An Ambient Assisted Living platform to integrate biometric sensors to detect respiratory failures for patients with serious breathing problems

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Abstract. Breathing problems such as chronic obstructive pulmonary disease, chronic bronchitis, or emphysema, present the need to carry out home respiratory therapy. This requires the deployment of specific devices for supplemental oxygen therapy and monitoring of the status of the patient. This paper presents an Ambient Assisted Living solution to carry out the treatments in their houses. This introduces technological innovations and advanced services to allow patient monitoring and supervision by remote monitoring centers. This paper shows the developed architecture, where the selected biomedical sensors for monitoring the reduction in breathing capacity have been integrated. The platform permits to connect wirelessly the sensors worn by the patient to the gateway deployed at the house, and the safe and global communication and secure communication with the remote monitoring centers and Intelligent Information Systems. This improves the current solutions presented, where only 42% of the patients, who receive this therapy satisfy at least 80% of the therapy prescribed by the pulmonologist. Since, this solution supervises continuously the compliance of the patient to the respiratory therapy.

Keywords: COPD; home respiratory therapy; e-Health; Internet of Things; 6LoWPAN; Ambient Assisted Living.

1 Introduction

The remote monitoring is a requirement to support the new generation of healthcare solutions based on Ambient Assisted Living environments (AAL). In particular, this work presents an AAL solution for the detection of respiratory failures in patients with serious breathing problems, where it is more evident the need to carry out assistance and the therapy in the patient’s house or specialized centers.

The solution presented is being defined in the frame of the Spanish project AIRE, whose goal is to design and develop a platform to support remote monitoring, and an intelligent system to detect and predict anomalies in the patients with serious breathing problems. Specifically, the goal of the system is to detect when the breathing capacity is being reduced, in order to warn the caregivers to avoid insufficient respiratory, which can cause serious health problems and situations each
time more dangerous, resulting even in some occasions in an irreversible consequence.

Nowadays, in the market can be found some projects and solutions to support home respiratory therapy, but they are partial solutions, where for example it is only supported the home oxygen therapy or the remote monitoring of some biometric sensors, where the collected data need to be interpreted by the specialist or caregiver. Other solutions are focused on a specific illness, instead of offer a generic framework with support of sensors for monitoring parameters from very different kind of sensors. For example, it can be found specific solution to measure the lung capacity with a spirometer, and more advance solutions are focused on pilot deployments, which are not yet arrived to a commercial solution [1]. Specifically, the most relevant related solutions found are, on the one hand, the project Medic4all [2] for monitoring of patients with chronic obstructive pulmonary disease (COPD) in Israel, with a pilot deployment of 1200 patients. This solution transfers the monitored data wireless in real time to two remote monitoring centers. This considers a basic alarm system based on the status of the parameters, this alarm system warns to the caregivers/specialists when an anomalous value is found, in order to visit to the patient. This project is only focused on the first level of COPD solutions, i.e. monitoring level. On the other hand, the solution Health Buddy System [3], presents a system for monitoring of multiple diseases, where is also considered COPD. The experiments with this system, in a living lab of 59 patients, have demonstrated that the patients monitored with this kind of solutions have presented a lower quantity of side effects, health problems and the ratio of hospitalizations has been reduced [4]. Both projects are not considering a second level of solutions focused on intelligent systems with predict models to detect anomalies before that present serious symptoms and health problems such as the mentioned insufficient respiratory. Our approach is focused on the definition of an intelligent system to predict the mentioned situations with continuous analysis of the collected information from the health status and the context (e.g. activity of the patient).

Therefore, the goal in this project is to reach an intelligent system to link some respiratory parameters such as oxygen saturation (SpO2) levels, breathing frequency, lung capacity and peak expiratory flow (PEF) with the anomalies, as such to detect breathing problems previously to reach a bad situation. Thereby, the risk of problem is reduced as is the suffering from the patient in these situations.

This solution is based on the technologies from the Internet of Things to make possible the connection of the sensors worn by the patient in their environment with the Intelligent Information System (IIS) and monitoring centers through Internet.

The IIS is currently a work in progress, which has been designed to detect the patterns and models of the different respiratory illness, in function of the collected data from the biometric sensors and context information from the platform.

This paper is focused on present the defined architecture based on the Internet of Things, which has been designed to support the continuous monitoring of the patient for the collection of the data, which will be required by the IIS, as such as the integration of the biometric sensors in the architecture, with the final purpose of be able to offer the respiratory assistance services required to supply adequate oxygen therapy in AAL environments.
2 Home Respiratory Therapy

World Health Organization (WHO) statistics determine that 210 million people around the world suffer chronic obstructive pulmonary disease (COPD), over 3 million deaths, i.e. 5% of the deaths around the world were caused by COPD in 2005 [5]. In Spain, more than 4 million people suffer COPD, who are 9% of the population, following the statistics from the Spanish Society of neumonology and thorax cirugy, and over 18,000 of these people die per year in Spain, following the National Spanish Institute of Statistics. Remark, that from the mentioned patients in Spain, 80% of them have not been diagnosticated, since they consider the symptoms as “normal” because of tobacco consumption. The main reason for these problems in Spain is because 26.4% of the population consumes tobacco regularly, which triggers an abnormal inflammatory response in the lung.

Right now, there are more than 300,000 patients, who are receiving respiratory therapy at their homes in Spain. The increase in the appearance of the breathing illness and the aging of the population are some of the factors which show the need for the next years of the Ambient Assisted Living (AAL) as the solution to satisfy the demand and requirements of the healthcare in the near future.

In particular, the domiciliary respiratory care means a set of treatments for patients with breathing problems at their own home. Pulmonologist or critical care patients require this kind of treatment of COPD, and other illness such as chronic bronchitis and emphysema for the lungs in which the airways become narrowed; this leads to a limitation of the flow of air to and from the lungs causing shortness of breath. Other respiratory problems can be side effects of cancer of the larynx. For instance, one of the patients considered for our study presents a chronic bronchitis complicated with a larynx cancer. Other common respiratory problems are asthma, pneumonia (bacterial, viral and chemical ones), collapsed lungs, emphysema, hyperventilation, pleurisy, pulmonary edema, pulmonary embolism etc.

The domiciliary solutions are suitable and much extended in the public health systems, such as those found in Spain, where the public health system rents the systems to third parties. However, the problem continues partially, since only the 42% of the patients, who receive this therapy, satisfy at least the 80% of the therapy prescribed by the pulmonologist. Therefore, the patient needs to be controlled to reach more powerful effect in the patient recovery and health status. Usually the patients with respiratory failure, who do not follow the treatment in a suitable way, are used to living with little oxygen, assuming as usual the breathlessness and tiredness. But they do not understand that is making more difficult that organs such as the heart recover from their illness, and that patients who comply with the treatment are noticing improvements. Finally, the patients need to receive additional treatments such as remove respiratory secretions (e.g. mucus) and clear airway to optimize respiratory function, which are ancillary to the oxygen therapy, such as presented in the Fig. 1.

Therefore, the AAL solutions permit to carry out the treatments for the mentioned patients in their houses, instead of the hospital. Thereby, this improves the quality of life for these patients and reducing the healthcare costs (especially for public health systems as that found in Spain). In case of that these AAL were not defined, these patients in risk, should stay in the hospital full time, in order to be alive.
The current solutions defined for the incorporation of home respiratory therapies, for patients with breathing problems such as the mentioned COPD, have not yet addressed the paradigm of predictive models applied in this environment.

Such as presented in Fig. 1, our model is based on the relationship between the levels of oxygen saturation and respiratory rate with their lung capacity, in order to try to predict that before respiratory failure with the goal of clearing respiratory via, removing mucus and apply oxygen therapy. In addition, it can be determined to carry out an analysis with a spirometer, in order to get more information, which can be used for the Intelligent Information System to determine whether the anomaly was caused only by an obstruction of the respiratory secretions, or it is a major problem, which can conclude in serious symptoms such as insufficiency respiratory.

During the continuous monitoring, the wearable sensors analyses are focused on detecting simple symptoms such as shortness of breath (i.e. dyspnea) with the breath amplitude sensors, which is one of the most common symptoms of several respiratory diseases such as emphysema, bronchitis and pleurisy. Other symptom considered is hyperventilation with the breath frequency, which can also occur as a consequence of various lung diseases, head injury, or stroke (central neurogenic hyperventilation, apneustic respirations, ataxic respiration, Cheyne-Stokes respirations or Biot's respiration). In addition, it is considered the oxygen saturation (i.e. SpO2), which is highly relevant to detect the insufficiency respiratory, such as presented in one of our previous works [6]. Finally, it is considered the temperature, which is one of the most relevant parameters used for COPD diagnosis, pleurisy and several of the respiratory diseases, which manifest fever. The ongoing work is considering noise sensors to detect wheezing and cough [7].
The continuous monitoring of these parameters is clinically relevant, since some illness such as emphysema usually develops slowly. Patients may not have any acute episodes of shortness of breath. Slow deterioration is the rule, and it may go unnoticed. In addition, after that the patient has been diagnosed, this continuous and real time analysis of the patient allows to detect anomalies, which can ask for some actions to the patient, such as check his current status with some additional sensors such as the spirometer (which offer a higher and accurate quantity of information, which allows to the system the verification of the detected anomaly), ask for the caregivers to clean the respiratory via in case of illness such as larynx cancer, where is required to take out the mucus and apply the oxygen therapy, or ask external attendance in the worst case.

The additional sensors considered in our solution, is a spirometer, which cannot be used continuously, since it needs that the patient must sit up straight, feet flat against the floor and head facing forward in order to get a valid measure. Spirometry has been chosen, since it is the most common test used to evaluate how well the lungs are functioning. Specifically, spirometry measures how quickly air moves in and out of the lungs, and measure the volume and speed of air. This offers several values, such as presented in the Fig. 2. Some of them are very relevant to detect earlier obstructions such as FEF25-75% [8-9]. The current status of the Intelligent Information System is work in progress. For that reason, it is not presented detailed in this paper.

Fig. 3 presents the general view of the home respiratory therapy solution, where are defined different kinds of continuous signals through a wearable system and discrete signals, which as monitored periodically or when an anomaly (i.e. alarm) is detected. The next section is going to present the sensors considered and the platform, to make feasible this home respiratory therapy.

Fig. 3. Home respiratory architecture proposed.
3 Home respiratory architecture proposed

The architecture proposed integrates the required sensors involved in the home respiratory therapy in a platform, which allows to communicate the sensors installed in the domiciliary for telemedicine purpose such as the spirometer, and the worn sensors by the patient for continuous monitoring with the Hospital Information System, Intelligent Information Systems, operation managements and remote monitoring centers, such as presented in the Fig. 4.

This kind of solution, for the integration of clinical environment (ICE) at the patient’s home can be classified in two levels of solutions. The first level, ICE1, is focused on the safety, which is the level where is found our current work. This level solves the issues such as ensure the integrity, reliability and accurate of the monitored information, interoperability of all the sensors with the platform, and functions to detect fault of the sensors i.e. self-monitoring and healing, auto-configuration, remote management, and finally integration with the second level, ICE, which is focused on clinical decision support, control loops clinical practice guideline conformance, revenue coding for episodes of clinical care.

On the one hand, in order to support the first level, ICE1, it has been defined smart adaptors for the sensors which permit to verify the integrity of the system, protect the data and carry out management tasks. On the other hand, in order to support the second level, ICE2, it is going to be defined by the Intelligent Information System which will manage the information generated by the sensors to detect the respiratory failures, verify continuously the patient status and alarm to caregivers. This second level is being carried out in the ongoing work, such as mentioned in the Section 2.

Our solution to define the ICE1 solution for this scenario is based on Internet of Things, which allows to connect all the devices around the patient such as sensors, and collecting context information such as patient’s activity.

The problems found to make feasible the ICE1 with the defined adaptors based on Internet of Things, which in order to reach a low cost, low power consumption, and reduced size, they present a low performance, reduced capacity and resources. Therefore, a set of challenges are defined to offer all the requirements of an ICE1, security and protection of the information, and adaptation to the changes of patients’ position, i.e. mobility support. The support for the mobility of the patients have been solved, with a novel mobility protocol, which has been designed to support mobile monitoring of patients and workers for AAL environments, hospitals and critical environments such as refineries [10]. On the other hand, this has been defined an advanced implementation of security based on public key cryptography, which allows the protection of the information end-to-end [11], since the privacy is one of the most relevant issues in healthcare domain.

The system has been designed to work with sensors for medical purpose from different vendors. Therefore, this system has a very flexible and open connectivity support. Specifically are supported medical sensors via RS232 (serial communication) and Bluetooth. But additionally, under this project we are adapting medical sensors to 6LoWPAN, it is a protocol defined by the Internet Engineering Task Force (IETF), which extends Wireless Sensor Networks (WSN) to Internet, adding to IEEE 802.15.4 a layer to support IPv6. 6LoWPAN presents advantages with respect to previous versions of AAL solutions based on Bluetooth, because with 6LoWPAN the value is
transmitted directly without user interaction, i.e. user does not need to set up a mobile phone or similar. That feature is very interesting for elderly patients, who are not very used to new technologies, and since COPD is very frequent in elderly population, it is a relevant feature.

The initial step to define this platform has been to determinate the sensors and biomedical devices for monitoring the reduction in breathing capacity, in order to satisfy the therapy presented in the section 2 and Fig. 3. The sensors considered have been, see table 1:

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Communication interface</th>
<th>Parameters measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&amp;D UA767PC</td>
<td>Serial</td>
<td>Blood Pressure</td>
</tr>
<tr>
<td>Nonin WristOx2 3150</td>
<td>Bluetooth</td>
<td>SpO2 and heart rate</td>
</tr>
<tr>
<td>Medlab EG00352</td>
<td>Serial (Wearable)</td>
<td>SpO2 and heart rate</td>
</tr>
<tr>
<td>CardioBlue MediTech</td>
<td>Bluetooth (Wearable)</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>Medlab EG01000</td>
<td>Serial (Wearable)</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>MIR Spirobank II</td>
<td>Serial</td>
<td>PEF, FEV1, FVC, FEF, SpO2</td>
</tr>
<tr>
<td>Medlab EG00700</td>
<td>Serial (Wearable)</td>
<td>Temperature</td>
</tr>
<tr>
<td>Avita TS-28BT</td>
<td>Bluetooth</td>
<td>Temperature</td>
</tr>
<tr>
<td>Asma-1 Vitalograph</td>
<td>USB</td>
<td>PEF, FEV1</td>
</tr>
</tbody>
</table>

Table 1. Sensors considered for the solution.

The selected biomedical sensors are being adapted to the developed personal device, presented in [12], where previously glucometers from different vendors were connected to a common adaptor with wireless Internet connectivity, in order connect wireless to the AAL gateway developed and presented previously in [13], this has been extended with the Bluetooth transceiver WT12 from Bluegiga, which supports Health Device Profile (HDP) in the 3.1.0 build 385 of the iWrap operating system, HDP is the profile defined by the Continua Alliance and the standard IEEE 1073 for the communication with clinical sensors based on Bluetooth sensors.

The wireless connectivity allows to the patients be monitored at the same time that they carry out their usual activities, the denominated activities daily living (ADL), the wearable sensors are the considered for continuous monitoring, and the selected for this purpose have been those offered by medlab, which allows the easy integration with the developed adaptor, through a simple serial communication.
4 Conclusions and Future Work

The proposed solution goal is to introduce technological innovations and advanced services in the home respiratory therapy to allow patient monitoring and supervision remotely by monitoring centers and the inclusion of intelligent systems to detect the respiratory failure in home therapies, supervising the patient’s compliance and alert when the lung capacity from the patient is being reduced. The ongoing work is to define end the definition of the intelligent system to detect the anomalies, and the future work is focused on the integration of the sensors and platform in an orthopedic bed, for patients who are suffering immobility, and the evaluation of the solution in 20 patients with breathing problems in Hospital “Mutua de Terrassa” in Barcelona.

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References
2. Bergma, David: Medic4All Medic4all's telemedicine solution was chosen by the Gertner Institute and Clalit Health Services to operate the largest COPD telemonitoring project in Israel. http://en.medic4all.it/index.php (last access 03/2011).