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Wireless System for Remote Monitoring of Oxygen Saturation and Heart Rate

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Abstract— This paper describes the realization of a wireless oxygen saturation and heart rate system for patient monitoring in a limited area. The proposed system will allow the automatic remote monitoring in hospitals, at home, at work, in real time, of persons with chronic illness, of elderly people, and of those having high medical risk. The system can be used for long-time continuous patient monitoring, as medical assistance of a chronic condition, as part of a diagnostic procedure, or recovery from an acute event. The blood oxygen saturation level (SpO_2) and heart rate (HR) are continuously measured using commercially available pulse oximeters and then transferred to a central monitoring station via a wireless sensor network (WSN). The central monitoring station runs a patient monitor application that receives the SpO_2 and HR from WSN, processes these values and activates the alarms when the results exceed the preset limits. A user-friendly Graphical User Interface was developed for the patient monitor application to display the received measurements from all monitored patients. A prototype of the system has been developed, implemented and tested.

I. Introduction

PULSE oximetry is a useful method of monitoring the heart rate and the level of oxygen in the blood in a noninvasive way. It represents a standard procedure for the measure the blood oxygen saturation of hemoglobin in hospitals (operating rooms, intensive care units, or sleep studies) [1].

Oxygen saturation (SpO_2) is defined as the ratio of oxyhemoglobin to the total concentration of hemoglobin. Along with heart rate, blood pressure, body temperature, and breathing rate, the SpO_2 is an important vital parameter, used for detection of hypoxemia. Optimal hemoglobin in O_2 is defined by the SpO_2 values ranging between 94 – 100%, slight hypoxemia by saturation values of 88 – 93%, average hypoxemia by saturation values of 83 – 88%, and severe hypoxemia by values less than 83%. From medical point of view it is considered that the decrease of the patient's SpO_2 below 93% must be followed immediately by compensatory measures.

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Heart rate (HR) is another physiological parameter commonly used by wireless patient monitoring systems. It allows an assessment of the condition of the patient, the cardiac arrhythmias can be recorded promptly and variations can be easily differentiated from normal/abnormal. This parameter was frequently used in studies and research projects, providing vital information on the cardiovascular function. HR is usually performed with devices that use the photoelectric plethysmography measurement method on peripheral arteries.

The homecare monitoring of patients with chronic diseases or elderly also represents an alternative to medical supervision within hospitals [2].

In the last two decades, the steady advances of the integrated circuits technology, wireless networks, and medical sensors have opened the way to miniature, low power, and intelligent monitoring pulse oximeters, suitable for many portable medical applications. On the market has also been a significant increase in various types and numbers of pulse oximeters, ranging from simple HR monitors to wireless digital pulse oximeters. Although widely used, they are not suitable for long time monitoring due to their limited power supply [3].

Monitoring patient's SpO_2 and HR within hospital or his home requires the use of sensors attached by wires to the medical devices, which limits the patient's activity. As an alternative, wireless devices are suitable for remote patient monitoring, giving him the freedom of movement [4].

The SpO_2 and HR are continuously measured by the proposed wireless system using commercially available pulse oximeters. The results of measurements may be wirelessly transmitted to central monitoring station by using Bluetooth or WiFi nodes, but they are more expensive, consume more power, require installing an expensive infrastructure, and are useful for high bandwidth applications. Another Bluetooth limitation is that the standard allows only a limited number of nodes. These issues make WiFi and Bluetooth nodes unsuitable for widespread wireless monitoring of patient's SpO_2 and HR. As an alternative, wireless sensor networks, containing compact sensor nodes and having low power consumption, represent a cost-effective solution. The ZigBee standard is similar to Bluetooth but is simpler, has a lower data rate, a less power consumption, an operational range of 10–75m, and allows up to 254 nodes, making it suitable for limited area applications.

This paper describes a system based on wireless sensor nodes for patient monitoring in a limited area. The sensor nodes contain commercially available devices that perform the measurements and transmit the results to a central monitoring station. Depending the distance of patient from the central monitoring station, the measurement can pass through multiple Range Extenders. The central monitoring station runs a patient monitor application that displays the results and activates the alarms when these exceed the preset limits.

II. System description

A. Overview of the proposed system

A conceptual view of the proposed system consists of the following components: a wireless sensor network (WSN) used to measure SpO_2 and HR from the patient, each sensor node has a pulse oximeter attached on the patient; several Range Extenders, distributed in WSN at fixed location, their number and density depending by the coverage requirements; a Central monitoring station running a patient monitor application that receives SpO_2 and HR from WSN, displays them as temporal waveforms, processes these values and activates the alarms when the results exceed the preset limits.

The overall architecture of the proposed wireless system is represented in Fig.1.

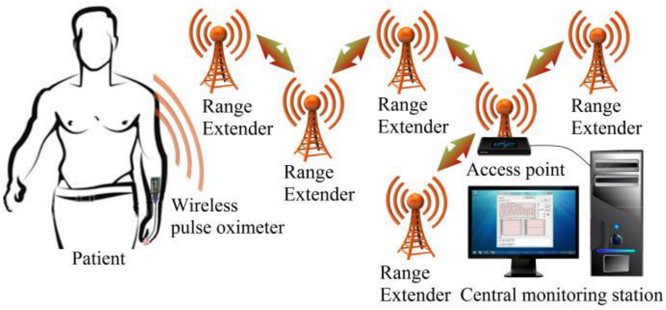

Fig 1. Wireless system for remote monitoring

Each sensor node contains a commercially available Micro Power Oximeter Board from Smiths Medical [5], used to acquire patient's SpO_2 and HR, and connected to an eZ430RF2500 module from Texas Instruments [6], as it is represented in the Fig.2.

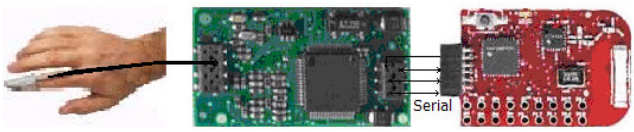

Fig 2. Micro Power Oximeter Board connected to eZ430RF2500

B. Oxygen Saturation and Heart Rate Acquisition

The pulse oximeter is used to collect the SpO_2 and HR from the patient and has the following specifications [5]: measurement range of 0–99% SpO_2 with ±2% accuracy for 70 – 99% SpO_2, and pulse rate measurement range of 30 – 254bpm with ±2bpm or ±2% accuracy.

We decided to use the finger clip sensor, but we can also use ear lobe or the nose probes when patient has cold or excessive hand tremor.

The pulse oximeter determines the SpO_2 and HR by passing two wavelengths of light, one in the visible red spectrum and the other in the infrared spectrum, through body tissue to a photodector. The SpO_2 is obtained by measuring the absorbance of light by blood for each wavelength, and then computing the ratio between these two intensities. The pulse oximeter's microcontroller processes the received light intensities, separates the time invariant parameters (tissue thickness, light intensity, or venous blood) from time variant parameters (arterial volume and SpO_2) to identify the signal produced by arterial pulsations, and computes the SpO_2 and HR. The pulse oximeter is connected to the MSP430F2274 from the eZ430RF2500 module through an asynchronous serial interface as it is represented in the Fig.2. The serial interface uses microcontroller's serial I/O pins at 3.3V. Data transmission between pulse oximeter and MSP430F2274 is performed at 4800bps with 60 packages per second. Each sampled data has 4 byte packets length and includes SpO_2 level, HR, Plethysmographic (PPG) signal, and Status bits [7].

C. Wireless network

The eZ430RF2500 module is a small wireless radio development kit from Texas Instruments based on the MSP430F2274 microcontroller [8] and CC2500 wireless transceiver [9]. The eZ430RF2500 module has a limited communication range (approx. 10m) and necessitates range extenders to send the measured data to central monitoring station.

The topology of the WSN we have used is a static routing infrastructure with one access point, a number of range extenders depending by the coverage area required by each application, and a number of mobile nodes. The access point and range extenders must be connected to a permanent power supply, but the nodes may operate on batteries. The network configuration is represented in the Fig 3.

The low power consumption of sensor nodes is an important characteristic of the WSNs and contributes not only to prolonged lifetime of the sensor nodes, but also to the system miniaturization. For a sensor node the overall power requirements are represented by the sum of power requirements of each component. The average current consumption of the pulse oximeter is 6.6mA. Therefore we also chose a low-cost 2.4GHz transceiver (CC2500) designed for very low-power wireless applications, circuit is intended for the 2400 – 2483.5 MHz ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency band. The transceiver consumes less than 21.2mA in transmission mode at 0dBm output power and 17.0mA in receiving mode [9].

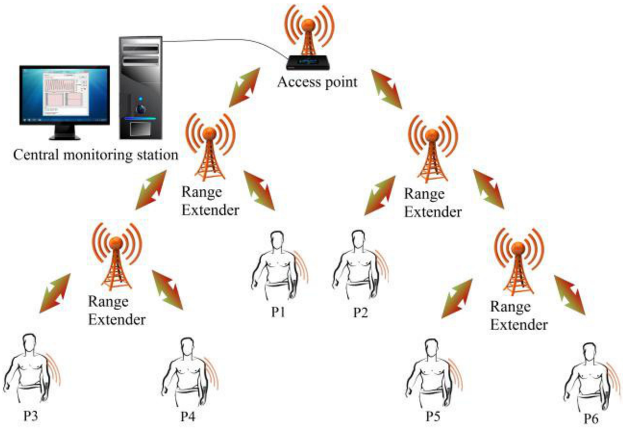

Fig 3. Wireless network configuration

As a network protocol, we decided to use the SimpliciTi[11] from Texas Instruments to transfer data from sensor node to central monitoring station. SimpliciTI has as the main features low memory needs, advanced network control, and sleeping modes support. It is intended to support the development of wireless networks containing battery operated nodes and require low data rates.

The eZ430RF2500 module connected to Micro Power Oximeter Board was configured as End Device (ED), the eZ430RF2500 connected to central monitoring station as Access Point (AP), and several others are configured as Range Extenders (RE). Data transmission rate between the ED and AP through RE was set at one transmission per second.

D. Microcontroller firmware

The flowchart of the firmware running on MSP430F2274 microcontroller from the ED is represented in the Fig. 4.

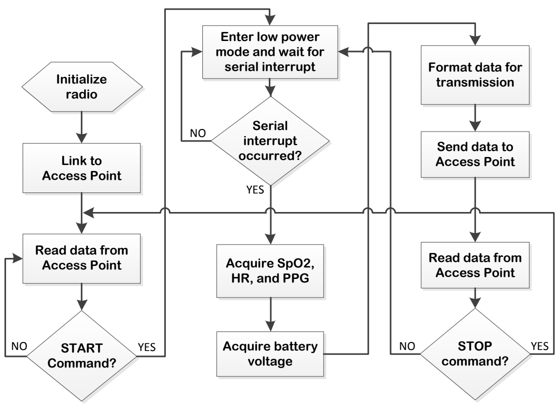

Fig 4. Flowchart of firmware running on the MSP430F2274.

In this instance, the eZ430RF2500 module initialize onto the network, then, after a START command, wakes up to read the SpO_2, HR and PPG from pulse oximeter. Also, the MSP430F2274 read the battery voltage and communicate the data to central monitoring station through RE and AP. In order to minimize the energy waste, since an important power consumer element is the radio transceiver, the CC2500 entered into low power mode after each transmission cycle.

E. Central monitoring station

A user-friendly Graphical User Interface (GUI) was developed for the patient monitor application, to display the received measurements and alarms from all monitored patients. The GUI running on the central monitoring station was developed by using LabWindows/CVI version 2009, and is represented in the Fig. 5. On the GUI, temporal waveform of SpO_2, HR, and Plethysmographic signal for selected patient are displayed, and the status of wireless pulse oximeter (the battery voltage and distance from the nearby RE or AP). The distance is represented in percent computed based on received signal strength indication measured on the power present in the received radio signal (RSSI).

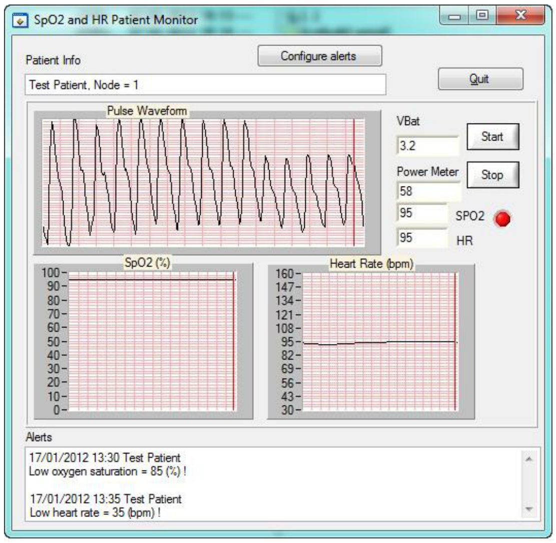

Fig 5. Central monitoring station GUI

The monitored patient has a name previously entered and information from his medical record (limits above the alarms become active) is used by the alert detection algorithm. The physiological conditions that may cause alerts are: low SpO_2 if $SpO_2 < 93\%$, bradycardia if HR < 40bpm, tachycardia if HR>150bpm, HR arrhythmia if $\Delta HR/HR$ over last 5 min. > 20%, HR variability if max HR variability > 10% /the last 4 readings, low battery voltage if VBAT < 1.9V, low value for RSSI if measured RSSI < 30%.

The types of arrhythmic heart rhythm are derived by performing the automated analysis on PPG signal. The PPG signal is used by the software running on the central monitoring station to compute the Pulse to Pulse Interval (PPI), as estimation to R to R Interval provided by the ECG signal.

III. Results

The prototype of the system described above has been implemented and tested. The prototype of the sensor node is represented in Fig. 6.

Fig 6. Prototype of the sensor node

The accuracy of measurements for SpO_2 and HR test was performed by using the METRON SpO_2 Simulator. The simulator is used for testing pulse oximeters accuracy with high precision and has following technical specifications: SpO_2 range 35 to 100% with ±0.5% accuracy and HR simulation frequency of 30 to 300bpm with resolution of simulated frequency of 5bpm.

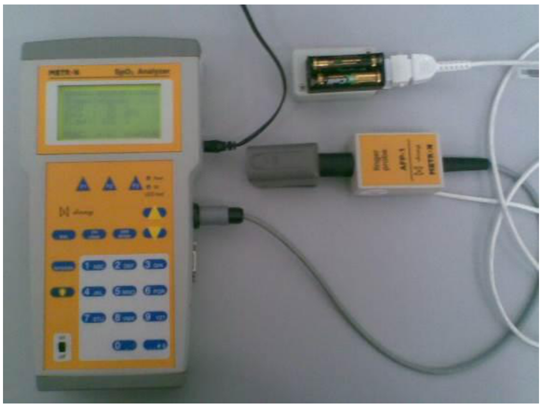

Fig 7. Pulse oximeter test hardware

The experimental results for input values of SpO_2 in the range of 40 to100%, with 1% increment are represented in the Fig 8. HR was kept constant at 60bpm.

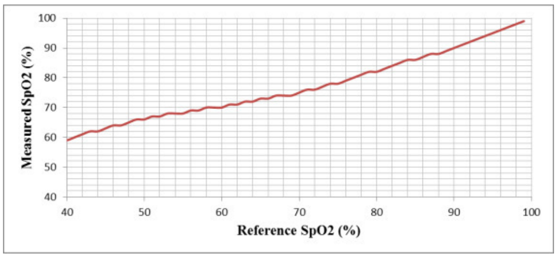

Fig 8. Measured results for different simulated SpO_2

Fig. 9 summarizes the measured values from simulated HR in the range of 30 to 300bpm. From Fig. 9 we can notice that highest HR measured by the system is above 230bpm. SpO_2 was kept constant at 96%.

The SpO_2 and HR were then forwarded through the WSN (configured as a sensor network with 1 AP and 3 RE) to the central monitoring station. The GUI running on the central monitoring station displays the data correctly. Finally, by using the same simulator, we tested the alert detection algorithm.

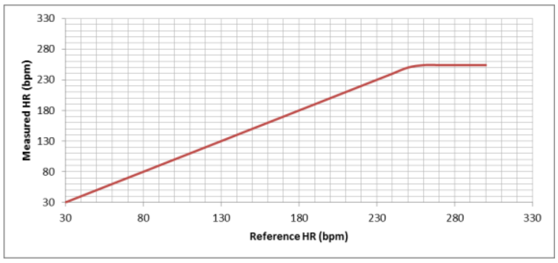

Fig 9. Measured results for different simulated HR

IV. Conclusions

A prototype of wireless oxygen saturation and heart rate system has been developed, implemented and tested.

The proposed system allows monitoring SpO_2 and HR from a remote location without requiring the physician to take the measurements.

Remote monitoring of patients with wireless devices, preventive or after major medical events became a usual procedure in medical practice.

The measurements of SpO_2 and HR may be disturbed in certain conditions: motion artifacts, the presence of colored blood, skin pigmentation, venous congestion, inability to detect SpO_2 values below 70% with high degree of accuracy, no peripheral pulse, or sources of electromagnetic radiation in the nearby.

The proposed system allows persons with chronic diseases or elderly people to be monitored within their home, as an alternative to medical supervision in hospitals.

The described implementation represents the second version of the system. Further improvements will focus on integrating additional facilities regarding: a location algorithm in order to track the patient movements, data encryption routines for wireless communication, and interface support with other portable medical instruments.

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