Design of Wearable Pulse Oximeter Sensor Module for Capturing PPG Signals

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Abstract—Monitoring one’s health regularly is a very critical thing and it may not be feasible to visit a Doctor at every instant when one feels the need to do so. Wearable gadgets can provide a high level of accuracy as there will be less human intervention and the whole system will be automated. Pulse oximetry is a technique used for noninvasively monitoring the oxygen saturation (SpO2) and pulse rate (PR). To calculate the SpO2 and Pulse rate PPG signals are essential. Good quality PPG signals will help us to calculate accurate PR and SpO2. It monitors the level of oxygen in a patient's blood and alert the healthcare worker if oxygen levels drop below safe levels, allowing rapid intervention. Reflectance-based pulse oximetry is a technique used for noninvasively monitoring the oxygen saturation (SpO2) and pulse rate (PR). In reflectance-based pulse oximetry, the incident light is passed through the skin and is reflected off the subcutaneous tissue and bone. SpO2 is calculated by obtaining the ratio of the AC and DC components of the red PPG and dividing that by the ratio of the AC and DC components of the infrared PPG.

I. INTRODUCTION

The measurement of the oxygen in a human hemoglobin (Hb) in parts of the circulatory system can give vital information about the state of organs such as heart, lungs and other important organs. The normal values of the blood oxygen saturation in human body are around 97% [2] and any deviations on those values can be associated to alarming situations. The development of oximeter based on non-invasive techniques became popular due to some limitations in the invasive method such as the problems in continuous monitoring of oxygen saturation and the loss of blood.

The technique of pulse oximetry is non-invasive based on the optical method for monitoring the oxygen blood saturation. It measures the intensity of light passing through the tissue and calculate blood oxygen saturation and pulse rate by analyzing variation of the light intensity. The necessity of non-invasive and real-time based measurement of oxygen saturation led to the development of Pulse oximetry. It derives SpO2 and pulse rate from a Photoplethysmogram (PPG). PPG is time domain signal obtained from oximeter sensor. It is obtained by measuring variation in light absorbing by the blood. PPG can be obtained by using Red and infrared wavelengths because these wavelengths are easily transmitted through tissues, which helps to calculate SpO2 from the ratio of the absorption of the red and infrared light.

II. BASIC PRINCIPLES OF PULSE OXIMETRY

The idea behind the operation of pulse oximeters is that haemoglobin changes color from dark red to bright red when oxygenated and reduces its absorption of red light. Hence, if we shine red LED light at 660 nm through one side of a patient’s finger and measure the transmitted light on the other side of the patient’s finger with a photo sensor (photoreceptor), we can obtain clues regarding the oxygen saturation, the percentage of hemoglobin molecules that are oxygenated in the blood of the patient’s finger. However, our absolute measurement will be affected by other tissues, such as skin and bone, that surround the arteries and veins that carry blood. Fortunately, arteries dilate and contract with each heartbeat so that during systole, the phase in which the ventricles of the heart contract and the blood pressure rises, relatively thicker arteries increase the absorption of light, and
during diastole, the phase in which the ventricles of the heart relax and blood pressure falls, relatively thinner arteries decrease the absorption of light.

By taking the ratio of the light measured by the photoreceptor at the peak and trough of heartbeat cycle, we can obtain information that is independent of the absolute light intensity of the LED and independent of tissues that do not contain arterial blood. This ratio is still exponentially dependent on the absolute concentration of haemoglobin molecules in the blood (oxygenated or deoxygenated), the absorption coefficient of red light by haemoglobin, and on the thickness variation of the arteries over a heartbeat cycle. Disappears in our final ratio as these unknowns are the same for both measurements and cancel in the final ratio. Our final ratio gives us information that is dependent only on the absorption coefficients of deoxygenated and oxygenated haemoglobin and on the percentage of haemoglobin that is oxygenated, the desired output of the oximeter SPO2. In this equation, R represents a parameter called the “ratio of normalized absorbance,” the quantity actually measured by pulse oximeters. The ac component of interest is the signal component at the heart rate (f_p) that is normally around 60–120 beats per minute (bpm) or, equivalently, 1–2 Hz in a healthy adult.

**III. ARCHITECTURE OF PULSE OXIMETER**

A. Existing Design

The most common model is the sensor placed on finger model, which displays the blood oxygenation level (SpO2) and pulse rate. The device is actually a finger model as the sensor is placed on a finger which is then connected to a wrist where results are displayed. But the model on the finger is quite uncomfortable and noticeable. For long period and continuous monitoring this model is not preferable.

![Figure 1: Finger based Pulse Oximeter](image)

B. Proposed Design

So a wrist based sensor design is done. The design for the sensor module was based on the need for a concentric photodiode arrangement around two LEDs, one infrared and one red. Since that a larger number of photodiodes would only benefit the device, the group decided to utilize 8 surface photodiodes.
In Figure 3, we can see the top view of the sensor module that the group developed. The red and infrared LEDs are placed in the center of 8 photodiodes which are able to pick up light from nearly every angle. The added effect of the photodiodes is also a benefit since summing up the current from all eight photodiodes maximizes the fraction of total backscattered light collected by the sensor.

The placement of the LEDs relative to the photodiodes was also important. Since the LEDs were much larger than the photodiodes, we had to consider how we could design the sensor so that the LEDs and photodiodes were the same level when placed on the skin. The top platform, which is the surface of the device that is placed against the skin, was used primarily for the placement of the photodiodes. A rectangular opening was then made in the center of the board to allow for the LEDs placed on the bottom platform to protrude through and allow the light to pass through the skin. To allow for portability and to reduce the weight of the sensor, we separated the sensor module from the actual circuitry and connected 4 wires from the sensor to the circuitry board. A block diagram of our pulse oximeter system is displayed in Figure 2.

For the photodiodes, we used an op-amp in photovoltaic mode so that the current output of the photodiodes is converted to a voltage. The voltage, which is directly related to the amount of light collected, is then sent through two Sample-and-Hold ICs (S/H) to separate the red and infrared signals. To accomplish this, the voltage output by the photodiodes were connected simultaneously connected to both S/H and used the LED driver signals for the red and infrared LEDs as the logic driver for each S/H respectively. Each S/H is able to sample the respective LED to which they are connected to and hold that value until the next time the LED is turned on. The output of each S/H provided the AC and DC components of the PPG required for calculating oxygen saturation. However, because the AC component is generally very tiny compared to the

DC component, it was necessary to filter this signal further so that the DC component can be removed and the AC component is amplified.
C. LED Driver circuit

The Freedom board which is used in the project is not able to supply sufficient current to the LED because it is a low power battery operated device. To achieve high brightness, today’s LEDs handle much higher current and have a higher voltage drop compared to traditional small-current LEDs. Since Brightness and intensity is important in this medical sensor it is important to have a LED driver which can provide high current to the LED in the circuit.

![Figure 5 H bridge LED driving circuit](image)

The LEDs in the sensor module are driven at alternating frequencies of 100Hz with a 2.5ms delay between each LED as it is turned on displays the timing diagram of the Arduino Microcontroller which is used as an LED driver. The board was programmed so that the first channel (in yellow) is ON for 2.5ms and OFF for 7.5ms while the second channel (in green) is OFF for 5ms, ON for 2.5ms and then OFF for 2.5ms.

D. Current to voltage conversion

The transimpedance amplifier is a current to voltage converter. Figure 6 shows the circuit diagram of a TIA. It is used to amplify the current generated by a sensor (not shown) which connected between the inverting input of the operational amplifier U1 and ground/supply voltage. The non-inverting input can be connected to ground (for dual supply opamps) or to a bias voltage Vbias (for a single supply voltage).

![Figure 6 Transimpedence amplifier](image)

The DC equations in the ideal case:

\[ \text{If} = \frac{\text{Vout}}{Rf} \]  

\[ \text{Vout} = \text{If} \times Rf + \text{Vbias} \]  

Hence the output voltage can be set by selecting the value of Rf.

E. Sample and hold circuit

The voltage, which is directly related to the amount of light collected, is then sent through two Sample-and-Hold circuit to separate the red and infrared signals. To accomplish this, the voltage...
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![Sample and Hold circuit](image)

**Figure 7** Sample and Hold circuit

F. Filtering

The pulse oximeter makes it possible to observe the PPG signal due to the changing of absorbance because of arterial blood pulsating throughout the body. In Figure 8 below we can see that the PPG which is commonly referred to as the pulsatile component or the AC component, is a small percentage of the total signal output which is generally riding on top of a large DC offset.

![Unfiltered output of a PPG signal](image)

**Figure 8** Unfiltered output of a PPG signal

This DC offset occurs due to absorbencies that are not changing such as skin or other non-arterial tissues which maintain a constant absorbance. When attempting to amplify the PPG for closer inspection, it is generally the case that the DC component is also amplified and as a result ends up saturating the signal. To properly amplify the PPG signal it is best to filter out the DC component through the use of a band pass or high pass filter.

![Figure 9 High Q Band Pass Filters](image)
To filter and separate the AC component from the AC and DC components, obtained from the S/H, each respective signal red and infrared was processed through a 2nd order bandpass filter. Both bandpass filters were designed with a frequency cutoff of 1.5Hz and bandwidth of 1.5Hz.

Once amplified, the PPG signal can then be used to calculate heart rate either visually or with the aid of special software that can calculate the frequency or count the number of peaks in a certain time interval.

IV. RESULTS

G. Transmitter section

Transmitter section is implemented which consist of Red and Infrared LED. H bridge is used to drive these LED. Red and Infrared is glowed alternatively using PWM function in Freedom board (FRDM-KL25Z). The board was programmed so that the first channel (in yellow) is ON for 2.5ms and OFF for 7.5ms while the second channel (in green) is OFF for 5ms, ON for 2.5ms and then OFF for 2.5ms.

![Figure 10 LED driver timing diagram with 2.5ms time increments](image)

![Figure 11 H bridge implementation](image)

H. Receiver section

Receiver section consist of Photodiodes and transimpedence amplifier to accurately capture the PPG signals. Different combinations or placement has been tried to proper PPG signals.

![Figure 12 Receiver section](image)
I. Interfacing of Transmitter and Receiver part

Both transmitter and receiver part is interfaced in such a way that both red and infrared light should reflect back from the wrist and photodiode should capture reflected light.

![Interfacing of Receiver and Transmitter](image1)

Figure 13 Interfacing of Receiver and Transmitter

J. PPG obtained from Transimpedence amplifier

![Unfiltered PPG](image2)

Figure 14 Unfiltered PPG

K. PPG obtained after filtering

![PPG After Filtering](image3)

Figure 15 PPG After Filtering

Once PPG is obtained peak to peak method is obtained to get AC components. Averaging methods are used to calculate DC components. Different algorithm can be applied to calculate SpO2 and Pulse rate. So accurate PPG can be obtained from the wrist which can be used as wearable device.

V. CONCLUSION AND FUTURE SCOPE

Wrist based sensor module is designed by placing photodetectors in concentric plane and placed on the wrist to obtain PPG signals. PPG signals is acquired from the wrist using reflectance based oximeter by using wrist based sensor module sensor module. This PPG signal is used to
calculate blood oxygen saturation and Pulse Rate. Future scope is to use the algorithm to calculate Blood oxygen saturation and the pulse rate using appropriate algorithm or programming.

VI. ACKNOWLEDGMENT

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REFERENCES