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A Real Time Analysis of PPG Signal for Measurement of SpO₂ and Pulse Rate

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ABSTRACT

Continuous measurement of oxygen level and pulse rate is very important for aged people, pregnant women and in many other critical situations. This is commonly monitored by a pulse oxymeter. This paper presents a low-cost and a miniaturized pulse oxymeter to continuously measure patient's blood-oxygen saturation level (SpO₂) and pulse rate. Change in intensity of light transmitted through tissue due to arterial blood pulse can be measured as a voltage signal called the photoplethysmographm (PPG). Oxygenated blood has different light absorption characteristics than deoxygenated blood under red and infra red wavelengths. So the hardware implementation is included placing of two LEDs (red and infra red) on the patient's finger and a photo detector on opposite side of the LEDs to get the corresponding PPG signals which are used to estimate the SpO₂ by comparing the absorption characteristics of the two different colored light (red and infra red). As the PPG signal is mostly corrupted by patient's hand movement, it is given to LabView window by DAQ card for further signal processing. In this paper a low pass filter is used for removing motion artifacts and a moving average algorithm is applied to remove high frequency noise content. The SpO₂ is calculated by computing the AC and DC components of both the red and infra red LEDs corresponding PPG signals. The pulse rate is determined by time domain peak detection algorithm in LabView signal processing module.

Keywords

Pulse oxymeter, SpO₂, PPG, signal processing, Peak Detection algorithm

1. INTRODUCTION

In addition to heart rate, blood pressure, respiration rate, and temperature, pulse oxymeter (PO) is considered to be the "fifth vital sign" of health status. Many vital organs become irreversibly damaged when not supplied with proper amount of oxygen, even for a short period. Among the body organs, the brain is by far the most sensitive to oxygen deficit [1]. The principal advantage of optical sensors for medical applications is their intrinsic safety since there is no electrical contact between the patient and the equipment. An added bonus is that they are also less suspect to electromagnetic interference. This has given rise to a variety of optical techniques to monitor physiological parameters: for example, the technique of Laser Doppler velocimetry to measure red blood cell velocity and pulse oxymetry for the non-invasive measurement of arterial oxygen

saturation in the blood. A pulse oxymeter is a medical device that indirectly monitors the oxygen saturation of a patient's blood (as opposed to measuring oxygen saturation directly through a blood sample) and changes in blood volume in the skin, producing a photoplethysmograph [2].

1.1 Photoplethysmography and PPG Signal

Photoplethysmograph is a non-invasive technique that measures relative blood volume changes in the blood vessels close to the skin [3]. The pulsatile component of the PPG waveform is often called the 'AC' component and usually has its fundamental frequency, typically around 1 Hz, depending on heart rate. This AC component is superimposed onto a large quasi-DC component that relates to the tissues and to the average blood volume. This DC component varies slowly due to respiration, vasomotor activity and vasoconstrictor waves [4] [5]. The time period of each pulse is dictated by the heartbeat and the amplitude by the concentration of various constituent parts of arterial blood and path length of light travelling through the arteries shown in Fig. 1.

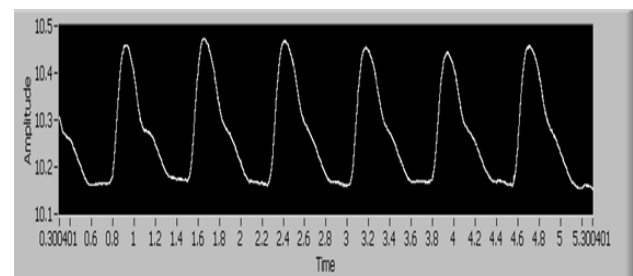


Fig. 1: PPG Signal Aquired in LabView Window

After the systole, blood volume increases in the arteries thereby reducing the received light intensity. During diastole, blood volume in the arteries decreases and hence in increasing in light transmission. Thus the PPG signal appears pulsatile in nature at the heart rate [6].

In this work, a low cost miniaturized pulse oxymeter is designed to acquire the real time PPG signal and measure the SpO₂ and pulse rate by LabView software. LabView (Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language that helps create flexible and scalable design, control, and applications [7].

2. WORKING PRINCIPLE

Oxygen saturation level can be achieved by employing a photo detector, Red and near-IR light emitting diodes (LED's) to measure the light that scatters through blood perfused tissue. Oxygen is transported in the blood by haemoglobin, and, depending on whether haemoglobin is bound to oxygen, it absorbs light at different wavelengths. The graphs of haemoglobin light absorption when it is saturated with oxygen and when it is not are shown in Figure 2 [8].

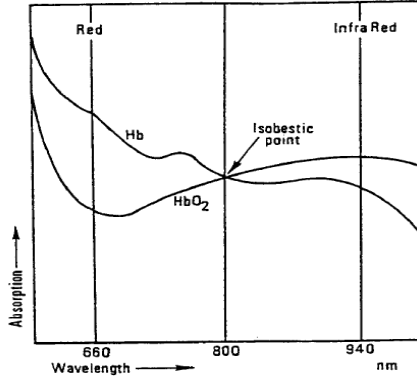


Fig 2: Absorption of Oxygenated and Non-oxygenated Haemoglobin at Different Wavelengths.

This effect is taken advantage of in oxymetry by using two LEDs with different wavelengths (typically 660 and 940 nm) and shining them through the tissue [9]. The ratio of absorption at the two wavelengths is used to determine the fraction of saturated haemoglobin. Previous research had indicated that oxy and deoxy haemoglobin has different optical attenuation characteristics. For best result the wavelengths are to be selected such that at one wavelength, the attenuation by Hb and HbO are different as possible and at the second wavelength they are nearly the same. The available pulse oximeter uses the light at 660nm (R) and 940nm (IR.). Based upon the ratio of changing absorbance of the red and infrared light caused by the difference in color between oxygen-bound (bright red) and oxygen-unbound (dark red or blue, in severe cases) blood haemoglobin, a measure of oxygenation (the per cent of haemoglobin molecules bound with oxygen molecules) can be made as in “(1)”[10].

$$SpO_2 = \frac{HbO_2}{HbO_2 + Hb} * 100 \quad (1)$$

Pulse oxymeter utilizes Beer-Lambert's law, which states that concentration of an absorbing substance in a solution can be determined from the intensity of light, transmitted through the solution [11]. Here the light intensity of transmitted light (I_0) is related to the light intensity of incident light (I_N) by “(2)”.

$$I_0 = I_N e^{-\epsilon c L} \quad (2)$$

Where ϵ is the wavelength dependent extinction coefficient, c is the concentration of the absorber and L is the optical path length

(cm). The light is absorbed while passing through the solution is expressed in terms of absorbance, given by” (3)”.

$$A = \ln \left(\frac{I_0}{I_N} \right) = \epsilon c L \quad (3)$$

Where A is the absorbance, a dimensionless quantity, normally termed the optical density (OD). Hence Beer's Lambert's law allow us to determine the unknown concentration if the absorbance of light is measured and extinction coefficient at the wavelength and optical path length are known. The DC values and AC amplitudes of the cardiac synchronous pulsatile portions in red and infrared PPG signals, DC_R and AC_{IR} and AC_R and AC_{IR} respectively are extracted. Then a normalized red to IR absorption ratio R is obtained as in “(4)”.

$$R = \frac{AC_R / DC_R}{AC_{IR} / DC_{IR}} \quad (4)$$

Once the R value is calculated from the two PPG signals, SpO_2 values are determined from R by using “(5)” [12].

$$\%SpO_2 = K * R \quad (5)$$

Where K is proportionality constant, which can be considered by calibration results.

3. HARDWARE IMPLEMENTATION

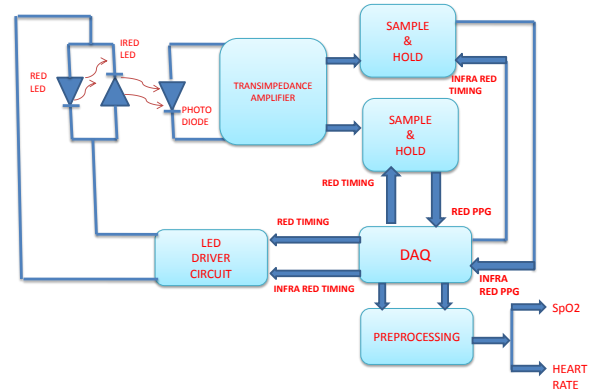


Fig 3: Purposed Pulse Oximeter Design

To calculate the SpO_2 and HR continuously a sensor is designed to acquire the PPG signal. The proposed design of the pulse oxymeter is give in Fig. 2. A SpO_2 probe containing two LEDs and the light sensor (photodiode) is placed on the finger of the patient. One LED emits red light (wavelengths of 660nm), and the other emits light in the near IR (wavelengths 940 nm) range. The LEDs are rapidly and sequentially excited by two current sources (one for each LED) whose dc levels depend on the LED being driven. The switching of the two LEDs is

controlled by the two control signals, red timing and infra red timing given to the LED driver circuit are given in Fig. 3. The control signals are generated by the NI 6025E DAQ.

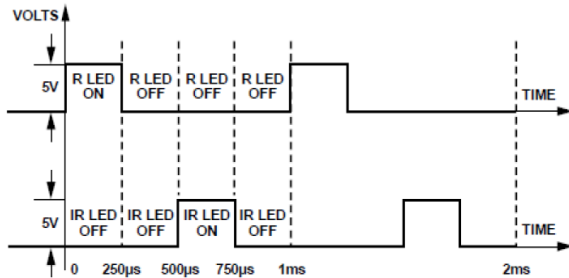


Fig 4: Pulse Oximeter Control Signal

When the current sinks are on, each is on only a certain amount of time, and not at the same time. This time is set by the duty cycle of the waveform driving its corresponding current. These waveforms are pulses with duty cycle of approximately 25% and a typical period of 1 ms (1 kHz). This means that each current sink is on during 250 µs in a 1 ms period.

The detector is synchronized to capture the light from each LED as it is transmitted through the tissue. Low power, precision current sources (if the current flows into the load) or current sinks (if the current flows out of the load) used in pulse oximeter deliver a few decades of milliamps. The light shining on the photodiode produces a small current that is converted to a voltage by an amplifier, transimpedance configuration (I/V). Usually a large resistor is used in the amplifier's feedback loop, so the circuit is very sensitive to small changes of light. The sample and hold circuits are used to separate the red and infra red PPG signals, according to the respective control signals. Then both PPG signals are given to the LabView software through the DAQ. The two PPG signals are pre-processed for removal of high frequency noise and then SpO₂ and heart rate are calculated with specified algorithms.

3.1 SpO₂ Probe

The nellcor SpO₂ probe is used in this project which contains minimal circuitry: the LEDs used are 660 and 940 nm. The probe contains the photodiode which detects the light. The photodiode requires up to 5 V to run. In total, the probe will connect to a bundle of five wires as shown in Fig 4. The wires are the input for each LED, the power for the photodiode, its output, and a ground reference.



Fig 5: SpO2 Nellcor Probe

A miniaturized and low cost pulse oximeter is designed according to the proposed methodology as shown in Fig 5.

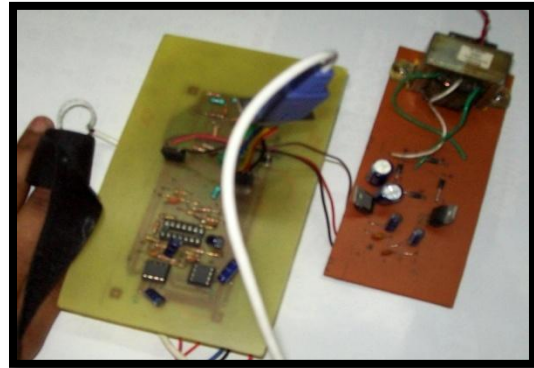


Fig 6: Pulse Oximeter Set Up

The timing signals for LED driver circuit are generated by DAQ 6025E card. These waveforms are pulses with duty cycle of approximately 25% and a typical period of 1 ms (1 kHz). This means that each current sink is on during 250 µs in a 1 ms period. The control signal for LED driven circuit is given in Fig 6.

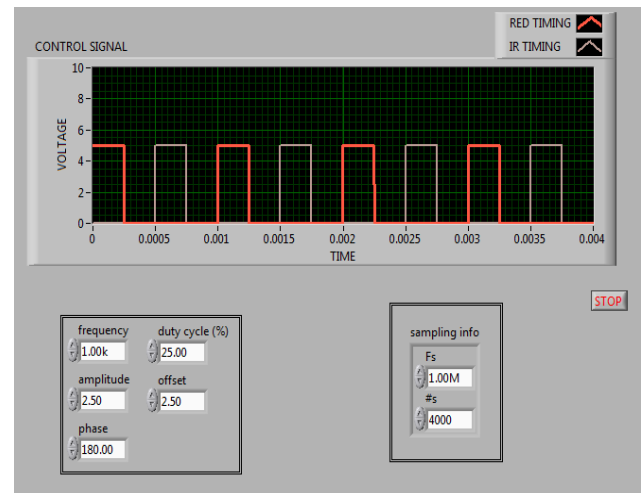


Fig 7: Timing Signal for LED Driver Circuit

4. SOFTWARE IMPLEMENTATION

The PPG signals can be pre-processed in the LabView. The normal frequency range of PPG signal is 0.5 Hz to 5 Hz. So the noise elements are cancelled by using low pass filter of cut off frequency 5 Hz. The PPG signal is highly affected by motion of the patient's hand. So to get a stabilized reading of SpO₂ a moving average filter is implemented with filter width 8 as shown in Fig 7[13].

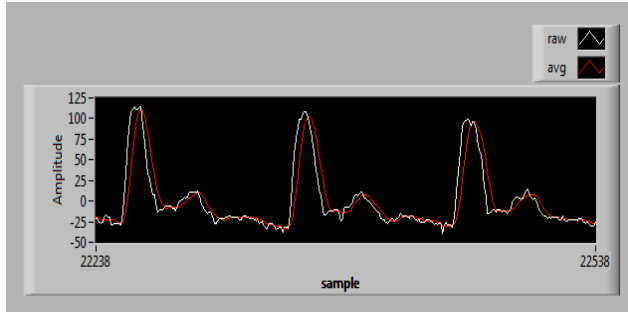


Fig 8: Noisy Signal (white Line) and Moving Averaged PPG Signal (red line).

By AC and DC estimator in LabView the AC and DC component of both Red and IR signal is calculated. By using these values, we calculate the R and then percentage of SpO₂ as per equation 5. From calibration results, the constant $K = 98.56$ can be obtained for calculating %SpO₂ level. The front panel showing %SpO₂ is given in Fig 8.

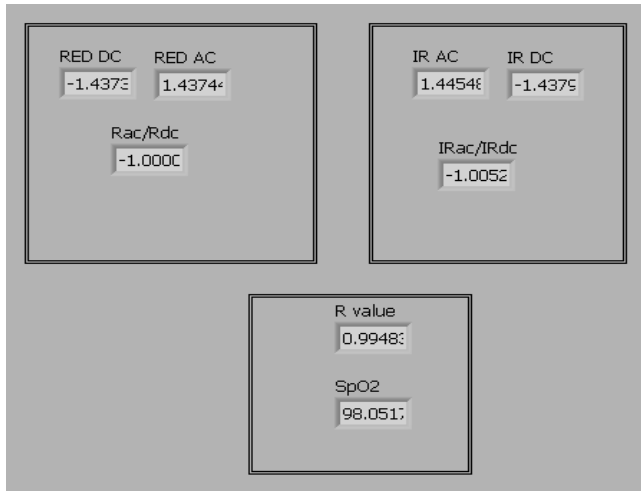


Fig 9: Front Panel Showing the SpO_2

For the subject the values of AC and DC for both red and infra red LED generated PPG signals are calculated as $AC_R = 1.4374$, $DC_R = -1.4373$, $AC_{IR} = 1.4456$, $DC_{IR} = -1.4374$. By the help of these values the R value is calculated as 0.9948 and %SpO₂ is estimated as 98.05.

The peak detection of the PPG signal is done by advanced peak detector.vi in LabView. First a threshold value is set by analyzing the PPG signal. The threshold value should be above the amplitude of small peak of the PPG signal and below the true peak of the PPG signal. The numbers of identified peaks in each 60-second recording is counted and provide a measure of the pulse rate as shown in Fig 9. If the pulse rate is exceeded

from its normal range then it is detected by glowing of red LED on the front panel of LabView and the glowing of green LED indicates the pulse rate is in normal range.

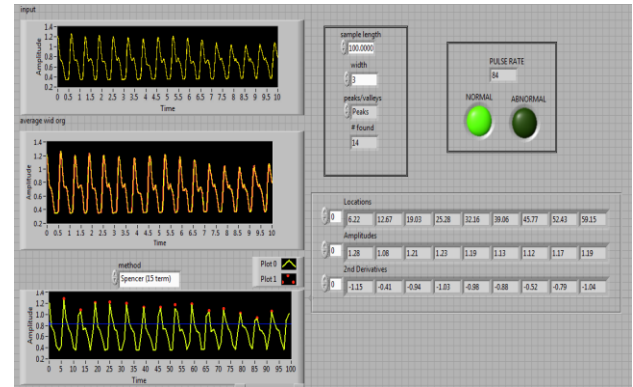


Fig 10: Front Panel Showing the Pulse Rate

The above proposed pulse oximeter measured %SpO₂ and pulse rate of 10 different subjects. The measured values were compared with a standard pulse oximeter device. The experimental values are shown in Table 1.

5. CONCLUSION

In this paper, a low-cost pulse oximeter is designed which is miniaturized in size. In this pulse oximeter two LEDs are used i.e. Red (660nm) and Infra Red (940nm) which are driven by a LED driver circuit. The transmitted light intensity is detected by a photodiode with peak sensitivity 850nm. The SpO₂ and pulse rate are calculated accurately with real time. The experimental values are compared with a standard pulse oximeter device. Because of patients' movement like older aged people and children, sometimes it is very difficult to calculate SpO₂ and pulse rate with real time and it will reduce the performance of the pulse oximeter. So in future a better signal preprocessing method can be developed to enhance the performance of the pulse oximeter.

Table 1. Experimental values for different subjects

Subject	Red signal AC	Red signal DC	IR signal AC	IR signal DC	$R = \frac{AC_R / DC_R}{AC_{IR} / DC_{IR}}$	%SpO ₂ =K*R	Pulse rate	Standard device result	
								%SpO ₂	Pulse rate
Subject 1	1.4374	-1.4373	1.4456	-1.4374	0.9948	98.05	98	99	98
Subject 2	1.4352	-1.4282	1.4323	-1.4172	0.9944	98.00	95	98	98
Subject 3	1.3211	-1.3141	1.3372	-1.2988	0.9765	96.24	90	98	98
Subject 4	1.5821	-1.6420	1.4982	-1.4321	0.9152	90.20	68	92	67
Subject 5	1.4126	-1.4201	1.4313	-1.4022	0.9745	96.05	85	97	85
Subject 6	1.4801	-1.4792	1.4556	-1.4482	1.0008	98.65	110	99	112
Subject 7	1.3988	-1.4011	1.4001	-1.3998	0.9981	98.37	102	98	102
Subject 8	1.4900	-1.4820	1.4844	-1.4111	0.9557	94.19	84	96	85
Subject 9	1.4443	-1.4381	1.5001	-1.4574	0.9757	96.17	90	96	90
Subject10	1.4226	-1.5470	1.4382	-1.4922	0.9541	94.04	80	94	80

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