A Mobile Healthcare Solution for Ambient Assisted Living Environments

Daniel F. M. Rodrigues[1], Edgar T. Horta[1], Bruno M. C. Silva[1], Fábio D. M. Guedes [1], and Joel J. P. C. Rodrigues[1,2]
[1] Instituto de Telecomunicações, University of Beira Interior, Covilhã, Portugal
[2] University ITMO, Saint-Petersburg, Russia

daniel_f_m_rodrigues@hotmail.com; {edgar.horta; bruno.silva}@it.ubi.pt; fdguedes12@gmail.com; joeljr@ieee.org

Abstract - Elderly people need regular healthcare services and several times are dependent of physicians' personal attendance. This dependence rises several issues to elders, such as the need to travel and mobility support. Mobile Health (m-Health) services and applications offer good healthcare solutions that can be used indoor or in mobility environments. This paper presents an ambient assisted living (AAL) solution for mobile environments. It includes elderly biofeedback monitoring using body sensors for data collection offering support for remote monitoring. The used sensors are attached to the human body (such as the electrocardiogram, blood pressure, and temperature). They collect data providing comfort, mobility, and guaranteeing efficiency and data confidentiality. Periodic collection of patients' data is important to gather more accurate measurements and to avoid common risky situations. The presented proposal monitors elderly people, storing collected data in a personal computer, tablet, or smartphone through Bluetooth. This application allows an analysis of possible health condition warnings based on the input of supporting charts, and real-time bio-signals monitoring.

Keywords - Mobile Health; Biofeedback Monitoring; Ambient Assisted Living; Body Sensor Networks; Mobile Wearable Sensors

I. INTRODUCTION

In the last decade several studies are showing that elderly population is quickly increasing. It is expected that about 2 billion people will be aged 60s and older by 2050 [1]. In 2010, 17.4% of the 27 European countries' population was over 65 years old and experts foresee that, in 2060, this value will attain to 30.0% [2]. Nowadays, people has the need and social duty to assist their older parents. This aged population needs regular healthcare services and, frequently, live alone. Nearly 10 million elderly Americans over 65 years old live alone [3]. This emergent reality presents several challenges and opportunities for new and innovative healthcare services. IT solutions have taken advantage of this fact directing resources and competencies to elderly related healthcare solutions. These solutions aim to provide an assisted life style, preventing their isolation by connecting them with relatives and the community.

Nowadays, there is a significant growing market of small sensors embedded in clothing, jewelry, watches, shoes, phones, and other mobile devices like the Chair-type Interface [4] that elderly can use daily. An elderly diagnosed with dementia illness would wear these small sensors allowing the assessment of health parameters without the need to go to a medical doctor office or to a healthcare center. Therefore, it allows a better quality of life (QoL) and reduces costs for the health insurance system.

Embedded health sensors are very important because they may be able to assist people using the sensors data or a simple query through a mobile device application. These wearable computing technologies enable mobility and flexibility in situations of continuous health monitoring, generally speaking, in ambient assisted living (AAL) environments. These technologies have had a tremendous development in recent years and they play a very important and active role in the elderly surveillance. Monitoring systems are also able to assist people with different levels of intellectual and physical abilities and capacities. These solutions allow people to have a more "free" and active life style. They can offer great individual levels of independence, comfort, and active involvement in the community with security due to effective caring and continuous health monitoring and location. These approaches aim to provide significant improvements in terms of QoL, reducing interventions to support the elderly in their lifetimes. With the establishment of multi-agent systems it is possible to deploy new assistive technologies [5]. This paper presents a solution that provides a mobile health monitoring in AAL environments. This proposal makes use of a multi-agent system with self-configured interventions.

The considered mobile healthcare environment enables the identification of possible hazard situations or diseases. Furthermore, whenever possible, it makes a readjustment of long-term medical treatment based on the analysis of previous stored data. The mobile application can also perform an outdoor intervention in presence of possible accidents or risky situations. Thus reducing the intervention time of healthcare professionals or institutions. The stored health data and the monitored real time data allows an historical analysis of the collected parameters as well as an immediate response in emergency situations, such as falls or other risk situations.

The remainder of the paper is organized as follows. Section II elaborates on the related work, while Section III describes the system architecture overview. Section IV presents the used technologies while the mobile solution and its main features are addressed in Section V. Section VI performs a demonstration and evaluation of the proposed solution. Finally, the paper is concluded in Section VII.

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II. Related Work

Wearable and embedded body sensors collect biofeedback information for the human being. The great variety of sensors and the different ways that they can be applied on persons have contributed to several approaches regarding elderly people monitoring. These approaches mentioned in the literature use several techniques and technologies to capture biometric signals. This section presents several approaches that use body sensors in healthcare approaches for elderly people. Thereby, improving the elderly quality of life through several AAL solutions.

Kang *et al.* present a wrist-worn integrated health monitoring device who collects data of six bio-signals measuring, which includes fall detection, electrocardiogram (ECG), blood pressure, pulse oximetry (SpO2), respiration rate, and body surface temperature measuring [6]. This solution provides information concerning current person condition, such as vital bio-signals and location information. The developed system provides rapid and appropriate directions in emergency situations and alerts the user or caregiver to manage changes in health condition.

In [7], the authors present a proposal to capture bio-signals in healthcare and sport-training systems. The system uses infrared sensors or vision cameras. It includes a mobile three-axis accelerometer motion system and smart shoes. The signals are measured and processed by a mobile device, allowing the analysis and diagnosis of postures during outdoor sports, as well as indoor activities. To improve the accuracy of the proposed motion capture, a frequency-adaptive sensor fusion method and a kinematic model are utilized to construct the whole body motion in real-time, and are continuously updated. Huang *et al.* present a wearing system with four sensors, ECG, three-axis accelerometer, temperature, and tight-switch, applied for remote monitoring system in home-care [8]. The ECG, measured with wearable electrodes using steel textile to generate the real-time heart-rate estimator. The heart-rate estimation is calculated to the movable textile electrodes in motion of user, performing a sophisticated work. The tight-switch sensor and FIR (Filter Impulse Response) filter technology are applied here to get the best heart-rate accuracy. The other biosensors can detect falls and body-temperature changes. Moreover, the device has low-power consumption to transmit detected bio-information from these four sensors and transmission turns it highly suitable for applications to remote healthcare and wellness.

In [9], the authors present a continuous monitoring of physiological parameters, such as, respiration, heart rate, temperature, and humidity. This solution aims to detect excessive sweating for health conditions, diagnostic reasons and the detection of life or health threatening events. This paper gives special attention to infants, especially those who cannot provide any oral or written feedbacks. A continuous monitoring under clinical and home conditions allows rescue calls as well as recognition of the development or progression of diseases at an early stage. Prototypes currently manufactured incorporate the chosen sensing principles with textile and textile-compatible technologies and are clinically tested for durability, handling, and signal quality.

Horta *et al.* presented a solution for fall detection in elderly people [10]. Falls can origin injuries that may cause a great dependence and even death in extreme cases. This system aims to prevent falls and advice the patient or even give instructions to treat an abnormal condition to reduce the risk of falling. Thus, this fall prevention system works in real time and the algorithms analyses bio-signals to thereby warn the user. Monitoring and processing data from sensors is performed by a smartphone that, in danger situations, can send eMails or SMSs (short message system) to a caretaker. The proposed solution was validated through a prototype and it is ready for use.

In [11], the authors propose the use of ECG, heart beat recognition, and peak detection that will offer the possibility to make diagnoses of heart diseases to prevent possible problems, through an "geometrical matching" rule evaluated and a local moving-window function procedure. This prevention is possible because of the Arrhythmia Database, which shows about 99% of positive identification for the R-waves through the low-order polynomial models. Rashidi and Mihailidis present a survey about the rapid emergence in assisted living technologies, against an aging society [12]. These technologies, tools, and techniques focus on biomedical data and an extensive range of healthcare applications to prevent possible situations of sickness. This information enables physicians to analyze the evolution of a patient and those trying to identify situations of stress or effort for a quick intervention in risk situations. They still look at current and future challenges, so give the elderly the comfort of their home and living independently.

Along with wearable and embedded sensors, a device that collects and saves bio-signals data, for example, during the absence of his caregiver is the Texas Instruments EZ430-Chronos programmable clock [13]. Furthermore, another solution that allows data configuration collecting specific parameters and real time location while communicating with a mobile device is the use of Shimmer sensors technology [14].

The proposed solution gathers contributions from the above-described approaches. Next sections present it in detail.

III. System Overview

This section describes the system architecture considered for AAL environments with mobility support. Figure 1 illustrates a scenario with actions set for communications, in real time. Through an Internet connection, the mobile App allows data collection from sensors and external access from users terminal. It receives all the sensors data through Bluetooth to a smartphone or tablet. The collected data are analyzed and sent to a remote database. It can be stored for a more extensive analysis of the medication in order to improve or even adjust it. The body sensors and Web services modules facilitate the information sharing through a simple interface, which is properly identified by users with specified permissions. Therefore, the information sharing is safely and effectively performed. Measurements can be tuned according to different levels that caregiver defines most relevant. Moreover, this is a flexible solution allowing the integration of new sensors, if needed.

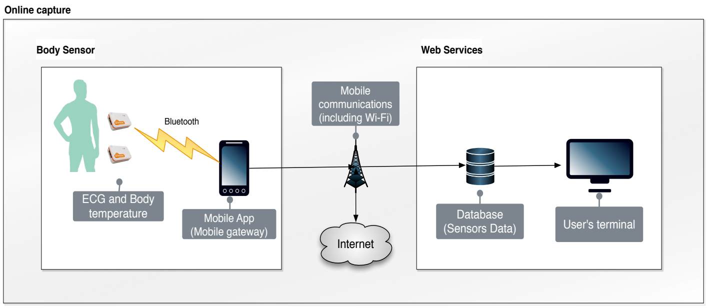

Fig. 1. Illustration of the system architecture, using ECG and temperature body sensors and external access through Web services for data visualization and storage.

Figure 2 presents the same approach but in offline mode. It stores data information to an offline database for later analysis. Offline bio-signal data is collected through radio frequency. Afterwards, a health care professional can analyze the stored data in order to verify whether the patient eventually needs any medication change or even another type of intervention.

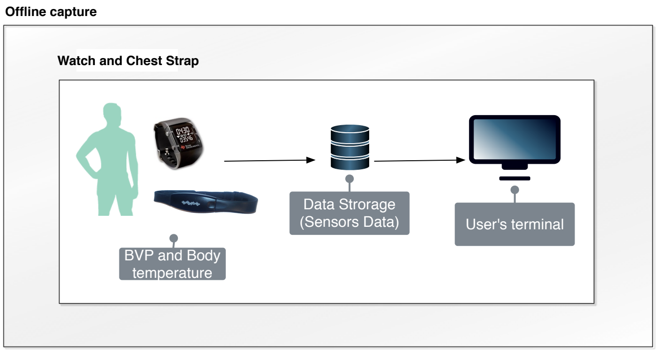

Fig. 2. Illustration of the offline system architecture considering the capture of blood volume pulse (BVP) and body temperature values.

Both presented architectures have common goals concerning the detection and analysis of bio-signals. They are responsible for detecting significant changes caused by common daily activities. These collected values can also infer significant changes of data through the sensors placed along the patients' body. The architecture presented in Figure 1 also allows inertial values collection that enables fall detections. This system includes the necessary amount of collected data to guarantee the well being of the elderly. It considers the interventions that a qualified healthcare team may find adequate for each user. So, there are two ways for collecting and storing data, either on-line or offline. Whether it is performed on-line (in real-time) or off-line, a later analysis points to the energetic efficiency of the various devices without compromising the reliability of biofeedback collected data.

IV. USED TECHNOLOGIES

This section mentions the used technologies on the proposed system. Small instruments are able to collect and achieve data related to temperature, electrocardiogram (ECG), and blood volume pulse (BVP) also known as heart rate. Moreover, other sensors for bio-signals collection can be used, such as, electromyography (EMG), galvanic skin response (GSR), breathing, or the inertial signals as triple axis accelerometer, gyroscope, magnetometer, and altimeter. The sensors referred on this section include the MSP 430 microcontroller (8MHz, 16Bit) with Bluetooth socket, which allows communication and information processing in real time.

A. TEXAS INSTRUMENTS EZ430-CHRONOS

The eZ430-Chronos watch, presented in Figure 3, needs disassembled to be reprogrammed with a custom application taking into account the needs of given users.

Fig. 3. Photo of the eZ430-Chronos watch: A) Chest Strap; B) Watch recording data (Temperature and Heart Rate).

The watch includes a 96-segment LCD display, an integrated pressure sensor, a temperature sensor, heart rate monitor through a chest strap, and a 3-axis accelerometer for motion sensitive control ability to operate on a central hub for nearby wireless sensors (such as pedometers). It was created an application that stores information about the temperature and heart rate from the patient's body using the chest strap. These instruments usually have a set of restrictions but, in this case, the watch performed well because it did not present any problems of flexibility, ergonomics, or discomfort resulting from time extended handling and use. Considering this, it is important to underline that the watch and chest strap autonomy are particularly large. During the whole process of acquiring data there was no need to change any batteries of either the watch or chest strap. For the CR2032 Coin Cell Lithium Battery, referred on the manual and according to its analysis, it was possible to observe that a continuous communication in BlueRobin Rx Mode (communication: chest strap to watch) the battery takes approximately 6.2 months, but if only need 1 hour of daily use, then, the battery works along 2 years. Otherwise, the SimpliciTI SYNC mode (communication: watch to computer) is more energetically costly because on continuous communication the battery takes about 8 days to be empty and with a 1 hour per day use it takes approximately 5.4 months. Despite the SimpliciTI SYNC mode has much higher energy costs, this is not a big problem because it is only used to send data to a terminal in this mode and this communication is performed in seconds.

B. SHIMMER SENSORS

Shimmer sensors offer two possibilities to communicate, the standard IEEE 802.15.4 or Bluetooth. Shimmers offer a plethora of body sensor bio-signals measurements, such as the

ECG, electromyography (EMG), temperature, etc. It is also able to perform respiration demodulation on-chip. It integrates a 10 DoF inertial sensing via accelerometer, gyroscope, magnetometer, and altimeter, each one with selectable range. Each sensor is equipped with a rechargeable 450mAh Li-ion battery, along with the advantage of being rechargeable within few hours.

In the proposal scenario seven types of sensors where used, as shown in Figure 4. The Shimmer ECG (A) records the electrical impulses through the heart muscle, having as starting point of four electrodes set (C) on the chest of the patient. It is also possible to record data on bedridden or home users, or even during exercise to provide information of the patient's heart, in real time. Furthermore, a temperature sensor (B) allows the collection of a patient's temperature when the sensor is placed in close proximity to the body. The digital interface signal experimented several sensors for validation purposes.

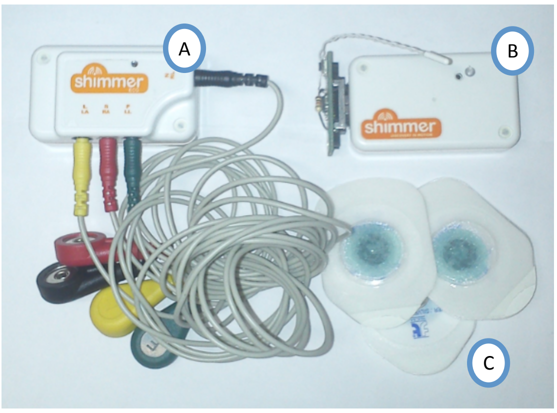

Fig. 4. Illustration of the body sensors - Shimmer: A) Electro-cardiogram; B) Temperature; C) Electrodes for Electro-cardiogram.

The Shimmer sensors can be applied to a wide range of scenarios, such as, heart function monitoring, premature ventricular contraction, atrial fibrillation, abnormal rhythm detection, fatigue analysis, muscle activity, sport technique, gait and posture disturbance, tremor analysis, and orthopedics biomechanics.

V. Mobile Application

The flexibility of the mobile devices enables more reliable and customizable mobile tools. Bio-signals monitoring allows the identification of possible and meaningful temperature, heart rate, or BVP changes. Additionally, the system can identify heart diseases like arrhythmia as well as other cardiac alterations. Moreover, the caregiver is able to define the risk degree of the patient under monitoring defining three levels of surveillance: low, normal, and critical [15-16].

This proposal allows a customizable and a non-invasive monitoring of ECG and temperature for a patient, making his/her daily life safer. Besides, it has the advantage of having a daily control in which all the information (numerical and graphical) is stored for future analysis whenever necessary. The mobile application behavior and procedures are presented in the activity diagram presented in Figure 5. This bio-signals monitoring solution use different Android activities to simultaneous tasks and several sensor readings. Therefore, the first step consists in the establishment of a Bluetooth connection. Once the connection is achieved, data collecting begins for ECG and temperature values. These are some considered sensors in this proposal. The collected data is analyzed and if it has expressive changes (for example, ECG values threshold per minute higher or irregular values), an alert is sent. In the same way the collected temperature is analyzed and if the values are very high or low, an alert is also sent to the elderly and/or to the caregiver.

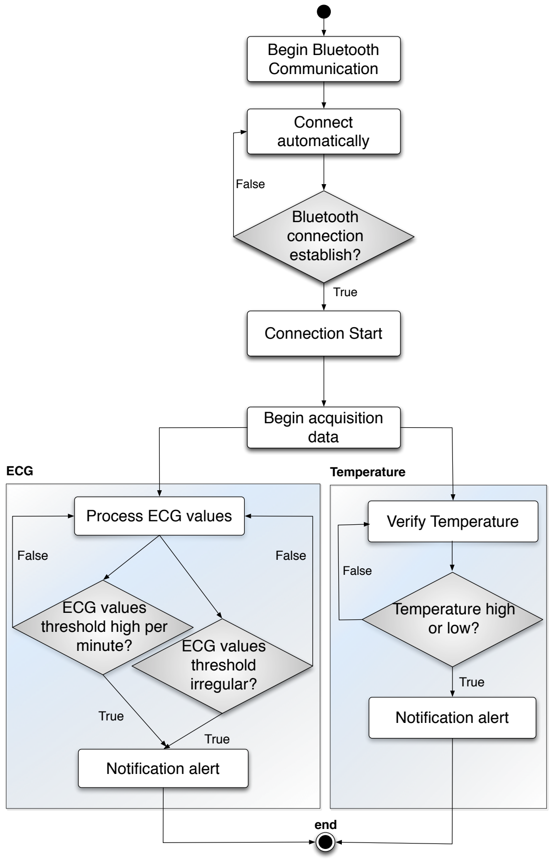

Fig. 5. Activity diagram illustrating the ECG and Temperature prevention, and detection procedures.

As above mentioned, there are several sensors that can be individually activated, such as, BVP, EMG, and GRS bio-signals measurement, but also some inertial sensors as gyroscope and magnetometer. These sensors can also be present in a smartphone allowing the detection of significant changes in user motion. Therefore it enables fall detection through the accelerometer. The proposal has the ability to use the smartphone or tablet GPS to provide the real-time location of the user.

The presented proposal alerts immediately as possible both elderly and caregivers of significant changes that might raise life threatening situations. Moreover it stores data for a later analysis. These data can identify, for example, flu symptoms, heart diseases, such as a possible beginning of cardiac problems.

VI. System Demonstration and Performance Evaluation

This section presents the system demonstration and performance evaluation. Obtained results are presented considering two approaches for collecting biomedical data: the Texas Instruments programmable watch; and Shimmer sensors. Three levels of observation where considered: ***low*** for patients that are experiencing low levels of biomedical changes; ***normal*** for a regular patients; and ***critical*** level for real-time monitoring.

The demonstration and performance evaluation included five volunteers, aged from 20 to 30 years with no previous health records information. A set of experiments has been carried out for evaluate the system performance considering the three levels of surveillance. For each value of the above-mentioned levels it was conducted a total of 30 trials distributed in three levels of alerts. On these trials it was collected and stored a total of 22 thousands samples of data.

A. System Demonstration

Figure 6 presents the gathered data (bio-signals) from one of the many experiments performed in this study. In each level, 10 samples were collected and analyzed afterwards. According to an average standard deviation of 10% and 15%. The levels obtained in situations considered dangerous for the patient, were stored in a database. The graphic visualization is presented with various colors for different types of sensors.

Collecting biomedical data with the Texas Instruments programmable watch allows offline supervision at home or outdoors within a short distance. This approach was considered to be preventive or for future analysis of possible symptoms. The volunteers did not present any complaint regarding the lack of flexibility, ergonomics, or any discomfort resulting from time extended handling and use of the chest strap. After collecting data from the watch, it is possible to analyze the same (as may be seen in Figure 6), identifying the situations of stress or major concern. It is possible to calculate average values, such as, body temperature or heart rate values. Finally, it is feasible to define warning parameters for future analysis. Thus, a list of alert situations can be obtained and stored. At the end of the analysis, the caretaker can save the identified alerts according to the previous defined warning parameters.

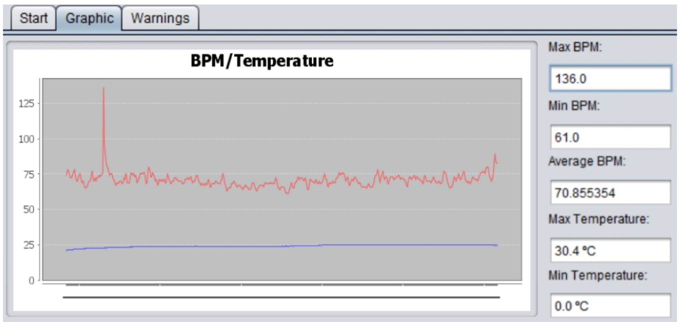

Fig. 6. Proposed application for the Texas Instruments watch showing collected data from temperature and heart rate from a given patient.

The normal monitoring level considers patients that have been recently ill or submitted to a surgery. In this context the monitoring process may occur in real time, however, with a gap time of 15 times per minute. This frequent monitoring identifies, changes on the body temperature, which may easily be a signal of an infection or an alteration of heart rate. However, these changes are not considered as "high risk" situations.

The critical monitoring level considers the surveillance of the patient's health, online and in real time. The data collection must be precise to immediately identify situations that might lead to the patient's death. In this case, patients must be in a hospital or another healthcare institution followed by qualified healthcare professionals. This allows the patient to have access to medical care and information as soon as possible.

This solution considers the collection of big amount of data. Therefore it is possible to recognize situations in that the patient health is in danger, online and in real time or by monitoring events offline. This way, it is possible to identify situations of disease, through body temperature alterations; high heart rates; premature ventricular contraction; abnormal rhythm detection; situations of cardiac arrhythmias and many other health situations that can be diagnosed.

B. Performance Evaluation

Several scenarios with the above-mentioned three levels of surveillance were considered to evaluate the performance of the proposed solution. Table I presents the total number of alerts per level of surveillance that shows the significant differences and improvements between levels of observation.

In the first observation level (***low***), volunteers were in a resting situation without making significant movements. Thus, emulating a situation of a bedridden elderly or an elderly with great physical limitations. In the second level (***normal***) the volunteers could have some movements performing daily tasks. This way, representing an elderly who is able to perform some of the household chores. The third level (***critical***) is for cases in which patients show signs of possible risky situations. In this level, all the variations of biomedical signals are considered dangerous for the well-being and for the health of the elderly.

TABLE I. Total Number of Alerts per Level of Surveillance (Low, Normal and Critical) with a Standard Deviation of 10% and 15% Considering the TI Watch and Shimmer Sensors, for the 30 Experiments.

	Texas Instruments watch		***Shimmer sensors***	
	Level 1 (10%)	***Level 2 (15%)***	***Level 1 (10%)***	***Level 2 (15%)***
Low	64	39	32	1
Normal	473	170	134	53
Critical	1754	788	504	250

The Shimmer sensors include little alerts, presenting more accurate data and resulting in an error reduction when increasing the standard deviation. Moreover, when alerts occurred, their time analysis was also important. When there is an alert in only one of the samples (in time), it is not considered meaningful. The alerts in one sample can be a misreading and it is only considered as meaningful and dangerous situation after several consecutive alerts.

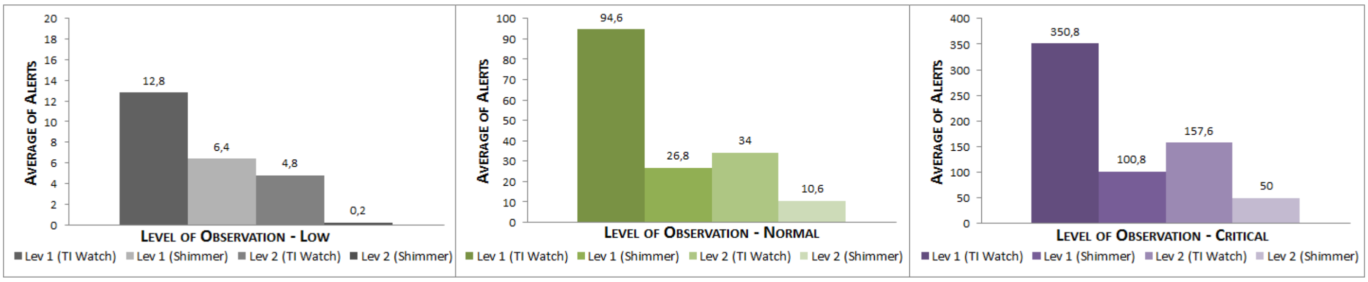

Fig. 7. Comparison of average alerts values to each level of observation system (Watch and Shimmer).

Figure 7 presents the comparison of average alert values to each level of observation. With the decrease and exclusion of possible errors, the results improve about 2%, for the Texas Instruments watch and about 0.8% for the Shimmer sensors. Furthermore, it is observed that various levels of observation have different amounts of alerts increasing the surveillance level. The Shimmer sensors have more capacity to read data in equal time intervals and in a worst-case scenario they are capable to detect a greater number of alert situations.

VII. Conclusion and Future Work

The presented mobile healthcare solution for AAL environments improves the lives of elderly people that live alone or in remote locations. It allows continuous assistance and monitoring of bio-signals to identify potential diseases or health risk situations. The eZ430-Chronos watch was used for prevention in an online and offline mode. According to the online analysis, Shimmer sensors are with no doubt an improvement allowing the collection of data within seconds. The use of mobile devices, such as, smartphones or tablets were considered for sending alerts in case of critical situations through data transmitted from various sensors and for mobility purposes. The solution is customizable and only the sensors required are enabled. Also, fall detection and real-time location are deployed. This proposed solution is extremely easy to place on the patient's body, flexible, and with no harm to his health. System demonstration and performance evaluation shows more precise results and increase the exclusion of possible error results about 2%, and about 0.8%, were obtained by the Texas Instrument watch, and the Shimmer sensors respectively.

Future work considers the deployment of two more types of sensors to analyze the patient's posture that will had a great value and a wider meticulousness on healthcare assistance to the elderly, all of these without compromising their flexibility of movements and autonomy or security.

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