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Non-Invasive Hemoglobin Blood Level Measurement System

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Abstract. A non-invasive system based on the optical scanning method can be used to measure hemoglobin blood level because hemoglobin has a characteristic of being able to absorb optimally at wavelength 660nm for oxyhemoglobin and 940nm for deoxyhemoglobin. This hemoglobin level measuring system uses the reflectance principle. The sensor probe was designed to be used on patients' fingers, so the sensor reading results were obtained for the reflection of light, which was reflected from patients' fingers. The used sensor was FD100 that could read wavelength at 350nm until 1100nm. The LEDs used were LEDs with each wavelength 600nm and 940nm. Raspberry Pi 3 microprocessor was used as the brain of this device; this microprocessor functions to regulate the light intensity, sensor reading, data processing, visualization, and data storage. The visual result of hemoglobin value (g/dl) is obtained. The equation searching was done by comparing the hemoglobin value to the High-Performance Liquid Chromatography method and sensor reading value. This equation was implemented inside the device, and the test was done to find out the accuracy of the device. Non-invasive blood hemoglobin measuring device that has been developed has an accuracy rate of 94.2% with a standard deviation of 4.7.

INTRODUCTION

Anemia is a deviation of hemoglobin blood levels, which below normal values. Anemia is caused by damage to red blood cells, blood loss, or disruption of red blood cell production [1,2]. According to WHO data, one from four people (24.8%) in the world has anemia [3]. There are some methods that can be used to measure hemoglobin blood levels, such as HemoCue, Cyanmeth, Automated Analyzer, and High-Performance Liquid Chromatography [4]. Those methods still use the invasive method, where blood sampling not only leaves pain in the patients but also allows the patients infected diseases [5]. A relatively long period of detection is also the drawback of this method. Additionally, an invasive method uses consumables that end up as infectious waste. As the development of technology, it is needed a hemoglobin-blood measurement tool that can be used to get an accurate and quick result. The tool also does not hurt the patients. Non-invasive hemoglobin blood level measurement, which uses a spectrophotometry principle with a reflectance approach, will efficiently measure the process. Hemoglobin can absorb light with certain wavelengths [6].

Hemoglobin is one of the proteins that is responsible for delivering oxygen throughout the body. Hemoglobin is divided into Oxyhemoglobin and Deoxyhemoglobin. Oxyhemoglobin is hemoglobin that carries oxygen and makes

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blood color brighter. Oxyhemoglobin can be seen in arteries. Deoxyhemoglobin is an oxygen release; Deoxyhemoglobin can absorb light well at a wavelength of 970 nm. However, a wavelength of 970 nm above is water absorption area in body tissues, so that a wavelength of 970 nm cannot be used to characterize the absorption of Deoxyhemoglobin. At a wavelength of 940 nm, light absorption by water in body tissues is very low, and Deoxyhemoglobin absorption is relatively high [7,8].

A non-invasive system is a system that allows us to measure hemoglobin levels continuously and in real-time based on photometric pulse measurement. Photospectroscopy works by the excitation of light on a substance to produce aquatic on various spectra. Light scattering can be used to indicate in the response of material that will be examined [9,10]. Examples of an optical scanner are visible light spectroscopy, mid-infrared spectroscopy, and near-infrared spectroscopy. The intensity of light received by the sensor is proportional to hemoglobin concentrate at the right wavelength. The wavelength of light must be precise because when testing is done at an incorrect light wavelength, it results in invalid testing data. When using the right wavelength, then changes the hemoglobin concentration slightly only, the sensor output value will occur quite large changes [11].

METHOD

Hardware Manufacture

Hardware manufacture was done at Material Physics Laboratory, Department of Physics, IPB University. The most common approach is using optical detection or optical scanner method (Fig. 1).

The probe was built based on the reflectance method (Fig. 2). The hardware used two LEDs with each wavelength was 660 nm and 940 nm [12,13]. The sensor used photodiode FDS100 from ThorLabs [14]. This sensor has a wavelength range at 350 nm – 1100 nm (Fig. 3).

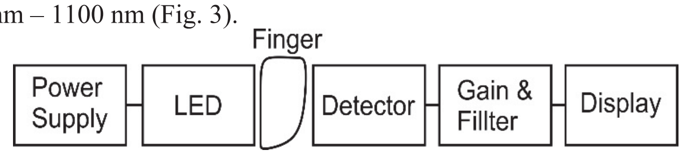

FIGURE 1. Block diagram of a measurement tool for non-invasive hemoglobin levels

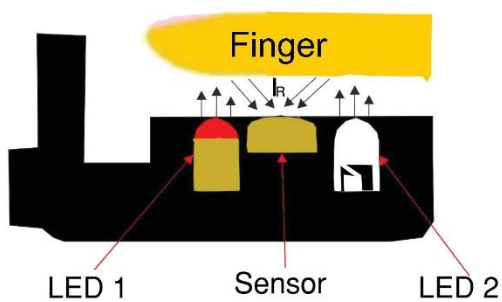

FIGURE 2. illustration of the probe by the reflectance method

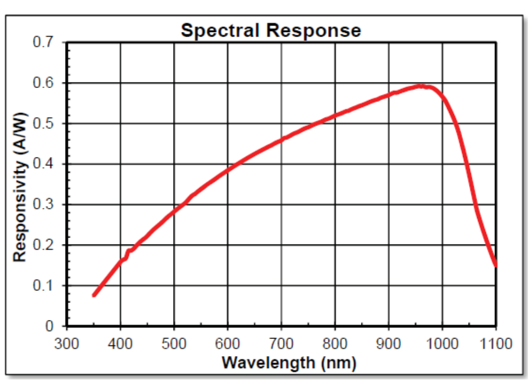

FIGURE 3. Spectral response of the FDS 100 sensor is based on the datasheet

LEDs and sensors were arranged by placing sensors between LEDs. Then, mounted on a probe by the reflectance method. The probe used was printed using a 3D printer with black PLA as the base material. The probe was designed to be used on fingers. The probe that had sensors and LEDs is then assembled on a PCB designed using Eagle software (Fig. 5). Next, PCB that had been combined with the probe was connected to Raspberry Pi, which works as the brain from the tool. Because Raspberry Pi did not have an analog pin to read the sensor, the ADS1115 was added to the PCB, which functions as an analog to digital converter so that the sensor reading could be translated to Raspberry Pi. For the visualization, an LCD was used which could produce the output of the sensor reading.

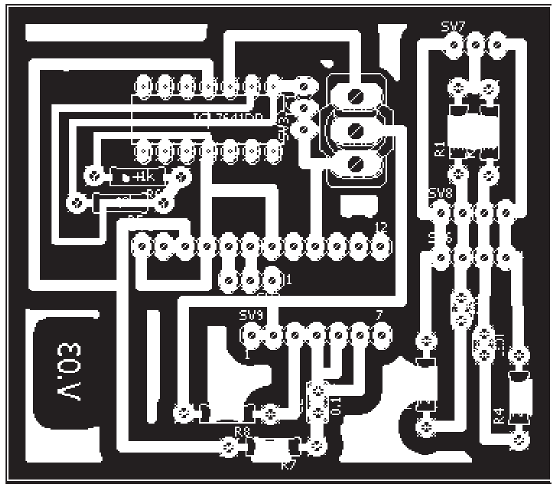

FIGURE 4. Circuit design on PCB

Software Design

Raspberry Pi was used as a microprocessor of this device. QtCreator software was used as a controller of this device, data processing, and visualization on the LCD screen. The sensor reading result would go to ADC to convert an analog value into a digital value. After it became digital value, the data would be inside the Raspberry-Pi. Next, the data was processed using an equation so that it would get the hemoglobin value in g/dl unit [15,16,17].

Respondents and Calibration

The search for respondents was done after getting ethical permission approval by the IPB ethics commission. Respondents that were chosen must fit the criteria in Table 1. The next process was the calibration process that was done by data sampling with the tools, and the result would be compared by HPLC (High-Performance Liquid Chromatography) method. The advantages of the HPLC method are speed, sensitivity, selectivity, and stability. For tool, calibration was done by collaborating with Prodia Clinic.

TABLE 1. Criteria for inclusion and exclusion of respondents

Inclusion Criteria	The academic community of the IPB University Sign a statement of clarification and agreement Age 20-60 years Healty or indicated anemia disorders Male or Female
Exclusion Criteria	Smoke Consuming alcohol Pregnant women

RESULTS AND DISCUSSION

Hardware

Probe for hardware where to place the LEDs and sensors made from black PLA material. The probe used has dimensions of 70 mm x 40 mm x 55 mm. The purpose of using black material was to minimize the light reflection from the probe that later would be read by the sensor, so that it would affect the result from the sensor (Fig. 6). The hardware test was done before it was used for data retrieval. This test was used to find out how precise the hardware of reading the sample, which was same as some repetitions. Based on the results obtained, the hardware had a precision value of 99.35%. After all, the hardware components are ready for use; an integrated circuit is carried out so that it becomes a single unit that is intact and ready to use (Fig. 7).

Software

The software used in this study is QtCreator with the C ++ programming language. The software display of the tool can be seen in Figure 7. The software works by taking data from analog values received and then processed using the best equation, so we get the results of reading hemoglobin with a device with a unit (g/dl). At the time of data retrieval, there are five adventures. The results of each test were averaged data and the output values on the tool. There were four repetitions. The first condition was when the second LED did not light, so the sensor does not read any signal.

The second condition was when the first LED lit up, and the second LED did not light up, so the sensor only read the signal from the first LED. The third condition was when the first LED did not light up, and the second LED lit up, so the sensor read the signal from the second LED only. The fourth condition was when the first LED and the second LED lit up. From each condition, there are 10 periods. The first period states the LED did not light up, the second period states the LED lit up with an intensity of 11%, the third period states the LED lit up with an intensity of 22%, the fourth period states the LED lit up with an intensity of 33%, and up to the 10 period, which states the LED lit up with 99% intensity. The results of each reading signal are stored by the software into a data file and can be seen later.

FIGURE 5. Probe design for hemoglobin measurement system.

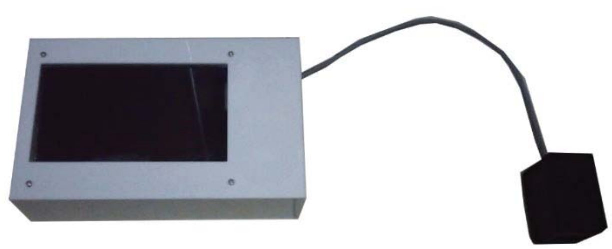

FIGURE 6. Non-invasive blood hemoglobin measurement tool

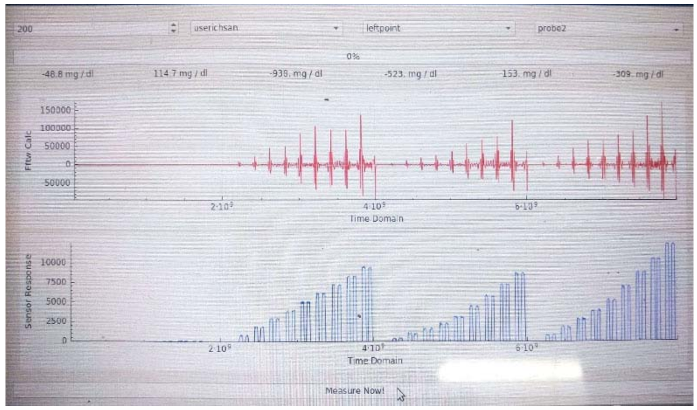

FIGURE 7. Display of a measurement tool

Calibration

Respondents who have filled out and approved the consent form were taken to the Prodia Clinic for 3 cc of venous blood drawn by WHO standard procedures. This blood draw was carried out by experts from the Prodia Clinic. The ethical Approval number is 076/TT3,KEPMSM-IPB/SK/2018. The number of syringes was the same as the number of respondents, so there was no repeat of the use of syringes, so the stability of the syringe could be guaranteed. Venous blood sampling aims to determine the hemoglobin value of each respondent in accordance with the High-Performance Liquid Chromatography (HPLC) method [18]. After taking blood, each respondent's finger was placed in the probe, and then measurements were taken using a device. The fingers used for measurement using a device were the lefthand ring finger. Table 2 shows the respondents' hemoglobin values using the HPLC method.

TABLE 2. Criteria for inclusion and exclusion of respondents

Responden	1	2	3	4	5	6	7	8	9
Hb Result (g/dl)	14.9	16.6	14.9	13.4	12.5	14.4	13.4	15	17.2

The measurement result that used the HPLC method will be a reference value to compare with the sensor reading value. The result of the reading by the sensor will be sought after its correlation with the Pearson correlation. The higher the correlation result, the reading sensor is getting closer to the real value of hemoglobin (Table. 3). From the correlation result, it is obtained that at period 29 and period 38 have the best correlation. Periode here mean different conditions for the intensity of the LEDs.

Referring to that correlation result, then in the period 29 and period 38, the mathematical equation was searched using software named ZunZun. The equation used two independent variables and one dependent variable. The Independent variable was a loosely variable that was taken from the combination period value for each probe. The dependent variable was a tightly variable taken from the Hb value that has been obtained from the HPLC method. A mathematical equation was obtained, then implemented to the tool (Equation 1). This equation obtains input value from analog sensor reading then results in hemoglobin value output (g/dl).

$$z = a \times \sin\left(3.14 \times \frac{(x - x_1)}{x_2}\right) \times \sin\left(3.14 \times \frac{(y - y_1)}{y_2}\right) + c \tag{1}$$

TABLE 3. Pearson correlation value of blood hemoglobin measurement

Periode	Pearson Correlation
11	0.05
12	0.02
13	0.02
14	0.00
15	0.04
16	0.01
17	0.04
18	0.09
19	0.09
20	0.17
21	0.04
22	0.14
23	0.21
24	0.17
25	0.28
26	0.39
27	0.17
28	0.28
29	0.35
30	0.15
31	0.2
32	0.22
33	0.23
34	0.27
35	0.25
36	0.01
37	0.1
38	0.35
39	0.05
40	0.08

After the equation was implemented to the tool, the next step was the accuracy test of tool reading with the real value. The result data and the real value are shown in Table 3. From Table 3, it can be seen that the equation made has an accuracy level of 94.2% with deviation standard of 4.7.

CONCLUSIONS

Based on the references, it was made a non-invasive hemoglobin blood measurement tool that was used a wavelength of 660 nm and 940 nm with an FDS100 sensor that could read a wavelength of 350 nm - 1100 nm. This tool used the reflectance principle so that the analog result which was read by the sensor was light reflectance result from fingers. Using mathematical equations that had been searched and implemented to the tool, the obtained accuracy was 94.2% with a standard deviation of 4.7.

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