Remotely Supporting Patients with Obstructive Sleep Apnea at Home

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Abstract. People suffering Obstructive Sleep Apnea are normally treated by using a device that provides continuous positive airway pressure. Currently solutions do not rely on any remote assistance and data gathered from that device are accessible to clinicians only when the patient goes to the annual visit. In this paper, we propose an IoT-based system that sends data to the cloud where are analyzed to support patients with Obstructive Sleep Apnea giving also a suitable feedback to lung specialists. The work is part of the Spanish project myOSA. Clinical trials with patients from the Hospital Arnau i Vilanova in Lleida (Spain) started on July 2016 and will last 6 months.

Keywords: Telemonitoring · Decision support systems · Internet of Things · eHealth · Obstructive Sleep Apnea · CPAP

1 Introduction

In the last decade, the Internet of Things (IoT) paradigm rapidly grew up gaining ground in the scenario of modern wireless telecommunications [1]. Its basic idea is the pervasive presence of a variety of things or objects (e.g., tags, sensors, actuators, smartphones, everyday objects) that are able to interact with each other and cooperate with their neighbors to reach common goals. Depending on the real-world scenario, different solutions to analyse data gathered from *things* may be applied. In case of patients' involvement, self-management tools [2], decision support systems [7], and recommender systems [4] may work with data from *things* to give support to the patients with the main goal of providing empowerment.

In this paper, we focus on eHealth and propose an IoT-based monitoring system aimed at giving automatic remote support to patients suffering Obstructive Sleep Apnea (OSA) [5], as well as a suitable feedback to lung specialists. In the literature, some work focused on monitoring patients with OSA relying on IoT has been proposed [3,6]. Our approach differs in monitoring patients to improve their adherence to the prescribed therapy. Moreover, as a secondary goal, the system also provides lung specialists with relevant monitoring information to enable a better patients' follow-up.

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2 The Proposed Solution

Currently in Spain, after a visit with a lung specialist, patients suffering OSA are treated with a continuous positive airway pressure (CPAP) machine at their home. CPAP providers guide patients on how to use the device properly and prescribe them to use the machine at least 4 h daily in order to benefit the therapy. From that moment on, the adopted medical protocol states the following visit with the specialist after 6 months and then once a year. Unfortunately, this extended period of time results in patients not following the recommended prescription and even abandoning the therapy. In fact, it may happen that, during a visit, they discover that the patients is using the CPAP less that 4 h or s/he is not using it at all. To improve patients compliance and better follow-up, we propose a solution that, connecting the CPAP with Internet and providing patients with an app in their smartphone, gives support to both patients and lung specialists. In fact, in so doing, CPAP automatically sends the collected data to the cloud where are analysed and sent back to the user through the app.

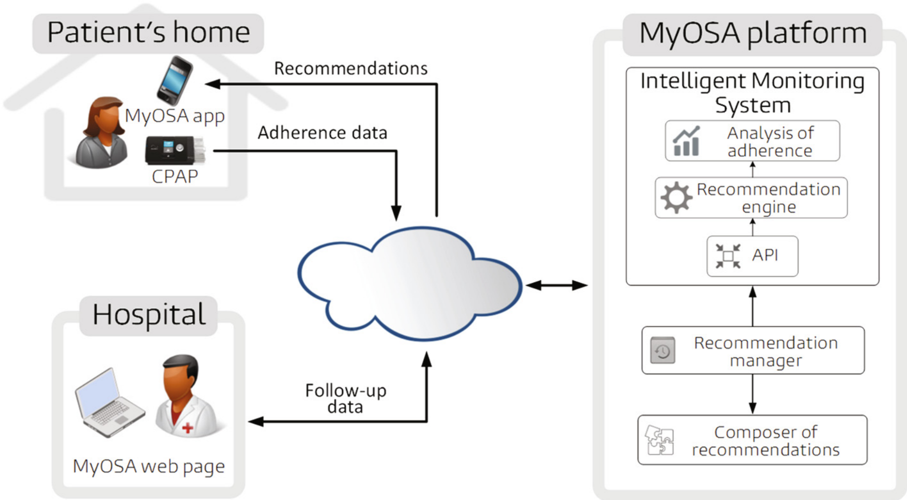
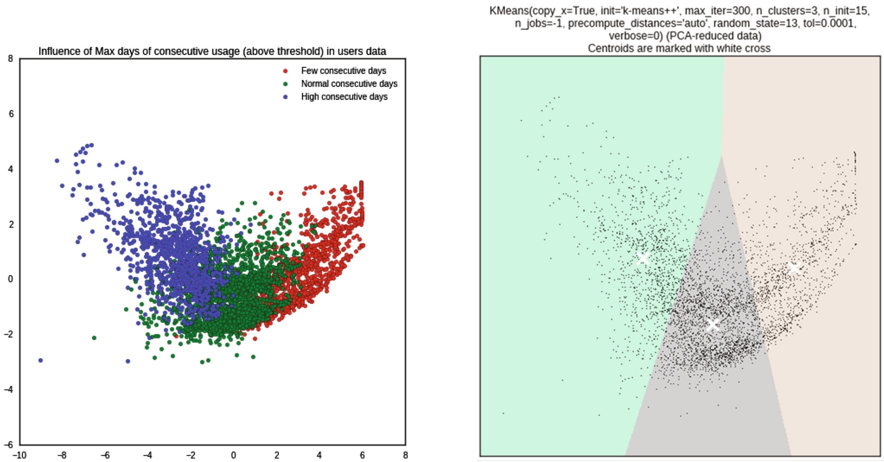


Fig. 1. Main components of the IoT-based system.

Figure 1 shows the high-level architecture of the system with its main components: *Patient's home*, *Hospital*, and *MyOSA platform*. At the *Patient's home* two devices are provided: the CPAP machine connected to Internet and a smartphone with the installed app. At the *Hospital*, lung specialists are provided with a web application that summarizes relevant information and it is aimed also to give a support in medical decisions[1]. Finally, the *MyOSA platform* is installed in the cloud and connects all the devices for data exchanging.

[1] The corresponding decision support system is out of the scope of this chapter.

The core of the *MyOSA platform* is the *Intelligent Monitoring System (myOSA IM)* that is composed of a set of intelligent algorithms aimed at identify the adherence level to the therapy by a given patient (*Analysis of adherence* in the Fig. 1). It includes also the *Recommendation engine* aimed at working with that adherence level to give to the *Composer of Recommendations* the list of cases that will be used to build the recommendations. The *Composer of recommendations* receives as input the cases from the *Recommendation engine* and composes the corresponding recommendations. Daily, the *Recommendation manager* receives the new monitoring data from the CPAP and puts in communication the *Composer of Recommendations* with the *Recommendation engine*, by means of the *API*, in order to get the appropriate recommendations. After that, the *Recommendation manager* sends those recommendations to the patient's app.



(a) (b)

Fig. 2. PCA and K-means clustering with k = 3. (Color figure online)

The *Analysis of adherence* module is aimed at detecting the current user adherence degree to CPAP therapy given a set of monitoring data. This module wraps up a predictive model based on unsupervised learning techniques. To build this model we used data from 4207 patients (980 women) using CPAP in the Spanish area. Each patient has her/his own profile composed of basic information (e.g., age, sex, marital status), as well as a set of extra features to provide a better description of the daily CPAP usage (e.g. number of minutes of usage per day, maximum number of consecutive days using the CPAP). Once the dataset was cleaned up, the most relevant features were extracted by means of a principal component analysis (PCA) on the normalized data. The first 2 components of the PCA achieved a 0.72 of explained variance ratio. This positive result allowed to suitably visualize the amount of data with only 2 dimensions. As an example, please consider Fig. 2-a where we have projected the whole amount of data on the 2 PCA dimensions highlighting in different colors users with few, normal and high consecutive usage of the CPAP machine. After feature reduction, k-means has been used to divide patients in suitable clusters. K-means models were built using different numbers of k and the corresponding results compared by using the silhouette metric. The best results were achieved with $k = 3$ obtaining a score of 0.31. With $k = 4$, $k = 5$ and $k = 10$ scores of 0.28, 0.25 and 0.23 were obtained, respectively. Figure 2-b shows the output of the adopted clustering technique, with $k = 3$. Once the best model was selected a post processing analysis was conducted to map the resulting clusters with adherence profiles. Table 1 summarizes the results for each cluster. According to the results, Cluster0 was assigned to "Compliant" (more than 4 h of usage, on average), Cluster1 to "No-compliant" (less than 3 h of usage, on average), and Cluster2 to "Regular" (in the range of 3–4 h of usage, on average).

Table 1. Results cluster centroids.

	Cluster0	Cluster1	Cluster2
MaxUsage (min.)	596.24	357.48	546.59
MinUsage (min.)	223.25	1.57	18.32
AvgUsage (min.)	458.35	198.79	328.42
NumDaysAboveUsage	0.97	0.17	0.77

The *Recommendation Engine* receives as input from the *Analysis of Adherence* a case composed of: the *PatientID*, which is the univocal identifier of the given patient (e.g., M1234); *Adherence*, which corresponds to the cluster to which the patient belongs (e.g., cluster "Compliant" corresponds to high adherence); *Probability* that is given by the k-means and indicates the reliability to belong to the cluster (e.g., 0.8); *Period*, which corresponds to the number of monitored days that have been analyzed (e.g., weekly); *Gradient*, which is the trend corresponding to the evolution of the adherence (e.g., negative); and *Evolution* that is the number of hours corresponding to the change in the adherence. With this information the *Recommendation Engine* builds a case by relying on a rule-based approach defined according to the expertise of lung specialists.

3 Current Implementation

The proposed IoT-based myOSA IM is part of the Spanish project myOSA. CPAP users in Catalonia have been involved in experimentation. The trials just started and a total of 50 patients will participate in the study.

Once a patient enters the program, s/he is provided with a CPAP to be installed at home and an app to be installed in her/his smartphone. In particular,

Table 2. Example of recommendations.

Period biweekly		Period quarterly		Recommendation
Adherence	Gradient	Adherence	Gradient	
C	↑	–	–	Keep it up but remember to be consistent Remember that sleep well is very necessary
NC	↓	–	–	You are not following the guidelines of your doctor, you must be constant Do not get discouraged and ask for help if you need it!
NC	↓	R	↓	It has worsened the use of CPAP lately It is very important to be consistent Please contact us if you have questions!
C	↑	NC	↑	You are using more CPAP during the last two weeks, keep it up Your body will appreciate it

we use the device Airsense 10 AutoSet by RESMED[2] that includes the hardware needed for storing and transmitting the data. Once a day, the CPAP sends data to the cloud where are stored and analyzed to identify the level of adherence (i.e., the cluster) the patient belongs to. Depending on the adherence (i.e., the clusters), different recommendations are sent. Three kinds of recommendations have been identified: awards, feedback, and alerts. *Awards* are given to outstanding patients when they considerably comply with the adherence. Moreover, awards are given to empower the patient when they move from an adherence level to a higher one (e.g., from regular to compliant). *Feedback* is given anytime patients need to receive some specific recommendation to improve the use of the CPAP or to be encouraged to use it more. *Alerts* are sent when the patient belongs to the no-compliant cluster and needs to be supported. Alerts may also be sent when a patient moves from an adherence level to a lower one (e.g., from regular to no-compliant). Table 2 shows an example of recommendations with the corresponding adherence level (C for Compliant, NC for No-Compliant, and R for Regular) and the gradient (↑ for positive and ↓ for negative).

Apart from recommendations, the app provides to patient the level of adherence; awards; feedback; and alerts, as well as specific information about the CPAP performance. Finally, through a Web application, lung specialists may access to the system and take a look to the state of a given patient.

4 Conclusions and Future Work

IoT, as a set of existing and emerging technologies, notions and services, can provide many solutions to delivery of healthcare systems and services to empower patients providing better care and remote monitoring. In this context,

[2] http://www.resmed.com/us/en/consumer/products/devices/airsense-10-cpap.html.

we presented an IoT-based system aimed at remotely support patients suffering Obstructive Sleep Apnea.

Clinical trials just started. In the near future we will refine the system improving the intelligent monitoring system by relying with more data and getting direct feedback from patients involved in the experiments. According to an iterative co-design approach we will also work together with lung specialists to improve and extend the set of recommendations.

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