Abstract—Measuring Oxygen Saturation Level is an important part in monitoring patient’s health condition. This is commonly monitored by a pulse oximeter, which has been widely adopted around the world as a standard measure during anesthesia, neonatal care and post-operative recovery. However, measuring Oxygen level continuously is very important for aged people, pregnant women and in many other critical situations.

This paper considers the problem of measuring Oxygen saturation level continuously, a method to measure Oxygen Level using Photoplethysmography (PPG) signal has been presented. A prototype transducer has been built to measure the PPG. The transducer needs to be in contact to the subject’s finger. Developed algorithm is presented that achieved accurate oxygen level and an experiment was also carried out on subjects’ finger

Keywords— Oxygen Saturation Level, Photoplethysmography, Pulse oximetry.

I. INTRODUCTION

Photoplethysmography (PPG) is a non-invasive method used to detect blood volume changes in the body caused by cardiovascular pulsations. It relies on the optical absorption characteristics of blood and living tissue, thus requiring a light source and detector to function. Some methodologies have been proposed to analyze the PPG signals. The signals could be possible to analyze in the time domain or frequency domain. However, due to the non-stationary nature of PPG signals, the use of time-frequency analysis appears to be extremely attractive.

Oxygen Saturation level (SpO2) is commonly monitored by a pulse Oximeter, which has been widely adopted as a standard measure during anesthesia, neonatal care and post-operative recovery [5, 6]. Pulse oximetry uses PPG that described above to measure the arterial oxygen saturation by a non-invasive spectrophotometric method [7]. Pulse Oximeters use these theories to evaluate the pulse rate and the blood oxygen saturation level of an individual. Their ability to measure these parameters non-invasively makes them preferred by the public. Because of real-time monitoring capabilities and accuracy, they are commonplace in the hospitals and continuously used by medical professionals for initial diagnosis. Pulse Oximeters that are currently available in the market perform remarkably well when the monitored subject is in the resting position. However, their reliability is significantly reduced when the subject moves, even when movements are only involuntary, such as shivering [11]. Therefore, the reduction of motion artifacts is one of the main concerns in the development of pulse oximeters, which then can be used as personal home health care.

Pulse oximetry relies on the ratio of the optical absorption of hemoglobin and oxy-hemoglobin [1]. It is widely based on the Beer-Lambert Law, which establishes a relationship between absorbance and concentration of an absorbing liquid under controlled conditions. Meanwhile, Dowla et al. proposed using a neural network together with a wavelet transform (WT) to estimate SpO2 in the presence of a motion artifact and found out that this technique performs better than conventional algorithm that detects peaks and troughs of the PPG signal for estimating SpO2 levels [2].

In this paper, the basic theory and algorithms of achieving Oxygen Saturation level will be discussed. Then the designed prototype will be shown with its measurements of subjects’ body. Finally the results will be discussed.

II. METHODOLOGY

Oxygen saturation level can be achieved by employing a photo detector and Red and near-IR light emitting diodes (LED’s) to measure the light that scatters through blood perfused tissue [9]. Basically these two LED’s are going to work as transmitters and the photodiode will behave as a receiver. The red light emitting diode with the wavelength of 660 nm and Infrared light emitting diode with wavelength of 940 nm will be used in the transducer. The point of interest is to detect Oxyhaemoglobin and De-oxyhaemoglobin by the Photodiode, for this reason these two LEDs are going to be used. The reason of making these as point of interest will be discussed later in this section with the help of mathematical equations.

As it has been mentioned earlier that the Beer- Lambert’s law [4] can be applied to find the properties of amount of light absorbed, the law can be expressed in a way from where it is possible to find the original intensity of light at a specific wavelength.

\[ I_{out} = I_{in} e^{-\varepsilon(\lambda)cd} \]  

Where, \( I_{in} \) is the original intensity of the light, \( \varepsilon(\lambda) \) is the extinction coefficient of absorptivity at a specific wavelength \( \lambda \),
$c$ is the concentration of the substance absorbing the light, and $d$ is the optical path length.

If two wavelengths of monochromatic light alternately illuminate a pulsating bed of vessels, the percentage ratio between the concentration of oxyhemoglobin and the sum of the concentration of oxyhemoglobin and De-Oxyhemoglobin can be calculated [3]. This ratio is commonly referred as the oxygen saturation level. So it can be expressed as,

$$\text{SpO}_2 = \frac{\text{HbO}_2}{\text{HbO}_2 + \text{Hb}} \times 100$$  \(2\)

Where, $\text{SpO}_2$ = Oxygen Saturation, $\text{HbO}_2$ = Oxyhemoglobin, $\text{Hb}$ = De-Oxyhemoglobin.

If the DC and AC component are known of two different wavelengths of light emitted by two diodes, then the Ratio (R) can be computed by the following equation [3], [11].

$$R = \frac{AC_{660} / DC_{660}}{AC_{940} / DC_{940}}$$  \(3\)

The DC component of the signal is primarily affected by the absorption in the intensity of light source, ambient light, sensitivity of the detector, tissue bed, bone, venous blood, capillary blood, and non-pulsatile arterial blood. The AC component captures the pulsating arterial blood [4]. The Fig. 1 below shows the fact.

![Absorption due to pulsatile arterial blood (AC)](image1)

We can rewrite the Beer-Lambert law, as there are two absorbers in this case.

$$I_{out} = I_{in} e^{-cd(SE_{\text{hbo}} + (1-S)E_{\text{hbo}})}$$  \(4\)

Where, $E_{\text{hbo}}$ = Extinction Co-efficient for Oxyhaemoglobin, $E_{\text{hbo}}$ = Extinction Co-efficient for De-Oxyhaemoglobin, $S$ = Oxygen saturation.

If the ratio of light intensity measured at two times with two different wavelengths is calculated, it can be shown that the Lambert-Beer Law can be written independent of both absorber concentration and path length [3].

$$R = \frac{\ln \left( \frac{I_{out}(t_1)}{I_{out}(t_2)} \right)}{\ln \left( \frac{I_{out}(t_1)}{I_{out}(t_2)} \right)}$$

$$R = -\Delta cd[(S E_{\text{hbo}}(\lambda_R) + (1-S)E_{\text{hbo}}(\lambda_R))]$$

$$-\Delta cd[(S E_{\text{hbo}}(\lambda_R) + (1-S)E_{\text{hbo}}(\lambda_R))]$$  \(5\)

Here $I_{out}(t_1)$ indicates the red light intensity exiting through the finger during systole and $I_{out}(t_2)$ is the red light intensity exiting through the finger during diastole. The denominator can be explained in the same way.

If we rearrange the equation (5) as an expression of $S$ or $\text{SpO}_2$ (Oxygen Saturation), we get the following equation.

$$\text{SpO}_2 = \frac{E_{\text{hbo}}(\lambda_R) - (E_{\text{hbo}}(\lambda_R) \times R)}{E_{\text{hbo}}(\lambda_R) - E_{\text{hbo}}(\lambda_R) \times (E_{\text{hbo}}(\lambda_R) - E_{\text{hbo}}(\lambda_R) \times R)}$$  \(6\)

Now to get the values of the extinction coefficient for both wavelengths, we can use the following Spectrum graph [4] in Fig. 2. The spectrum graph shows the extinction coefficient values for different wavelengths of light. Here our point of interest is to get the values of extinction coefficient for 660 nm and 940 nm wavelength of light.

![Absorption Spectrum](image2)

The following table I shows the values that have been extracted from the above Fig. 2.

From the table I, we find the necessary extinction coefficient values that can be used in equation (6).

Therefore, $E_{\text{hbo}}(\lambda_R) = 0.81$, $E_{\text{hbo}}(\lambda_R) = 0.18$, $E_{\text{hbo}}(\lambda_R) = 0.08$ and $E_{\text{hbo}}(\lambda_R) = 0.29$.
TABLE I: EXTINCTION COEFFICIENT FOR HAEMOGLOBIN [11]

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Extinction Coefficient (L/mmol/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hb</td>
<td>0.81 ± 0.006</td>
</tr>
<tr>
<td>HbO2</td>
<td>0.08 ± 0.005</td>
</tr>
<tr>
<td>660 (Red)</td>
<td>0.18 ± 0.003</td>
</tr>
<tr>
<td>940 (IR)</td>
<td>0.29 ± 0.002</td>
</tr>
</tbody>
</table>

So substituting the values in Equation (6), we get the following.

\[ SpO_2 = \frac{0.81 - (0.18 \times R)}{0.81 - 0.08 + (0.29 - 0.18 \times R)} \times 100 \]
\[(7)\]

Therefore,

\[ SpO_2 = \frac{0.81 - (0.18 \times R)}{0.73 + (0.11 \times R)} \times 100 \]
\[(8)\]

We only need to find the value of \( R \) to solve the above equation. To achieve the value for \( R \), we can use the equation (3). Then we can calculate the Oxygen saturation level from the above equation.

By calculating the ratio of the AC components and the ratio of the DC components of the two light sources, \( SpO_2 \) can be obtained from every single pulse of a PPG signal. To stabilize the reading, we can use the Weighted Moving Average (WMA) method [11]. To get more reliable result, we can take the values of \( SpO_2 \) in an 8 second period, then we can take the average value of those eight values that we could obtain.

Moreover, if we know the value of \( R \), we can get the Oxygen saturation level straight away from the graph below since it had been proven that the ratio is empirically related to Oxygen Saturation [4]. Fig. 3 shows the relationship between the ratio (R) and Oxygen Level.

![Figure 3. Pulse Oximeter Calibration Curve [4]](image)

### III. EXPERIMENT

To implement the above concept, a real experiment was performed to measure the Oxygen Saturation Level. First of all, an Acquisition Board was build, which was an electronic circuit. The purpose of the circuit was to achieve the PPG signals from the subject’s finger. The circuit consists of two LEDs- one Red and one Infrared and a photodetector. Two LEDs of different wavelengths were used as source of light that passed through the tissue and the photodetector was used as receiver. Thus two PPG signals for two different wavelengths can be achieved. Fig. 4 shows the circuit schematic.

![Figure 4. : Circuit Schematic](image)

The original circuit in the Vero board is shown in the Fig.5.

![Figure 5. : Original Circuit on Vero Board](image)

When the circuit was powered up, subject’s fingers were in contact with both the LEDs and Photodetector. It needed few minutes to get stable PPG signals. The output of the circuit was transmitted to personal computer and estimation software was used to display the PPG signals and using LABVIEW software to do some of the analysis. The PPG signals displaying on the LABVIEW window consist of both DC and AC level. Now to achieve Oxygen level, AC and DC components need to be estimated separately. DC and AC estimation function of LABVIEW can do that to get the most accurate values. Then these values have been substituted in the equations mentioned earlier. Thus the ratio of DC and AC components for both wavelengths has been achieved and again using the final equation the Oxygen saturation Level can be estimated. To check the reliability of the system estimation, Pulse Oximeter Calibration Curve has been used.

### IV. RESULTS

The PPG signals that achieved from subject’s finger are shown in the Fig. 6. Every step before achieving Oxygen level is also displayed in the LABVIEW window and finally using those steps, estimated Oxygen saturation level was also shown in the Fig. 6. Here to mention that block diagram was drawn into the LABVIEW using different functions like filtering, AC-DC estimating, formula etc.

From the PPG signals of Subject’s finger, DC and AC components were estimated as follows.

DC level for IR: 3.89911, AC level for IR: 0.0261483
Moreover, another experiment has been done to compare the measurements from our built transducer and an oximeter (Model: Mallinckrodt N-20E) that currently available in the market. Two subjects were used in the experiment. First reading was taken in a normal condition and the second reading was taken after a deep breathing for each subject. The comparison is shown in the Table II.

<table>
<thead>
<tr>
<th>Component</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC level IR</td>
<td>3.89911</td>
<td>3.55509</td>
<td>3.69003</td>
<td>4.04749</td>
</tr>
<tr>
<td>AC level IR</td>
<td>0.02614</td>
<td>0.09732</td>
<td>0.05037</td>
<td>0.03589</td>
</tr>
<tr>
<td>DC level Red</td>
<td>3.71914</td>
<td>3.49037</td>
<td>2.78973</td>
<td>3.31003</td>
</tr>
<tr>
<td>AC level Red</td>
<td>0.01039</td>
<td>0.03762</td>
<td>0.01221</td>
<td>0.00916</td>
</tr>
<tr>
<td>RATIO</td>
<td>0.424771</td>
<td>0.39372</td>
<td>0.32068</td>
<td>0.31215</td>
</tr>
<tr>
<td>Oxygen Level</td>
<td>94.44%</td>
<td>95.58%</td>
<td>98.30%</td>
<td>98.62%</td>
</tr>
</tbody>
</table>

Moreover, another experiment has been done to compare the measurements from our built transducer and an oximeter (Model: Mallinckrodt N-20E) that currently available in the market. Two subjects were used in the experiment. First reading was taken in a normal condition and the second reading was taken after a deep breathing for each subject. The comparison is shown in the Table III.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Condition</th>
<th>Built Transducer Result</th>
<th>Standard Device Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal</td>
<td>96.56%</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>Deep Breath</td>
<td>97.33%</td>
<td>99%</td>
</tr>
<tr>
<td>2</td>
<td>Normal</td>
<td>96.82%</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>Deep Breath</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

VI. DISCUSSION AND CONCLUSION

An Oxygen Saturation value of 95% is clinically accepted in a patient with a normal hemoglobin level [8]. So the results that have been achieved from the conducted experiment on four different subjects are within normal range. Moreover, the comparison Table III shows the accuracy of the built prototype as the results from standard device and built transducer are close enough. However, the results are not exactly identical. Noise from the wire comes out from our built prototype might hamper the result. So when the manufacturer would build it, the noise will be totally saturated and it would give better result.

Therefore, the experiment performed in this project clarifies the conformity of implementing the method that has been described earlier in this paper. As the experiment gave expected result, the idea can be implemented in a more compact device. Thus the most accurate Oxygen level can be achieved using the idea described in this paper and can be used continuously.

VI. FUTURE WORK

The future work might be to build the microcontroller and program it using the algorithms described in this paper. The output of the transducer can be connected to the microcontroller and the whole system can work in a stand alone condition. The size of the whole system will be smaller, even it could be possible to fit the transducer and microcontroller in a small ring. The infrared micro controller can make the life easier as it can be used wireless communication, in addition to alarming system for the subject and related health care provider.

REFERENCES