REMOTE RESPIRATION MONITORING SYSTEM FOR SLEEP APNEA DETECTION

C. Rotariu¹, H. Costin²³
“Gheorghe Asachi” Technical University of Iași
1. Faculty of Automatic Control and Computer Engineering
University of Medicine and Pharmacy “Grigore T. Popa” – Iași
2. Faculty of Medical Bioengineering
3. Institute of Computer Science of Romanian Academy, Iași Branch

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(Abstract): Sleep is a dynamic physiological process, its primary function being the restoration of the central nervous system. Because sleep disorders affect a significant part of the population the dynamic long term monitoring of human respiration plays a very important role in diagnosis and treatment. Material and methods: We describe a remote monitoring system designed for in-hospital or at-home detection with a high degree of accuracy of sleep-related disorders in patients experiencing episodes of obstructive sleep apnea. Patient’s respiratory rate is continuously measured by using wireless devices and then transferred to a central monitoring station via a wireless sensor network. The central monitoring station runs a respiration monitoring application that receives the patient’s respiratory rate from the network and activates an alert upon detection of a sleep apnea episode. Results: A user-friendly graphical user interface was designed for the respiration monitoring application that displays patient’s respiratory rates and sleep apnea alerts. A prototype of the system has been developed, implemented and tested. Conclusions: The described system allows persons with respiratory diseases or elderly to be monitored at their homes, as an alternative to medical supervision in hospitals. Keywords: APNEA DETECTION, REMOTE MONITORING, WIRELESS SENSOR NETWORKS.

Sleep is a naturally recurring state of rest for the mind and body, a third of life being spent. During sleep the whole central nervous system is restored. Therefore, good sleep is an important component of a healthy lifestyle. However, sleep disorders affect a significant part of the population. According to the American Academy of Sleep Medicine approximately 20% of the population in modern societies suffers from sleep disorders. For instance, in Europe the prevalence of obstructive sleep apnea is estimated at 2% of women and 4% of men, having a direct impact on their quality of life (1).

The remote sleep monitoring devices, integrated into a system, allow patients to be monitored from a distance, for example at their homes, the recorded signals being transmitted to a monitoring centre and allowing sleep specialists to analyze the evolution of the patient.

The long term monitoring of human respiratory dynamics plays a very im-
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important role in the diagnosis and treatment of a number of medical conditions such as hypertension, circadian rhythm analysis, atherosclerosis, stroke, or even sudden death syndrome. Long term respiratory monitoring is a widely used method in the diagnosis of obstructive sleep apnea (OSA).

Respiratory rate (RR) is a physiological parameter used by some wireless monitoring systems as it allows the assessment of OSA, as RR can be recorded promptly and normal and abnormal variations can be easily differentiated.

A widely used method for the diagnosis of sleep-related diseases is polysomnography that records a number of physiological variables including brain and heart activity, patient motion, RR, or oxygen saturation. However, polysomnography test is expensive, requires well trained medical personnel and keeps the patient in hospital overnight with many electrodes and sensors attached to him. To overcome these problems, numerous systems for home sleep monitoring are already in use. For example, some respiratory activity monitoring methods use thermistor based sensors (2), others use piezoelectric elastic bands placed around the chest (3), dual frequency microwave radars (4) or respiratory inductive plethysmography (5). Other methods use the ECG signals to extract the RR (6). All these, although acceptable for shorter periods of time, involve sensors attached to patient, connected by some unwieldy wires to monitoring devices that are not very comfortable for the sleeping patient. In order to avoid this situation, our system uses low power wireless devices and radio transceivers.

Many available home systems are not adequate for monitoring as they require the patients to be in conscious state able to press the alarm button. Other systems record the sleep data on a memory card and process the signals the next day, making them improper for real time operation. To solve this problem, we propose a wireless sensor system for real-time sleep apnea detection which enables remote monitoring while the patient is at home.

This paper describes a remote respiratory monitoring system for the detection of sleep disorders based on wireless sensor nodes. The sensor nodes contain commercially available modules that are connected together, perform the measurements, compute the results and transmit them to a central monitoring station. The central monitoring station runs a patient RR monitoring application that displays the RR in real-time and activates the alarms when an OSA episode is detected.

MATERIAL AND METHODS

The proposed remote monitoring system for sleep disorder detection (fig.1) consists of a wireless sensors network (WSN) used to measure the RR and transmit it to a central monitoring station running a patient RR monitoring application. Each sensor node in the WSN contains a wireless low power device attached to the sleeping patient used to compute the RR. There are also several repeater nodes distributed in WSN at fixed location, their number and density depending on the specific coverage requirements. An access point acting as a WSN coordinator is connected to the monitoring station through a USB connection. The central monitoring station running a patient RR monitoring application that receives the RR data from WSN, displays it as temporal waveforms, and activates the alarms when an OSA is detected.
Each sensor node contains an eZ430RF2500 circuit (Texas Instruments) (7). The eZ430-RF2500 is a complete wireless development tool for the MSP430F2274 microcontroller and CC2500 wireless transceiver that includes all the hardware and software required to develop a WSN in a convenient USB stick. MSP430F2274 is a 16-bit RISC ultra-low-power mixed signal microcontroller, has a memory structure that includes a 32 kb flash memory and 1kb on-chip SRAM. Other features of the MSP430 include: two built-in 16-bit timers, a fast 10 bit 200 kbps A/D converter with internal reference, enhanced universal serial synchronous/asynchronous communication interfaces USART, I2C, SPI. The internal digitally controlled oscillator allows wake-up from low-power modes to active mode very fast, facility that is used to extend batteries life.

The CC2500 wireless transceiver is a low-cost 2.4 GHz transceiver designed for very low-power wireless applications. The circuit uses for data transmission the 2400 MHz ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency bands, supports various modulation formats, has a configurable data rate up to 500 kBaud, and consumes less than 21.2 mA in transmission mode at 0 dBm output power and 17.0 mA in receiving mode.

We used the SimpliciTI protocol from Texas Instruments to transfer data from sensor node to central monitoring station. SimpliciTI is a proprietary, low-power radio-frequency network protocol used with small-scale WSNs that requires less memory than the widely used ZigBee protocol. This network contains battery-operated devices which require long battery life, low data rate, and have a limited number of nodes talking directly to each other. SimpliciTI network protocol supports End Devices (ED) in a peer-to-peer network topology, an Access Point (AP) to store and forward the data, and Range Extenders
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(Re) to extend the range of the network.

Airflow detection using a nasal thermistor is one of the most frequently used methods to sense breathing pattern. Thermistors are electric circuit elements made of semiconductor materials that are characterized by a high negative temperature coefficient (NTC) or a high positive temperature coefficient (PTC). A NTC thermistor acts like a resistor, with temperature coefficients of typically $-3\%$ to $-5\%/\degree C$. The high sensitivity allows the thermistor circuit to detect minute changes in temperature, which could not be observed with other temperature detectors such as a thermocouple circuit. Thermistors placed in front of a nose detect the inspiratory and expiratory temperature fluctuations between ambient temperature (inhalation) and lung temperature (exhalation). It is known that the difference in temperature between the inhaled and exhaled air is about $10\degree C$. We use two 0603 SMD type thermistors (fig. 3) with the following characteristics: $R_{\text{nom}} = 10 \, \text{k}\Omega$ at $25\degree C$, $B = 3380$, 5% tolerance, connected as in fig. 2.

**Fig. 2.** Thermistors to MSP430F2274 microcontroller interface

**Fig. 3.** Thermistor

**Fig. 4.** Chest belt
Another wireless device uses Pneumotrace II chest belt respiration transducer. The chest belt is a rugged, piezo-electric respiration transducer, which linearly generates a high level signal in response to changes in thoracic circumference associated with respiration. It generates 20 to 200 mV into a 1 MΩ load. Practically, for signal acquiring we use the same device, replacing the thermistor with the chest belt (fig. 4).

Power supply to the devices in fig. 3 and fig. 4 is provided by a CR2032 lithium battery and the A/D sampling frequency is 20 Hz.

A third wireless device uses a small accelerometer to detect the chest movements associated with respiration. It is a three-axis accelerometer (ADXL330 – fig. 5) with buffered outputs, connected to the 10 bit A/D inputs of the MSP430F2274. ADXL330 has the following technical specifications: 3-axis sensing, small, low power consumption: 200 μA at VS = 2.0 V (typical), single-supply operation: 2.0 V to 3.6 V, excellent temperature stability. The typical sensitivity shift over temperature for supply voltages of 3 V is typically better than ±1% over the −25°C to +70°C temperature range. To detect the RR, accelerations signals from the three axes are acquired at a sample rate of 20 Hz, 10 bit/sample, then the microcontroller identifies the peaks in the filtered acceleration signal \( a = \sqrt{a_x^2 + a_y^2 + a_z^2} \), where \( a_x \), \( a_y \) and \( a_z \) are accelerometer outputs (fig. 6).

**RESULTS AND DISCUSSION**

The flowchart of the software running on MSP430F2274 microcontroller in each node of the sensor network, including radio communication, is presented in fig. 7. After initializing, authentication and a START command, the sensor node wakes up to read and process the analogue signals. To minimize the energy waste, since an important power consumer is the radio transceiver, CC2500 enters a low power mode after each transmission cycle.

A user-friendly Graphical User Interface (GUI), running on the central monitoring station, was developed for real-time RR monitoring and apnea alert. GUI was developed by using LabWindows/CVI (fig. 8). On the GUI, temporal waveform of RR signal for selected patient are displayed, and the status of each sensor node (the battery voltage and the measured power from the received radio signal, used as
estimation for the distance between the wireless pacemaker and nearest Range Extender or Access Point).

The prototype of the above described system has been implemented and tested. The RR of three patients was computed by the wireless devices described above, and transmitted via WSN to the central monitoring station. The GUI running on the monitoring station displayed the RR correctly. Then, some apnea events (pauses in breathing lasting at least 10 seconds) were simulated, and the interface also displayed these alerts correctly.

Finally we measured the power consumption of the each sensor node. Knowing that CC2500 wireless transceiver is the largest contributor to overall power consumption, the average per-node estimate of power consumption is 0.44 mA. Calculating the battery life span (lithium battery 2240 mAh) ideally assuming that batteries maintain constant terminal voltage throughout life span, we obtained a value of approximately 23 days.

CONCLUSIONS

The prototype of a flexible, scalable and cost-effective medical remote monitoring system for the detection of OSA has been developed, implemented and tested. The system is suitable for continuous long-time monitoring of human respiration for a number of medical conditions requiring analysis of respiratory rate, sleep-related respiratory disorder or ischemic heart disease.

The described system allows persons with respiratory diseases or elderly to be...
monitored at home, as an alternative to medical supervision in hospitals.

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REFERENCES

CD35 PROTEIN AND EPSTEIN-BARR VIRUS

Epstein-Barr virus (EBV) is member in the human herpesvirus family. EBV affects nine out of 10 people and can cause infectious mononucleosis. Also it was the first human virus found to be associated with several types of cancer and with autoimmune disorders. To enter into the host cell, EBV attaches to the receptor CD21 of the primary B-cell membrane complementary with envelope glycoprotein EBV gp350/220. A recent study conducted by Fingeroth and Ogembo, show that the EBV glycoprotein gp350/220 is able to bind also a second receptor represented by the CD35 protein. This protein, which exists only in humans, was identified as a malaria receptor and as target in autoimmune diseases. Researchers showed that the CD35 receptor has a role in primary infection and reveals the importance of EBVgp350/220 for the development of a vaccine able to prevent or reduce the risk of infectious mononucleosis and EBV-associated pathology (Ogembo JG, Kannan L, Ghiran et al. Human Complement Receptor Type 1/CD35 Is an Epstein-Barr Virus Receptor. Cell Reports, 2013; 3 : 371-85).

Cătălina Luncă