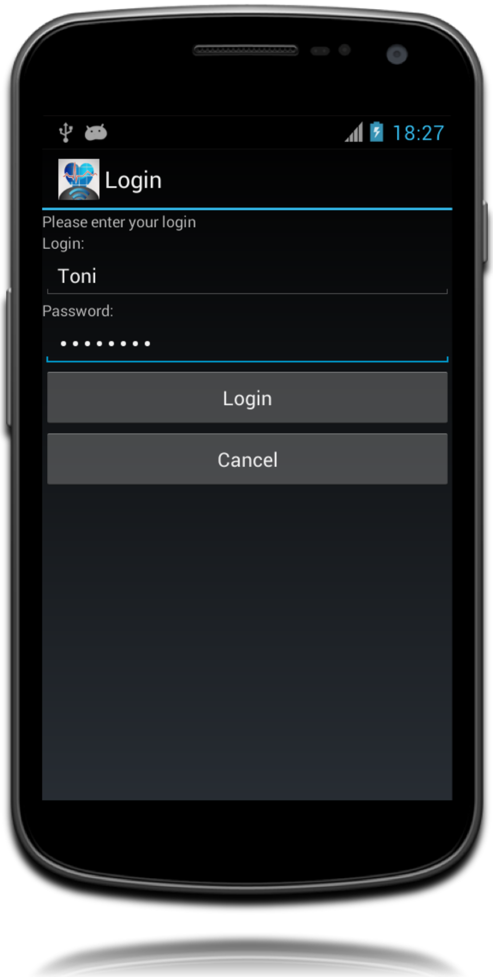


Figure 31 - Login Window.

After logging the application is ready to receive data from the health sensors and communicates with Web service to send users information.

5.3. Biofeedback monitoring tool

Monitoring physiological activity is a non-invasive body control technique based on the theory of electrical conductivity. The biofeedback application software presented in this dissertation represents an important component for problems screening and therapy developing because it is designed to monitor body responses, compile progress data, and reporting it.

The biofeedback status is directly related to certain health issues. The biofeedback-monitoring tool is designed to work with specific monitoring equipment described on Chapter 4.

This software was developed to work with available professional biofeedback tools that include most of the needed components to conduct a biofeedback session. During a biofeedback session, a patient wears sensor devices that are placed on the skin. The sensors are plugged to a sink node (also known as a base station) and through Bluetooth connection it is synchronized with a mobile device (smartphone or tablet) for data acquisition.

The application features include chart graphing options, multiple window options to display more than one body response at the same time, and storage databases to track and review progress. It is possible to control the output signal and the frequency in each pitch to do a sample frequency, in Hertz, and a final digital signal to analyse, in Volts. It also features audio notifications to users and outside alerts by sending a short message service (SMS) or electronic mail (eMail) to a caretaker.

In Figure 32, a smartphone shows the ECG signal with values ranging from 1362609123800 milliseconds to 1362609124200 milliseconds. This date timer is obtained from the local date system by the number of milliseconds that have elapsed since midnight, January 1, 1970. This collection of values in this time interval is important because an event tries to evaluate a pre-fall when it occurs.

A pre-fall is detected by the accelerometer algorithm, presented on Figure 32 in the tablet computer, showing the variation of G force signal, emerging a warning to the user and an important value to the system when a fall is detected by the algorithm.

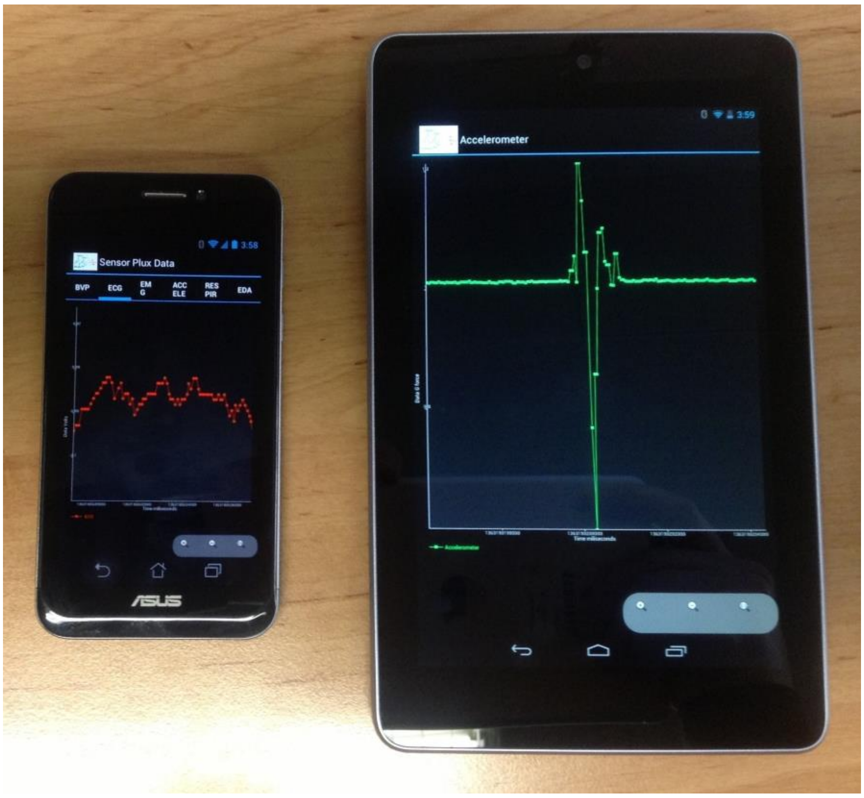


Figure 32 – Photo of a real deployment of the proposed Solution with the ECG and Accelerometer charts during a fall experiment in a real scenario.

When a fall occurs the values from the sensors are sent and saved to the database. The importance of this time interval is to detect some happenstances, before and after, to identify anomalies in order to be analysed in more detail by specialists, who detect important scenes in the fall event to discover and describe the fall occurrence. In this real scenario only the vital signs are used to detect whether values have changed to the normal rhythm of the user. The distance and the variability of the ECG waves with a threshold value were experimented returning a Boolean value whether the ECG has right signs or not [91]. When a fall is confirmed and the patient has anomalies in vital signs the system will trigger an alert.

Figure 33 represents the signs tendency in a pre-fall occurrence for the EMG sensor. The pre-fall incident is marked with the red circle at 1362609124000 milliseconds time. When it occurs the chart goes to its maximum and, immediately after, it registers one low period of values. Through it, it is possible to make diagnose of neuromuscular diseases and also muscular disorders given a poor balance in muscle legs that may cause falls.

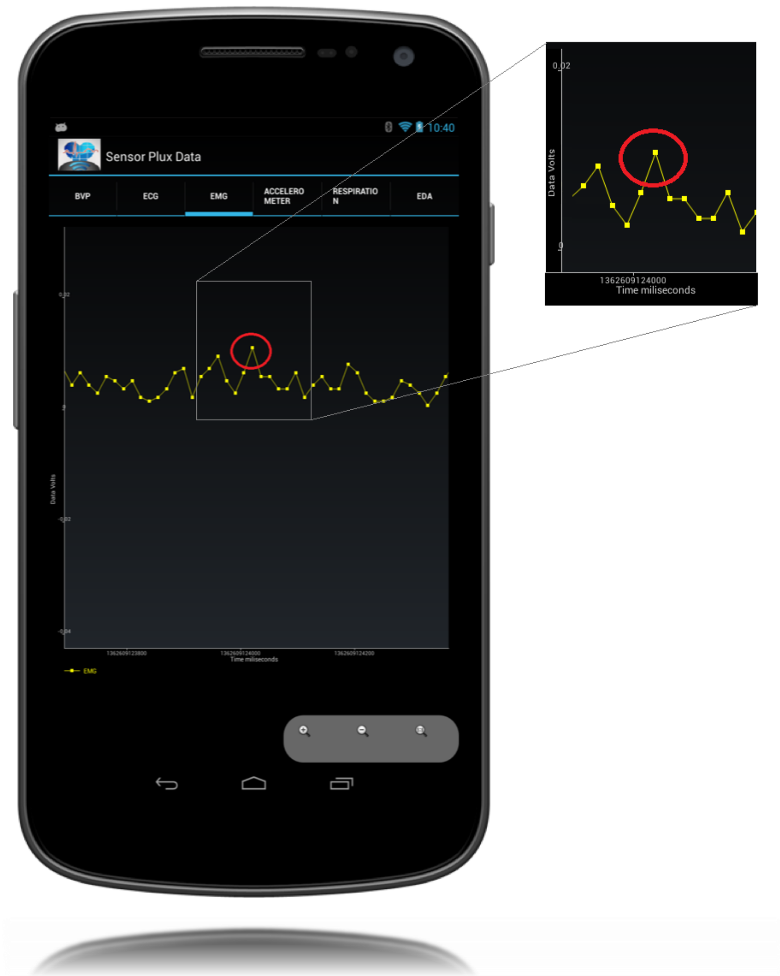


Figure 33 - Illustration of the measured biosignal values of EMG during a fall essay.

Figure 34 also shows a pre-fall important time interval to pull knowledge of the respiration sensor and as may be seen on the chart, in the moment of a pre-fall detection the signal changes to stagnation level due to a lack of respiration.

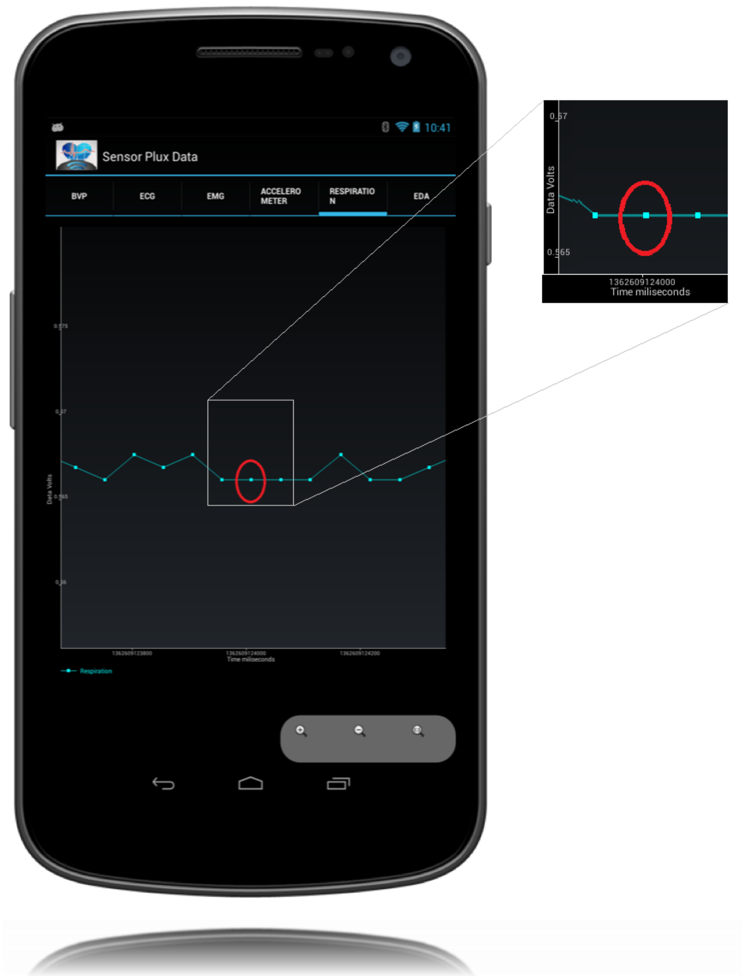


Figure 34 - Illustration of the measured biosignal values of Respiration sensor during a fall essay.

In Figure 35 the EDA sensor is presented. This electrical conductance in a person's skin is correlated directly to their emotional state. Therefore, the excited state of a person can be observed to detect psychological situations less favourable during a pre-fall event.

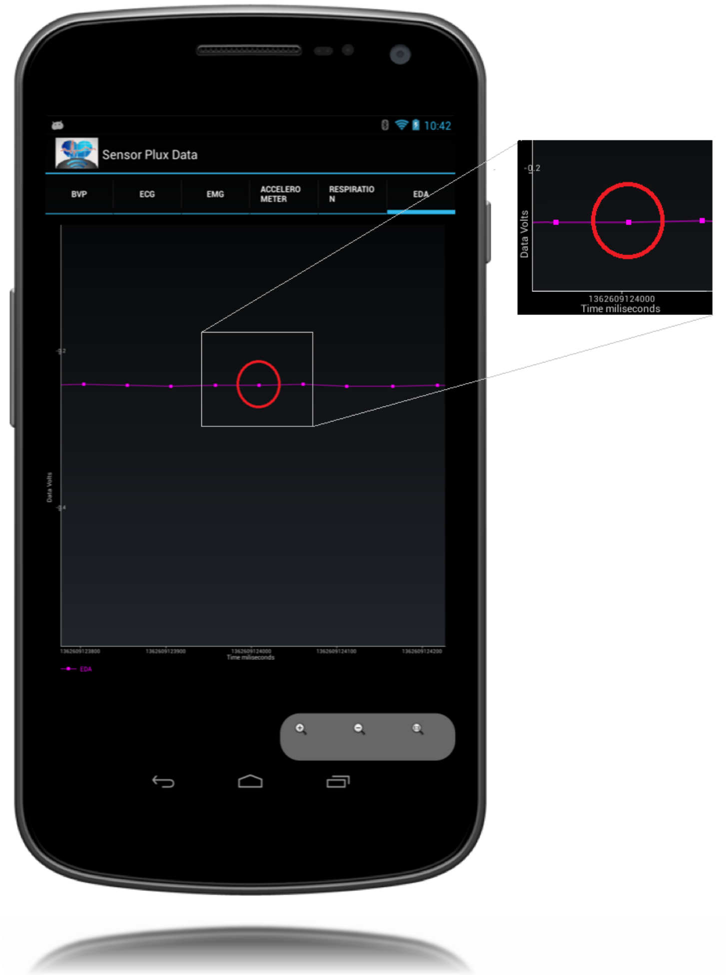


Figure 35 - Illustration of the measured biosignal values of EDA during a fall essay.

Figure 36 represents the BVP where may be seen the heartbeat variation. During a pre-fall, the value reaches its maximum value and gradually decreases over the time.

Figure 36 - Illustration of the measured biosignal values of BVP during a fall essay.

The points in the line charts represent the values saved in the database in Volts. The presented charts are Zoom In to a small time interval in order to get an idea how small - e.g. the time latency of sensors are 0.001 seconds (sampling rate of 1000 Hz), in ideal transmission conditions. However, the accelerometer of the smartphone or tablet includes other specifications depending on the manufacturer and uses a bigger period of latency.

In order to improve the graphics visualization several colours were used for the different type of sensors (red for ECG, green for the Accelerometer, yellow for EMG, blue for Respiration, cyan for EDA, and white for BVP). It is also possible do Zoom In and Zoom Out for a particular interval in time.

The proposed system is based on the collection of information carried out by the different sensors to a smartphone or a tablet. For the potential occurrence of a patient's health problem or more serious situations such as a fall, monitoring and data collection by sensors in a certain period of time it can be easily accessed and evaluated to facilitate diagnosis and patients monitoring [92].

5.4. Falls Detection technique with External Alerts

The falls detection and patient motion recognition system works by measuring a user body acceleration and position, getting acceleration values from accelerometer and then it will transform the values in G force. If a fall is detected, an automatic outside alert with several patients' information will be sent to the caretaker or emergency.

5.4.1. Patient Motion Recognition

To improve falls detection and prevention techniques, artificial intelligence and machine learning concepts have applied in order to detect on time a patient motion specific type. This motion detection can be an important factor in the evaluation of daily patient activity to make possible a better and quicker diagnosis. For the development of this methodology, are used the values of the following attributes acceleration, time, and its respective motion class. The following motion classes are chosen because they are the most relevant in balance problems. The possible classes are Walking, Running, Sitting, Jumping and Falling. So through a decision tree algorithm presented in Figure 37, that uses the value of the acceleration and a timer it is possible to detect in an exact time interval to what class it belongs [84].

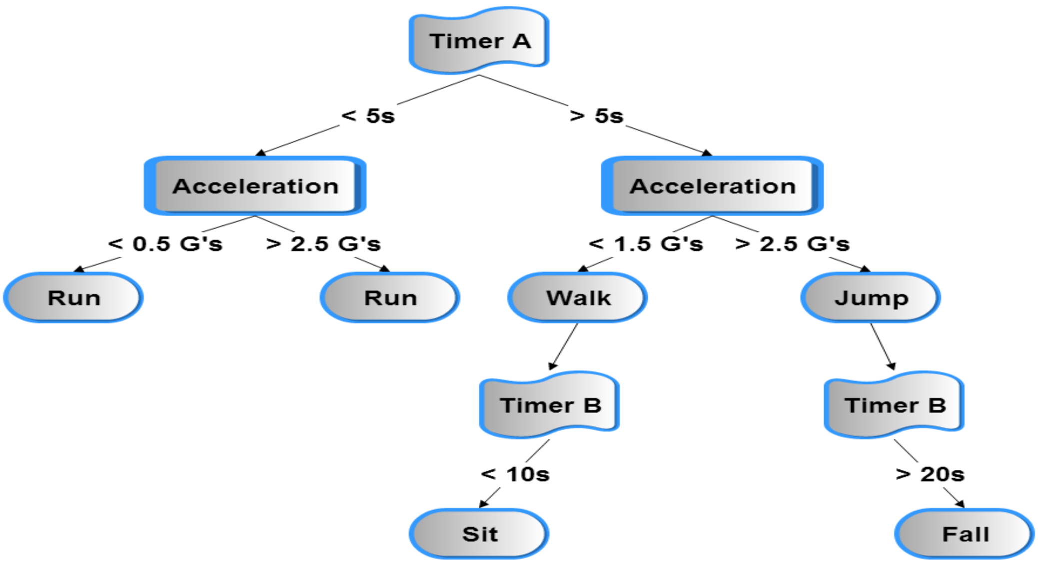


Figure 37 - Illustrations of the decision tree to patient motion detection.

Values presented in decision tree are examined and studied with the aid of a machine learning tool to extract knowledge calling WEKA [85]. In the tree if the timer A is over an interval greater than 5 seconds it contains acceleration greater than 2.5 G's and the if the timer B counts a value greater than 20 seconds a fall is detected, or this time instant is classified as Jump motion. Next, the timer A and B restart again with whole process.

5.4.2. Falls Detection and External Alerts

Figure 38 shows the values captured by the accelerometer in a time interval where a fall was detected and confirmed. In Figure 39 notification is shown on the user mobile device highlighted with a red circle and the current location of the user mobile device is captured to send an outside alert.

Figure 38 - Accelerometer Values and toast message Fall confirmed.

Figure 39- User Falls Detection Notification and Current Location to external alert.

Through the magnitude of the G force at a given moment followed immediately by inactivity and considering the position of the device, a fall may be detected. All the collected information is stored in a local database and sent to Web service.

Nevertheless, if it was a false falling and the user does not need help, the user will be able to open the notifications bar to take some actions. Next Figure 40 shows the notification actions to do in the tools bar of a patient Android mobile device.

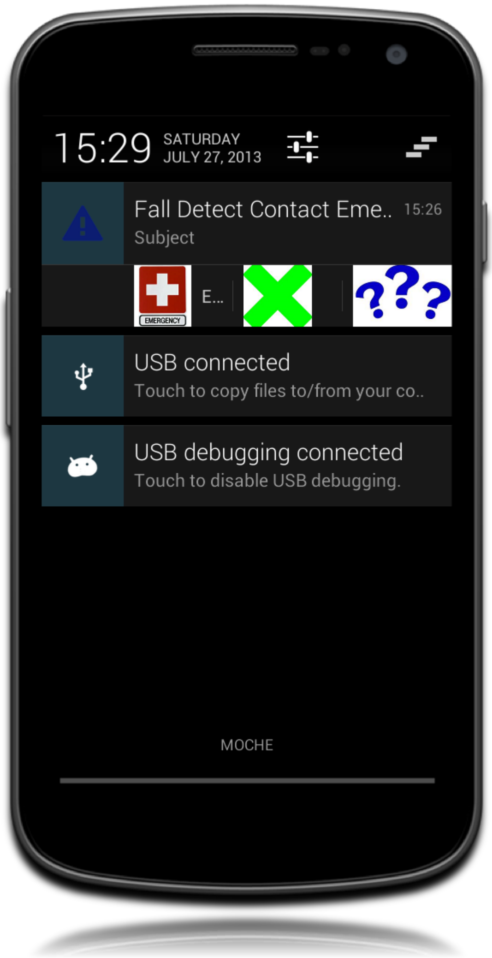


Figure 40 - Illustration of the Android tools bar fall detect notification.

When the system detects a fall it automatically contacts the emergency response centre or a caretaker sending alerts as an SMS or an eMail with the current location of patient and information about the detected problem. However, the patient may ignore and send cancel current alerts in the green cross button. In the emergency button he/she can contact immediately with emergency call and in the question marks read some advices about what steps to take.

5.5. Falls Prevention Methodology with Notification Alerts

Many biological processes can be measured from a person. Physiological signals measurement can offer important information about body behaviour in a given time. For biofeedback monitoring, the use of biosignal sensors and inertial sensors is proposed. They will allow a better detection of problems that can be associated with falls and possible diseases.

5.5.1. Monitoring Techniques Based on Body Sensors

With biofeedback signals monitoring it is possible to detect common types of physiological anomalies related to balance problems or more serious diseases. Biosignal balance is related to those health problems. Through the sensors readings it was possible to detect problems as cardiac disorders using electrocardiogram, muscle activity with electromyography, and anxiety and flutter with galvanic skin response or electro dermal activity. Also through the tri-axial accelerometer, it was possible to monitor and classify movements to detect anomalous patterns preceding a crisis.

This system uses the capabilities of the accelerometer to identify situations of potential fall and identify motion to improve and alert if a patient has a bad postural control or perform fast movements, which endanger their equilibrium.

Electro cardiology monitoring is used to detect different states of problems with ECG as illustrated in Figure 41. For that, it was used an automatic R crests detection algorithm that is based on EMD (Empirical mode decomposition) and an adaptive thresholds technique in order to reduce the possibility of errors and bad interpretation of the measured signal.

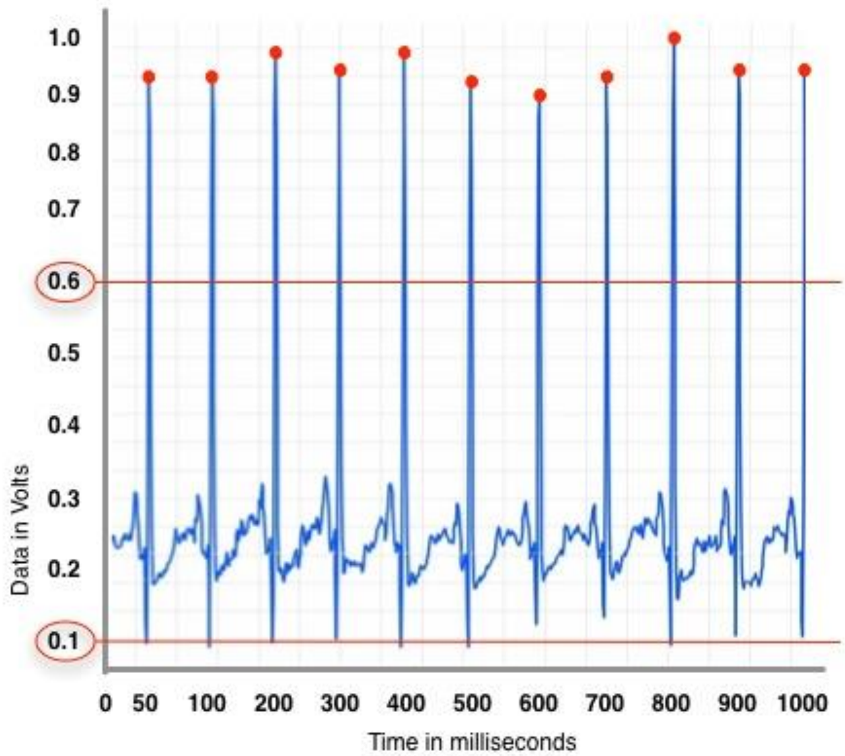


Figure 41 – Illustration of an ECG analytical signal.

The R peaks were identified by computing the relative maximum of each complete cardiac cycle where the phenomenon PQRST occurs. To detect heartbeat problems, the system count the number of P crest per minute in order to detect if heartbeat is normal, fast, or slow. To detect irregular heartbeat possible arrhythmia, the time between the P crest was measured (in milliseconds).

The warning sign, red notification Figure 42 is a type of danger sign that indicates a hazard ahead on the health that may not be readily apparent to a patient.

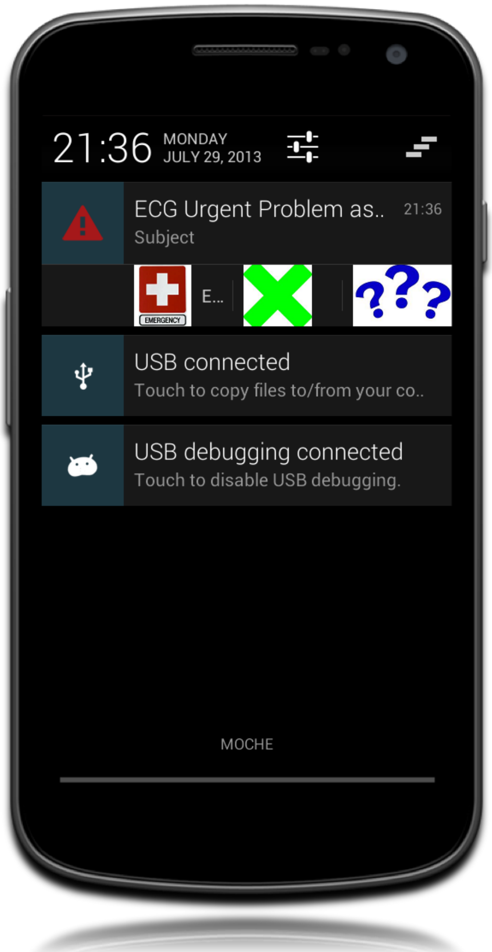


Figure 42 - Illustration of the Android tools bar ECG problem notification.

This notification is the most danger that the patient will have. Upon receiving this notification warning, patient should urgently consult a health care professional.

Galvanic skin response (GSR), also known as the electro dermal activity (EDA), is a method for measuring the electrical conductance of the skin in a patient body, which changes with its moisture level. This is interesting because the sweat glands are controlled by the sympathetic nervous system that controls emotions. Figure 43 shows a sample GSR or EDA signal. A patient can present multiple states of stress and it is possible to be measured by the wavelengths variance.

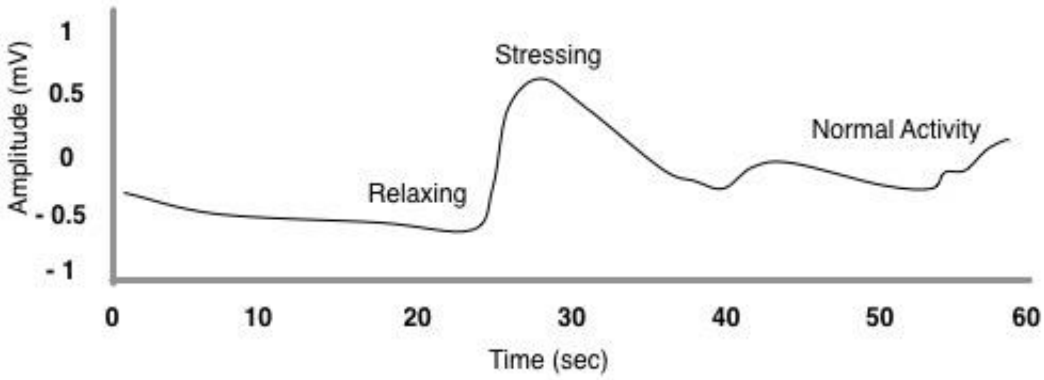


Figure 43 - Illustration of the GSR or EDA variations for diagnoses multiple states of stress.

Electromyography is a technique to evaluate the recording of electrical activity produced by skeletal muscles cells when electrically or neurologically activated. The electromyography is used to diagnose neuromuscular disorders and the control muscular movements. Figure 44 represents the detection of balance disorders. The changes observed in EMG signals are caused by modifications of the electrical impedance of the skin-muscle system.

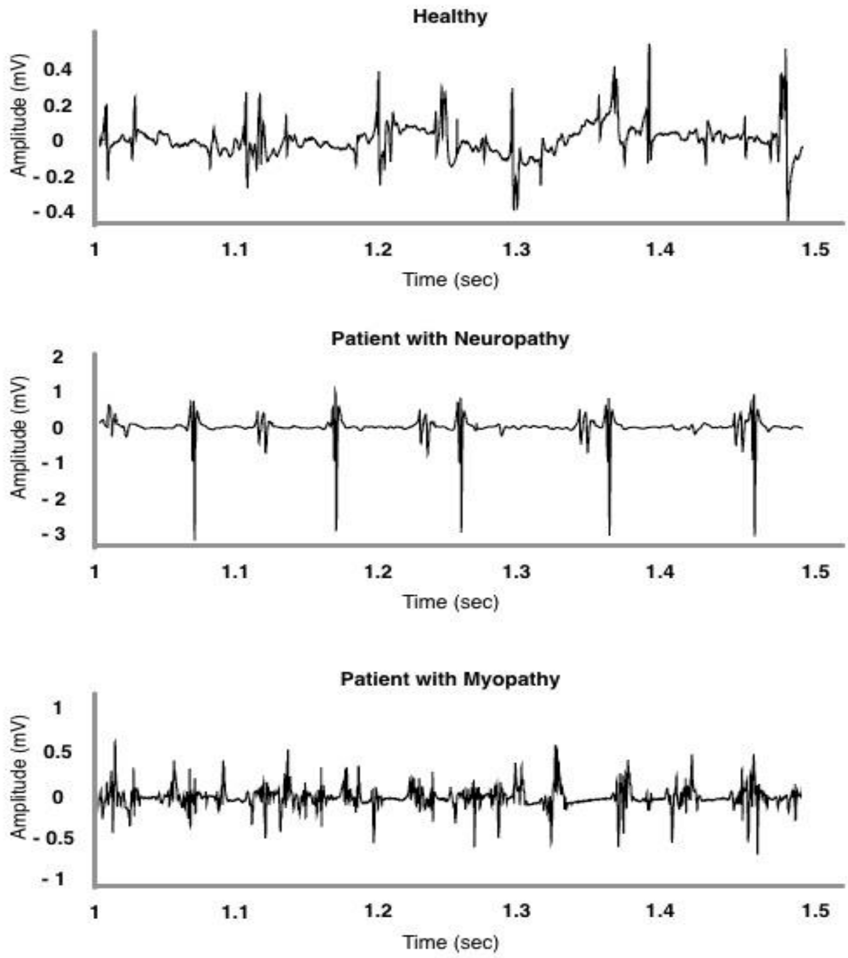


Figure 44 – Illustration of EMG wavelengths variations associated to diseases.

The different EMG wavelengths represent standards of the possible variations observed in a patient. The Figure 44 presents a healthy person, a diagram with an abnormal condition Neuropathy and a diagram with Myopathy which refers to a critical condition.

Skin conductance measurement is a component of polygraph devices and it is used in scientific research to capture emotional or physiological arousal. The skin electrical conductance of a person is directly correlated to his/her emotional state and it is used to detect excitement events. Therefore, the excited state of a person can be observed and it can be detected psychological situations less favourable to the welfare and patient health, and when he/she may be more unprotected for fall events. The falls prevention system with biofeedback uses skin conductance to measure and present an individual stress response in real time. It aims to help the patient to control their anxiety and prevent a possible fall.

The warning sign, yellow notification Figure 45 is a type of danger sign that indicates balance and muscular problems interrelated with falls that may not be readily apparent to a patient.

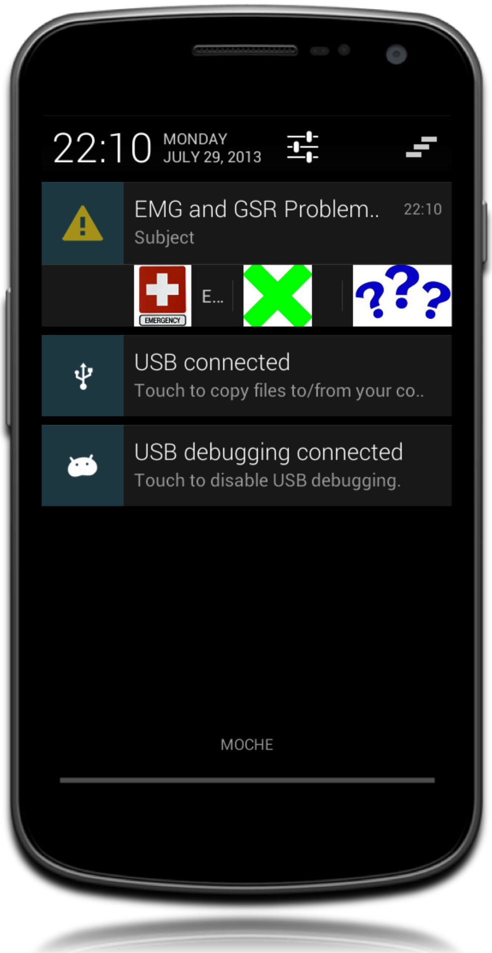


Figure 45 - Illustration of the Android tools bar EMG and EDA problem notification.

With this notification the patient should remain calm. This is the second most danger notification that the patient will have. Upon receiving this notification warning, patient should try to fix the emotional or physiological arousal problems.

5.5.2. Ubiquitous Sensors Thresholds Adjustments

In the progression of the experiments, sudden variations presented by waveform values of all sensors were identified. An implicit variation corresponds to different types of signal acquisition in each individual. Although subjects shown, different skin resistance levels and behavioural actions that may justify those variations. It seemed that circumstances at the data acquisition time can influence their variation. If data collection is performed indoor or outdoor environments induces significant distinction for both emotional and physical patient state. The procedure to quantify physical and mental effects is based on sensors datum; therefore, the quality of collected data is extremely important. Some trials were conducted in a noiseless ambient and they were compared to trials driven in the presence of background noise.

In order to increase the system reliability and turn it also more adaptive to users, several actions were considered. After placing the system properly in a patient the first ten to fifteen minutes are used to relax the user and for system adjustments to him/her (the calibration period). The threshold values are adjusted to a pre-defined range of accepted values that are considered as normal. In any case, if the parameters were out of the ordinary values, it could mean that the sensor was bad placed or even in a wrong position. A warning message is sent with a problem description and the user can fix it.

5.5.3. Notification Alerts

The health sensors signal allows the falls prevention algorithm to analyse a typically phenomenon in patients distinguishing variations as previously indicated in the falls prevention methodology Section 5.5. In combination with other signals (e.g. between heart rate and respiration signals), transient classification changes allow a more detailed diagnosis known as electro cardio respiration to detect only specific types of pathologies.

The notification alerts for falls prevention is the main feature to warn patients whether something is wrong with their health. As previously shown, through the data collected by ECG, EMG, GSR or EDA, respiration, accelerometer, and gyroscope it becomes possible to identify patterns that can expose the patient to a possible fall. A different kind of warnings seen by the patient changes depend on the severity of the problem detected, as shown in Figure 46.

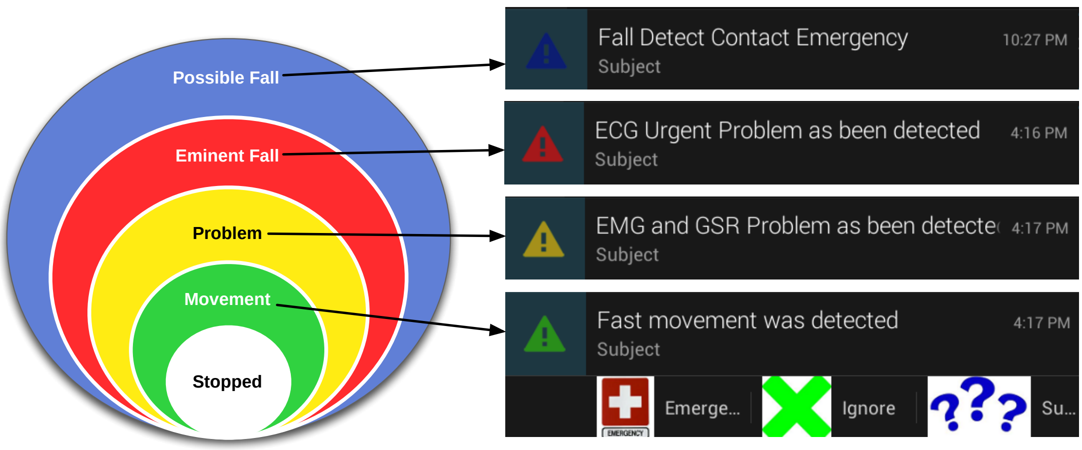


Figure 46 - Event different types notification warnings description associated to biofeedback sensors.

The colours shown in Figure 46 represent the warning severity. When it is "Stopped" it means the patient is standing and defines the threshold values, which delimits the sequence of warnings. The patient must know these warnings in order to correct deficiencies for helping himself/herself to prevent a fall and avoid him/her entering in a danger situation.

5.6. Web services

Nowadays, more and more Web services are present in application, consuming a service or serving information. In the scenario of distributed applications, this service provides a method of communication between two electronic devices over a network and it is a solution used in systems integration and communication among different applications.

Web services provide well-defined interfaces for distributed functionality, which are independent from hardware platform, operating system and also programing language.

5.6.1. Mobile Gateway

The mobile gateway (mobile devices smartphones or tablets) through Wi-Fi or Edge/3G/3.5G/4G is used to communicate among Web services interface with the purpose of distributing information from health sensors. The mobile gateway sends this data received to Web service (storage) and it allows subsequent queries.

In the mobile gateway all the collected data saved in local database is sent to a remote database through the hypertext transfer protocol (HTTP) protocol using REST Web services. When a node sends information, the request goes directly to the database; the sender node makes the REST solicitation and the Web service stores data in database.

The mobile gateway is the key point in the architecture that depends on selected technologies that are leading and proven. It provides a system asset, to process and share information securely and effectively. It also offers a flexible integration solution to aggregate new technologies, if needed.

5.6.2. Health Care Services

Health care services (medical terminal) request information to Web services. The requester node makes the REST solicitation; the Web server will verify the request to find out what kind of request is. When the requester nodes receive the information the node can handle the information to allow displaying information in database tables or charts.

Figure 47 presents a user’s medical terminal with falls detection information about several patients.

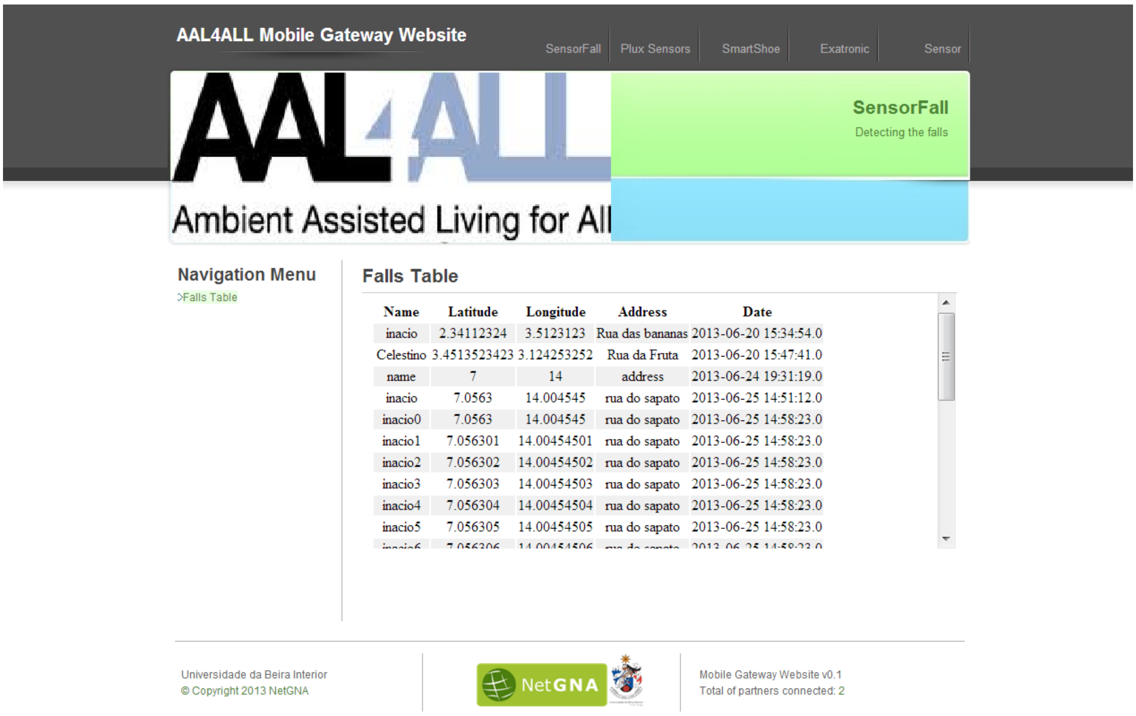


Figure 47 - Web Service request falls detection information.

Falls detection information table web page about several patients to be consulted by caretakers or medical staff. This table indicates useful information about patients as well as the fall place and the date.

Figure 48 presents a user's medical terminal with ECG Chart information about a patient.

Figure 48 – Web Service request ECG Chart.

To display charts in the web page the Google Developers line charts tools were used. This web page allows visualize graphical charts about patients who are using the system to perform real time lectures or have used the system that allows making a later consultation.

5.7. Summary

In this chapter, it was demonstrated in real scenario the AAL mobile solution. The system Architecture was introduced and described in Section 5.1 presenting all system modules for falls detection, prevention and biofeedback monitoring. Then, in Section 5.2, it was presented the graphical interface appropriated for elderly people. Section 5.3 performed and explained the biofeedback monitoring tools with all features. Section 5.4 referred to the falls detection techniques and patient motion recognition algorithm with outside alerts in emergency situations. Section 5.5 discussed falls prevention methodologies for the health sensors used in the prototype with users' notifications trying to avoid dangerous health situations. Section 5.6 has shown the Web service from the client side (mobile gateway), server side (Web service) and the health care service (medical terminal).

6 Performance Evaluation and System Validation

This section focuses on the performance evaluation and validation of the AAL mobile solution developed. To evaluate the solution several trials are performed in order to estimate the percentage of success (accuracy) of the different experimental approaches. First, Section 6.1, the AAL mobile application falls detection with an ECG analyses is performed, therefore several falls simulations with three volunteers in order to evaluate and demonstrate the solution in a real experimental scenario. Afterwards, Section 6.2, for the same three healthy individuals several trials are performed to evaluate the falls prevention system in different types of motions.

Finally a system validation and results are discussed for both approaches, concluding with an overall evaluation of the proposed solutions.

6.1 Falls Detection and ECG Experimental Analysis

The mobile application was deployed on several devices in order to validate the proposed solution, and also in order to be possible essays for volunteers. The application ran effortlessly on all the used devices. The experiments were approached based on several fall simulations with 3 volunteers, each one with 38 trials, in a total of 114 trials. The mobile devices, smartphone or tablet obtained results for one experiment with the sensors monitoring several bio-signals during a fall experiment.

To evaluate the solution two trials were experimented to find the significant differences and improvements between them, as shown in Table 4. In order to reach a final average to the two solutions, several measurements were archived.

Table 4. Experimental results control table comparison between Pre Fall and Pre Fall + ECG.

Action	*Number of trials*	*Trials errors*	*Right Trials*	*Average*
Pre Fall	114	10	104	91%
Pre Fall + ECG	114	6	108	95%

A total of 114 trials were performed under the same conditions for the two solutions. The trial errors were counted when the experimented solution did not detect a pre-fall, the system did not capture significant values from sensors or because the system presents failures and performed an exception.

In the first essay, Pre Fall results shown in Figure 49, only the accelerometer to conduct the experiment in a total of 114 trials was used. The system detected 104 falls with accuracy and only 10 of them did not detect a fall. In the second essay, Pre Fall + ECG results also shown in Figure 49, the ECG was added to the system and the results got slightly better, passing from 104 falls to 108 falls detected and only 6 trial errors.

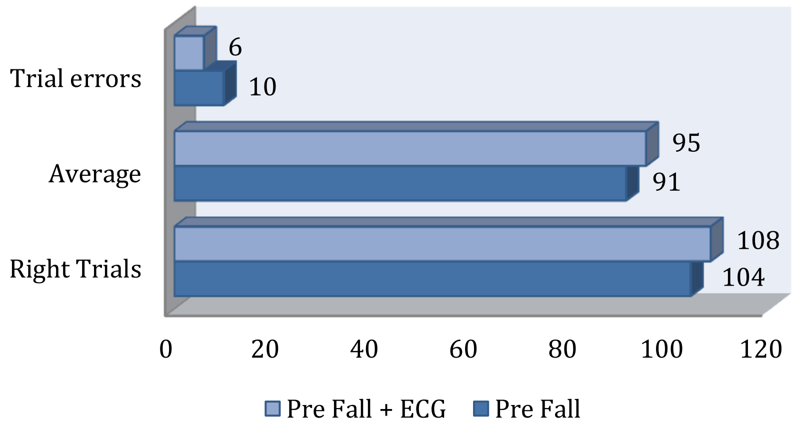


Figure 49 - Bar Chart Values Ordered for Pre Fall and Pre Fall + ECG.

The results present the estimation of only pre-fall is 91% and the solution with pre-fall and ECG increases about 4%. Results show a better fall detection, as expected. It is important to note that this second solution Pre Fall + ECG, brings improvements in real catastrophic scenarios, such as when the fall was detected and the user is unconscious or suffered from a cardiovascular disease or heart attack.

6.2 Falls Prevention Experimental Analyses

The presented results aim to analyse quantitatively the applicability of the system in a real scenario. Therefore, in Table 5, the data was acquired from three healthy individuals in different motions to perform the experiment and the alerts for fall prevention were considered.

A total of 50 experiments were performed under the same conditions for each action. The total values line represents a sum of alert values for each motion.

Table 5. Experimental Results for falls prevention.

Alerts	*Number of Warnings during the Action*				
	Walking (5m)	Running (10m)	Sitting	Jumping	Falling
Movement (Green)	28	32	14	46	43
Problem (Yellow)	6	21	4	41	27
Eminent Fall (Red)	0	45	0	38	36
Possible Fall (Blue)	0	2	1	1	48
Total	34	100	19	125	154

Table 6 represents the expected values and shows an estimated amount of alerts, which is considered correct for each type of motion to allow calculate the average.

Table 6. Falls prevention expected Values of the experimental results.

Expected Values					
Movement (Green)	30	35	15	50	50
Problem (Yellow)	8	25	5	45	30
Eminent Fall (Red)	0	45	0	45	40
Possible Fall (Blue)	0	5	0	2	50

Table 7 presents the average Values for each type of motion. The activities with larger accuracy are Sitting, Walking and Falling.

Table 7. Average Values for each Motion in falls prevention.

Alerts	*Walking (5m)*	*Running (10m)*	*Sitting*	*Jumping*	*Falling*
Movement (Green)	93%	91%	93%	92%	86%
Problem (Yellow)	75%	84%	80%	91%	90%
Eminent Fall (Red)	100%	100%	100%	84%	90%
Possible Fall (Blue)	100%	40%	100%	50%	96%
Total Average	92%	79%	93%	79%	91%

During the Walking action a total of 34 warnings were triggered, 28 under the movement alert, and 6 for the problem alert. It was expected 30 for the movement alert and 8 for the problem alert. For the eminent fall and possible fall alerts it was not triggered any warning but it was not expected any warning, presenting a percentage of 92% of accuracy during the Walking action.

In the Running action, a total of 100 warnings were triggered, 32 in the movement, 21 in the problem, 45 in the eminent fall, and 2 in the possible fall. For this action, 35 warnings for the movement, 25 for the problem, 45 for the eminent fall, and 5 for the possible fall were expected. It shows about 79% of accuracy in this action.

For the Sitting action a total of 19 warnings were triggered, 14 for the movement, 4 for the problem, and 1 for a possible Fall. It was expected 15 warnings for the movement and 5 for the problem. A total of 93% of accuracy was reached.

In the Jumping action a total of 125 warnings were triggered, 46 for the movement, 41 for the problem, 38 for the eminent fall, and 1 for the possible fall. It was expected about 50 for the movement, 45 for the problem and eminent fall, and 2 for a possible fall. About 79% of accuracy was reached during this action.

Finally, for the Falling action, a total of 154 warnings, 43 for the movement, 27 for the problem, 36 for the eminent fall, and 48 for the possible fall were triggered. For this action, about 50 warnings for the movement, 30 for the problem, 40 for the eminent fall, and 50 for the possible fall were expected. A total of 91% of accuracy in this action was found.

Figure 50 presents a line chart to visually distinguish and evaluates the average for each type of motion and the notification received.

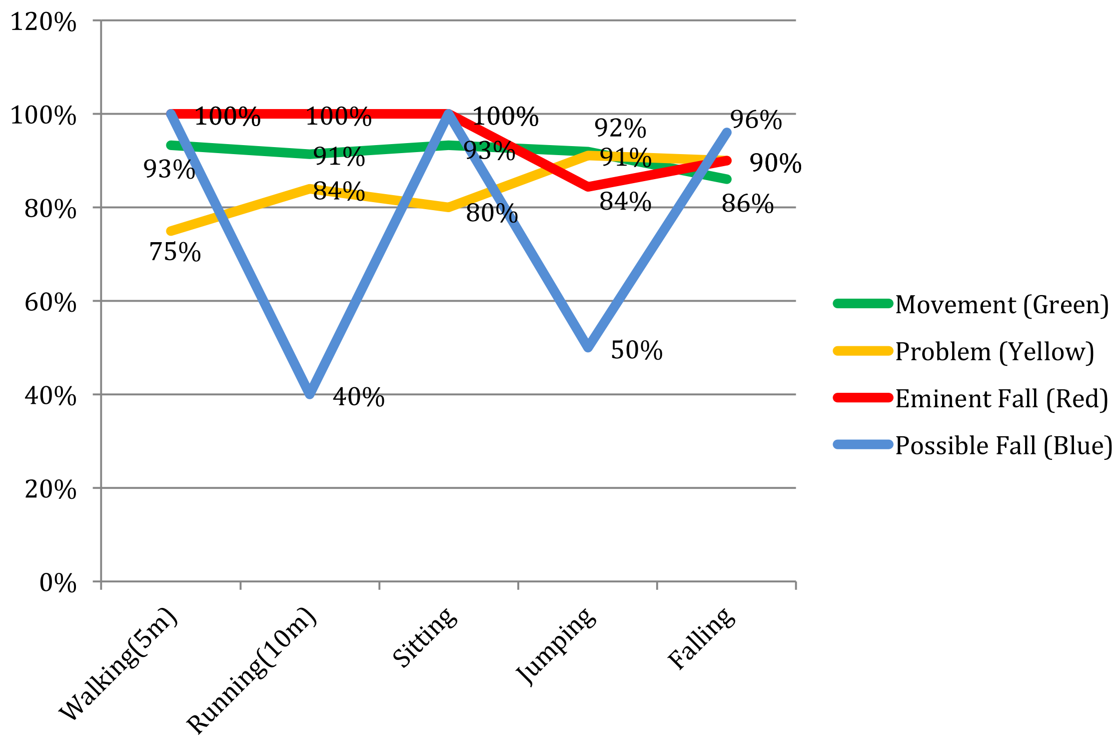


Figure 50 - Line Chart of the Average Values for each Motion in falls prevention.

Evaluating the result and the effectiveness of the proposed algorithm, to estimate the average value is necessary to determine how to improve it. Figure 51 shows the average value of 50 experiments for each type of motion.

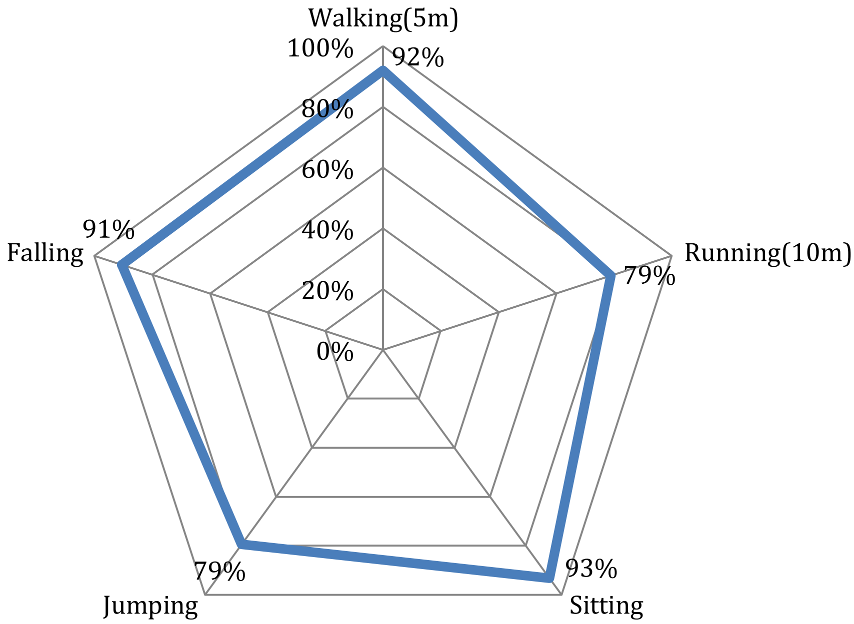


Figure 51 – Performance Comparison of Average Values for each Action.

It was identified for movements which require more physical activity (e.g. Run and Jump) that the accuracy is lower, but with a nice value. The final average evaluation of the program for all types of motions is about 86.8% for 250 trials.

6.3 Summary

In Section 6.1 the AAL mobile application falls detection with an ECG analyses is performed, therefore several falls simulations with three volunteers in order to evaluate and demonstrate the solution in a real experimental scenario were shown. In Section 6.2, falls prevention methodologies are laid proofed.

These applications experimental analysis, which was carried out by NetGNA research group, aims the falls detection and prevention and also diseases recognition to treatment through service oriented architecture.

Results clearly show that the use of this mobile solution can provide obvious and demonstrated benefits for users.

7 Conclusions and Future Work

This chapter presents a synthesis of this dissertation along with the main achievements that result from this work. It also points some directions for further work.

7.1 Conclusions

The main objective of this dissertation was the development, design, constructing, deployment, and performance evaluation of an AAL mobile solution for mobile environments application on mHealth with built in several mechanisms as biofeedback monitoring tool, falls detection, falls prevention and Web services.

This system is prepared for being computationally powerful, performing data collection and processing a large amount of collected information. In a matter of efficiency the battery lifetime for smartphone and base-station is also considered. The system is responsible for receiving data from sensors in real time and sends them to a smartphone or tablet. It should serve as a support platform for medical health for monitoring or to identify, e.g. a stroke, falls and other incidents that endanger the lives of patients. The application also offers visual tools through the device screen for monitoring the related graphics using the data received from sensors that can be created and observed in real time. This tool is based on four modules as shown in the system architecture, including fall detection, data processing and visualization of information from sensors, and communication through Web services with user's terminals (Medical staff) and external database storage so data can be accessed by medical staff, available from outside.

The increased use of mobile devices is growing exponentially. Currently, these devices offer a wide range of features that were previously only found on personal computers. Being more compact, mobile devices allow an improved ease to use and mobility, making it possible to access to the newest tools and applications like the one proposed in this dissertation. However, mobile devices have the flexibility to become a better tool, to aid in everyday tasks, and much more e.g. a medical monitoring assistive tool.

Biofeedback monitoring with fall detection is a solution that enrich the knowledge of bio-signals before, after, and during a fall. Another objective of this system is the identification of fall characteristics collection for fall prevention strategies through biofeedback.

This dissertation also proposes a system for falls prevention that tries to avoid them. It attempts to bring a higher expectancy average and better quality of life for debilitated and/or elderly people. One of the main obstacles found in this work was the lack of appropriate methodologies for each sensor. The sensors do not work alone but together like a body sensor network. With data collection and processing from sensors in real time (by smartphones or tablets), it becomes possible the creation of a warning system through a notification solution for fall prevention and detection simultaneously.

Unfortunately the technology cannot detect all the falls. Furthermore, trying to avoid a fall, it is better for users' health and a solution to increase the accuracy rate of the mobile solution.

It was shown that not all the falls are preventable but many of them can be avoided with this system. The proposed solution was evaluated and demonstrated and it is ready for use.

Web services are a solution for distributed information but they are not the most suitable solution in case there is the exchange of huge amounts of messages daily because if the server has little processing power or a connection network failure, the customer is waiting for the response from the Web service to send the next message, thus existing the possibility of lost data during runtime of the application.

The greatest difficulty in the developed system was the interdisciplinary character of the solution. The proposed system was efficient and reliable during rehearsals showing that it can be applied in reality presenting advantages over available solutions, especially in the AAL scenario where the continuous monitoring is a key issue. This new approach demonstrated that the biofeedback with fall detection could be a useful instrument for more detailed diagnoses in order to identify the cause of a fall and to improve patient safety.

The performance evaluation and comparison with available solutions are difficult to perform but are necessary to uphold the claim that biofeedback data can be used as a method to derive the level of usability in patients.

7.2 Future Work

To conclude this work, it just remains to make suggestions in terms of future developments and research directions based on current work:

- The development and update of the APPs and APIs for other mobile platforms, such as iOS from Apple and Windows Phone.

- Furthermore, the data retrieved from the other sensors for example Electroencephalography (EEG) beyond ECG, EMG, EDA, BVP, Respiration and accelerometer can be used to accomplish the falls prevention and detection.

- The mobile devices smartphones or tablets may be used to collect data embed health sensors and become specific devices for example a Body Health Sensor Smartphone.

- A performance assessment study through simulation considering different danger scenarios and evaluate the scalability of the proposed solution, may also be considered.

References

[1] “Population projections 2008-2060 - From 2015, deaths projected to outnumber births in the EU27 Almost three times as many people aged 80 or more in 2060,” Eurostat 2008, (STAT/08/119), 26AD.

[2] M. Mulvenna, W. Carswell, P. McCullagh, J.C. Augusto, Huiru Zheng, P. Jeffers, Haiying Wang, S. Martin, "Visualization of data for ambient assisted living services," IEEE Communications Magazine, vol.49, no.1, January 2011, pp.110,117.

[3] M. A. Estudillo-Valderrama, L. M. Roa, J. Reina-Tosina, and I. Román-Martínez, “Ambient Assisted Living: A methodological approach,” 2010 IEEE Engineering in Medicine and Biology Society (IEEE EMBC 2010), Buenos Aires, ARG, August 31 – September 4, 2010, pp. 2155–2158.

[4] V. Venkatesh, V. Vaithyanathan, M.P. Kumar, P. Raj, "A secure Ambient Assisted Living (AAL) environment: An implementation view," Computer Communication and Informatics (ICCCI), 2012 International Conference, 10-12 January 2012 , pp.1-7.

[5] T. Penzel, K. Kesper, and H. F. Becker, “Biosignal monitoring and recording,” in Information Technology Solutions for Healthcare, pp. 288–301, 2006.

[6] C.P. Figueiredo, O.S. Gama, C.M. Pereira, P.M. Mendes, S. Silva, L. Domingues, K. -P Hoffmann, "Autonomy Suitability of Wireless Modules for Ambient Assisted Living Applications: WiFi, Zigbee, and Proprietary Devices," Sensor Technologies and Applications (SENSORCOMM), 2010 Fourth International Conference on, 18-25 July 2010, pp.169-172.

[7] M. Mulvenna, W. Carswell, P. McCullagh, J.C. Augusto, Huiru Zheng; P. Jeffers, Haiying Wang; S. Martin, "Visualization of data for ambient assisted living services," Communications Magazine, IEEE , vol.49, no.1, January 2011, pp.110-117.

[8] Dunkel, Jurgen; Bruns, Ralf; Stipkovic, Sebastian, "Event-based smartphone sensor processing for ambient assisted living," Autonomous Decentralized Systems (ISADS), 2013 IEEE Eleventh International Symposium, 6-8 March 2013, pp.1-6.

[9] J. J. P. C. Rodrigues, O. R. E. Pereira, and P. A. C. S. Neves, "Biofeedback Data Visualization for Body Sensor Networks," in Journal of Network and Computer Applications, Elsevier, ISSN: 1084-8045, Vol. 34, No. 1, January 2011, pp. 151-158.

[10] C. Goldberg, “A practical guide to clinical medicine,” 2009 [Online] Available: http://meded.ucsd.edu/clinicalmed/vital.htm, [Accessed: April, 2013].

[11] N. Shiozawa, S. Arai, S. Okada, and M. Makikawa, "Gait analysis of sit-to-walk motion by using portable acceleration monitor device for fall prevention," 2012 IEEE International Conference on Biomedical and Health Informatics (IEEE BHI 2012), Hong Kong, China, 5 - 7 January, 2012, pp. 563-564.

[12] B. R. Greene, Alan O. Donovan, Roman Romero-Ortuno, Lisa Cogan, Cliodhna Ni Scanaill, and Rose A. Kenny, "Quantitative falls risk assessment using the timed up and go test," 2010 IEEE Transactions on Biomedical Engineering, vol. 57, no. 12, pp. 2918-2926, Dec. 2010.

[13] Ayan Banerjee and Sandeep KS Gupta, "Your mobility can be injuriou to your health: Analyzing pervasive health monitoring systems under dynamic context changes," 2012 IEEE International Conference on Pervasive Computing and Communications (IEEE PerCom 2012), Lugano, Switzerland, March 19 – 23, 2012, pp. 39-47.

[14] Ivo C. Lopes, Binod Vaidya, and Joel J. P. C. Rodrigues, "Towards an Autonomous Fall Detection and Alerting System on a Mobile and Pervasive Environment," Telecommunications Systems, Springer, 2011.

[15] Diansheng Chen, W. Feng, Y. Zhang, Xiyu Li, and Tianmiao Wang, "A wearable wireless fall detection system with accelerators," 2011 IEEE International Conference on Robotics and Biomimetics (IEEE ROBIO 2011), Karon Beach, Thailand, 7 - 11 December, 2011, pp. 2259-2263.

[16] C. Gagné and M. Parizeau, "Genericity in Evolutionary Computation Software Tools: Principles and Case-Study," International Journal on Artificial Intelligence Tools, vol. 15, no. 2, pp. 173–194, Apr. 2006.

[17] G. N. Rodrigues, V. Alves, R. Franklin, and L. Laranjeira, "Dependability Analysis in the Ambient Assisted Living Domain: An Exploratory Case Study," presented at the 2010 Fourth Brazilian Symposium on Software Components, Architectures and Reuse (SBCARS),, Bahia, Brazil, 2010, pp. 150–159.

[18] V. Fuchsberger, “Ambient assisted living,” presented at the SAME '08 Proceedings of the 1st ACM international workshop on Semantic ambient media experiences, New York, USA, 2008, pp. 21–24

[19] P. Almeida, R. Neves, “As quedas em idosos institucionalizados. Suas características.,” [Online] 2013 EFDeportes.com, Revista Digital, Buenos Aires. Available: http://www.efdeportes.com/efd177/as-quedas-em-idosos institucionalizados.htm, [Accessed: May, 2013].

[20] Mary E. Tinetti, “Facts about Falls - Preventable” 2010 [Online] Available: http://www.fallprevention.org/pages/fallfacts.htm, [Accessed: April, 2013].

[21] Hong Sun, V.De Florio, Ning Gui, C. Blondia, "Promises and Challenges of Ambient Assisted Living Systems," Information Technology: New Generations, 2009. ITNG '09. Sixth International Conference, 27-29 April 2009, pp.1201-1207.

[22] P. Rashidi, A. Mihailidis, "A Survey on Ambient-Assisted Living Tools for Older Adults," Biomedical and Health Informatics, IEEE Journal of , May 2013, vol.17, no.3, pp.579-590.

[23] E. Ras, M. Becker, J. Koch, , "Engineering Tele-Health Solutions in the Ambient Assisted Living Lab," Advanced Information Networking and Applications Workshops, (AINAW '07. 21st International Conference) , vol.2, 21-23 May 2007, pp.804-809.

[24] W. Kurschl, S. Mitsch, J. Schoenboeck, "Modeling Situation-Aware Ambient Assisted Living Systems for Eldercare," Information Technology: New Generations, 2009. (ITNG '09. Sixth International Conference), 27-29 April 2009, pp.1214-1219.

[25] A. Reichman, M. Zwiling, "The architecture of ambient assisted living system," Microwaves, Communications, Antennas and Electronics Systems (COMCAS), 2011 IEEE International Conference, 7-9 November 2011, pp.1-4.

[26] P. Antonino, M. Orfgen, D. Schneider, T. Hussain, M. Becker, "Evaluating Adaptation Behavior of Adaptive Systems," Software Engineering Advances (ICSEA), 2010 Fifth International Conference of the IEEE, 22-27 August 2010, pp.488-493.

[27] M. A. Estudillo-Valderrama, L. M. Roa, J. Reina-Tosina, I. Román-Martínez, "Ambient Assisted Living: A methodological approach," Engineering in Medicine and Biology Society (EMBC 2010), Annual International Conference of the IEEE, August 31 2010 September 4 2010, pp.2155-2158.

[28] A. Sasikanth, Amit Baxi, and David Kotz, "Privacy in mobile technology for personal healthcare," *ACM Comput. Surv.* 45, 1, Article 3, December 2012, 54 pages.

[29] A.H.H.M. Mohamed, H. Tawfik, D. Al-Jumeily, L. Norton, "MoHTAM: A Technology Acceptance Model for Mobile Health Applications," Developments in E-systems Engineering (DeSE 2011), 6-8 December 2011, pp.13-18.

[30] S. Fox, M. Duggan, "Mobile Health 2012," [Online]. Available: http://www.pewinternet.org/~/media//Files/Reports/2012/PIP_MobileHealth2012_FINAL.pdf, [Accessed: April, 2013].

[31] S. Kumar, W. Nilsen, M. Pavel, and M. Srivastava,, "Mobile Health: Revolutionizing Healthcare Through Transdisciplinary Research," IEE Computer Society , vol.46, no.1, pp.28-35, 2013.

[32] M. Weiser, “The Computer for the 21st Century,” IEEE Pervasive Computing, vol. 99, no. 1, pp. 19–25, 2002.

[33] J. Cheng, “Testing and Debugging Persistent Computing Systems: A New Challenge in Ubiquitous Computing,” in IEEE/IFIP International Conference on Embedded and Ubiquitous Computing (EUC 2008), Shanghai, China, December, 2008, vol.1, pp.408-414.

[34] Z. Rashid, U. Farooq, J-K. Jang, and S-H. Park, “Cloud computing aware Ubiquitous Health care system,” in E-Health and Bioengineering Conference (EHB), Lasi, Roumania, November 2011, pp. 1-4.

[35] S. Sano, T. Yoshihisa, and M. Tsukamoto, “Design and Implementation of Device with Alterable Functions for Ubiquitous Computing,” in International Symposium on Ubiquitous Multimedia Computing (UMC 2008), Hobart, Australia, October 2008, pp.226-231.

[36] S. Yoo, S. Jung, J. Choi, and R. Dongwooo, “Development of Ubiquitous Health Monitoring System,” in International Conference on Convergence Information Technology, Gyeongju, South Korea, November 2007, pp.1116-1120.

[37] J. Rodrigues, M. Oliveira, and B. Vaidya, “New Trends on Ubiquitous Mobile Multimedia Applications,” Journal on Wireless Communications and Networking (EURASIP 2010), vol. 2010, no. 1, p. 689517, 2010.

[38] C. Z. Qiang, M. Yamamichi, V. Hausman, D. Altman, and I. Unit, “Mobile Applications for the Health Sector,” [Online]. Available: http://siteresources.worldbank.org/INFORMATIONANDCOMMUNICATIONANDTECHNOLOGIES/Resources/mHealth_report.pdf, [Accessed: March, 2013]

[39] Google, "Google Android Operating System," [Online]. Available: http://www.android.com/ [Accessed: February, 2013]

[40] Apple, "Apple iOS," [Online]. Available: http://www.apple.com/ios/. [Accessed: February, 2013]

[41] Google, "Google Play," [Online]. Available: https://play.google.com/. [Accessed: February, 2013]

[42] Apple, "Apple Store - iTunes," [Online]. Available: http://itunes.apple.com/. [Accessed: February, 2013]

[43] B. Kumar, S. P. Singh, and A. Mohan, "Emerging Mobile Communication Technologies for Health," presented at the International Conference on Computer and Communication Technology (ICCCT 2010), Allahabad, India, September 2010, pp. 828–832.

[44] V. Della Mea, "What is e-Health (2): The death of telemedicine?, " , Journal Article J. Med. Internet Res. (JMIR) [online]. Available: http://www.jmir.org/2001/2/e22/. [Accessed: February, 2013].

[45] X. Ge, R. F. Paige, and J. A. McDermid, "Domain analysis on an electronic health records system," presented at the First International Workshop on Feature-Oriented Software Development (FOSD 2009), New York, USA, 2009, pp. 49-54.

[46] "ISO/TR 20514, Health informatics - Electronic health record - Definition, scope and context," American National Standards Institute (ANSI), 2005, p. 34.

[47] W. Yina, "Application of EHR in Health Care," on second International Conference on Multimedia and Information Technology (MMIT), Kaifeng, China, April 2010, pp. 60-63.

[48] C. Nosteboom, D. Bastola, and S. Qureshi, “Cycles of Electronic Health Records Adaptation by Physicians: How Do the Positive and Negative Experiences with the EHR System Affect Physicians EHR Adaptation Process?,” Maui, Hawai, USA, January 2012, pp. 1530-1605.

[49] I. Díez, M. Antón-Rodríguez, and F. J. Díaz-Pernas, “Mobile Web Application Development to Access to Psychiatric Electronic Health Records,” Telemedicine Techniques and Applications, Prof. Georgi Graschew (Ed.), ISBN: 978-953-307-354-5, InTech,, 2011, ch.10, pp. 241-257.

[50] D. Patra, S. Ray, and J. Mukhopadhyay, “Achieving e-Health Care in a Distributed EHR System,” in the 11th International Conference on e-Health Networking, Applications and Services (Healthcom 2009), Sydney, Australia, December 2009, pp.101-107.

[51] B. Oladosu, F. A. Ajala, and O. O.Popoola, “On the use of use of Web Services technology in e-health applications,” Journal of Theoretical and Applied Information Technology, 2009.

[52] MedlinePlus, “Electrocardiogram, ” A service of the U.S National Library of Medicine (NIH), [online]. Available: http://www.nlm.nih.gov/medlineplus/ency/article/003868.htm. [Accessed: February, 2013]

[53] Zeli Gao, Jie Wu, Jianli Zhou, Wei Jiang, Lihui Feng, "Design of ECG Signal Acquisition and Processing System," Biomedical Engineering and Biotechnology (iCBEB), 2012 International Conference, 28-30 May 2012, pp.762-764.

[54] Nobelprize.org, "Electrocardiogram, " The official web site of the Nobel Prize, [online]. Available: http://www.nobelprize.org/educational/medicine/ecg/. [Accessed: February, 2013]

[55] A. Elbuni, S. Kanoun, M. Elbuni, N. Ali, "ECG parameter extraction algorithm using (DWTAE) algorithm," Computer Engineering & Systems, International Conference (ICCES 2009), 14-16 Dec. 2009, pp.315-320.

[56] Gu-Young Jeong; Kee-Ho Yu, "Design of Ambulatory ECG Monitoring System to detect ST pattern change," International Joint Conference SICE-ICASE, 2006, 18-21 Oct. 2006, pp.5873,5877.

[57] K.V. Suarez, J.C. Silva, Y.Berthoumieu, P. Gomis, N. Mohamed, "ECG Beat Detection Using a Geometrical Matching Approach," Biomedical Engineering, IEEE Transactions, vol.54, no.4, April 2007, pp.641-650.

[58] Programa Harvard Medical School Portugal, "Electromiografia (EMG) e estudos de condução nervosa, " [online]. Available: http://hmsportugal.wordpress.com/2011/08/31/electromiografia-emg-e-estudos-da-conducao-nervosa/. [Accessed: February, 2013]

[59] Chul-Gyu Song; Keo-Sik Kim; Yang-Su An; Jeong-Hwan Seo, "Comparison of bio-impedance changes and EMG activity during daily events," Biomedical Circuits and Systems Conference IEEE , (BioCAS 2008), 20-22 Nov. 2008, pp.369-372.

[60] S.M. Rissanen, M. Kankaanpaa, M.P. Tarvainen, A. Meigal, J. Nuutinen, P. Jakala, O. Airaksinen, P.A. Karjalainen, "Discrimination of EMG and acceleration measurements between patients with Parkinson's disease and healthy persons," Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, Aug. 31 2010-Sept. 4 2010, pp.4878-4881.

[61] R.T. Lauer, C. A. Laughton, M. Orlin, B.T. Smith, "Wavelet decomposition for the identification of EMG activity in the gait cycle," Bioengineering Conference, 2003 IEEE 29th Annual, 22-23 March 2003, pp.142-143.

[62] R. G. Haahr, "Reflectance pulse oximetry sensor for the electronic patch," MSc. Dissertation, Technical University of Denmark, Lyngby, Nov. 2006. [online]. Available: http://www.yumpu.com/en/document/view/5788465/reflectance-pulse-oximetry-sensor-for-the-electronic-patch.
[Accessed: February, 2013]

[63] Chao Li, Jing Zhai, A. Barreto, "Signal processing quantification of changes in the blood volume pulse (BVP) waveform due to exercise," Engineering in Medicine and Biology Society, 2003. Proceedings of the 25th Annual International Conference of the IEEE, vol.4, 17-21 Sept. 2003, pp.3180-3183.

[64] Ming-Zher Poh; N.C. Swenson, R.W. Picard, "A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity," Biomedical Engineering, IEEE Transactions, vol.57, no.5, May 2010, pp.1243-1252.

[65] J. Fleureau, C. Penet, P. Guillotel, C.H. Demarty, "Electrodermal activity applied to violent scenes impact measurement and user profiling," Systems, Man, and Cybernetics (SMC), 2012 IEEE International Conference , 14-17 Oct. 2012, pp.3310-3315.

[66] C. Rovira, S. Coyle, B. Corcoran, D. Diamond, F. Stroiescu, K. Daly, "Integration of textile-based sensors and Shimmer for breathing rate and volume measurement," Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference , 23-26 May 2011, pp.238-241.

[67] Dimension Engineering, "A beginner's guide to accelerometers," Robotics Radio control Power electronics [online]. Available: http://www.dimensionengineering.com/info/accelerometers. [Accessed: February, 2013]

[68] E. Thammasat, J. Chaicharn, "A simply fall-detection algorithm using accelerometers on a smartphone," Biomedical Engineering International Conference (BMEiCON), 5-7 Dec. 2012, pp.1-4.

[69] E. Campo, E. Grangereau, "Wireless fall sensor with GPS location for monitoring the elderly," Engineering in Medicine and Biology Society, 30th Annual International Conference of the IEEE (EMBS 2008), 20-25 Aug. 2008, pp.498-501.

[70] E. -H. Jang, B. –J. Park, S. –H. Kim, Y. Eum, J. Sohn, "Identification of the optimal emotion recognition algorithm using physiological signals," Engineering and Industries International Conference, (ICEI 2011), Nov. 29 2011-Dec. 1 2011, pp.1-6.

[71] D. S. Liu, W. H. Chang, A. M. K. Wong, S.-C. Chen, K.-P. Lin, and C.- H. Lai, "Development of a biofeedback tilt-table for investigating orthostatic syncope in patients with spinal cord injury," 2007 Medical and Biological Engineering and Computing, vol. 45, no. 12, 2007, pp. 1223-1228.

[72] Mary E. Tinetti, T. F. Williams, and R. Mayewski, "Fall risk index for elderly patients based on number of chronic disabilities," The American journal of medicine, 1986, vol. 80, pp. 429-434.

[73] J. Allanson and G. M. Wilson. "Physiological computing," in 2002 Human factors in computing systems (CHI 2002), pp. 912-913, ACM, 2002.

[74] N. Shiozawa, S. Arai, S. Okada, and M. Makikawa, "Gait analysis of sit-to-walk motion by using portable acceleration monitor device for fall prevention," 2012 IEEE International Conference on Biomedical and Health Informatics (IEEE BHI 2012), Hong Kong, China, 5 - 7 January, 2012, pp. 563-564.

[75] P. Jantaraprim, P. Phukpattaranont, C. Limsakul, B. Wongkittisuksa, "Improving the accuracy of a fall detection algorithm using free fall characteristics," Electrical Engineering/Electronics Computer Telecommunications and Information Technology International Conference (ECTI-CON), 19-21 May 2010, pp.501-504.

[76] Aiguang Li, Shaofeng Wang, Huabin Zheng, Lianying Ji, Jiankang Wu, "A novel abnormal ECG beats detection method," Computer and Automation Engineering The 2nd International Conference (ICCAE 2010), 26-28 Feb. 2010, pp.47-51.

[77] A. Phinyomark, G. Chujit, P. Phukpattaranont, C. Limsakul, and H. Hu, "A preliminary study assessing time-domain EMG features of classifying exercises in preventing falls in the elderly," 2012 IEEE 9th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (IEEE ECTI-CON 2012), Hua Hin, Thailand, May 2012, pp. 1-4.

[78] M. P. Tarvainen, P. A. Karjalainen, A. S. Koistinen, and M. V. Valkonen-Korhonen, "Principal component analysis of galvanic skin responses," 22nd Annual Int. Conference of the IEEE In Engineering in Medicine and Biology Society, vol. 4, July 23–28, 2000, pp. 3011-3014.

[79] Object Management Group, “UML,” [Online]. Available: http://www.uml.org/ [Accessed: February, 2013].

[80] Google, “Android versions distribution,” [Online]. Available: http://http://developer.android.com/about/dashboards/index.html [Accessed: May, 2013].

[81] Google, “Android Software Development Kit,” [Online]. Available: http://developer .android.com/sdk/index.html [Accessed: April, 2013].

[82] C. Pautasso and E. Wilde, “RESTful web services: principles, patterns, emerging technologies,” presented at the WWW '10 Proceedings of the 19th international conference on World wide web, Raleigh, USA, 2010, pp. 1359–1360.

[83] Oracle Corporation, “MySQL Workbench,” [Online]. Available: http://www.mysql.com/products/workbench/ [Accessed: April, 2013].

[84] S.K. Tasoulis, C.N. Doukas, I. Maglogiannis, V.P. Plagianakos, "Statistical data mining of streaming motion data for fall detection in assistive environments," Engineering in Medicine and Biology Society, 2011 Annual International Conference of the IEEE (EMBC), Aug. 30 2011 - Sept. 3 2011, pp.3720-3723.

[85] WEKA Data mining Software, “WEKA 3,” [Online]. Available: http://www.cs.waikato.ac.nz/ml/weka/ [Accessed: April, 2013].

[86] elinux, “Android Architecture,” [Online]. Available: http://elinux.org/Android_Architecture [Accessed: April, 2013].

[87] Google Android, “Android Developers,” [Online]. Available: http://developer.android.com/reference/android/app/Activity.html [Accessed: April, 2013].

[88] A. Banerjee and S. K. S. Gupta, "Your mobility can be injurious to your health: Analyzing pervasive health monitoring systems under dynamic context changes," in IEEE International Conference on Pervasive Computing and Communications (IEEE PerCom 2012), 2012, pp. 39-47.

[89] Shimmer, “Shimmer Android ID,” [Online]. Available: http://www.shimmersensing.com/shop/shimmer-android-id [Accessed: April, 2013].

[90] Google, “Google Official Blog,” [Online]. Available: http://googleblog.blogspot.co.uk/2013/03/update-from-ceo.html [Accessed: April, 2013].

[91] H. Mamaghanian, N. Khaled, D. Atienza, and P. Vandergheynst, "Compressed sensing for real-time energy-efficient ECG compression on wireless body sensor nodes", In IEEE Transactions Biomedical Engineering 2011, vol. 58, no. 9, pp. 2456-2466.

[92] C.-J. Hsieh, C.-Y. Chiang, C.-N. Huang, C.-T. Chan, and S. J. Hsu, "Development of Fall Characteristics Collection System for Fall Prevention Strategies," in 5th International Conference on Bioinformatics and Biomedical Engineering (IEEE iCBBE 2011), 2011, pp.1-4.

Appendix

This appendix includes the papers containing the main contributions to this dissertation. The first paper is entitled “A Mobile Health Application for Falls Detection and Biofeedback Monitoring” and was published and presented at the International Workshop on Service Science for eHealth (SSH 2013), co-located with the IEEE HEALTHCOM 2013, Lisbon, Portugal, October 9-12, 2013.

The second paper was published at the 15th International Conference on eHealth Networking, Application & Services in IEEE HEALTHCOM 2013, Lisbon, Portugal, October 9-12, 2013. It is entitled “Real Time Falls Prevention and Detection with Biofeedback Monitoring Solution for Mobile Environments”.

A Mobile Health Application for Falls Detection and Biofeedback Monitoring

Edgar T. Horta[1], Ivo C. Lopes[1], Joel J. P. C. Rodrigues[1], and Mario L. Proença Jr.[2]
[1] Instituto de Telecomunicações, University of Beira Interior, Covilhã, Portugal
[2] State University of Londrina, Brazil
edgar-horta@hotmail.com; ivo.lopes@it.ubi.pt; joeljr@ieee.org; proenca@uel.br

***Abstract*— A mobile health application solution with biofeedback based on body sensors is very useful to perform a data collection for patients remote monitoring. This system allows comfort, mobility, and efficiency in all the process of data collection providing more confidence and operability. Falls represent a high risk for debilitated elderly people. Falls can be detected by the accelerometer presented in most of the available mobile devices. To reverse this tendency, more accurate data for patients monitoring can be obtained from the body sensors attached to a human body (such as, electro cardiogram, electromyography, blood pressure, electro dermal activity, and temperature). Then, this paper proposes a mobile solution for falls detection and biofeedback monitoring. The proposed system collects sensed data that is forwarded to a smartphone or tablet through Bluetooth. Mobile devices are used to display information graphically to users. All the process of data acquisition is performed in real time. The proposed system is evaluated, demonstrated, and validated through a prototype and it is ready for use.**

Keywords*— Mobile Health; Biofeedback Monitoring; Fall Detection; Body Sensor Networks; Mobile Computing

INTRODUCTION

Advances on technologies for healthcare along with the increase of elderly people around the world, new challenges arise for better quality of life focusing on this population [1]. It is observed that elderly people last longer with the best quality of life as possible. In this context, ambient assisted living (AAL) is emerging as an ecosystem that aims to describe and identify resources and services, which enable through the use of technology, facilitate and improve lives of the disabled, elderly, and chronically ill people. This technology appears as an asset in the current context for integration into a patient monitoring systems aiming to improve the quality of life. To identify accidents or high-risk situations in which it is possible to act in order to detect them so as to reduce the time response to these critical events is a major concern [2].

Mobile applications appear as a personal emergency response system (PERS) that contributes to AAL solutions, improved with the use of electronic body sensors (BS). These sensors can be placed to patient body and communicate with mobile devices (such as, smartphones or tablets) through short-range communications, like Bluetooth. With the use of tablets, smartphones, and integration of physiological sensors, the information and communications technology for the next-generation patient physiological mobile solutions, offers excellent conditions to create innovative solutions and techniques for remote and real-time people monitoring with mobility support. These systems can collect sensed data from patient in real time. Mobile devices can store and process incoming data and also forward them to storage systems in real time, including the Internet [3]. Furthermore, the patient can also have information that can be useful to him/her, allowing a detailed and on time information that can be extremely relevant for diagnosis and treatment adjustments for people from healthcare systems (physicians, nurses, and paramedics).

The historical record of physiological sensed data is very useful for diagnosing further problems as the causes of falls and habits that may increase the patient risk. Thus, trying to increase patients' independence, offering a good AAL solution with mobility support, this paper presents a fall detection system combined with a biofeedback monitoring, data processing, and presentation solution, using body sensors. This proposal is embedded on a mobile device, such as a smartphone or a tablet, and with a complement of body sensors and the accelerometer already included in the mobile device, proposes a fall detection solution and a biofeedback monitoring activity in real time with mobility support.

The remainder of the paper is organized as follows. Section II presents some insight on related work, while Section III presents the system architecture and the importance of the mobile solution. Section IV elaborates on the mobile solution, Section V designates the devices used on the prototype, while Section VI describes the results obtained from the performance evaluation, demonstration and validation of the solution. Finally, the paper is concluded in Section VII.

RELATED WORK

Several approaches based on tools and techniques for falls detection can be found in the literature. Generally, they are mainly concerned with health of elderly and incapacitated people, using techniques based on accelerometers movement data collection and a fall detection algorithm. Considering the contributions available in the approaches [4, 5], the differences between them come from the fact that one uses a smartphone and the other is based on an embedded accelerometer sensor solution. Many solutions of monitoring biofeedback are also reported but all of them have in common an explanation of the importance of data acquisition in healthcare systems for surveillance of patient's physiological signals [6]. A more static and non-adaptive system showing a biofeedback monitor to handle a specific type of health problem is presented in [7]. A relatively large amount of scientific work has been performed on this topic and there is a considerable convergence between all of them, mentioning that physiological data is vital for the treatment, monitoring, and prevention of various diseases. Many of these works are quite recent given these systems should be computationally powerful, as to collect and process large amounts of data in a short time interval. However, accidental falls represent the sixth cause of death among elderly people [8]. It is estimated that one out of three people aged over 65 years old is at risk of falling and also higher probability of suffer from health problems not knowing this fact. The main novelty in the approach presented in this paper is the combination of these two important approaches (fall detection and biofeedback monitoring in real time) in a single solution, so that new findings and future development may arise.

The concept of fall detection and the context of biofeedback monitor are not new and these technologies have been suffering more significantly technological advancement from the year 2000. Biofeedback evaluation partly contributes to the advancement of health diagnoses like stress assessments, inattention, heart rate, anxiety disorders, depression, and chronic diseases. They contribute significantly and turn possible the development of new treatments and ways to diseases combat. Monitoring physiological parameters is an established topic and is used in diverse areas of medicine and sports. Such technologies are commercially available and, in order to encourage their usability, it is important to demystify the technology turning available what is it, how does it work and what quality of information can be expected from it. To development of fall prevention strategies based on fall characteristics [9] to upgrade solutions.

There is an extensive range of healthcare applications with biofeedback monitoring from critical monitoring of physiology scenarios of terminal illness up to the own patient make diagnoses of himself. The proposed solution gathers contributions from related work available in the literature.

System Architecture

This section presents the system architecture based on a body sensors solution and a fall detection system. Figure 1 presents a scenario that illustrates the proposed system architecture with main actions defined for communications.

The mobile device receives data directly from the mobile phone accelerometer and from the base station (sink) of body sensors through Bluetooth. All the collected data is sent to a remote database through the HTTP protocol using REST Web services. The proposed system architecture considers the following three modules: the fall detection, the body sensors, and medical services. The fall detection is responsible for detecting the accelerations caused from the user daily movements and interprets the values in order to detect user fall. The body sensors are responsible for collecting body parameters from the sensors placed along the user body in order to obtain the vital parameters and extra information to the fall detection.

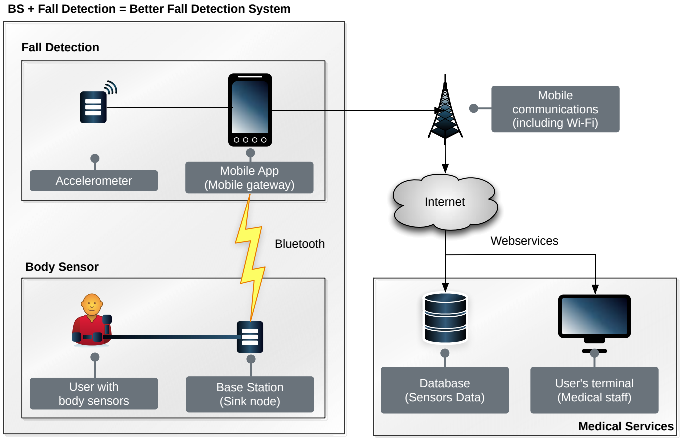


Fig. 1. System Architecture with the three modules (body sensors, fall detection system, and medical services).

Mobile Application

The increased use of mobile devices is growing exponentially. Currently, these devices offer a wide range of features that were previously only found on personal computers. Being more compact, mobile devices allow an improved ease to use and mobility, making possible access to newest tools and applications like the one proposed in this paper. However, mobile devices have the flexibility to become a better tool, to aid in everyday tasks, and much more e.g. a medical monitoring assistive tool.

A. Development of monitoring tool

The proposed system is based on the collection of information carried out by the different sensors to a smartphone or a tablet. For the potential occurrence of a patient's health problem or more serious situations such as a fall, monitoring and data collected by sensors in a certain period of time can be easily accessed and evaluated to facilitate diagnosis and patients monitoring.

This system is prepared for being computationally powerful, performing data collection and processing a large amount of collected information. In a matter of efficiency the battery lifetime for smartphone and base-station is also considered. The system is responsible for receiving data from sensors in real time and sends them to a smartphone or tablet. It should serve as a support platform for medical health for monitoring or to identify, e.g. a stroke, falls and other incidents that endanger the lives of patients. The application also offers visual tools through the device screen for monitoring the related graphics using the data received from sensors that can be created and observed in real time.

This tool is based on three modules as shown in the system architecture, including the fall detection, data processing and visualization of information from sensors, and communication through Web services with user's terminals (Medical staff) and external database storage so data can be access by a medical staff, available from outside.

B. Falls detection algorithm

The fall detection process was deployed using paradigms of multi-threading to make possible the simultaneous combination of several tasks and several sensors readings. In a specific case, the different Android activities with different sensors readings should be considered simultaneously.

The diagrams shown in Figure 2 and 3 represent the sequence of the application and its data flow are presented and described. Each Android activity is presented as a thread. So the threads can be launched in a cooperative state beyond the primary that is created automatically by the system and everything is handled synchronously.

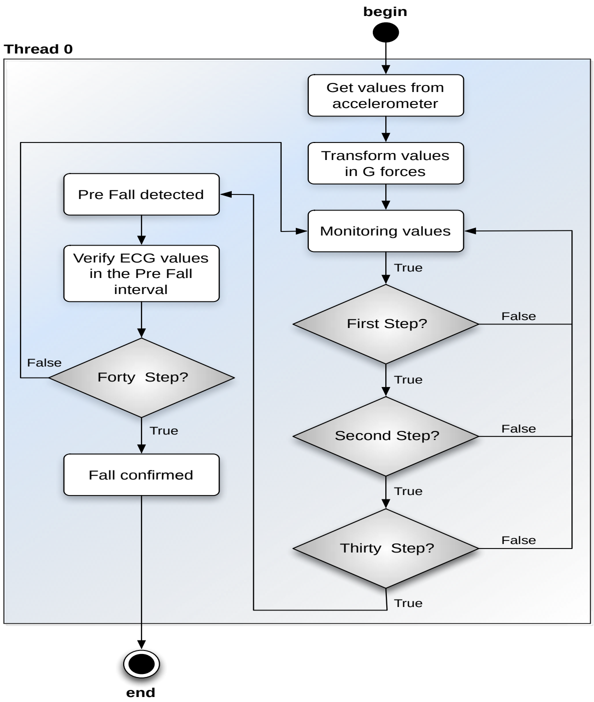


Fig. 2. Fall detection (Thread 0) activity diagram.

Figure 2 presents the workflow of the first thread (called Thread 0). The process starts from getting the accelerations values from the accelerometer and then transforms the values of axes X, Y, and Z received from accelerometer in G force, using the equation (1). The thread will always be active and monitoring the user activity. In the first step, if G force is lower than 0.5, the process advance to a second step. In the second step, if G force is great than 2.5, it will go to the third step. In the third step, if the first and second steps presents a flag as *True*, it will start counting a 10 seconds timer, if in the time interval some movement occurs, it is declared as false alarm. In the other case, if there is no activity and the verifying data from sensors (e.g. the ECG values) are too weak comparing with normal values using a threshold value or have irregularities, it is possible the user is unconscious or immobilized and need help. Then, the system will trigger the fall alert, the time interval in milliseconds, and data from sensors are saved on the database to compare the values in the same moment of time.

$$G = \frac{\sqrt{x^2 \times y^2 \times z^2}}{9{,}8} \qquad (1)$$

C. Processing and information visualisation from sensors

New threads are created for the others activities, with the remaining sensors and visualization, launched in simultaneous and synchronized (Figure 4).

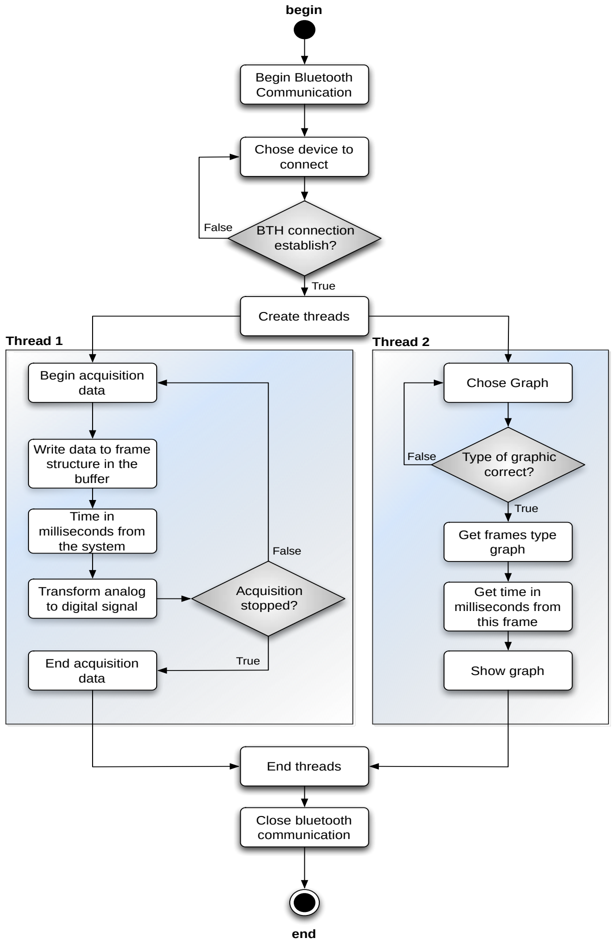


Fig. 3. Bluetooth Connection, Receive, Store, and processing Data (Thread 1), other Show Charts (Thread 2) activity diagram.

The workflow of the Figure 3 starts with the Bluetooth communication and verification, displaying Bluetooth devices that are in range of the base-station. After a successful connection, the system will create two threads for each sensor, one for the data acquisition and another for the visualization of the values in a graph. When a connection is established, the Thread 1 will start acquiring data from the connected sensors and the device starts to receive data frames that are placed on the buffer and saves it on the database. In order to convert the analog signal output *VoutAnalog* collected, a 12-bit integer, which is given a sampling frequency in Hertz, to a digital signal *VoutDigital* (in volts), the equation (2) was used. The Voltage *Vrange* value ranges from 0 to 5, specifically for each type of sensor. At the same time, the Thread 2 starts drawing the graphs according to the values from the sensor. If the acquisition stops, the acquisition mode will finish and close the Bluetooth socket communication.

$$VoutDigital = \frac{VoutAnalog * Vrange}{4095} \qquad (2)$$

The Thread 2 displays charts using the Android library for chart graphs (named Achartengine). In the proposed application it is possible to choose different types of graph to be presented. It is also possible to display several charts simultaneously.

DEVICES USED ON THE PROTOTYPE

Many biological processes in a patient can be measured. For biofeedback monitoring the authors propose one inertial sensor and five physiological sensors to extract precious information from patient's body.

The authors chose the Bioplux system because it offers flexibility, a big range of health sensors, adaptive, and a great capacity for portability and autonomy. Nevertheless, it can also be adapted to others available sensor systems. The Bioplux system base-station, shown in Figure 4.B, is a device that collects signals from the sensors, transmitting them via Bluetooth to other devices where the signals are shown in real-time. This base station is a sink of body sensors (BS), with smart sensor nodes. The sensors chosen for this study are the following: the accelerometer, the Electro-cardiogram (ECG) characterized by six crests and troughs, the Electromyography (EMG), the Blood Volume Pulse (BVP), the Electro Dermal Activity (EDA), and the Respiration sensor.

Bluetooth and Wi-Fi connection are the most important requirements to support this system on a mobile device. On the market, the majority of smartphones and tablets include this technology. In this scenario, various versions of Android system are supported, from version 1.6 to the current 4.2. The low cost, wide variety, and versatility are direct benefits for users. This application was developed for Android 4.2 Jelly Bean but also experimented on other previous Android versions.

D. Arrangement of the sensors in patients body

A good arrangement of BSs in the patient's body (shown in Figure 4.A and 4.C) is essential for proper readings. These readings will be transmitted to the patient's device, smartphone or table.

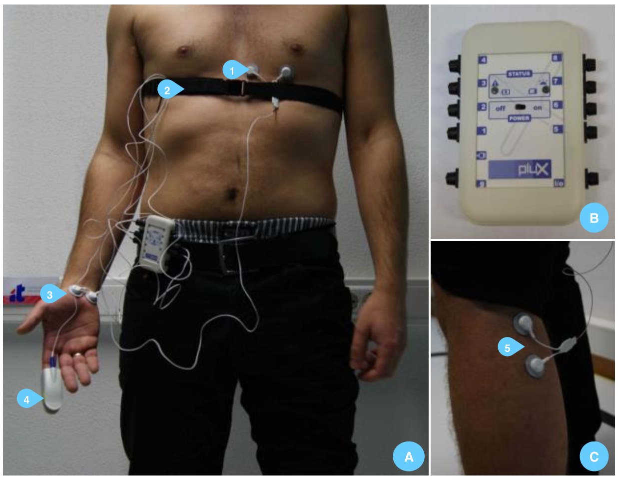


Fig. 4. Placement of the sensors in the human body;
A) 1- Electro-cardiogram; 2-Respiration; 3- Electro Dermal Activity; 4- Blood Volume Pulse; B) Base station (Sink node); and C) 5- Electromyography.

It will also have a communication range with the sink node or sensor base station (shown in Figure 4.B) approximately 10 meters in ideal conditions and without other equipment's which will cause interference within this operating range. In Figure 4.A the sensors are placed on the proper local and the base station is synchronized with a smartphone for data acquisition.

Sensors are placed on the patient body with the procedure of Figure 4.A and 4.C, in a specific area of the body. The ECG (1) and Respiration (2) sensors were placed on the chest (heart area), the EDA (3) was positioned on the palm of the hand and the BVP (4) was placed on the fingertips while the EMG (5) was placed on the tibialis anterior and gastrocnemius muscles on the leg.

Modeling a BS in a human body to be prepared for a fall detection is not particularly easy. Sensor readings will have to be performed in ideal conditions of data acquisition or else can become unviable. The flexibility and robustness of the hardware used are taken into account to allow system reliability.

SYSTEM DEMONSTRATION AND VALIDATION

The mobile application was deployed on several devices in order to demonstrate and validate the proposed solution, and also in order to be possible essays for volunteers. The application ran effortlessly on all the used devices. The experiments were approached based on several fall simulations with 3 volunteers, each one with 38 trials, in a total of 114 trials. The devices, shown in Figure 5, obtained results for one experiment with the sensors monitoring several bio-signals during a fall experiment.

E. System Demonstration

In Figure 5, a smartphone shows the ECG signal with values ranging from 1362609123800 milliseconds to 1362609124200 milliseconds. This date timer is obtaining from the local date system by the number of milliseconds that have elapsed since midnight, January 1, 1970. This collection of values in this time interval is important because an event tries to evaluate a pre-fall when it occurs. A pre-fall is detected by the accelerometer algorithm, presented on Figure 5 in the tablet computer, showing the variation of *G* force signal, emerging a warning to the user and an important value to the system when a fall is detected by the algorithm. When a fall occurs the values from the sensors are sent and saved to the database. The importance of this time interval is to detect some happenstances, before and after, to identify anomalies in order to be analyzed in more detail by specialists, who detect important scenes in the fall event to discover and describe the fall occurrence. In this real scenario only the vital signs are used to detect whether values have changes to the normal rhythm of the user. The distance and the variability of the ECG waves with a threshold value were experimented returning a Boolean value whether the ECG have right signs or not. When a fall is confirmed and the patient has anomalies in vital signs the system will trigger an alert.

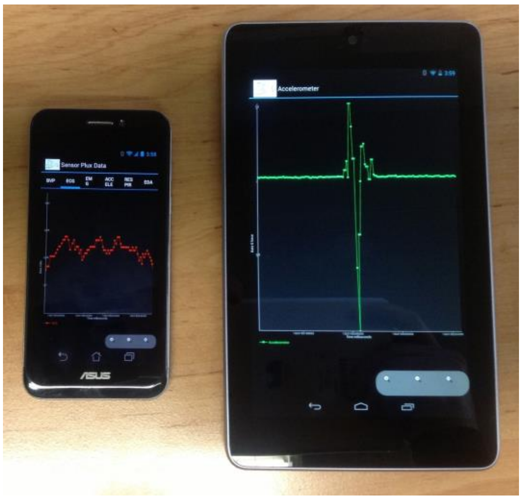


Fig. 5. Photos of a real deployment of the proposed solution with an Electrocardiogram and Accelerometer during a fall experiment in a real scenario.

The points in the line charts represent the values saved in the database in Volts. The presented charts are *Zoom In* to a small time interval in order to get an idea how small - e.g. the time latency of sensors are 0.001 seconds (sampling rate of 1000 Hz), in ideal transmission conditions. However, the accelerometer of the smartphone or tablet includes other specifications depending of the manufacturer and uses a bigger period of latency. In order to improve the graphics visualization various colors were used for the different type of sensors (red for ECG, green for the Accelerometer, blue for EMG, cyan for Respiration, light green for EDA, and black for BVP). It is also possible do *Zoom In* and *Zoom Out* for a particular interval in time.

F. Performance Evaluation

To evaluate the solution two trials were experimented to find the significant differences and improvements between them (shown in Table I). In order to reach a final precision to the two solutions, several measurements were archived. A total of 114 trials were performed under the same conditions for the two solutions. The trial errors were counted when the experimented solution did not detected a pre-fall.

EXPERIMENTAL RESULTS.

Action	***Number of trials***	***Trials errors***	***Right trials***	***Average***
Pre fall	114	10	104	91%
Pre Fall + ECG	114	6	108	95%

In the first essay, only the accelerometer to conduct the experiment in a total of 114 trials was used. The system detected 104 falls with accuracy and only 10 of them did not detect a fall. In the second essay, the ECG was added to the system and the results got slightly better, passing from 104 falls to 108 falls detected and only 6 trial errors. The results show the estimation of only pre-fall is 91% and the solution with pre-fall and ECG increases about 4%. Results show a better fall detection, as expected. It is important to note that this second solution brings improvements in real catastrophic scenarios, such as when the fall was detected and the user is unconscious or suffered from a heart attack.

CONCLUSION AND FUTURE WORK

Biofeedback monitoring with fall detection is a solution that enrich the knowledge of bio-signals before, after, and during a fall. Another objective of this system is the identification of fall characteristics collection for fall prevention strategies through biofeedback. This novel approach demonstrated that the biofeedback with fall detection could be a useful instrument for more detailed diagnoses in order to identify the cause of a fall and to improve patient safety. In terms of future developments, the mobile device may be used for collecting data from several body sensors, with different calibration thresholds. As a result, different user profiles can be associated to a specific sink MAC address for easier connection configuration.

II. ACKNOWLEDGMENTS

This work has been partially supported by the *Instituto de Telecomunicações*, Next Generation Networks and Applications Group (NetGNA), by Plux Biosensor Engineering, Portugal, by National Funding from the FCT – *Fundação para a Ciência e a Tecnologia* through the PEst-OE/EEI/LA0008/2011 Project, by the AAL4ALL (Ambient Assisted Living for All), project co-funded by COMPETE under FEDER via QREN Programme.

III. REFERENCES

"Population projections 2008-2060 - From 2015, deaths projected to outnumber births in the EU27 Almost three times as many people aged 80 or more in 2060," Eurostat 2008, (STAT/08/119), 26AD.

M. A. Estudillo-Valderrama, L. M. Roa, J. R.Tosina, and I. R.Martínez, "Ambient Assisted Living: A methodological approach," 2010 IEEE Engineering in Medicine and Biology Society (IEEE EMBC 2010), Buenos Aires, ARG, August 31 – September 4, 2010, pp. 2155–2158.

O. R. E. Pereira, P. A. C. S. Neves, and J. J. P. C. Rodrigues, "Mobile Solution for Three-tier Biofeedback Data Acquisition and Processing," 2008 IEEE Global Communications Conference (IEEE GLOBECOM 2008), New Orleans, LA, USA, Nov. 30 – Dec. 4, 2008, pp. 1-5.

D. Chen, W. Feng, Y. Zhang, X. Li, T. Wang, "A wearable wireless fall detection system with accelerators," 2011 IEEE International Conference on Robotics and Biomimetics (IEEE ROBIO 2011), Phuket Island, Thailand, 7 - 11 December 2011, pp. 2259-2263.

I. C. Lopes, B. Vaidya, and J. J. P. C. Rodrigues, "Towards an Autonomous Fall Detection and Alerting System on a Mobile and Pervasive Environment," Telecommunications Systems, Springer, 2011.

J. J. P. C. Rodrigues, O. R. E. Pereira, and P. A. C. S. Neves, "Biofeedback Data Visualization for Body Sensor Networks," in Journal of Network and Computer Applications, Elsevier, ISSN: 1084-8045, Vol. 34, No. 1, pp. 151-158, January 2011.

D. S. Liu, W. H. Chang, A. M. K. Wong, S.-C. Chen, K.-P. Lin, and C.-H. Lai, "Development of a biofeedback tilt-table for investigating orthostatic syncope in patients with spinal cord injury," 2007 Medical and Biological Engineering and Computing, vol. 45, no. 12, 2007, pp. 1223-1228.

Tracy Chippendale, J. Bear-Lehman, "Falls, Older Adults, and the Impact of the Neighborhood Environment," American journal of Occupational Therapy, vol. 65, no. 6, 2011, pp. e95-e100.

C.-J. Hsieh, C.-Y. Chiang, C.-N. Huang, C.-T. Chan, and S.J. Hsu, "Development of Fall Characteristics Collection System for Fall Prevention Strategies,"in 5th International Conference on Bioinformatics and Biomedical Engineering (iCBBE 2011), pp.1-4, IEEE, 2011.

Real Time Falls Prevention and Detection with Biofeedback Monitoring Solution for Mobile Environments

Edgar T. Horta[1], Ivo C. Lopes[1], Joel J. P. C. Rodrigues[1], and Sudip Misra[2]
[1] Instituto de Telecomunicações, University of Beira Interior, Covilhã, Portugal
[2] School of Information Technology, Indian Institute of Technology-Kharagpur, India
{edgar.horta; ivo.lopes}@it.ubi.pt; joeljr@ieee.org; smisra@sit.iitkgp.ernet.in

***Abstract* — With the elderly population growing around the world, falls increase the risk progressively with age. Those falls can origin injuries that may cause a great dependence and debilitation to the elderly, and even death in extreme cases. This paper reviews the related literature about this topic and introduces a mobile solution for falls prevention, detection, and biofeedback monitoring. The falls prevention system uses collected data from sensors in order to control and advice the patient or even to give instructions to treat an abnormal condition to reduce the falls risk. In cases of prolonged symptoms it can even detect a possible disease. The signal processing algorithms play a key role in a fall prevention system. In real time, based on biofeedback data collection, these algorithms analyses bio-signals to thereby warn the user, when needed. Monitoring and processing data from sensors is performed by a smartphone that will issue warnings to the user and, in gravity situations, send them to a caretaker. The proposed solution for falls prevention and detection is evaluated and validated through a prototype and it is ready for use.**

Keywords— Fall prevention; Biofeedback monitor; Mobile health application; Fall detection; Body sensor networks; Mobile computing

INTRODUCTION

Falling is something natural in the life of a human being from birth to death. A fall may have multiple origins, some of them can be avoided but others not. In elderly people the consequences of a fall increase with higher age. With the increase of elderly people around the world, new challenges arise to give greater quality of life for these senior citizens. So they can last longer and with the best quality of life as possible.

In a perfect scenario it would be possible to predict when a fall will occur and try to avoid it. Based on this fact, the proposed solution try to detect situations where the risk of fall shall be eminent and then warn the patient in order to prevent it. The patient receives the notice and can try to avoid a fall. The warning messages can be issued through a smartphone or tablet. Biofeedback sensors used by the user forward raw data through a Bluetooth connection to a smartphone or a tablet in order to measure the patient physiological parameters. A body sensor networks (BSN) attached to a human body can obtain more accurate data from patients monitoring signals (such as, electro cardiogram, electromyography, blood volume pressure, electro dermal activity, and galvanic skin response). These real time collected data from sensors are handled through an automatic algorithm, which is a critical piece for falls prevention. For falls detection a kinematic sensor accelerometer included in most of the available mobile devices through an algorithm provides this benefit. This mobile health tool monitors the body sensors using a real time communication through Bluetooth with a mobile device. A device (smartphone or tablet) uses its computational power to perform a fall detection algorithm, analyzing physiological signals received at the smartphone. If an abnormal behavior is detected the patient is notified immediately. Furthermore, the patient caretaker and/or physician can also be notified if needed. In this paper, a methodology for falls prevention is included considering biofeedback monitoring, data processing, and presentation using data collected by body sensors. This solution is embedded on a mobile device and tries to perform user biofeedback activity, fall detection, and transmits to the patient distress signals to prevent fall occurrences.

The remainder of the paper is organized as follows. Section II reviews the related literature. Section III presents the proposed system architecture. Section IV elaborates on the mobile application and features, while Section V performs a demonstration, validation and evaluation. Finally, Section VI concludes the paper.

RELATED WORK

The capture and processing biofeedback signals with sensors to a smartphone became possible and increasingly used due to the development and generalized use of these devices for personal use. Several approaches for falls prevention, detection, and biofeedback monitoring may be found in the related literature, using different techniques, tools, and devices [1]. Fall detection is a topic with abundant information where algorithms use sophisticated methods to detect falls, but it is also closely related to describe motion and movements by the patient body. This detection is performed by kinematic sensors such as accelerometers and gyroscopes coupled to the most of mobile devices available in the market. In [2], a quantitative falls risk positions using the kinematic sensor was presented to identify an association with different types of falls risk. In [3], a wearable fall detection system with use of accelerometry techniques and a fall detection algorithm is proposed. Both are mainly concerned with the health of elderly and incapacitated people. In order to develop a fall prevention system, a collection of fall characteristics to determinate and train fall events that use strategies with existing resources were reviewed [4]. A detailed methodology for electro cardiogram (ECG) sensor was included in [5]. It uses ECG beat detection and treat their data waves to heart beat recognition, R-wave detection procedure or peak detection to make diagnoses of heart diseases and prevent possible problems. An electromyography (EMG) analysis was performed to investigate the changes that occur in the parameters of the patients electrical signals by increased risk of falling and balance disorders [6]. The galvanic skin response was a simple method to detect arousal and analyses physical stimulus in a patient to thereby check if patient had or not imminent risk of falling [7]. All these systems and techniques above described offered important contributions to the solution proposed in this work.

System Architecture

Figure 1 illustrates the fall prevention and detection scenario to illustrate the proposed system architecture and the sensors communication process with the mobile application and the healthcare.

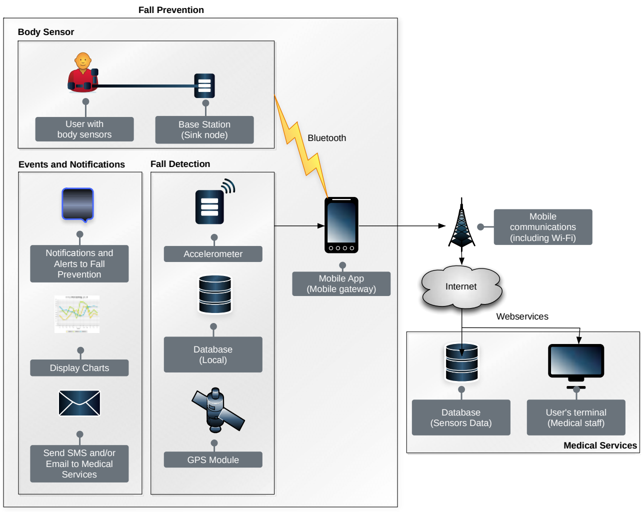


Fig. 6. Illustration of the fall prevention and detection system architecture with the four modules (body sensors, fall detection system, events and notifications and medical services).

The accomplishment of the system architecture begins with the user needs as well as how it fits in a real context. The mobile gateway is the key point in the architecture that depends of selected technologies that are leading and proven. It provides a system asset, user interface, and important aspects in processing and share information securely and effectively. It also offers a flexible integration solution for new sensors, if needed. In the falls detection module the mobile gateway receives data directly from the GPS navigation system, embedded accelerometer, and the base station (sink) of body sensors through Bluetooth. All the collected data is sent to a remote database through the hypertext transfer protocol (HTTP) protocol using REST Web services.

Mobile Application

a. Biofeedback monitoring toll

Monitoring physiological activity is a non-invasive body-control technique based on the theory of electrical conductivity. The biofeedback application software presented in this paper represents an important component for problems screening and therapy developing because it is designed to monitor body responses, compile progress data, and reporting. The biofeedback status is directly related to certain health issues.

The biofeedback-monitoring tool is designed to work with specific monitoring equipment. This software was developed to work with available professional biofeedback tools that include most of the needed components to conduct a biofeedback session. During a biofeedback session, a patient wears sensor devices that are placed on the skin. The sensors are plugged to a sink node (also known as a base station) and through Bluetooth connection is synchronized with a mobile device (smartphone or tablet) for data acquisition.

The application features include chart graphing options, multiple window options to display more than one body response at the same time, and storage databases to track and review progress. It is possible to control the output signal and the frequency in each pitch to do a sample frequency, in Hertz, and a final digital signal to analyze, in Volts. It also features audio notifications to users and outside alerts by sending a short message service (SMS) or electronic mail (eMail) to a caretaker.

b. Falls detection and alerts

The falls detection system works by measuring a user body acceleration and position, getting acceleration values from accelerometer and then transforms the values in *G* force. Through the magnitude of the *G* force at a given moment and inactivity immediately after, considering the position of the device, a fall may be detected. When the system detects a fall it automatically contacts the emergency response center or a caretaker sending alerts as an SMS or an eMail.

Unfortunately the technology cannot detect all the falls. Furthermore, trying to avoid a fall, it is better for users health and a solution to increase the accuracy rate of the mobile solution.

c. Methodology for falls prevention

Many biological processes can be measured from a person. Physiological signals measurement can offer important information about body behavior in a given time. For biofeedback monitoring, the use of physiological and inertial sensors is proposed. They will allow a better detection of problems that can be associated with falls and possible diseases.

i. Monitoring techniques based on body sensors

With biofeedback signals monitoring it is possible to detect common types of physiological anomalies related to balance problems or more serious diseases. Physiological balance is attached to those health problems. Through the sensors readings it was possible to detect problems as cardiac disorders using electrocardiogram, muscle activity with electromyography, and anxiety and flutter with galvanic skin response or electro dermal activity. Also through the tri-axial accelerometer, it was possible to monitor and classify movements to detect anomalous patterns preceding a crisis. This system uses the capabilities of the accelerometer to identify situations of potential fall and identify motion to improve and alert if a patient had a bad postural control or perform fast movements, which endanger their equilibrium.

Electro cardiology monitoring is used to detect different states of problems with ECG (as illustrated in Figure 2). For that, it was used an automatic *R* crests detection algorithm that is based on EMD (Empirical mode decomposition) and an adaptive thresholds technique in order to reduce the possibility of errors and bad interpretation of the measured signal.

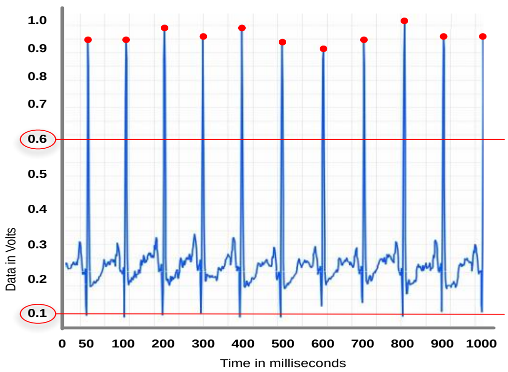


Fig. 7. Illustration of an ECG analytical signal.

The *R* peaks were identified by computing the relative maximum of each complete cardiac cycle where the phenomenon PQRST occurs. To detect heartbeat problems, the system count the number of *P* crest per minute in order to detect if heartbeat is normal, fast, or slow. To detect irregular heartbeat possible arrhythmia, the time between the *P* crest was measured (in milliseconds).

Galvanic skin response (GSR), also known as the electro dermal activity (EDA), is a method for measuring the electrical conductance of the skin in a patient body, which changes with its moisture level. This is interesting because the sweat glands are controlled by the sympathetic nervous system that control emotions. Figure 3 shows a sample GSR or EDA signal. A patient can present multiples states of stress and it is possible athwart measured by the wavelengths variance.

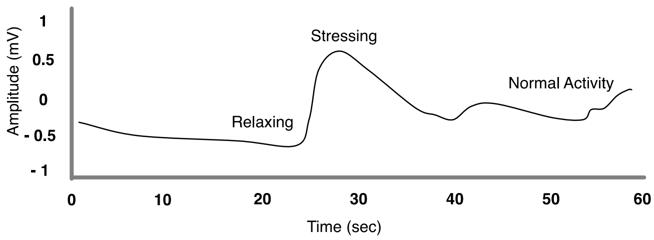


Fig. 8. Illustration of the galvanic skin response (GSR) or electro dermal activity (EDA) variations for diagnose multiple states of stress.

Electromyography is a technique to evaluate the recording of electrical activity produced by skeletal muscles cells when electrically or neurologically activated. The electromyography is used to diagnose neuromuscular disorders and the control muscular movements. Figure 4 represents the detection of balance disorders. The changes observed in EMG signals are caused by modifications of the electrical impedance of the skin-muscle system.

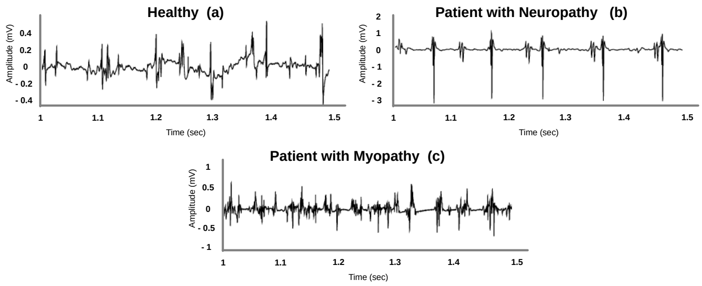


Fig. 9. Illustration of electromyography (EMG) wavelengths variations.

The different EMG wavelengths represent standards of the possible variations observed in a patient. The Figure 4 a) presents a healthy person, the Figure 4 b) shows a diagram with abnormal condition, and the Figure 4 c) diagram refers a critical condition.

Skin conductance measurement is a component of polygraph devices and it is used in scientific research to capture emotional or physiological arousal. The skin electrical conductance of a person is directly correlated to his/her emotional state and used to detect excitement events. Therefore, the excited state of a person can be observed and detect psychological situations less favorable to the welfare and patient health, and when he/she may be more unprotected for fall events. The falls prevention system with biofeedback uses skin conductance to measure and present an individual stress response in real time. It aims to help the patient to control their anxiety and prevent a possible fall.

ii. Obliquitous sensors thresholds adjustments

In the progression of the experiments sudden variations presented by waveform values of all sensors were identified. An implicit variation corresponds to different types of signal acquisition in each individual. Although subjects shown different skin resistance levels and behavioral actions that may justify those variations. It seemed that circumstances at the data acquisition time can influence their variation. If data collection is performed indoor or outdoor environments induces significant distinction for both emotional and physical patient state. The procedure to quantify physical and mental effects is based on sensors datum, therefore, the quality of collected data is extremely important. Some trials were conducted in a noiseless ambient and they were compared to trials driven in the presence of background noise.

In order to increase the system reliability and turn also it more adaptive to users, several actions were considered. After placing the system properly in a patient the first ten to fifteen minutes are used to relax the user and for system adjustments to him/her (the calibration period). The threshold values are adjusted to a pre-defined range of accepted values that are considered as normal. In any case, if the parameters were out of the ordinary values, it could mean that the sensor had bad placed or even in a wrong position. A warning message is sent with a problem description and the user can fix it.

d. *Falls Prevention with Notification Alerts*

The health sensors signal allows the falls prevention algorithm to analyze a typically phenomena in patients distinguishing variations as previously indicated in the methodology section. In combination with other signals (e.g. between heart rate and respiration signals), a transient classification changes allows a more detailed diagnosis known as electro cardio respiration to detect only specific types of pathologies.

The notification alerts for falls prevention is the main feature to warn patients whether something is wrong with their health. As previously shown, through the data collected by ECG, EMG, GSR or EDA, respiration, accelerometer, and gyroscope becomes possible to identify patterns that can expose the patient to a possible fall. A different kind of warnings seen by the patient changes depending on the severity of the problem detected, as shown in Figure 5.

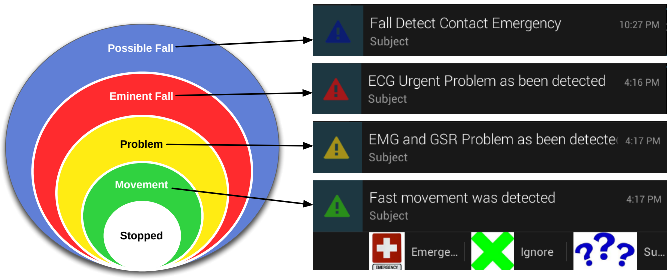


Fig. 10. Event warnings description (an example).

The colors shown in Figure 5 represent the warning severity. Stopped means the patient is standing and defines the threshold values, which delimit the sequence of warnings. The patient must know these warnings in order to correct deficiencies for helping himself/herself to prevent a fall and avoid him/him entering in a danger situation.

The diagram shown in Figure 6 presents the sequence of the application and its data flow. The modules *health sensors* and *movement sensors* are launched in a cooperative state and the Android activities are handled synchronously. By the predefined threshold values and the timers, it is possible to detect real life disturbances (in real time) using body sensors (electro cardiology, electromyography, galvanic skin response, and electro dermal activity). With Android notifications it is possible to alert users for disorders, which endanger their wellbeing. A notification is displayed for each type of sensor according to the severity of the detected problem. It shows different suggestions according to the detected issue. Then, the user becomes aware and tries to solve the situation by himself/herself to prevent a further even worse situation.

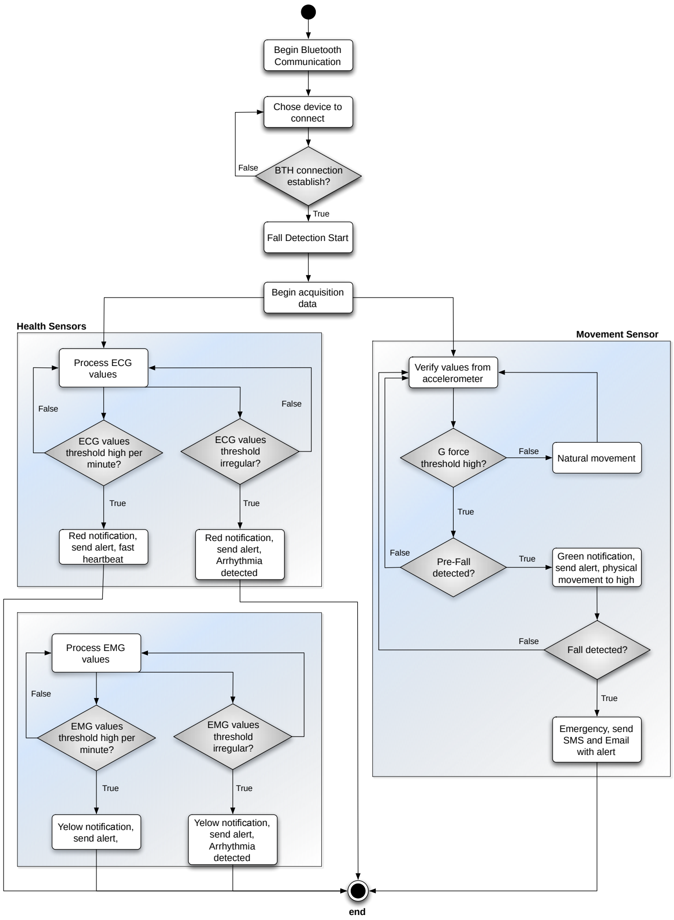


Fig. 11. Fall prevention activity diagram.

SYSTEM DEMONSTRATION AND VALIDATION

e. *Experimental Setup*

This section introduces the setup used in the performed experiments. The Shimmer Research solution system offers flexibility and Bluetooth connection, a great capacity for portability and autonomy. Shimmer equipment was used in this study. The sensors chosen for the experiments are the following: an accelerometer, an electrocardiogram (ECG) characterized by six crests and troughs, an electromyography (EMG), a blood volume pulse (BVP), an electro dermal activity (EDA), and the respiration sensor [8]. The important and unique aspects of the setup provide the Bluetooth connection. Each base station has power supply and body sensors with smart sensor nodes, allowing plugging in simultaneously up to different types of health sensors.

f. *Experimental Results*

The presented results aims to analyze quantitatively the applicability of the system in a real scenario. Therefore, in Table 1, the data was acquired from three healthy individuals in different motions to perform the experiment and the alerts for fall prevention were considered. A total of 50 experiments were performed under the same conditions for each action. The *total* value represents a sum of alert values for each motion and the expected values shows an estimated amount of alerts, which is considered correct to calculate the average.

EXPERIMENTAL RESULTS

Alerts	Number of warnings during the action				
	Walk(5m)	*Run(10m)*	*Sit*	*Jump*	*Fall*
Movement (Green)	28	32	14	46	43
Problem (Yellow)	6	21	4	41	27
Eminent Fall (Red)	0	45	0	38	36
Possible Fall (Blue)	0	2	1	1	48
Total	34	100	19	125	154

Expected values					
Movement	30	35	15	50	50
Problem	8	25	5	45	30
Eminent Fall	0	45	0	45	40
Possible Fall	0	5	0	2	50

During the *Walk* action a total of 34 warnings were triggered, 28 under the movement alert, and 6 for the problem alert. It was expected 30 for the movement alert and 8 for the problem alert. For the eminent fall and possible fall alerts it was not triggered any warning but it was not expected any warning, presenting a percentage of 92% of accuracy during the *Walk* action. In the *Run* action, a total of 100 warnings were triggered, 32 in the movement, 21 in the problem, 45 in the eminent fall, and 2 in the possible fall. For this action, 35 warnings for the movement, 25 for the problem, 45 for the eminent fall, and 5 for the possible fall were expected. It shows about 79% of accuracy in this action. For the *Sit* action a total of 19 warnings were triggered, 14 for the movement, 4 for the problem, and 1 for a possible *Fall*. It was expected 15 warnings for the movement and 5 for the problem. A total of 93% of accuracy was reached. In the *Jump* action a total of 125 warnings were triggered, 46 for the movement, 41 for the problem, 38 for the eminent fall, and 1 for the possible fall. It was expected about 50 for the movement, 45 for the problem and eminent fall, and 2 for a possible fall. About 79% of accuracy was reached during this action. Finally, for the *Fall* action, a total of 154 warnings, 43 for the movement, 27 for the problem, 36 for the eminent fall, and 48 for the possible fall were triggered. For this action, about 50 warnings for the movement, 30 for the problem, 40 for the eminent fall, and 50 for the possible fall were expected. A total of 91% of accuracy in this action was found.

g. *Performance Evaluation*

Evaluating the result and the effectiveness of the proposed algorithm, to estimate the average value it is necessary for determining how to improve it. Figure 7 shows the average value of 50 experiments for each type of motion.

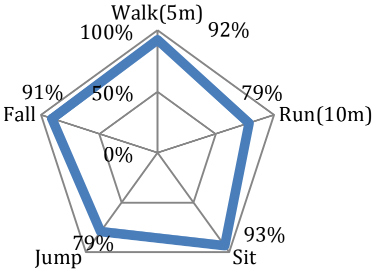


Fig. 12. Performance comparison of average values for each action (Walk, Run, Sit, Jump, and Fall).

It was identified for movements requiring more physical activity (e.g. *Run* and *Jump*) the accuracy is lower, but with a nice value. The final average evaluation of the program for all types of motions is about 86.8% for 250 trials.

CONCLUSIONS

This paper proposed a system for falls prevention that tries to avoid them. It attempts to bring a higher expectancy average and better quality of life for debilitated and/or elderly people. One of the main obstacles found in this work was the lack of appropriate methodologies for each sensor. The sensors do not work alone but together like a body sensor network. With data collection and processing from sensors in real time (by smartphones or tablets), it becomes possible the creation of a warning system through a notification solution for fall prevention and detection simultaneously. It was shown that not all the falls are preventable but many of them can be avoided with this system. The proposed solution was evaluated and demonstrated and it is ready for use.

2 ACKNOWLEDGMENTS

This work has been partially supported by the *Instituto de Telecomunicações*, Next Generation Networks and Applications Group (NetGNA), by National Funding from the FCT through the PEst-OE/EEI/LA0008/2011 Project, by the AAL4ALL Project (Ambient Assisted Living for All) supported by QREN, Portugal.

3 REFERENCES

N. Shiozawa, S. Arai, S. Okada, and M. Makikawa, "Gait analysis of sit-to-walk motion by using portable acceleration monitor device for fall prevention," 2012 IEEE International Conference on Biomedical and Health Informatics (IEEE BHI 2012), Hong Kong, China, 5 - 7 January, 2012, pp. 563-564.

B. R. Greene, Alan O. Donovan, Roman Romero-Ortuno, Lisa Cogan, Cliodhna Ni Scanaill, and Rose A. Kenny, "Quantitative falls risk assessment using the timed up and go test," 2010 IEEE Transactions on Biomedical Engineering, vol. 57, no. 12, pp. 2918-2926, Dec. 2010.

Ivo C. Lopes, Binod Vaidya, and Joel J. P. C. Rodrigues, "Towards an Autonomous Fall Detection and Alerting System on a Mobile and Pervasive Environment," *Telecommunications Systems*, Springer, 2011.

Diansheng Chen, W. Feng, Y. Zhang, Xiyu Li, and Tianmiao Wang, "A wearable wireless fall detection system with accelerators," 2011 IEEE International Conference on Robotics and Biomimetics (IEEE ROBIO 2011), Karon Beach, Thailand, 7 - 11 December, 2011, pp. 2259-2263.

Kleydis V. Suárez, Jesus C. Silva, Yannick Berthoumieu, Pedro Gomis, and Mohamed Najim, "ECG beat detection using a geometrical matching approach," 2007 IEEE Transactions on Biomedical Engineering, vol. 54, no. 4, pp. 641-650, April, 2007.

A. Phinyomark, G. Chujit, P. Phukpattaranont, C. Limsakul, and H. Hu, "A preliminary study assessing time-domain EMG features of classifying exercises in preventing falls in the elderly," 2012 IEEE 9th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (IEEE ECTI-CON 2012), Hua Hin, Thailand, May 2012, pp. 1-4.

M. P. Tarvainen, P. A. Karjalainen, A. S. Koistinen, and M. V. Valkonen-Korhonen, "Principal component analysis of galvanic skin responses," 22nd Annual Int. Conference of the IEEE In Engineering in Medicine and Biology Society, vol. 4, pp. 3011-3014, July 23–28, 2000.

Ayan Banerjee and Sandeep KS Gupta, "Your mobility can be injurious to your health: Analyzing pervasive health monitoring systems under dynamic context changes," 2012 IEEE International Conference on Pervasive Computing and Communications (IEEE PerCom 2012), Lugano, Switzerland, March 19 – 23, 2012, pp. 39-47.