Development of a System for Telemonitoring of Respiration Parameters for Patients with Obstructive Sleep Apnea

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Abstract—**Obstructive Sleep Apnea is a chronic sleep disorder affecting a large number of the global population. Telemonitoring has been successfully evaluated as an alternative method to traditional care. This paper identifies drawbacks of the current telemonitoring approaches and presents a universal wireless system for continuous monitoring of basic respiration parameters. The proposed system monitors four parameters, namely respiratory flow, airway pressure, Carbon Dioxide (CO_2) and Oxygen (O_2) gas concentrations. Data are wirelessly transmitted to a computer which acts as a web server. The system will allow remote evaluation of home ventilation support efficiency and the application of custom algorithms for decision support and respiration event detection.**

I. Introduction

Obstructive Sleep Apnea (OSA) affects 1% to 6% of the adult world population [1]. OSA is a chronic sleep disorder manifested as limitation or absence of respiratory air flow during sleep. It is diagnosed during overnight stay in sleep laboratories.

The standard OSA treatment is the application of positive airway pressure support during sleep. The goal of the treatment is to minimize hypopnea, apnea, snoring and respiratory effort related arousal events; reducing complications of OSA. Support could be continuous (Continuous Positive Airway Pressure CPAP), automatically adjusted (Auto-titration Positive Airway Pressure APAP) or at two pressures levels (BiPAP). CPAP and BiPAP requires a sleep technician to identify optimal preset pressure(s) setting during a sleep lab study, while APAP automatically (unattended study) adjusts pressure levels, within clinical preset limits, based on monitored physiology variables [2].

Both CPAP and APAP treatments reduce Apnea Hypoxia Index [3]. Bibliographic evidence suggests that both methods exhibit drawbacks; periods of Oxyhemoglobin de-saturation are evident for both methods [3], manual titration is considered the golden standard but optimal pressure is subject to change [4], safety considerations apply to APAP [4] and event detection technologies affect performance [4, 5].

Clinical guidelines [3], pressure prediction formulas [6, 7], Clinical Decision Support Systems (CDSS) [2] and Artificial Intelligence techniques [8] have been suggested for improving titration levels efficiency. Recent studies suggested that there is no significant difference in clinical outcome between auto titration and algorithmically defined fixed pressure [9, 10].

Research co-funded by European Social Fund and Greek National actions; action "Archimedes III – funding of research groups in T.E.I.".

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II. Background

The utilization of Information and Communications Technology (ICT) in respiratory medicine is limited [11]. It has been shown that the application of telemonitoring home based ventilation support could match traditional care both for adults and pediatric patients [12, 13].

Most commercial CPAP devices incorporate both data storage and computer communication. Recorded data are either stored and downloaded or transmitted in quasi real time; most commonly through an RS232 interface. This latter feature has been used or suggested as a method for providing remote monitoring. Evers and Van Loey [14] have proposed the use of non-medical devices, such as RS232 to Ethernet converters, for adding telemonitoring and remote control functionality to mechanically ventilated patients. Dellaca et al. [15] developed a ventilator communication system which acts as a server. The system is capable of bidirectional communication over the internet through the mobile phone network. The device was tested on patients with OSA [16]. Hospital technicians tele-monitored flow, pressure and air leaks and remotely controlled CPAP pressure. Authors concluded that telemetric CPAP titration was effective.

The use of the CPAP computer interface for the purpose of telemetry has several drawbacks, which are summarized in Table I.

TABLE I. PROBLEMS WITH THE USE OF CPAP COMPUTER INTERFACE FOR TELEMTRY

No	***Problem statement***	***Discussion***
1	Communication protocols depend on manufacturer	Communication software should adapt to different manufacturers. Therefore there cannot be a universal system. Data encryption should be implemented by the communication device.
2	Number and quality of measured data depends on manufacturer's technology	CPAP devices detect snoring either by airway's pressure vibrations or flow vs. time curves [4] and airflow is detected either by transducers or estimated based on blower's speed [4].
3	Respiratory events identification is dictated by the algorithms developed by device's manufacturer	A Hyponea criterion is the magnitude reduction of the flow signal below 50% of basal value [17]. Similarly apneas are marked when flow drops below 10% of basal value [17]. However as Otero et al. [17] argues, basal value is not adequately defined and it does not remain constant during sleep

To overcome the first two problems (Table I), researchers and manufacturers have developed custom acquisition and communication systems. Alice PDx from Philips Respironics [18] records polysomnographic (PSG) data during sleep study. It utilizes store and retrieve technique for viewing and processing recorded data. A CleveMed [19] wireless PSG product was evaluated by Kayyali et al. [20] on ten home patients. Sleep technicians remotely evaluated real time PSG data, transmitted through a cell phone Gateway. Chih-Ming et al. presented a telemonitoring solution [21]. The system is processing microphone recordings for detecting snoring and OSA symptoms.

Different methods have been applied for detecting respiratory events as an alternative to sound and flow based threshold algorithms [17]. Artificial Intelligence techniques, such as Neural Networks [8], Fuzzy Logic [22 -24], and Experts systems [25] have been successfully evaluated for identifying pathological events.

III. AIMS

The paper presents the development of a universal respiration parameter bedside tele-monitor. The proposed system is designed to overcome the limitation described in Table I. Table II presents the proposed design solutions to the communication problems stated in Table I.

TABLE II. DESIGN SOLUTIONS ON CPAP COMPUTER INTERFACE PROBLEMS FOR TELEMETRY

No	*Problem statement*	*Proposed Design Solutions*
1	Communication protocols depend on manufacturer	The system transmits wirelessly and encrypted to a computer, the measured data utilizing a standard XBee (IEEE 802.15.4) protocol [26]. Data are quasi real time transmitted and stored in European Data Format (EDF) [27]. Furthermore the use of 802.15.4 protocol incorporates networking capabilities, thus enabling simultaneously communication of more than one XBee devices.
2	Number and quality of measured data depends on manufacturer's technology	Pressure and Flow measurement is performed by calibrated and temperature compensated piezo-resistive transducers; flow utilizes a differential pressure flow transducer.
3	Respiratory events identification is dictated by the algorithms developed by device's manufacturer	Data are transmitted as raw data, allowing further processing with the utilization of custom software. This feature allows the extraction of respiration related parameters, such as respiration volume and frequency as well as the application of custom respiratory events detection algorithms.

Additionally the system is equipped with CO_2 and O_2 gas concentration transducers which measure concentration on an aspired sample (side stream technology). The location of the aspiration port is determined by the user, therefore expired CO_2 or delivered O_2 could be measured.

IV. METHODS

The developed system's block diagram and photo is presented in Figures 1 and 2 respectively.

The system consists of a Parallax [28] Propeller multi core microcontroller, a Parallax BOE development platform, two Freescale pressure transducers, MPXV7002DP and MPXV4006GP for measuring flow and airway pressure respectively, an XBee 802.15.4 wireless module from Digi [26], a MG811 gas sensor for CO_2 from HANWEI Electronics CO Ltd [29], a LumiOX gas sensor for O_2 from SST Sensing Ltd [30] and a miniature pump for air sample aspiration.

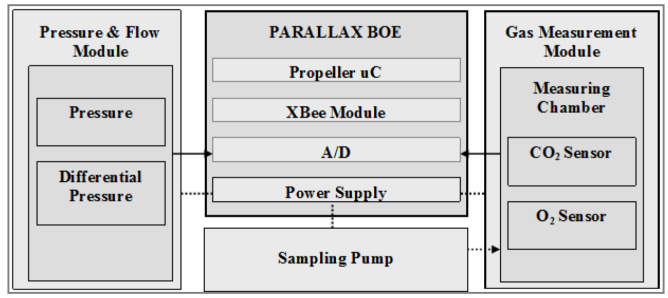

Figure 1. Block Diagram of Respiration Monitor

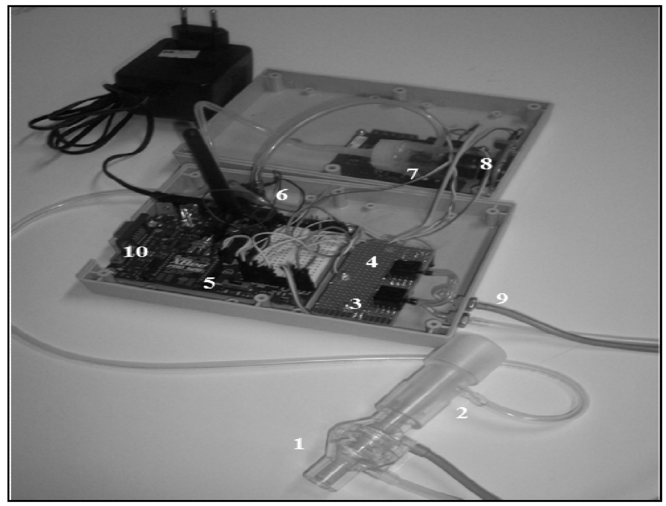

Figure 2. Photo with annotations of the system: (1) Differential pressure flow transducer, (2) Sampling port, (3) Differential pressure transducer, (4) Pressure transducer, (5) XBee module, (6) Micropump, (7) O2 sensor, (8) CO2 sensor, (9) sensor tubing ports, (10) USB programming port.

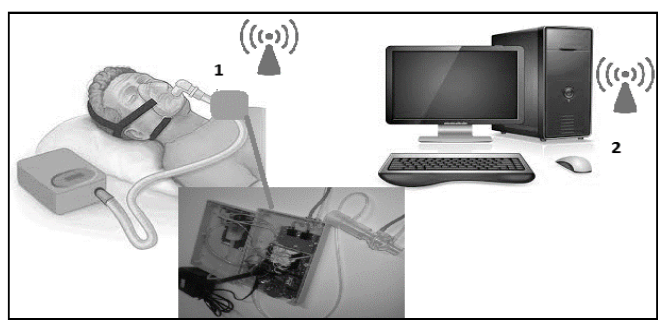

Figure 3. Overview of the System: (1) Respiration monitor, (2) Remote PC.

The Parallax [28] BOE platform incorporates Propeller microcontroller and peripherals, power supply for peripheral boards, USB connectivity for communication and programming, four 10bit channels Analog to Digital converter (ADC) and XBee module support. The LumiOX gas sensor [30] is factory calibrated and uses the principle of fluorescence quenching by oxygen for measuring O_2. LumiOX is mounted on an evaluation Interface Board by SST sensing Ltd [30], and provides a 0 to 5V analog output.

The CO_2 sensor [29] adopts solid electrolyte cell principle. The CO_2 sensor is mounted on a module (MG-811 gas sensor module), providing 0 to 5V analog output for measurements. Both gas sensors are located inside a sampling chamber for measuring gas concentrations on the aspired sample.

Analog signals from pressure and differential pressure flow transducers are sampled at 100 Hz, while signals from gas transducers are sampled at 20 Hz.

The respiratory monitor was calibrated with the use of medical graded testers and devices [31 – 33].

The computer (Figure 3) is equipped with an XBee USB stick for wireless communication, and could act as a standalone monitoring and processing station or as an internet server for remote viewing / storing measured data.

V. Evaluation - Calibration

The system's sensor peripheral modules where calibrated with the use of ventilator testers and capnography medical devices.

The pressure MPXV4006GP sensor was calibrated by applying quantized pressures via a syringe and simultaneously measuring QA-PT tester reading (from Fluke Biomedical former Metron [33]) and sensor's voltage output (Figure 4). The sensor's response was linear for the measuring range (0 to 60 mbar).

The flow measuring module, consisted of the flow differential pressure (DP) transducer and the differential pressure sensor MPXV7002DP, were calibrated by applying quantized flow rates with the use of an AMETEKTIP MICROJammer blower [32]. Flow rates were measured with the PF-300 imtmedical Flow Analyzer [31], and sensor's voltage output were recorded (Figure 5). The system was linear for bidirectional flow measurements in the range of -145 to 185 L/min.

The CO_2 gas sensor module was calibrated with the use of a medical capnographer (Normocap 520). Subjects were exhaling into a restricted space (Figure 6). Readings from the capnographer and CO_2 module's voltage output were recorded. The system was linear in the range of 0 to 47 mmHg.

The O_2 module was calibrated with the use of an Oxygen canister and a ventilator tester (Fluke Biomedical VTplus HF tester [33]). The gas was sampled from a close circuit, where O_2 concentrations were manually varied. The tester's reading and the module's voltage output were simultaneously recorded. The O_2 module's response was linear in the range of 0 to 37% O_2 concentrations.

The operation of the system was preliminary evaluated with the use of a CPAP device. An artificial lung and an exhalation valve were mounted on the CPAP tubing. The CPAP pressure was set to 13 mbar and the respiration phases were manually initiated by applying mechanical pressure to the artificial lung. The remote viewing station was recording and displaying the transmitted data from the respiration measurement system. The software calculates the delivered volume, as well as, the respiration rate (RR) from the transmitted data (Figure 8).

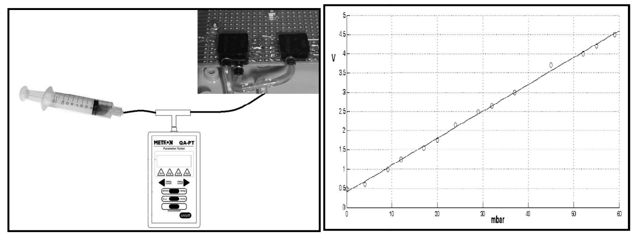

Figure 4. Pressure Sensor calibration: (left) Calibration schematic, (right) Calibration data (Y: Sensor's output in V, X: Pressure in mbar)

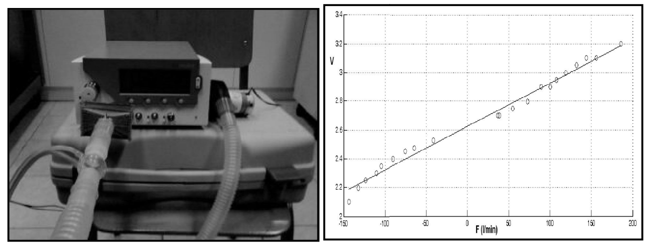

Figure 5. Flow Sensor Calibration: (left) calibration arrangement, (right) Calibration data (Y: Sensor's output in V, X: Flow in L/min)

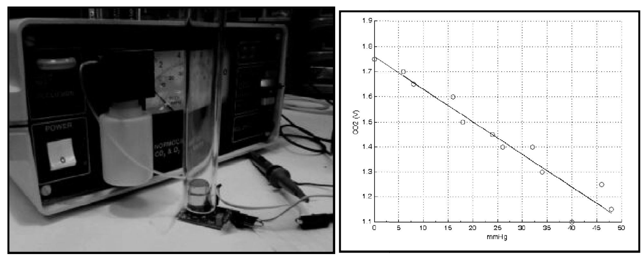

Figure 6. CO_2 Sensor Calibration: (left) calibration arrangement, (right) Calibration data (Y: Sensor's Output in V, X: CO_2 in mmHg)

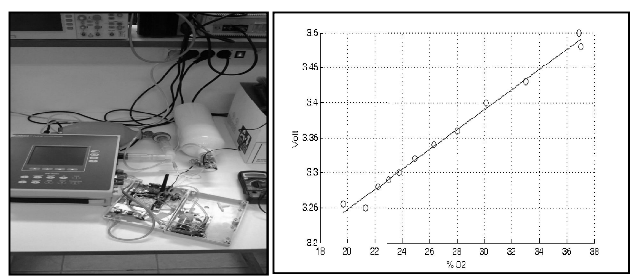

Figure 7. O_2 Sensor Calibration: (left) Calibration arrangement, (right) Calibration Data (Y: Sensor's Output in V, X: O_2 %)

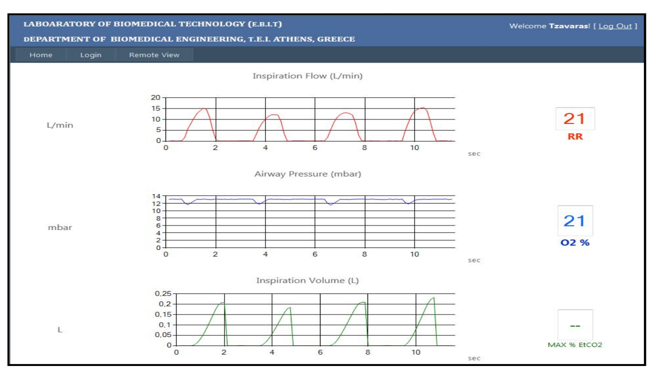

Figure 8. Screenshot of remote viewing software

VI. Discussion

The paper presents the development of a bed side respiration parameters monitor and reports on system's bench test preliminary evaluation. The proposed design exhibits several advantages over relevant published work. The system wirelessly transmits encrypted measured data, utilizing standard protocols, to a remote pc that could act as a local monitor or a remote viewing server. The measured values do not depend on manufacturer's measuring principle and the data could be further processed by custom algorithms for detecting respiratory related events.

We will investigate in future work the use of volume recordings as the appropriate parameter for evaluating hypopnea and apnea events. Flow threshold detection algorithms are problematic both in terms of establishing a basal value and relating flow peak to inspired volume.

A system's evaluation on OSA patients is planned for the future. The system will be evaluated in combination with the developed wireless Electrocardiogram and Oxygen Saturation system [34] and the CPAP titration clinical decision support system [2].

Acknowledgment

This research project has been co-funded by the European Union (European Social Fund) and Greek National resources under the framework of the "Archimedes III: Funding of Research Groups in TEI of Athens" project of the "Education & Lifelong Learning" Operational Programme.

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