aal@home: a New Home Care Wireless Biosignal Monitoring Tool for Ambient Assisted Living

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Abstract. In this article we describe a new wireless biosignal system which monitors in a long-term basis, the users at their homes. The system consists of wearable sensors that measure heart rate, blood oxygen saturation and physical activity levels, sending data to a mobile phone and from this to a remote monitoring station located in a clinical facility. Whenever an abnormal situation occurs, an alarm is triggered and caregivers can provide assistance. The system has been deployed at a major Portuguese public hospital and 30 patients under long-term oxygen therapy have been continuously monitored remotely. The results report that the patients feel comfortable and safe when they are continuously remote monitored and for caregivers the system allows them to optimize their time and give better and faster assistance.

1 Introduction

Life expectancy has been increasing in the last years. In Europe, in 1960, it was of 45.6 years old for men and 49.7 for women while in 2050, projections show that it will increase to 79.7 and 85.1 years old for men and women, respectively. Also, a clear shift is being witnessed from 1960 up to now regarding the proportion of elderly people (65 years and over) in the overall population [Steg et al., 2006]. According to Eurostat base scenario, in 2008 the proportion of old people in Europe (EU 27) was 17.08% (84 million), in 2020 it will be 20.06% (103 million) and in 2050 it will be 28.81% (148 million) [Giannakouris, 2009; eur, 2010]. As a consequence, the old age dependency ratio in the EU 27 is rising from 25.39% in 2008 up to 50.42% in 2050 [Giannakouris, 2009; eur, 2010]. This situation will have an enormous economic and social impact in a number of areas, namely in healthcare systems. The increase of the number of elderly people will lead to an increase in the proportion of population with physical or mental impairments, disabilities and chronic illnesses which can difficult the accomplishment of daily life activities and consequently increase the potential need for assistance. Faced with this problem, Europe is coming across a challenge: to develop health and social means that allow to provide safety, comfort and good quality of life to the older population.

At the same time, technology has also been evolving and it has now spread across several areas such as telecommunication services, education, research and healthcare, among others. The results obtained in Research and Development studies in the fields of electronics, signal processing and wireless communications, have shown that we have now technology with potential to respond to the challenge of providing tools to enhance healthcare, safety and quality of life of the elderly and other disabled population groups. Taking advantage of these base technologies, the Ambient Assisted Living (AAL) solutions are now emerging and this is currently one of the most important research and development areas, where accessibility, usability and learning play an important role [Stephanidis, 2007]. AAL solutions aim to apply intelligent technology in order to help people with specific demands, such as disabled or elderly population to live independently at their homes longer [Stephanidis, 2007]. Thus, AAL has potential to improve the quality of life of elderly people and to decrease the costs associated with this population.

Several studies have been reported in the last years, presenting solutions and technologies for AAL field. For example, Hristova et al. [Hristova et al., 2008] presented a prototype system with a number of context-aware services such as heart rate monitoring, medication prompting, generation of agenda reminders, weather alerts and emergency notifications for ambient assisted living applications. Flynn et al. [Flynn et al., 2006] have developed a wireless biomonitor for AAL which integrated a wearable blood pressure and ECG sensors. On the other hand, Stelios et al. [Stelios et al., 2008] have developed a system capable of providing localization data for ambient assisted living, integrating an event detection platform.

Despite the advantages of the AAL solutions, the acceptance of technology by elderly people still is a threat. There are some examples of the high acceptance of technology in this sector of the population, such as the usage of mobile phones, ATM machines. However, people do not accept everything that is technological possible and available. The use and acceptance of technologies depend on adequate design, advantage and practical use of the device, biographical experience of the potential user as well as physical, mental and cognitive skills. Therefore, the main requirements of an AAL product involve not only health, safety and independence aspects but also mobility and social contact [Steg et al., 2006].

In this article we will describe a new system designed for home care and independent living proposes, aiming to provide an infrastructure for continuous long term biosignal monitoring in near real-time. The target group for using this system is composed by the senior users who still have full mental capabilities and are able to have their independence but need to have some of their physiological parameters monitored on a long-term basis. An example of potential users are people with chronic respiratory or cardiac problems. For example, cardiovascular disease is the most frequent cause of death among the European population aged 65-84, both for men and women. This includes not only ischaemic heart diseases and other heart pathologies but also cerebrovascular diseases [Niederlaender, E., 2006].

The rest of the paper is organized as follows: Section 2 describes the AAL system; Section 3 presents the system validation; Section 4 details the main results and Section 5 highlights the main results.

2 aal@home

Our AAL system, aal@home, was developed aiming the continuous long term monitoring of patients in their homes. The system is based on five features: (a) wearable system; b) integration and modular system; c) wireless communication; (b) continuous monitoring; (c) portability.

The aal@home system uses wireless communication in order to provide portability and give comfort and mobility to the users. These characteristics are further enhanced because the system is based on miniaturized and light-weight sensors that can be easily worn by the users all day long. The real-time continuous monitoring allows the doctors, nurses and orderlies to monitor in real-time the physiological parameters of each end-user throughout day.

Monitoring different physiological parameters generally implies the use of different devices from different brands. However, the use of several devices at the same time is not comfortable for the user, contributing for the loss of portability and usability of the solution. Regarding this issue, we have developed a modular system which enables the integration of multiple parameters into a single brand system. With this design, we improve the usability of the system and provide the caregivers with a tool that allows to choose monitoring cardiovascular and activity parameters simultaneously or just one of these parameters.

2.1 Overview

aal@home consists in a wearable system used for biosignal acquisition that integrates one or two independent wireless sensor nodes, depending on the needs of the patient. Data acquired is sent wirelessly to a mobile phone that operates as a mobile gateway, promoting the interaction between the wireless sensor nodes and a remote monitoring station. This monitoring station is located in a clinical facility and allows the medical staff to monitor the status of a number of patients, at the same time. Each mobile gateway is associated with a number that allows the system to identify each end-user. The mobile gateway also provides local on-screen visualization of the monitored physiological parameters: physical activity, heart rate and oxygen saturation level. This feature provides the user with ”self-monitor” capabilities, giving him a sense of conscience and responsibility for the status of its health. In situations for which the mobile phone is out of network coverage, the software on the mobile gateway is enabled with data buffering and re-transmission capabilities.

The remote monitoring station is provided with a database containing information about each end-user and is the point where the collected signals are stored. Through a web interface also installed in this computer, the caregivers can monitor the physiological parameters that are being sent by the mobile gateways. A schematic representation of the web interface is represented by Figure 1. Furthermore, the aal@home system detects anomalous situations and sends notifications and alarms to the central monitoring station whenever the end-user has his/her physiological parameters out of the established boundaries. This feature ensure that a fast and effective assistance is provided to the patient whenever he needs it.

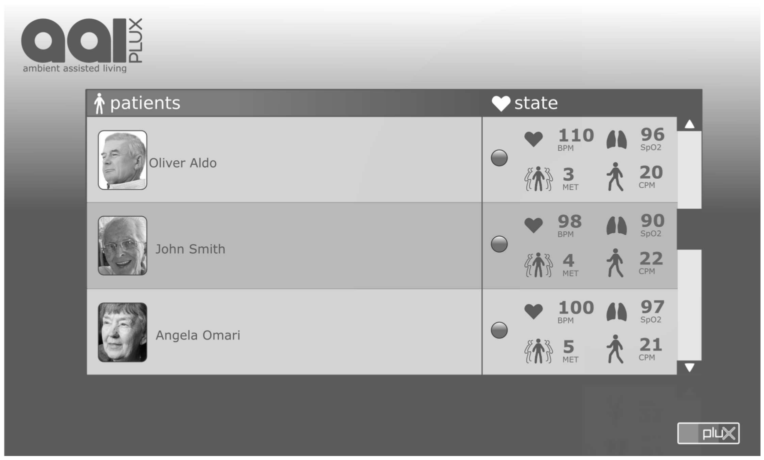

Fig. 1. Schematic representation of the web interface of aal@home.

2.2 Sensors

Currently, aal@home monitors three physiological parameters: activity level, heart rate and blood oxygen saturation. In order to accomplish these measurements, the system integrates two kinds of sensors: a tri-axial accelerometer and a pulse oximeter.

Tri-axial accelerometer Physical activity level is monitored throughout day by a portable and miniaturized wireless tri-axial accelerometer placed at level the waist level, represented by Figure 2. The technical specifications of the accelerometer are listed in Table 1.

Fig. 2. Wireless tri-axial accelerometer

Table 1. Specifications of the accelerometer

Connectivity	Class II Bluetooth Connectivity; 10 m range
Resolution	12 bit
Sampling Rate	1000Hz
Measurement Range	$\pm$ 3G
Weight	74g
Dimension	84x53x18 mm
Battery	Li-On; 7.4V; 800mAh

Physical activity level is determined by correlating acceleration magnitude with the physical activity intensity level, expressed in ”Counts” and ”MET” units. From the acceleration magnitude, the system calculates the Counts that are the base physical activity measurement unit. Counts are then converted into METs (”Metabolic Equivalent of Task”), which is a standard unit to characterize energy expenditure in physical activities [Ainsworth et al., 1993, 2000]. The conversion of Counts to MET is performed through a non-linear signal processing algorithm. This processing algorithm correlates Counts values with MET values using two regression equations based on the method described by Crouter et al. [Crouter et al., 2006]. This way, the physical activity level is classified according to the respective MET value [Ainsworth et al., 2000], as shown in Table 2.

Table 2. Activity levels classification according to MET values

MET Value	Intensity of the activity
≤ 3	Light
$3 >$MET ≥ 6	Moderate
MET >6	Vigorous

Pulse Oximeter We have integrated in the aal@home system a pulse oximeter for measuring heart rate (HR) and blood oxygen saturation (SpO_2) [Medeiros et al., 2010], allowing to monitor heart failures or vascular problems. The device, represented by Figure3 has a finger clip pulse oximeter sensor [Medeiros et al., 2010] and is enabled with Bluetooth connectivity, to transmit the data in real-time to the mobile phone. Currently, we have a Bluetooth finger clip sensor under development that will be used for this purpose in the future. Table 3 presents the technical specifications of this sensor.

2.3 Data-Flow

In aal@home, data-flow is made in two phases: first from the sensor nodes to the mobile gateway, and then from the mobile gateway to the remote monitoring station. Each user has its own mobile gateway and is monitored by wireless sensor nodes, for which the

Fig. 3. Wireless Pulse Oximeter

Table 3. Technical specifications of the pulse oximeter

IR Wavelength	870 nm
RED Wavelength	635
Bandwidth (-3dB)	0.5 Hz to 6 Hz

alarm thresholds are remotely configured by the practitioners at the monitoring station. The interaction between aal@home components is shown in Figure 4.

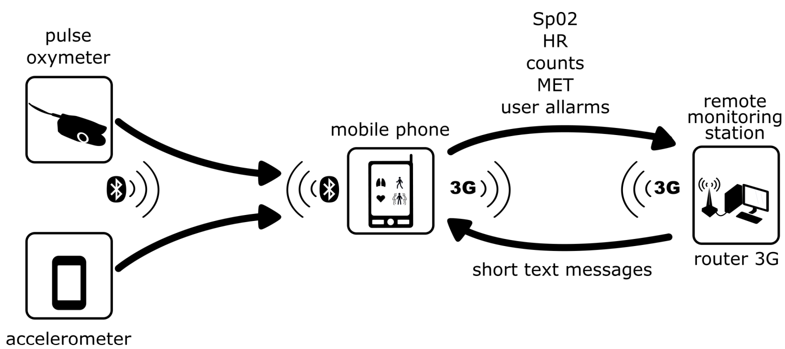

Fig. 4. Data-flow between aal@home components

The raw signals are measured at 1000Hz by the accelerometer and at 200Hz by the pulse oximeter. The data is sent in real-time and via Bluetooth RF connection to the mobile gateway, which buffers and processes this data, showing the Counts, MET, HR and SpO_2 values continuously on-screen. From the mobile gateway, data is streamed to the remote monitoring station by TCP/IP socket connection over cellular 3G or 802.11 WiFi network. The remote monitoring station consists of an Internet-enabled computer, installed at the healthcare institution. A MySQL relational database management system runs on the computer and allows the system to receive and store all incoming data from each mobile gateway, associating that data to the corresponding patient record.

In the remote monitoring station, caregivers can access to the data through a web interface and monitor the evolution throughout time of physiological parameters of each end-user. This interface also enables the caregivers to define the regular bounds of each physiological parameters and communicate with the end-users.

It may occur that the mobile devices are out of network coverage, causing loss of data in the central monitoring station. In order to prevent this situation, a protocol was developed for transactional management of the transmitted data, that together with the buffering capabilities of the mobile gateway, avoids data loss due to lack of network coverage or communication problems. From the remote monitoring station it is possible to check the status of the mobile communication.

2.4 Safety

For monitoring the physiological parameters and consequently to ensure the safety of the patients, aal@home uses a real-time communication protocol that contributes for the enhancement of the speed and effectiveness of the assistance that is provided to patients at their homes.

From the web interface of the remote monitoring station, caregivers can define the physiological regular bounds for each end-user's signals. Whenever some abnormal situation occurs, alarms and notifications are generated in the mobile gateway and sent to the remote monitoring station in order to inform caregivers of the users' need of assistance. The alarms and notifications can also be generated by the user itself by pressing a pre-defined key on the mobile gateway. Furthermore, when caregivers detect some deviations in the physiological parameters, they can also send a short text message to the end-user, advising them on how to proceed, through the same communication channel but in the inverse order: remote monitoring station $\rightarrow$ mobile gateway $\rightarrow$ end-user.

The system is also prepared to send notifications to the central monitoring station whenever the connection is lost, or low battery or incorrect sensor placement are detected on any of the devices worn by the end-users.

Thus, the aal@home system provides a bilateral communication tool not only for monitoring the end-users but also to provide the means to quickly and effectively detect problems and take the necessary actions.

3 Validation

3.1 Pilot Installation

aal@home has been deployed at a major Portuguese public hospital and 30 patients have been continuously monitored remotely by doctors. The selected evaluation group was composed by patients with an average age of 55 years old, and suffering from Chronic Obstructive Pulmonary Disease (COPD) under long-term oxygen therapy. These patients need periodic visits to the hospital unit on a weekly basis. The selection of patients with respiratory insufficiency was based on the fact that frequent travels to the hospital are difficult and demanding on their health, therefore, a home based long term monitoring could be more beneficial. Consequently, the number of hospital visits would tend to decrease as well as the associated costs. Also, the quality of the assessments would improve since the patients would be monitored in a continuous basis instead of just visiting the doctor on a weekly basis. The pilot study started on December 2009 and is currently still ongoing.

3.2 Training

Before starting this study, all the people involved in the process, from caregivers to patients and including other agents that provide individual assistance to end-users at home have received basic usage training with aal@home. For this purpose, a quick guide was prepared, summarizing the most elementary information regarding the regular usage of the devices, such as: connecting, disconnecting and charging the wireless sensor nodes and mobile gateway, interpreting the on-screen data and SMS visualization.

Furthermore, caregivers received an initial training, focused on essential aspects related to the system such as: features available on each device, alarm management, device assignment and replacement procedures and charging.

4 Results and Discussion

The results obtained from the Pilot Installation are centered on the usability of the system and the practitioners' acceptance regarding its application in a real life scenario. The results was acquired based on the observation and feedback of the patients and caregivers.

The tests also report that the patients feel comfortable and safe when they are continuously monitored by the wearable equipments. Their independence and autonomy are not compromised by the use of the sensors nor by the fact that they are being continuously monitored by a remote system. Also, as a result of the training program, there were no major issues with the use of the system both by the end-users at their homes or by the caregivers. Our support technical staff was involved in the training on a more continuous way: they were available to help the users or caregivers whenever they needed in order to enhance the learning process. From the caregivers' perspective, results show that the system is a useful tool which enables the caregivers to optimize their time and provide better and faster assistance to the patients. Moreover, aal@home allows caregivers and clinical practitioners to have a closer contact with the patients, and follow them up on a much more regular basis, contributes to improve the diagnosis process, customize, and enhance the assistance given to the patients. Moreover, since the system can provide a greater long term communication between the clinicians and the patients, the number of visits to the hospital decreases, improving the quality of life of the users.

The tests show that usability is a key issue regarding the applicability of our system: the users (both the monitored people and the practitioners at the clinics) need to be capable of understanding all features of the equipments and be able to comfortably use them. Only having this knowledge, the full potentialities of this remote monitoring tool may be used. Regarding this issue, our present goal is to improve the usability of the system so that the training step becomes more straightforward and thus takes less time to be performed. Therefore, we are now engaged in the creation of intuitive and more user-friendly software applications for the project, so that interpretation of the presented data on the central monitoring station is straightforward, this way further enhancing the caregivers' performance. All modifications and new developments, that are being done with this purpose, take in consideration the feedback of the patients as well as the health specialists that are participating in the Pilot Installation.

Comparing this system with others, aal@home system presents a functional prototype with a portable and miniaturized sensors. The sensors are provided for being integrated as wearable sensors, and so to increase the comfort of the patients. Moreover, the system monitors at least three physiological variables, while other systems only monitor one or two variables [Flynn et al., 2006; Stelios et al., 2008]. This way, aal@system takes advantage not only in terms of usability, but also in terms of design, since it was projected as a multifunctional system.

5 Conclusion

We are facing an increase in the proportion of elderly people with respect to the overall population. As a consequence, the demands of this fraction of the population are also increasing and becoming more delicate towards the society. This problem is having a strong impact on the national healthcare systems. However, technology is growing faster and we believe that it has now the potential to create innovative tools and infrastructures that allow the governments and private institutions to respond to the society needs. AAL is one of the most viable and promising solutions to bridge the lack of tools for assisting and enhancing the quality of life of the elderly population.

In this article we presented a wireless and portable system for long-term monitoring in long term physiological parameters, adapted to people who have special needs.The system allows to monitor HR, SpO_2 and activity level through wearable sensor nodes. This feature together with wireless communication and miniaturization makes the system comfortable for the patient and easy to carry with him/her during the normal daylife. aal@home's main feature is the safety tool which provides caregivers with an easy-to-use resource to closely follow up the users at distance, this way creating the conditions for a faster and more effective assistance to the patient in case of emergency.

Despite the fact that the system is still in pilot phase, the results so far are very positive and demonstrate that according to the requirements, it has a good usability and portability and is able to enhance the caregivers' quality of work. Moreover, patients have been feeling comfortable and safe since they are continuously monitored. For caregivers, aal@home is being a good tool for a closer monitoring process and for customizing the assistance to each patient. Additionally, the pilot tests are showing that the number of visits of the patients to the hospital can be decreased with aal@home. This fact will certainly have a strong impact not only at social levels but also at economic level because aal@home can provide a mean for decreasing the costs of the visits as well as the number of people in the hospitals.

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