A high-availability architecture for continuous monitoring of sleep disorders

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Abstract. We present a complete technical solution for continuously monitoring vital signs required for observing sleep apnoea events, one of the major sleep respiratory disorders. Based on industry accepted medical devices, we developed a GSM-based remote data acquisition and transfer module that is integrated via a set of web services into the server side of the application. The back-end is responsible with aggregating all the data, and, based on machine learning techniques, it provides a first level of filtering in order to warn about possible abnormalities. The proposed solution is currently under the test phase at the “Victor Babes” Hospital in Timisoara, Romania.

Keywords. Apnea, Sleep Apnea Syndromes, Health Information Systems, Medical Devices

Introduction

Obstructive sleep apnoea (OSA) is a disorder that consists of abnormal breathing pauses, irregular or superficial breathing that occurs during sleep [2, 11]. It has often been indicated as a serious, frequent but mostly underrated clinical problem. The reported incidence of apnoea varies, but there are about 1 in 4 men and 1 in 10 women with OSA in USA [1]. The morbidity risks entailed by the fact that many sleep apnoea cases are not discovered and treated in time are well documented by many comprehensive studies. Maybe the best known link is between sleep apnoea and cardiovascular problems, leading to hypertension, stroke and even death [13].

As such, we propose a monitoring framework that can improve the doctor-patient collaboration by providing real-time assessment of vital signs during sleep. This information should prove invaluable for doctors as they can monitor patients with sleep apnoea from a distance. Apart from this capability, it was essential to develop a filtering mechanism so that the physician can be pinpointed to relevant results, if any.

Important concerns arise from the strict requirements for professional drivers to be screened for sleep disorders, this being a well known cause of fatigue and inducing possibly fatal sleepiness [3-6].
1. Methods

Our solution is developed around two major sides of the problem, presented in Figure 1. First, we try to tackle the problem of heterogeneity in the spatial demographics of our patients, of which quite a few are in rural areas. On the other side, we want to automate as much as possible of the menial tasks the physician is required to carry out when a patient presents himself at the clinic for periodic reading and interpretations of the polysomnography data.

Regarding the problem of data acquisition the design of our solution consists of a hardware and software pluggable architecture over various polysomnography devices. For the actual clinical tests that are currently carried out, and at the level of the current discussion, we detail the solution applied for Philips Respironics Stardust II, one of the most popular devices for polysomnographic measurements[8].

The Stardust II device (as presented in Figure 2) is a low-power fully integrated solution for monitoring the major parameters of the observed patient which are necessary for establishing a diagnostic in the area of sleep apnoea: oxygen percentual saturation (SpO₂) and respiration rate. The continuous monitoring of these parameters provides means of assessing the evolution of the treatment.

The typical use-case involves working with our patients which, after being assigned with specific medical treatments and/or even a CPAP (i.e., Continuous Positive Airway Pressure) device, have to be monitored in order to adjust the treatment, depending on the actual response of the body.
All data is collected for the specified amount of time and is downloaded by the physician or other care-giver at a subsequent moment in time, when the patient is completing the periodic check-up. Using this approach, we identify two major issues. The first relates to the fact that there are no fast correction methods for dosage and treatment: the patient has to wait until the next visit in order to get the treatment adjusted. The second, of logistical nature, refers to the efficient scheduling of around tens of patients in order not to overwhelm the daily running of the clinic while having the required time for thorough analysis and interpretation of the data.

**Figure 2.** Philips Respironics Stardust II polysomnography device. The left sub-figure emphasizes the communications controller for RS232 while in the right one we can observe the mating board to board connector, the microcontroller with the associated EEPROM and the three sensor connectors, for the SpO₂, respiration rate and serial data transfer to the computer.

**Figure 3.** High level architecture of the enterprise monitoring and reporting system, detailing the information datapath and scalable server side of the solution

Based on the specific therapeutic protocols currently employed when dealing with sleep disorders in the spectrum of apnoea, we designed and implemented a system
(Figure 3) responsible of remotely collecting all the data from individual sleep recording devices and uploading them via an Internet connection to a dedicated server, while the physician is able to log-in and browse a much more extended data-set, perform various data analysis techniques on the samples, track the evolution of the patient in time, and much more [9].

We decided in the early stages of the design not to re-implement the functionality of a sleep recorder, which would require additional strict certifications, testing and validation [10]. Instead, the solution relies on existing devices, therefore the only implemented custom module is designed for remote data acquisition and reliable transport of Internet via a set of standardized web-services.

The available Stardust II, which is in the same time one of the most prevalent devices in the sleep medicine in Romania, is using a custom serial connection for interfacing with the Stardust II Client Software, managed by the on-board TI chip. Applying specific techniques we extracted the structure of the data frames and inferred the semantics of the various commands and fields so to be able to masquerade as a valid terminal computer running valid Stardust II software. At this moment there are two ways we can use our solution: one is to simply upload all the data via an SFTP connection to the processing queue of the server, while the other is to apply local semantic processing over the field in order to extract only the traces of interest. While the second approach gives us promising results, we are using only the first one for the moment in order to have a higher certainty for the validity of data.

The gateway uses a custom developed PCB around and ARM Cortex-M3 microcontroller with Quetc M10 GSM modem. A M2M data-plan was chosen from the data carrier.

The server back-end is deployed in the Amazon EC2 cloud running on Ubuntu LTS Server 13. A web-service was written in Python using ZeroMQ as high performance queuing stateless server. Using vsftpd as a FTP server configured for accepting secure FTP connections, we were able to implement the queuing mechanism for asynchronous uploads from various devices.

Two consuming services were developed and implemented: one is based on a rich web 2.0 interface with real time update of the data via AJAX, with jQuery and JS Charting framework, while a more simplified interface is deployed for Android mobile devices.

Using an external service under the form of Google Compute Engine API, we are experimenting with machine learning techniques for improving the alerting system in order to reduce the number of false-positive messages. This is not of high priority because right now the solution is implemented only for bridging the space-time problem between the patient and the physician.

2. Results

We present a set of three fully functioning modules for Stardust II which regularly send the vital sign data of patients to the central server. In order to shorten the development and update cycle, we use two modules within the “Victor Babes” hospital, while a third one is used for field tests being given to selected tech-savvy patients that are able to perform a simple update of the firmware, if required. The update process implies downloading a program received via email, connect the module through USB to a PC, and run the firmware update application.
After two months of testing we made 12 updates and collected 56 data dumps which are currently analyzed using the official Stardust II software. Work is carried towards improving the reliability of the systems and obtaining corresponding certifications and approvals.

3. Discussion

Obstructive sleep apnoea is an underrated respiratory problem with very high incidence among the world's population. However, it is still a widely unknown and underrated clinical problem. The diagnosis and treatment involves a time and money-consuming methodology. Through our present contribution, we pave the way for an improved methodology of diagnosing OSA before patients actually reach specialized help, as we create the infrastructure to automatically predict, with a high degree of accuracy, whether a patient is prone to developing this disease.

Acknowledgement

This work is supported by the Linde Real Fund 2014, through research grant “Morpheus: A Screening and Monitoring System for Sleep Apnoea Syndrome”.

References