Design of Low Cost Pulse Oximetry Based on Raspberry Pi

S Bakhri1, E Rosiana2, R C Saputra3

1 Department of Informatics, Faculty of Engineering, Universitas Pamulang, Indonesia. 15310
2,3 Department of Electrical Engineering, Faculty of Engineering, Universitas Pamulang, Indonesia. 15310
Email:{dosen00047@unpam.ac.id1, dosen00689@unpam.ac.id2, rivaldy.saputra@gmail.com3}

Abstract. Pulse Oximetry is a non-invasive method for monitoring blood oxygen saturation. The oxygen saturation in blood is expressed in percentage of saturation of total hemoglobin (SpO2). This method utilizes the different wavelengths of red light (660 nm) and infrared light (940 nm) captured by the light sensor after passing through vessels and capillaries at the tip of the index finger. In this study a red and infrared LED that is directed to the fingertips and light passing through the blood vessels captured by photodiode are utilized. The signal from the photodiode is sent to Raspberry pi and processed to get a percentage of oxygen saturation in the blood. This paper presents the comparability of the produced prototype with the commercial standard equipment. It was also demonstrated that the error accuracy is relatively comparable with commercial one while the price are relatively lower.

1. Introduction

Oxygen is one of element which is very important for the body human. Oxygen through a series the process reach existing cells inside the body. Because the function of oxygen is very important in the body, then information regarding oxygen levels bound inside the blood is very important to be determined. Especially for the intensive care patients and monitoring anesthesia patients [1]. Oxygen present in circulation blood is bound by one component of blood, namely Hemoglobin (Hb). The color of the blood with lots of oxygen binding compare with that little oxygen binding will be different. Based on this, then if the blood red color level can be determined then the oxygen levels dissolved in the blood can also be known. A light source which penetrate thin human parts describe how the spectrum the color of blood in the skin, which in turn will show the oxygen level inside the person's blood [2]. The equipment which is the function is to measure this dissolved oxygen known as oximetry.

The standard pulse oximetry devices which can be used for the patient assessment conditions available in the market is still relatively expensive, so requires a lot of money for the equipment at the health facility. Based on the previous background, design of the oximetry considering how the light captured by the photodiode can processed by a relatively low cost and reliable embedded hardware platform. The Raspberry Pi can be implemented as the oxygen saturation blood measurement platform. Therefore, the aims of this paper is to utilize the Raspberry Pi 3 platform for the low cost and reliable oximetry.

2. Theory

2.1. Pulse oximetry

Pulse oximetry is a non-invasive method for monitoring oxygen saturation in the blood. Oxygen saturation (SpO2) is the percentage of hemoglobin containing oxygen. Pulse Oximetry works on the
condition that hemoglobin with dissolved oxygen (HbO2) absorbs light with wavelengths that are different from hemoglobin that does not bind oxygen (Hb). This method utilizes the different wavelengths of red light (660 nm) and infrared light (940 nm) which are captured by a light sensor after passing through the veins and capillaries at the tip of the index finger.

Pulse oximetry sensors use light to measure oxygen saturation. Sensor placement is recommended for thin body tissues such as fingertips or ears. The way this tool works are by comparing the intensity of light absorbed by the photosensor after passing through the fingertips and interacting with red blood cells that flow at the fingertips. Red and infrared light that passes through the fingertips has a different reduction in light intensity. Absorption and the reduction in light intensity from red and infrared light are compared and processed to obtain a percentage value of oxygen saturation in the blood (SpO2). The graph of light absorption by hemoglobin is shown in Figure 1.

![Figure 1. Graphs the absorpsi light by hemoglobin [10].](image)

Oxygen saturation in arterial determined as the ratio of the total Hb, HbO2 available on the arteries. The comparison can be seen in the following equation:

\[
SpO2 = \frac{[HbO2] + [Hb]}{[HbO2] + [Hb]}
\]

where :

\(SpO2\) = Percentage of oxygen saturation.

\(HbO2\) = Hemoglobin containing oxygen.

\(Hb\) = Hemoglobin that doesn't contain oxygen.

Pulse Oximetry devices use red and infrared LEDs (Light Emitting Diode) together with photosensors to measure the intensity of light that has passed through the fingertips. The intensity of light that has passed through the fingertips has decreased in intensity. This reduction in intensity is caused by blood flow to the veins, blood flow to the arteries and tissues. Reduction of light intensity by venous blood flow and tissue produces a relatively stable signal, which is a DC signal. Reducing the intensity of light by arterial blood flow produces a relatively unstable signal, which is an AC signal. The absorption of red light over infrared light is an indication of low oxygen saturation, and conversely infrared light absorption over red light is an indication of high oxygen saturation [4].

The value of oximetry can be calculated by finding the value of R. R is a comparison of the absorption of red and infrared light which produces AC and DC components:

\[
R = \frac{ACred/DCredd}{ACired/DCired}
\]

After R value is known, then the value of SpO2 can be determined by entering the R value into the following linear equation.

\[
SpO2 = 110 - 25R
\]

where :

R = Voltage ratio results from absorption of red and infrared light.
\[ AC_{red} = \text{Value of AC voltage from absorption of red light.} \]
\[ DC_{red} = \text{Value of DC voltage from absorption of red light.} \]
\[ AC_{ired} = \text{Value of AC voltage from infrared light absorption.} \]
\[ DC_{ired} = \text{Value of DC voltage from infrared light absorption.} \]

### 3. Methodology

#### 3.1. Oximetry sensor IC max30100

Oximetry Sensor IC MAX30100 is a sensor module package whose main component is IC MAX30100. IC MAX30100 is IC which is composed of red and infrared LEDs and signal conditioners integrated in one IC package. Function from this sensor module is to retrieve voltage data to search SPO2 value and detect pulses. Block diagram and placement sensor module can be seen in the Figure 2.

![Figure 2. Block diagram and IC placement MAX30100.](image)

This MAX30100 sensor module placed on the body's tissues thin like a fingertip. Light from the second LEDs are red and infrared activated alternately with 100Hz frequency. Light from both LEDs is emitted to the fingertips so that some are absorbed by the tip finger and reflected back. Light which is reflected by the photodiode on IC MAX30100 so that cause voltage on the photodiode and the voltage is forwarded to conditioner signal that already integrated in IC MAX30100. Signal which comes from the sensor module MAX30100 is forwarded to Arduino Uno using the I2C Communication protocol. The Schematic sensor oximetry module MAX30100 can be seen in the Figure 3.

![Figure 3. Schematic sensor oximetry module MAX30100.](image)
3.2. Rasberry Pi
Raspberry Pi is a single board computer (Single Board Computer) almost small size matching the size of a credit card. Raspberry pi can be used to run program office space, game computer, play audio and video and can interact with equipment input and output through GPIO ports (General Purpose Input Output). Raspberry Pi is made and developed by a foundation A non-profit named Raspberry Pi Foundation from Cambridge University, England [5]. Raspberry Pi used to process data be accepted from Arduino and display it in graphical form and SPO2 percentage. The following is physical form of Raspberry Pi can be seen in the Figure 4.

![Figure 4. Raspberry Pi 3](image)

3.3. Block diagram
The Pulse Oximetry tool created inside this research was designed with diagrams block in Fig 5:

![Figure 5. The block diagram of the oxymetry](image)

Oximetry IC MAX30100 sensor emits light Red and infrared alternately, then light which affects the fingertips reflected and captured by the photodetector on The IC. Voltage data generated the IC is sent to Arduino use I2C serial communication. The received data by the Arduino is sent to the Raspberry Pi through USB communication line (Universal Serial Bus). Data are sent by Arduino in the form of a voltage value from the detected red and infrared light which are accepted by IC MAX30100. Voltage data on the Raspberry is then calculated using formula of oximetry to produce a level of the saturated oxygen in the blood. Then, the value is displayed on the LCD along with the graph of red and infrared light components.

3.4. Employed Program
Employed Program The program uses for the design are both the language of Arduino and Raspberry Pi. Data from the oximetry MAX30100 sensor is forwarded to Arduino to be processed and forwarded to Raspberry via USB. On Raspberry, data from Arduino are processed using equations (2) and (3) to obtain the percentage value of SPO2.

3.5. Testing and validation stage
Pulse Oximetry is an easy to use tool for health assessment. However, the accuracy of Pulse Oximetry can be a real concern. Measurement error on Pulse Oximetry can cause misdiagnosis in patients. Therefore, the accuracy of Pulse Oximetry must be determined. The Pulse Oximetry tool produced in this research was tested by comparing with the commercial pulse oximetry device that has been standardized and calibrated. This stage also aims to minimize measurement errors. Data validation is done to obtain the performance of the oximeter and the measurement error. The tool used for the comparison is the Schiller type Side Monitor Bed Argus LCX as given in Fig. 6. The produced Pulse Oximetry in this research is given in Fig. 7.
4. Result and discussion

4.1. Data collection result

Data collection is carried out by taking the SPO2 percentage in the tool, then compared with standard tools to find the percentage of errors. The following is a table of data collection results of five volunteers.

Table 1. Result of percentage data collection SPO2.

| No | Name   | Measurement | Produced Tool SPO2 (%) | Standard Commercial (%) |
|----|--------|-------------|------------------------|-------------------------|
| 1  | Rivaldy| 1           | 101.27                 | 100                     |
|    |        | 2           | 98.4                   | 100                     |
|    |        | 3           | 95.2                   | 100                     |
|    |        | 4           | 101.6                  | 99                      |
|    |        | 5           | 97.83                  | 100                     |
| 2  | Bambang| 1           | 93.86                  | 98                      |
|    |        | 2           | 94.5                   | 97                      |
|    |        | 3           | 95.8                   | 96                      |
|    |        | 4           | 95.52                  | 95                      |
|    |        | 5           | 96.34                  | 96                      |
| 3  | Adit   | 1           | 96.79                  | 100                     |
|    |        | 2           | 99.05                  | 99                      |
|    |        | 3           | 95.59                  | 98                      |
|    |        | 4           | 96.49                  | 97                      |
|    |        | 5           | 94.98                  | 97                      |
| 4  | Jaya   | 1           | 96.87                  | 100                     |
Data taken from the produced tool is a percentage of SPO2 at the time of measurement and a graph of the pulse representation of each of the different components of light, namely red and infrared. Fig. 8 shows the results of the retrieval data.

|   |      |      |
|---|------|------|
| 2 | 98.09| 100  |
| 3 | 98.68| 100  |
| 4 | 98.92| 100  |
| 5 | 98.47| 100  |
| 5 | Denis|      |
| 1 | 95.09| 100  |
| 2 | 96.37| 98   |
| 3 | 96.96| 97   |
| 4 | 96.07| 96   |
| 5 | 98.45| 96   |

4.2. Data Analysis and comparison

Data that has been taken is analysed by comparing with the standard equipment. Fig 9 and Fig 10 show measurement example of the graph both from the produced oximeter and standard oximeter respectively. It was found that the comparison of the produced and standard oximeter after five consecutive test of the first volunteer is 98.86 % and 99.8 % respectively.

Figure 9. The test results of the produced oximeter for the first volunteer
Figure 10. The test results of the standard oximeter for the first volunteer

The precision value of the produced oximeter can be determined by a standard deviation of measurement data. The measurement results of the produced oxymeter are 98.86 ± 2.37%. The percentage of errors with the standard comparator instrument is about 0.94%. This small value shows a good quality and achievement during the design. The complete error assessment compared with the standard equipment is given in Table 2.

Table 2. Data table result of comparison of SPO2 percentages

| No | Name  | Average SPO2 Tool (%) | Average Comparative SPO2 (%) | Error (%) |
|----|-------|-----------------------|-------------------------------|-----------|
| 1  | Rivaldy | 98,86                 | 99,8                          | 0,94      |
| 2  | Bambang| 95,2                  | 96,4                          | 1,24      |
| 3  | Adit   | 96,58                 | 98.2                          | 1,65      |
| 4  | Jaya   | 98,21                 | 100                           | 1,79      |
| 5  | Denis  | 96,59                 | 97.4                          | 0,83      |

Average Error (%) 1,29

Table 2 shows that the measurement results of the SPO2 percentage have an average error (error) with the standard commercial equipment is about 1.29% (or the accuracy is around 98.71%). The error percentage means that the produced oximetry is comparable with the commercial one.

4.3. Comparison with Similar Tools

The Pulse Oximetry tool made in this study still has several differences with similar devices used in health facilities and with those sold in the market, in the form of advantages and disadvantages. The following are the advantages of the tools designed in this study, such as:

- Easier to design, because it uses components commonly used in the learning process, such as Arduino and Raspberry Pi.
- Relatively cheaper.
Easier to use for data collection and measurement for a momentarily measurement (non-continuous measurement).

Besides having advantages, the tools designed in this study also have several limitations, as follows:

- Not mobile, because it hasn’t equipped yet with batteries.
- It is relatively difficult to make continuous measurements, because the sensor is not tied to the tip of the finger, but only touched to the tip of the finger (see Fig. 11). Whereas in the standard commercial type, the sensor clamps the fingertip so that it is firmly bound at the fingertip (Fig. 12). It is planned in the future such system will be elaborated.

![Figure 11. Sensor of the produced pulse oximetry](image1)

![Figure 12. Sensor of the standard commercial pulse oximetry](image2)

In addition, to show the advantage of the produced prototype price compared with the standard, here is some of the popular brands in Table 3.

| No | Brands                  | Price         |
|----|-------------------------|---------------|
| 1  | GE Health-care (Tuffsat)| Rp.13,736,250 |
| 2  | GE Health-care (Trusat) | Rp. 40,445,625|
| 3  | Nonin Medical (GO2)     | Rp. 1,917,000 |
| 4  | Bionet (Oxy9-wave)      | Rp. 5,995,000 |
| 5  | Unpam (prototype)       | Rp. 1,163,000 |
5. Conclusion
It can be concluded that the oximetry is relatively comparable with the commercial one. The accuracy and error obtained so far with five volunteers shows promising results. It is about 1.29% error. However, more test and real condition of several patient conditions are needed for further validations. The price of proposed prototype is also affordable and cheaper compare with the commercial one while the quality of the measurement may comparable. Further improvements can be made such as better sensor for continuous measurements and additional online reporting system with various patients automatic condition reporting system.

6. References
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