PC-Based Pulse Signal and Blood Oxygen Level Monitor

Nemanja Mišić, Marjan Tričković, Borisav Jovanović

Abstract – The paper describes the system consisting of electronic circuits and software application, which are used to measure photo-plethysmographic signals. The system is capable to find pulse signal waveforms and levels of oxygen saturation in blood (SpO_2). The pulse oximeter sensor is attached to the system through connector. Software application displays pulse signal waveforms in real time and performs complex calculations providing SpO_2. The system can be very useful to doctors in making correct diagnosis of patient's health condition.

I. Pulse oximetry fundamentals

Pulse oximetry is a non-invasive method of determining the amount of oxygenated and deoxygenated hemoglobin in a person's blood. A pulse oximeter is a non-invasive medical electronic device that measures the oxygen saturation. The word non-invasive means that there is no direct contact between the patient's blood and measuring equipment. Instead, pulse oximeter sensors are placed on fingers or ears causing no discomfort to the patient. The device enables prompt recognition of hypoxemia.

The method is based on the principles of Beer-Lambert law which relates the amount of absorbed light when transmitted through the blood to the concentration of oxygen in blood [1]. The absorption of the light, transmitted through the blood, can be calculated as follows:

$$I_{OUT}=I_{IN}\, e^{-A} \tag{1}$$

where I_{OUT} is the intensity of the light transmitted through the blood, I_{IN} is the intensity of the light going into the blood, and A is the absorption factor of blood [2].

Different values of light absorption levels exist for oxygenated and deoxygenated hemoglobin at different wavelengths. This is because the two common forms of the molecule, oxidized hemoglobin (HbO_2) and reduced hemoglobin (Hb) have significantly different optical spectra in the wavelength range from 500nm to 1000nm, as shown in Figure 1.

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Traditionally, pulse oximeters utilize red (λ=660nm) and infrared light (λ=940nm) to determine oxygen saturation in blood. These two wavelengths are chosen because, at 660nm, deoxygenated hemoglobin has a higher absorption, whereas at 940nm, oxygenated hemoglobin has a higher absorption [3]. Therefore, pulse oximeter device utilizes sensor which has two LED diodes – one red and one infrared.

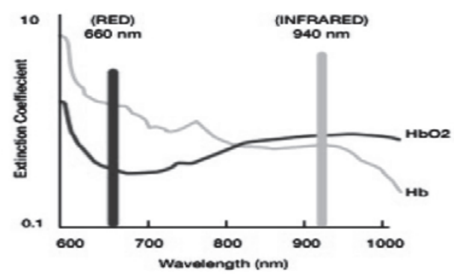

Fig. 1 Hemoglobin light absorption at different wavelengths.

A photo detector in the sensor detects the non-absorbed light from the LEDs. At each wavelength, the light detected by the photodiode consists of a cardiac synchronous AC signal arising from arterial blood volume pulsations, superimposed on a DC level. The DC level depends on LED intensity, tissue absorption, path length, and detector sensitivity. The AC component represents the variable arterial blood (Figure 2) which is useful for calculation of oxygen saturation in blood [1].

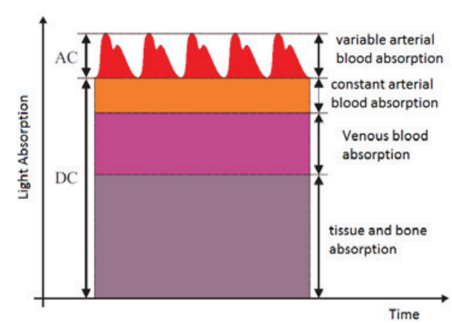

Fig. 2 Light absorption diagram.

Oxygen saturation, which is often referred as SpO_2, is defined as the ratio of oxygenated hemoglobin (HbO_2) to the total concentration of hemoglobin present in the blood (oxygenated hemoglobin + reduced hemoglobin). Under normal physiological conditions arterial blood is between 87% and 97% saturated.

The ratio of red and infrared signals after normalization is calculated and is related to oxygen saturation. The SpO_2 is finally calculated using the equation which is derived based on Beer Lambert law. To determine the SpO_2, it is necessary to measure AC and DC components of the two wavelengths and to determine the following ratio (Eq. 2):

$$R = \frac{\log_{10} \frac{I_{\lambda 1}}{I_{DC\lambda 1}}}{\log_{10} \frac{I_{\lambda 2}}{I_{DC\lambda 2}}} \tag{2}$$

The calculation procedure is much easier if the DC component is maintained constant and can be omitted from the previous formula:

$$R' = \frac{\log_{10}(I_{AC})_{\lambda 1}}{\log_{10}(I_{AC})_{\lambda 2}} \tag{3}$$

Calculated value of R' which is equal to 1 corresponds to SpO_2 value of 85%. The ratio R' of 0.4 represents SpO_2 of 100%, and a ratio of 3.4 represents SpO2 of 0 %. In order to be more reliable, the function SPO_2 of R' must be based on experimental measurements of healthy patients (Fig. 3).

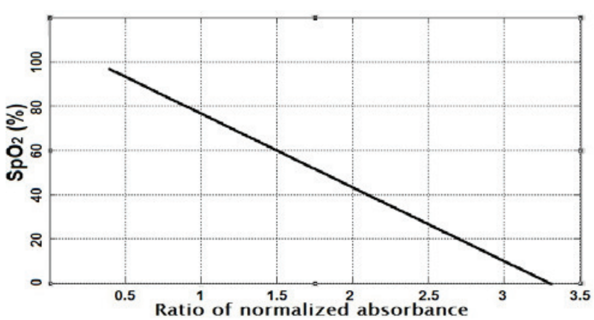

Fig. 3 The function SpO2 (%) of ratio value R’.

II. SYSTEM IMPLEMENTATION

The hardware part of a system consists of analog circuits that are connected to the pulse sensor, microcontroller and USB communication controller.

A. Interfacing pulse oximeter sensor

The photo-pletysmographic sensor consists of three diodes. Two of them emit the light through the finger. These are the red and infrared diodes. For the signal reception an additional photo diode is used [4].

The diagram of sensor is given in Fig. 4. Red and infrared diodes emit the light through the nail of the finger, then the light passes through finger to the opposite side where the photo diode is positioned. The photodiode generates the current which is proportional to the received amount of light. The red and infrared diodes emit the light alternately, when one emits the light, the other is turned off. We have used Nelcor-DS100a photo-pletysmographic probe which is attached to our system through DB9 connector. Principal schematic of sensor is shown in the Figure 4. The figure presents the method how the infrared, red and photo diodes are connected to the pins of DB9 connector.

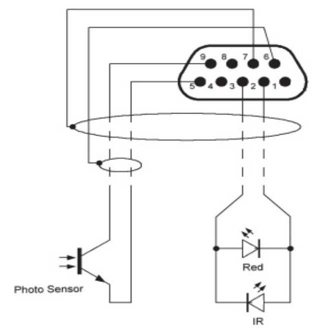

Fig. 4 Neclor-DS100a sensor.

Photodiode detectors normally operate with reverse bias applied to the p-n junction and resulting light current is seen as a large increase in the reverse diode current. This current needs to be converted to appropriate voltage in order to be converted by AD converter. Therefore, both current to voltage converter and amplifier circuit are used, which operation is explained in the following sections.

B. Analog signal processing

The signals determined by two light emitting diodes are first separated in red and infrared pulse signals. Then, their AC components are amplified, and finally, used to calculate pulse rate and oxygen saturation level in blood [5]. Constant current feedback circuits are employed for driving the LEDs in a particular sequence. The photo-detector output is fed to sample-and-hold circuits for de-multiplexing the red and infrared pulse signals.

The pulse oximeter analog circuit consists of two identical sections used for separate red and infrared pulse signals processing, and one section which is shared between both red and infrared signals processing blocks. The shared section is used for amplification of photo diode current, dependent on transmitted amount of light.

The light, detected by the photodiode, is amplified and converted to a voltage using an operational amplifier configured as current-to-voltage converter. At this point, in the circuit, the signal is fed to two identical analog signal processing sections, one for each of the transmitted wavelengths. Since the light is pulsed, a sample-and-hold circuit was needed to reconstitute the waveforms at each of two wavelengths: red and infrared. For the construction of sample-and-hold circuit IC4066 is used together with operational amplifier configured as unity-gain amplifier. The microcontroller which turns on and off the red and infrared LED drivers is also used to provide the control pulses for the corresponding sample-and-hold circuits. The IC4066 control pins Sample_Red and Sample_Infrared are driven by microcontroller. The short pulse on the Sample_Red or Sample_infrared is generetad during time interval when the corresponding diode is emitting the light. Because it is known that the bandwidth of pulse signals is in range from 0.5Hz to 5Hz, additional low pass filter with cut-off frequency of 5Hz is used to remove high frequency noise.

The outputs from sample-and hold circuit are filtered with a high-pass filter (with 0.5 Hz cut-off frequency) in order to remove the signal DC component. The resulting signals represent the red and infrared pulse signal waveforms and these are further amplified before they are converted by AD converter. The gain is set to the value of 50.

The output from each sample-and-hold is also passed to a Miller integrator circuit, composed of operational amplifier, resistor and capacitor. This circuit represents a part of an automatic LED current control circuit which adjusts the light intensity of LEDs so that the DC level of pulse signal always remains at the same invariantly of the thickness or skin characteristics of the finger.

Namely, the automatic LED current control is achieved by negative feedback which consists of: photo detector, current to voltage convertor, sample-and hold circuit, Miller integrator circuit, voltage to current convertor and LED diode and patient’s finger. If the thickness of the patient’s finger demands larger light intensity (and therefore large LED current), the output voltage of Miller integrator circuit is raised up. In the case of thinner finger, this voltage level is decreased.

At final stage, circuit comprised of operational amplifier, resistors, and bipolar transistor, represents the voltage-to-current converter circuit used to drive the LED diodes. The voltage at the output of Miller integrator circuit is attenuated by voltage divider circuit and converted to the current driving the red and infrared diodes.

C. *Microcontroller (digital processing)*

For conversion of signals from analog to digital domain we used the AD convertor which is the embedded into the microcontroller Microchip PIC18F2520 [6]. The AD converter converts analog input signal to a corresponding 10-bit digital number. After AD conversion was complete, the signals are processed digitally.

The microcontroller’s firmware executes most of instructions in the infinite while loop. The timer of microcontroller is set to generate interrupts in time periods of 100μs. Additional counter is used to measure longer periods of 4ms which corresponds to sampling frequency of 250Hz. The system operates at 250Hz which is locked with power line frequency. In each 4ms time period a certain number of operations are performed which are presented in the Figure 5. The operations include turning on and off the red and infrared diodes, sample commands to acquire new samples of red and infrared signals. The LED diodes of the sensor are turned on during the short period of 300μs. The diodes are turned on and off once in the time interval of 4ms.

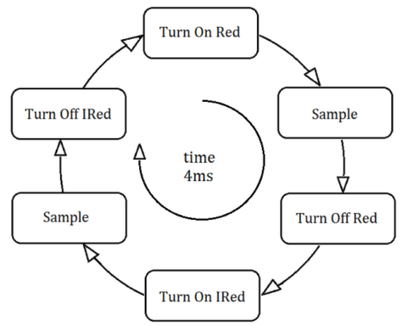

Fig. 5. Sampling process.

After samples are acquired, digital signals for red and infrared signals are stored in two 16-bit variables, the part of MCU RAM memory. The system contains two operating modes: Online and Event.

In Online mode digital values of red and infrared signals are sent continuously first to RS-232 to USB communication controller chip [7]. After that, the data is sent to PC through USB cable. The software application is used for displaying the red and infrared signals. The data bytes containing red and infrared signals are sent in the data packets. The content of the packet is given in the Fig. 6.

0	1	2	3	4
0xAA	0x00	0x00	0x00	Red 9-2
5	**6**	**7**	**8**	
IRed 9-2	0x00	Red 1-0	IRed 1-0	

Fig 6. Data package format.

D. *Pulse waveform storing on SD Card.*

In the second operating mode, called Event, pulse signals are measured and stored temporarily in Micro SD memory card. The Micro SD card is connected to MCU over Serial Protocol Interface (SPI). After request (the on board taster button has been pressed), the signals are read from the Micro SD card and sent to the PC.

The digital conversion of three 10-bit pulse samples Sample 1, Sample 2 and Sample 3 is illustrated in the Fig. 7. The samples are converted into four data bytes Byte0, Byte1, Byte2 and Byte3. These four bytes are stored further into SD memory card.

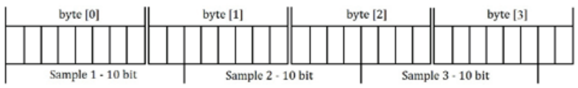

Fig 7. Packing samples.

The byte arrays consisting of 512 bytes are sent to SD memory card. The process of SPI data transmission requires some amount of microcontroller's time, depending on SPI communication speed and microcontroller's operating frequency. Since the MCU has to convert pulse waveform signals without any interruption, we have used two 512-byte arrays. While one array is filled with the pulse waveform samples produced by AD converter, the other is sent to Micro SD card.

E. Software application

The monitor software is comprehensive high-end application for monitoring of pulse signal waveforms. It runs under Windows operating system and has user-friendly graphical interface. The pulse signals are shown on PC monitor. The application provides plenty useful features for recording and analyzing pulse signals. Numerical values of heart rate derived from both pulse signals and SPO2 value are shown on the screen.

The software application provides high and low alarm settings of SpO2 and pulse rate setting from 30 BPM to 250 BPM. It also gives alarm conditions if the probe is accidentally disconnected from the finger. Besides the pulse waveforms, it is also used for displaying the ECG signals [8].

Fig 8. The vital signs monitor's software.

III. Conclusion

This paper describes the realization of a simple pulse oximeter device. The proposed device receives pulse signals from sensor which contains red, infrared diodes and photo diode. The connection to computer is achieved through USB port. The system is capable of finding pulse signal waveforms and levels of oxygen saturation in blood (SPO2). The device is reliable, easy for use and it is very efficient in identifying patient health condition.

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