Designing New Low-Cost Home-Oriented Systems for Monitoring and Diagnosis of Patients with Sleep Apnea-Hypopnea

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Abstract. The Sleep Apnea Hypopnea Syndrome (SAHS) is a symptomatology that affects between 2-5% of world populations and from which a high percentage have not been diagnosed. This syndrome presents serious consequences in daily life of the people who suffer it. Its detection requires an analysis in a hospital with specialized professionals and medical equipment, which entails long waiting lists. The new trends in Bring your Own Device (BYOD) and communication technologies allow designing new alternatives to current systems of diagnosis. In this paper a low-cost home-oriented system for remote monitoring and diagnosis of SAHS is presented. This system is based on the Service Oriented Architecture (SOA) approach and it is made up by different role-oriented subsystems, following a modular design in order to facilitate an incremental number of patients (scalability) and add new functionalities (extensibility). This system is proposed as a low-cost alternative to other detection methods currently implemented, with the main objectives of allowing a greater outreach to the population and reducing waiting lists in hospitals.

Keywords: Wireless and Mobile Computing, Multiple Sensory Devices, Service Oriented Architecture (SOA), eHealth, Sleep Apnea Hipopnea Syndrome (SAHS), Patients Monitoring

1 Introduction

The current economic recession has a direct impact on the lives level of people. Healthcare is one of the sectors most affected by this situation and also one of the most worrying factors for the future [13], mainly for three reasons, the ageing of the population, the demographic downturn and the steady reduction in health system funding. In order to provide a high-quality, accessible and sustainable
healthcare systems, governments are investing a great deal of resources in research. In this context, new information and communication technologies (ICT) play a key role by providing the capabilities needed to deliver more efficient, effective, reliable and fast services, achieving an improvement in the diagnosis and treatment of patients, reducing waiting times and saving costs [8]. It will favour access to health care of the general population and especially the most vulnerable groups (elderly or disabled, among other). However, the implementation of these new systems spending could be a profitable long-term economic.

In particular, a common problem in the people’s daily life is not getting a non-restful sleep. In this case, person may be suffering some sleep disorder from among the more than 90 cases that exist [19]. Specifically, the Sleep Apnea-Hypopnea Syndrome (SAHS) [5] is classified in the dyssomnias group and is characterized by drowsiness, cardiorespiratory and neuropsychiatric disorders, that lead to repeated episodes of obstruction in the upper airway during sleep. All this implies high blood pressure, a serious decrease in quality of life, traffic and workplace accidents or even die asleep.

Nowadays, between the 2-5 % of the world’s population suffer from this syndrome and from which close to 90-95 % have not been diagnosed. This disorder affects people of all ages, children and adults, but the symptoms and treatments are different for both. In general, the probability of developing this disease in adulthood is higher in the case of men. When men reach the age of 40 and woman reaches menopause, tends to equalize the probability. Other factors that increase the probability of developing this disease are overweight, hypertension, abnormalities or defects that can affect the upper airway, among others. Some of the most common symptoms of SAHS are asphyctic episodes, observed apnea, abnormal movements and frequent awakenings.

Usually, for diagnosis of SAHS it is necessary to perform a test in a specialized room called Sleep Room (nocturnal polysomnography). One of the great disadvantages is that such installations are scarce for the high demand that exists, therefore, it leads to a long waiting list of patients. The sleep test requires that the patient remains asleep for several hours. Likewise, the patient is in a strange environment so in many cases makes it more difficult for sleeping, which requires to repeat the test with the repercussions that this have on the own patient and on the waiting list. Furthermore, the sleep room has a sophisticated, static, heavy and expensive medical equipment which allows detailed studies of patients. In addition, a specialized medical staff is required to place the sensors in the body of the patient. This medical staff also monitor the patient while he or she sleeps, and in the case that there are any problem with the equipment or the patient needs an urgent medical attention, because he/she is in a critical state, the medical staff can intervene. At present the nocturnal polysomnography is the most reliable study used to detect whether a person suffers from this disease [3].

Currently, it is important the good acceptance that the new technologies and trends as Bring your Own Device (BYOD) [12], are having between the population. Moreover, the cloud infrastructure is increasingly popular owing to the
advantages offered, such as scalability or accessibility. The cloud may be the solution to the limited resources of mobile devices. This combination allows creating portable systems, with low economic cost and wireless connections, which implies a more feasible distribution of the system among users, it is possible to dispose more units for the same price and it is more comfortable to use, due to the reduced wiring and connections between system elements. This research work makes use of this type of system, thus medical specialists can realize a diagnosis and monitoring of the patient’s status, as well as to specify a treatment and to control his/her evolution. Furthermore, the tests can be repeated as many times as necessary, owing to availability and low cost of the equipment. Moreover, the patient would be in a familiar environment e.g. (at home) and then more comfortable, which may help the effectiveness of test performed.

In this paper, a system for remote monitoring and diagnosis is presented. This system aims to facilitate the analysis, monitoring and diagnosis of patients who could suffer the sleep apnea-hypopnea syndrome. The system aims to reach a major to reach to a major number of people at the same time, to offer a more attainable service to people who have certain difficulties, for example, elderly or handicap people, who could have difficulties to move to medical center. In addition this could reduce the long waiting-lists for the test of polysomnography.

The rest of this paper is structured as follows. Section 2 presents related work. In Section 3, the design of the system for monitoring and diagnosis of patients with SAHS symptoms is presented. Finally, conclusions and future work are summarized in Section 4.

2 Related Work

The acceptance of technology among the population, favours the appearance of new health care systems, which are intended to improve the daily life of the patients. Such systems have great potential, since they offer new functionalities and provide support to medical specialists, patients and families [11]. There are currently several platforms for monitoring patients at home, these platforms are used by people with different needs (health and physical), such as elderly or disabled people, and/or with chronic diseases, among other.

Hygehos Home [18] is a system of remote monitoring and patient tracking that allows monitoring the different diseases, measuring of vital signs, controlling medication intake, providing information of the disease and establishing direct contact with medical specialists. In [14] a platform, called NOCTURNAL, for monitoring the rooms of the house of a person with dementia is presented. The aim is to extend the stay of people with this disease in their homes to improve their quality of life. In [16] a framework for analyzing the optimal deployment of services and applications of an eHealth monitoring system is proposed. This framework is based on the use of the cloud and mobile devices as a computing combined unit. In [17] a platform for remote monitoring of patients with brain injury is presented. The system allows to carry out a track of daily activities that the patient performed and to perform rehabilitation exercises.
Regarding the sleep apnea, in [2] a system for the monitoring and detection of sleep apnea which makes use of the patient’s mobile device and sensors is proposed. The application processes the information received by the sensor, applies a personalized classifier and sends the gathered information to a server, where a general classifier (independent of a specific patient) is applied. The general classifier is deployed on a server, owing its high resource consumption. In the patient’s device, a sub-classifier is generated from the general classifier, on the basis of patient’s profile and the most representative characteristics. It is a lighter classifier which can be executed in a mobile device. In [4] the creation of a Virtual Sleep Unit, as the extension of a real Sleep Unit, is proposed. To this end, in a hospital, a room will be enabled, where some patients will be monitored from a remote Sleep Unit. A cardiorespiratory polygraph is used to collect the information about the patient’s state and it is sent, along with the images captured by a webcam, in real time to the Sleep Unit. Patients are supervised by a locally nurse, who has been instructed to solve any problems that might arise during the study and with the use of biosensors. In [20] it is proposed an intelligent self-adjusting pillow for detecting and perform an apnea treatment. To detect sleep apnea a blood oxygen sensor is used and according to the parameters captured by that sensor, the pillow is adjusted automatically both in height and form, in order to fit the position of the patient body adequately. In [15] a sound monitoring system is proposed, in order to quantify the snoring sound and the severity of Obstructive Sleep Apnea (OSA), through a smartphone. NOWAPI [9] is a system that provides a remote control of CPAP treatment. It detects the efficiency of treatment, the time of use and events occurred.

However, some of this works do not deal directly with the problems of sleep apnea syndrome. The others more related to this disease, only provide local mechanisms to try to mitigate their symptoms. This proposal aims to design a system of remote diagnostic for sleep apnea, in order to facilitate and expedite the work of specialists, and provide comfort to patients.

3 Design of a Service-based System for SAHS Symptoms

In this section a system for monitoring and diagnosis of patients is presented [1]. The main objectives of the system is to provide benefits such as:

- To offer the possibility of continuous monitoring and in real-time, i.e., the patient will be monitored or as long as necessary.
- To reduce costs in monitoring patients, in order to repeat the test as many times as necessary.
- To use low economic cost devices that allow performing the test successfully, with the aim of acquiring a greater number of devices, allowing a greater outreach to the population. This feature, together the previous point, could help to decrease the lists of patients which are waiting to be attended.
- To establish a continuous and committed relationship between patients and medical specialists.
To perform the monitoring in a familiar environment for the patient could help him/her to improve his/her quality of sleep. Moreover, the tests performed will be more reliable, owing to the patient’s status shall not be affected by the nervousness of being in a strange place.

To improve the quality of life and safety of patients. Thus, it is possible that increase the safety by monitoring his health.

The system seeks for offering the possibility to perform a remote monitoring, without the need, for the medical staff and patients, to be in the same physical space or in a nearby place.

3.1 Architectural Design

This system is based on the service-oriented architecture (SOA) to guarantee interoperability, platform independence and reusability, among others quality attributes. This facilitates the coupling and integration of various services, in order to build composite services of high level, so that the initial system is extended without the need to develop new services which perform specific functions.

The system is made up of four independents subsystems. Figure 1 shows the architecture of the proposed system. Three of these subsystem are targeting users with different roles (patient, specialist medical and relative of the patient), in order to provide a joint attention to improve monitoring and continuous control. The another remaining subsystem provides support for these subsystems and is made up of two main services (“Database Management” and “Patient Information Management” services).

Fig. 1. Monitoring and diagnosis system architecture.
The three role-oriented subsystems cooperate among each other: (1) monitoring subsystem, which is located at patient’s home, i.e., a home-oriented subsystem. This subsystem allows carrying out measurement of the patient’s vital signs, taking into account the requirements of a specific patient. To do this, the patient makes use of a medical equipment (biosensors) that he/she should place in his/her own body. The sensors act as nodes that should be strategically positioned to capture the medical data and communicate among themselves. In this way, monitoring system use emerging wearable wireless body area networks (WBANs), following one of the most promising approaches [10]. (2) A subsystem for a relative, which receives information from monitoring subsystem about patient’s status, in order to allow a collaborative supervision from relative. This subsystem aims to offer the possibility to relatives of the patient of collaborating in the monitoring of the patient, whenever they want to get involved. The relative of the patient can be at home or at patient’s house. Finally, (3) medical subsystem, which allows a medical specialist to supervise the patient from his or her workplace or access the reports generated from the studies conducted in each sleep session. Both, medical specialist and relative of the patient can access to these information through a mobile device. Therefore, the system design ensures, through different subsystems, an intuitive and customizable environment for different users and devices that share information. In this way, a modular design approach has been followed in order to facilitate scalability in terms of numbers of patients who can use the system, and functional extensibility.

The support subsystem provides two main services, which has been designed and implemented, taking into consideration that the security in the management of the data (gathering, storing, communicating, querying, modification and deleting) should be guaranteed in every moment. This is because these are personal data and other health information, i.e., patient’s sensitive information. (1) “Database Management” service is responsible of storing the information about patients and provides a query service. Furthermore, this service acts like an intermediate layer for security purposes, since it provides restriction mechanisms in data access and modification. (2) “Patient Information Management” service provides complex information through processing of the basic information, in order to reduce the workload of mobile devices and to allow code reusability, the same information will be accessed by different subsystems. It is important to mention that these services can be deployed in a local server, which ensures information control, or on the contrary, in a cloud infrastructure.

3.2 Subsystems Design

In this section, the four subsystem mentioned above (Figure 2) are described in detail by defining the main objectives and the responsibilities of each subsystem.

**Patient Monitoring.** The objective of the Patient Monitoring subsystem is to emulate the sleep room of the medical center. It is made up of biosensors and a central component. Biosensors are devices of low economic cost (compared to the
equipment used in a sleep room), however, they guarantee reliable measurements, which allows the correct monitoring of the patients. This central component is a gateway which receives and filters the data from the sensors and sends it to Database Management service. Moreover, if a disconnection occurs during the monitoring session, and it has no connection available with the service, it stores the information collected locally, to subsequently send it, when the connection is reestablished, applying synchronization defined in [7]. This central component can be the patient’s computer or an embedded system specifically designed for this task.

Monitoring is carried out each time the patient goes to sleep, however, even if it is for a brief period of time, in order to analyze, a correct treatment, and any potential representative data that could occur during sleep. Information collected by biosensors during each monitoring session, is associated with a sleep study, for future reference and analysis.

Regarding to biosensors, it is necessary that patients learn to use them, before taking them home, in order to obtain correct measures. When the patient goes to sleep, he or she must place the sensors in his/her body as indicated by the medical specialists. Subsequently, biosensors must connect with the central unit in order to start a new monitoring session and sending data. Thanks to the reduced price of the biosensors used and the performance of the sleep study at the patient home, it is possible to repeat the study as many times as necessary, (without causing any delays in waiting lists). The system makes use of wireless and ergonomics devices to guarantee patients’ comfort and not unduly interfere his or her sleep.

**Specialist Supervisor.** Through the subsystem Specialist Supervisor, the medical specialist can monitor the patient in real-time, consult the reports generated from conducted the studies (Figure 3, left), access the patient’s personal data and manage biosensors registered in the system; assign/unassign biosensors to patients in real time and remotely (from his or her workplace). Note that this allows specialist to monitor more than one patient at a time, without having to visit each patient’s location. Furthermore, in complex cases, where one medical
Fig. 3. (Left) Example of a study performed to a patient. (Right) Example of an alert message in “Relative Supervision Subsystem” application.

opinion is needed, it is possible that a group of medicals can work together and collaboratively, each one from their respective workplace, in order to obtain the best result in the monitoring and diagnosis of the patient.

The monitoring of a patient in real-time, allows the medical to perform a control of the vital signs of the patient and other relevant information that determines health status of the patient at each particular time instant. Part of the information is displayed in a set of graphs which allow to view and compare captured values in each time instant, it is also possible to view values in individual graphics. In both cases, the graphical representation facilitates detection of the peak values that could be related to other values corresponding to other measurements. Besides the graphical representation, other more complex information appears. This information is the result of processing the values captured by the biosensor, such as, maximum, minimum, and average values and number of occurrences, among other, which are relevant for the medical supervision.

The subsystem is provided with an alarm system. The medical specialists can activate the alarms for each biosensors independently. He/she can establish the limits of the alarm values (maximum and minimum) and if captured values by the biosensors exceeds the limit, a notification (audible and written signals) will be sent to the medical specialist. The notification contains some information about the patient who is at risk situation when threshold is exceed. While this situation continues or recurs, the notification will be sent periodically. Also, volume and sound type can be customized, and these notifications can be enabled or disabled in general. Furthermore, it is possible to assign/unassign biosensors to patients
in real-time and remotely, when it is required to make measurements of new biosensors and other sensors, in order to work with patient information and their environment (context information).

Additionally, the subsystem Specialist Supervisor allows to managing the personal data of a patient, because in disorders sleep is important to know factors such as age, sex, physical constitution of the patient, among others. These factors can be an important part of the causes of the disorder.

Once the monitoring session is ended, the study of the patient’s sleep contains the following information: date and time of procurement (start and end), patient weight and height, and for each biosensor connected to patient: maximum and minimum value reached during the study, upper and lower limits specified by the specialist, times reached, average, standard deviation and an interactive graph. This view is dynamically generated for each study depending on biosensors used and the profile of each patient.

Finally, for more flexibility, these functionalities are available via a mobile device, such a tablet or smartphone.

Relative Supervisor. The Relative Supervisor subsystem allows relatives of the patient to collaborate in his or her monitoring. This subsystem operates on the mobile device of the patient’s relative and allowing, his or her to monitor the patient condition in real-time.

The subsystem displays the values captured by the biosensors and indicates if patient’s condition is normal or a condition of risk is detected (Figure 3, right). Additionally, the subsystem is endowed by an alert service connected to the specialist subsystem, if the values captured by the biosensors exceed the values established by the specialists, the system sends an audible notification to the patient’s family, which allows the patient’s family to react to a critical case.

Services. This subsystem provides support and facilitates the information exchanged between the role-oriented subsystems. It provides two main services:

- **Database Management.** This service provides an abstraction layer between data and application, offering functionalities that allow manage data at high level, reducing the efforts of the developers. The Database Management will be responsible to guarantee the security in access and management to external databases. Moreover, standards of web services, such as SOAP and WSDL, are being used for uniform access and to provide independence from platform, in this way, different devices with different properties, at hardware and software level, can access to this service. Furthermore, thanks to this services the system could interoperate with other systems, services or different applications, i.e, it is allowed exchange and access to information of other independent systems, services or applications.

- **Patient Information Management.** This service allows to perform a processing of the information with objective to provide complex information that may require an intensive computing. Operation is as follows, this service receives a request of an application, it processes the request and determines
the basic queries that compose it. Then, it is contacted with the Database Management Service, which sends the requested information, and the Patient Information Management Service processes the information received in order to obtain the request high level information. As in the previous case, this service also ensures security, interoperability and platform independence.

Services can be run on a local server, in the cloud or on a mobile device, but each case have their advantages and disadvantages. On the local server, the data is stored in a private location on which security mechanisms are established for ensuring the inaccessibility of the data by unauthorized users. The cloud server, provides flexibility, accessibility to information, promotes system scalability, offers large computational and storage capacity (on demand), but the problem is the difficulty in ensuring data privacy, something fundamental in e-health systems. Mobile devices have a performance unthinkable a few years ago, but their resources are limited (computing capacity, storage capacity, bandwidth network and battery or autonomy, among others) [6] for continuous control, so that local and cloud servers provide performance benefits, possibly most appropriate for such environments. Furthermore, for the deployment of services is essential to analyze the service quality requirements.

4 Conclusions and Future Work

In this paper a service-based system which enables remote home-oriented monitoring and diagnosis of patients with possible symptoms of SAHS has been presented. The system has been designed and implemented with the aim to improve health care for patients and is mainly composed of four different subsystems, three role-oriented subsystem and a support subsystem. Biosensors and devices of low economic cost used allow performing correct measurements to the patients which allows a greater outreach to the population. In this way the system that has been created allows monitoring of patients in their own homes, while the specialist in charge of treating them is in the hospital. This system is proposed as a possible alternative to other detection methods currently implemented. Thus, it aims to reduce waiting lists, that can reach up to two years, to repeat the test easily and to improve the health and the quality of life of patients. The proposal promotes continuous monitoring in a non-intrusive manner and avoids the movement of patients to the hospital, promoting better and faster patient recovery, economic savings in the health system and greater flexibility in the management and care of patients.

The system has been designed and implemented under the Service-Oriented Architecture (SOA) approach, providing advantages such as platform independence, scalability, reusability and autonomy. Finally, the system stems from a modular design which facilitates scalability and allow adding new biosensors and new functionality easily in the future.

As future work, the diagnostic system will be extended, with the incorporation of new services and biosensors. It is exploring the possibility of providing capabilities to the services, such as adaptivity, adaptability, extensibility and
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configurability, in order to get the most appropriate system at any time and improving performance. It is intended to use sensors that capture information of the patient environment to combine with values corresponding to the vitals signs of the patient, with the objective of providing to medical specialist a better support from the utilization of data mining tools that allow to generate a possible diagnosis. Finally, the system has been already developed and also informally validated, an experimental evaluation is being carried out with different users in order to analyse benefits more formally and address potential improvements.

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References