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A Wireless Low-Power Pulse Oximetry System for Patient Telemonitoring

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***Abstract* – In this paper we present the realization of a wireless low power pulse oximetry telemonitoring system capable to measure and transmit patient's arterial blood-oxygen saturation (SpO2) level and heart rate (HR). The use of the proposed system is suitable for continuous long-time patient monitoring, as a part of a diagnostic procedure. The patient can achieve medical assistance of a chronic condition, or can be supervised during recovery from an acute event or surgical procedure. We use commercially available devices, low power microcontrollers and RF transceivers that perform the measurements (SpO2 and HR) and transmit them to the patient monitoring device. The monitoring device, in form of a PDA that running a personal SpO2 monitor application, receives the SpO2 level and HR, activates the alarms when the monitored parameters exceed the preset limits, and communicates periodically to the telemonitoring server by using WiFi or GSM/GPRS connection.**

***Index Terms* — low power supply, telemonitoring system, wireless pulse oximeter.**

I. Introduction

Pulse oximetry represents a standard procedure for the measurement of arterial blood-oxygen saturation (SpO_2) in the operating rooms, intensive care units, pediatric care and sleep studies. SpO_2 is considered one of the most important vital signs of the human body and it is used for early detection of hypoxemia.

Successfully trauma management requires accurate monitoring of several important physiological parameters, including SpO_2, so that proper action can be taken to help maintain critical functionality.

Recent advances in integrated circuits, wireless communications and physiological sensing opens the way to miniature, lightweight, low power and intelligent monitoring pulse oximeters suitable for many portable medical applications [1].

Also, the home-care monitoring for chronically ill patients or elderly also becomes an alternative to medical supervision in hospitals [2].

During the last few years there has been a significant increase in the number of various pulse oximeters on the market, ranging from simple pulse monitors to portable wireless digital pulse oximeters. Although they still remain the most used devices, they are impractical for continual long time monitoring because their limited power supply.

Conventional pulse oximeter probes are attached to the medical device by wires. This technology may limit the patient's activity and also their comfort. As an alternative, wireless pulse oximeters are suitable for remote patient monitoring.

Wireless data transmission between the pulse oximeter and monitoring device may be performed by using either Bluetooth or WiFi standard, but they are more expensive, consume more power and are useful for applications that require high bandwidth. As a limitation Bluetooth allows only a limited number of nodes to communicate.

Reducing the power consumption of wireless pulse oximeters is a critical step for continual long time monitoring applications.

II. Materials and Methods

Our wireless pulse oximetry system is composed by the following components that are near patient: a wireless pulse oximeter attached on the patient, a monitoring device in form of a PDA, a telemonitoring server and terminal monitors (for displaying the signals and processing). A conceptual view of our system is represented in Fig. 1.

After local signal processing made by monitoring device, according to the specific monitored feature (SpO_2 an HR), the salient data are transmitted via one of WiFi or GSM/GPRS to the telemonitoring server.

In this paper we address only the implementation of the wireless low power pulse oximeter and monitoring device.

Fig. 1. Wireless pulse oximetry system

Our wireless low-power pulse oximeter is realized by using commercially available devices (Micro Power Oximeter Board), a low power microcontroller board (eZ430-RF2500 board from Texas Instruments) and a PDA (HTC X7500). It's also used a server application to store the achieved data and a software application special created for doctors.

The wireless puls oximeter is built around Micro Power Oximeter Board from Smiths Medical [3]. The board is used to collect the SpO_2 and HR from the patient. Its technical specifications are: SpO_2 measurement range 0-99% (1% step), accuracy ±2 for 70-99% SpO_2, and pulse rate range of 30-254 bpm (with 1bpm step) and accuracy ± 2 bpm or ± 2%.

The probe can be placed on a peripheral point of the body such as a fingertip, ear lobe or the nose. The probe includes two light emitting diodes (LEDs), one in the visible red spectrum (660 nm) and the other in the infrared spectrum (905 nm). The percentage of oxygen in the body is computed by measuring the intensity from each frequency of light after it transmits through the body and then calculating the ratio between these two intensities.

The Micro Power Oximeter board's microcontroller processes received light intensities and gives the blood oxygen saturation in percent.

The SpO_2 values ranging between 94-l00%, reflecting an optimal hemoglobin (Hb) in O_2, saturation values of 88-93% define slight hypoxemia, saturation values of 83-88% average hypoxemia, and values less than 83% severe hypoxemia.

It is considered that the decrease in SpO_2 below 93% must be followed promptly by compensatory measures. The pulse oximeter may be disturbed in certain conditions: the presence of colored blood, sources of electromagnetic radiation in the vicinity, no peripheral pulse, venous congestion, repeated use of the tourniquet.

Fig. 2. Micro Power Oximeter Board and eZ430-RF2500

The eZ430-RF2500 is a complete MSP430 wireless development tool providing all the hardware and software for the MSP430F2274 [4] microcontroller and CC2500 2.4GHz wireless transceiver [5].

Low power consumption is an important characteristic of our system. Low power consumption contributes not only to prolonged lifetime, but also to system miniaturization, because the size of a battery occupies more than 50% of volume. It is well known that the most power consumer component in a wireless system is the wireless transceiver. Therefore, we carefully chose a very low power transceiver that consumes less than 21.2mA in transmission mode (0 dBm output power) and 17.0mA in receiving mode.

Operating on the 2.4 GHz unlicensed industrial, scientific and medical (ISM) bands, the CC2500 provides extensive hardware support for packet handling, data buffering, burst transmissions, authentication, clear channel assessment and link quality.

The eZ430-RF2500 has a limited communication range (approx. 10m) and does not necessitate a repeater to send the acquired data to monitoring device.

The Micro Power Oximeter board is connected to MSP430F2274 from eZ430-RF2500 module through asynchronous serial interface. The serial interface uses URXDO and UTXD0 microcontroller's pins and the signals levels adjustment for 3.3V. Data transmission between pulse oximeter and eZ430-RF2500 is performed at 4800bps and a rate of 60 packages per second. The communication settings are One Start Bit, Eight Data Bits, No Parity and One Stop Bit. The data is formatted in 4 byte packets and includes Pulse Rate, Signal Strength Bargraph, Plethysmogram diagram and Status Bit data.

The power supply of the pulse oximeter is provided by two 1.5V AAA alkaline batteries through a voltage stabilizer, which is achieved with TPS60204 circuit [6] (DC/DC converter which provides a 3.3V stabilized output voltage for maximum current value 100mA and an input voltage between 1.8-3.6V).

The prototype of the pulse oximeter is presented in Fig. 3.

Fig. 3. Micro Power Oximeter Board and custom interface

In Fig. 4 present the monitoring device, which was implemented by means of a PDA (HTC X7500). The PDA has the following technical specifications: CPU Intel XScale PXA270 at 624MHz, 128MB RAM, 256MB ROM, 8GB HDD, a large TFT display with resolution 640 x 480 pixels, WiFi, GSM/GPRS and Bluetooth (client/host) interfaces and running Windows Mobile 5 as operating system.

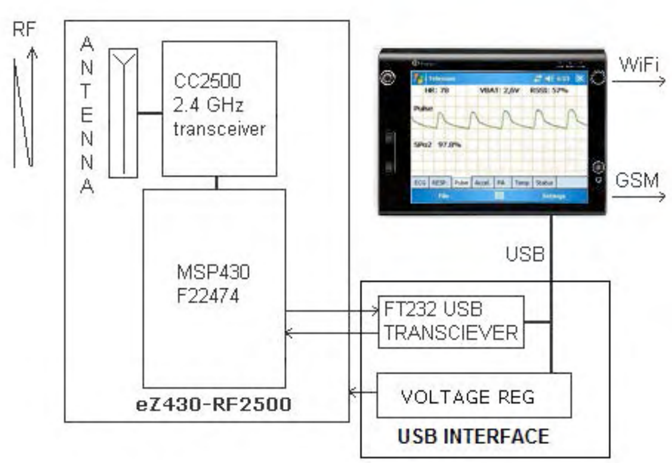

Fig. 4. Monitoring device (block diagram)

The custom USB interface is realized by using a serial to USB transceiver (FT232BL) from FTDI [7] and enables the eZ430-RF2500 to remotely send and receive data through USB connection using the MSP430 Application UART. All data bytes transmitted are handled by the FT232BL chip. It also contains a voltage regulator (TPS77301) to provide 3.3 V to the eZ430-RF2500.

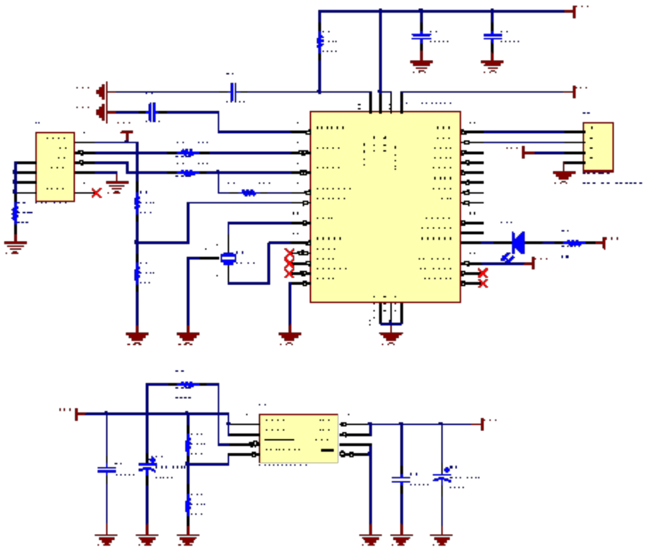

Fig. 5. Custom USB interface (transceiver and voltage regulator)

Figure 5 presents the configuration used by the FT232BL circuit to interface with 3.3V logic devices. In this configuration, a 3.3V regulator (TPS77301) is used to supply the 3.3V logic from the USB [7]. The VCCIO pin is connected to the output of the 3.3V regulator, which will cause the I/O pins of the UART interface to operate at 3.3V level. The same 3.3V is also used to provide power supply to the eZ430-RF2500.

The wireless protocol used to transfer data from pulse oximeter to monitoring device was SimpliciTi [8]. SimpliciTi is an open-source protocol for networks that typically contain battery operated devices which require long battery life, low data rate and have a limited number of nodes. The eZ430-RF2500 connected to pulse oximeter was configured at End Device and the eZ430-RF2500 connected to monitoring device was configured at Access Point. Data transmission between the two eZ430-RF2500 modules was set at one transmission per second.

The software running on the monitoring device, presented in the Fig. 6, was written using C# from Visual Studio.NET, version 8. The software displays temporal waveform of Plethysmographic signal, numerical values for SpO2 and HR and the status of pulse oximeter (the battery voltage and distance from the monitoring device). The distance is represented in percent of 100 computed based on RSSI (received signal strength indication measured on the power present in the received radio signal).

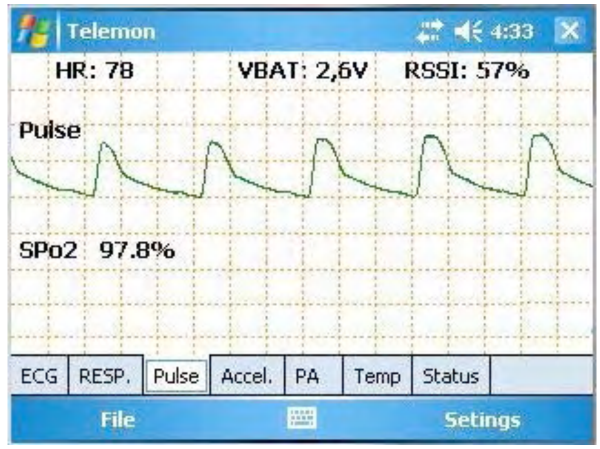

Fig. 6. Monitoring device interface

If the patient has a medical record that has been previously entered, information from the medical record (limits above the alarm become active) is used in the alert detection algorithm.

The following physiological conditions cause alerts:

- low SpO_2, if $SpO_2 < 93\%$;
- bradycardia, if $HR < 40$ bpm;
- tachycardia, if $HR > 150$ bpm;
- HR change, if ΔHR / 5 min > 20%;
- HR stability, if max HR variability from the last 4 readings > 10% ;
- low battery voltage, if VBAT < 1.9V;
- low value for RSSI, if RSSI < 30%

III. Results

The prototype system described above has been implemented and tested.

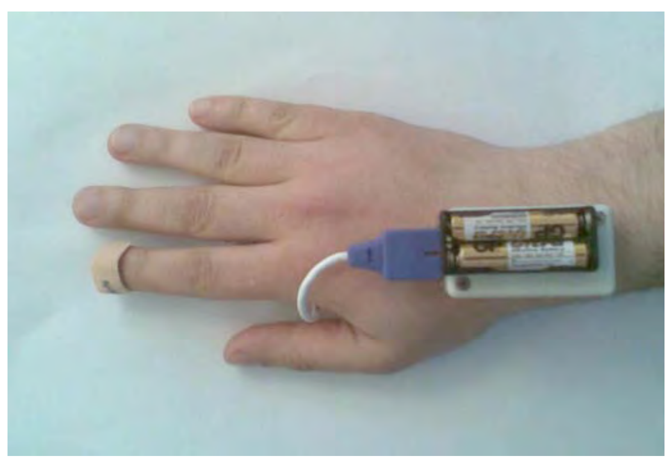

Fig. 7. Wireless pulse oximeter (prototype)

In order to test the accuracy of measurements for SpO_2 and HR we use the Metron SpO_2 Simulator. It is used for testing pulse oximeter accuracy with high precision.

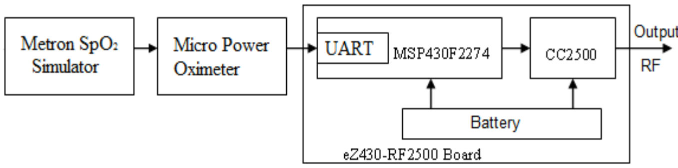

Fig.8. Pulse oximeter test hardware

Metron SpO_2 Simulator has following technical specifications: SpO_2 range: 35-100% with accuracy: ±0.5% for 65 % < SpO_2 < 100% and ±1% for SpO_2 30 % < SpO_2 <65%, heart rate simulation frequency: 30-300 bpm with resolution of simulated frequency of 5 bpm.

Measured results for different values of SpO_2, acquired with 1% increment in the range of 70-100% are presented in the Fig 9. HR was constant and set at 60 bpm.

Fig. 10 summarizes the experimental results from different simulated HR, in the range of 30-300 bpm. From Fig. 10 we can observe that highest HR measured by our wireless pulse oximeter is above 230 bpm. SpO_2 was constant and set at 96%.

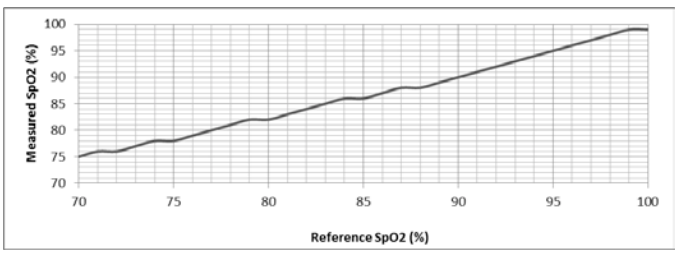

Fig. 9. Measured results for different simulated SpO_2

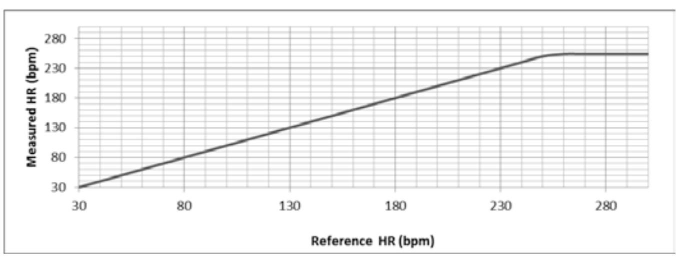

Fig. 10. Measured results for different simulated HR

We have computed the life expectancy of our wireless pulse oximeter assuming that two AAA batteries still maintain a 1250 mA*hr rating under the hypothetical condition in which the batteries hold their voltage ideally and until their capacity is exhausted and we found a value of 205 hours (at an average measured current consumption of 6.1 mA).

IV. Conclusions

A prototype of wireless low power pulse oximetry system has been designed, implemented and tested.

The hardware was implemented by using commercially available devices.

The proposed system provides the possibility to access the SpO_2 and HR from different locations via Internet.

Remote monitoring of patients in real time, preventive or after major medical events is a procedure increasingly used in medical practice. It requires medical devices with continuous improving performances in order to obtain more accurate acquisition and transmission of vital parameters.

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