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Design and Development of a Measuring Instrument for Cholesterol Level Detection in The Blood Using Non-Invasive Techniques Based on the Wemos D1 R1 Microcontroller

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Abstract

Cholesterol level checks are generally performed either invasively or using a portable blood test strip. It requires a long laboratory analysis time and causes pain in the body, so a non-invasive tool is needed to check cholesterol levels. The study aims to detect cholesterol levels in the blood with a non-invasive technique based on the Wemos D1 R1 Microcontroller using the DS100A Oximeter Sensor. This tool is equipped with a Liquid Crystal Display (LCD) as a cholesterol level display and an LED light as a cholesterol level indicator that will light up red when cholesterol is high (≥ 240 mg/dL), light up yellow when cholesterol is at the high limit (200-239 mg/dL), and light up green when cholesterol is normal (≤ 200 mg/dL). Cholesterol level measurement is done by utilizing the red LED light emission on the sensor attached to the finger. Then, the photodiode will capture the light intensity from the red LED into a voltage value. A 10-bit ADC on the microcontroller then reads the voltage value. The ADC value was then converted into a cholesterol level in milligrams per deciliter (mg/dL) using a linear regression equation. The designed device is capable of detecting cholesterol levels in the range of 150-240 mg/dL. Test results indicate that the non-invasive cholesterol level test device has been successfully developed, with a precision of 98.85% and an error of 1.15%. Accuracy testing yielded a value of 97.14% with an error of 2.86%.

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Abstrak

Pengecekan kadar kolesterol pada umumnya dilakukan secara *invasive* atau melukai tubuh dengan menggunakan test strip alat cek darah portable. Hal ini membutuhkan waktu analisa laboratorium yang cukup lama dan menimbulkan nyeri pada bagian tubuh, sehingga dibutuhkan alat *non-invasive* untuk mengecek kadar kolestrol. Penelitian yang bertujuan untuk mendeteksi kadar kolesterol dalam darah dengan teknik *non invasive* berbasis Mikrokontroler Wemos D1 R1 menggunakan Sensor Oximeter DS100A. Alat ini dilengkapi dengan *Liquid Crystal Display* (LCD) sebagai penampil kadar kolesterol dan Lampu LED sebagai indikator kadar kolesterol yang akan menyala merah ketika kolesterol tinggi (≥ 240 mg/dl), menyala kuning saat kolesterol berada pada batas tinggi (200-239 mg/dl), dan menyala hijau pada kolesterol normal (≤ 200 mg/dl). Pengukuran kadar kolesterol dilakukan dengan memanfaatkan pancaran cahaya LED merah pada sensor yang dipasangkan di jari. Kemudian, fotodioda akan menangkap intensitas cahaya dari LED merah menjadi nilai tegangan. Nilai tegangan kemudian dibaca oleh ADC 10 bit pada mikrokontroler. Nilai ADC selanjutnya dikonversi melalui persamaan regresi linear menjadi nilai kadar kolesterol dengan satuan mg/dl. Alat yang telah dirancang mampu mendeteksi kadar kolesterol dalam rentang 150-240 mg/dl. Hasil pengujian menyatakan bahwa alat cek kadar kolestrol secara non-invasive telah berhasil dibuat dengan nilai presisi alat sebesar 98,85% dengan *error* 1,15%, sedangkan pengujian akurasi didapatkan nilai sebesar 97,14% dengan nilai *error* sebesar 2,86%.

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1. Introduction

One of the health challenges in Indonesia is related to Non-Communicable Diseases (PTM) (Irwan, 2007). Types of PTM with the highest incidence and prevalence rates are catastrophic PTM, including heart disease, cancer, stroke, kidney failure, cirrhosis of the liver, thalassemia, leukemia, and hemophilia. Throughout 2022, BPJS Health is expected to handle approximately 23.3 million cases of catastrophic diseases. Cases of this disease increased by 18.6% compared to 2021 (Humas BPJS, 2023). PTM can be prevented by controlling risk factors through early detection and intervention. One of the risk factor management activities includes checking cholesterol levels (P2PTM, 2019).

Cholesterol has long been a topic of concern, particularly in Indonesia, where the number of sufferers is increasing. According to an article issued by the Ministry of Health of the Republic of Indonesia in October 2022, the prevalence of individuals with high cholesterol reached 28% of Indonesia's population. If handled too late, high cholesterol will endanger health and can even cause death (KEMENKES, 2022).

Checking cholesterol levels is generally done invasively or by pricking the body using a portable blood test strip test kit. Invasive measurement of blood cholesterol levels has several drawbacks, including the cost of checking which is quite expensive, the results of laboratory analysis require quite a long time, can cause pain in the part of the body where the needle is pierced to take blood samples, and can cause fear (phobia) for some people, causing people to ignore the importance of the initial examination to detect disorders of fat metabolism (Fitri & Maisoha, 2020). Therefore, another alternative method is needed to replace invasive methods, namely, non-invasive methods. Non-invasive methods are one of the methods used to check blood without causing injury to the patient.

Fitri & Maisoha (2020) conducted analytical tests on invasive and non-invasive real-time blood cholesterol measurement devices. The results showed that the non-invasive device was five times more efficient than the invasive device in detecting cholesterol levels. However, this non-invasive device still had a significant error rate of 17.72%, resulting in an accuracy of 82.28%. Nurmar'atin (2021) also developed a non-invasive cholesterol monitoring device based on red light absorption using the DS100A Oximeter Sensor, with an accuracy of 82.76%.

This research aims to develop a non-invasive tool for accurately detecting blood cholesterol levels within the permitted limits of medical devices. This research will utilize the DS100A Oximeter Sensor, which is capable of producing voltage changes in the liquid medium. Then, using the Wemos D1 R1 microcontroller, the data from the sensor is processed and converted into cholesterol levels in units of mg/dL, which are then displayed on the LCD. In addition, adding components in the form of green, yellow, and red LED lights as indicators of normal cholesterol levels, moderately high and high.

2. Research Methods

The tools and materials used in this research include the Wemos D1 R1, Oxymeter DS100A Sensor, Light-Emitting Diode (LED), Liquid Crystal Display (LCD), Power Supply, Step-down Converter, and DB9 connector.

2.1 Sensor Oximeter DS100A

The ability of a pulse oximeter to detect arterial blood SpO₂ is based on the principle of fluctuations in the amount of red and infrared light during systole/diastole. Some light passes through the tissue without being absorbed by the photodetector, creating a relatively stable and non-pulsating wave known as direct current (DC). In contrast, the pulsating wave is called alternating current (AC) (Sucandra & Astiti, 2016). The DS100A oximeter sensor has several pins, as shown in **Figure 1**.

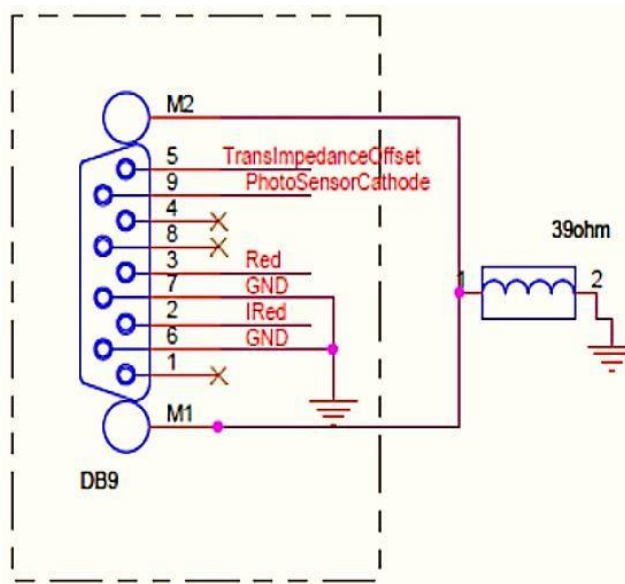


Figure 1. DS100A oximeter sensor pin (Lopez, 2012)

The functions of each pin on the DS100A oximeter sensor are presented in **Table 1**.

Table 1. DS100A Oximeter Sensor Pins (Lopez, 2012)

Pin	Function
6,7	Ground
2	Anoda LED Infrared
3	Anoda LED merah
5	Photodiode Anode
9	Photodiode Katoda

2.2 Overall Design of the Tool

The system planning block diagram is divided into three parts: input, process, and output. The input section contains an Oximeter DS100A Sensor to measure an analog signal from the LED light intensity. The analog signal is then converted to a voltage value by the sensor. Wemos D1 R1 will process the voltage value into an ADC value, and then it will be converted into a cholesterol level value through a linear regression equation. The output from Wemos will be displayed on the LCD screen, and an LED light will serve as an indicator of cholesterol levels. The system planning block diagram is shown in **Figure 2**.

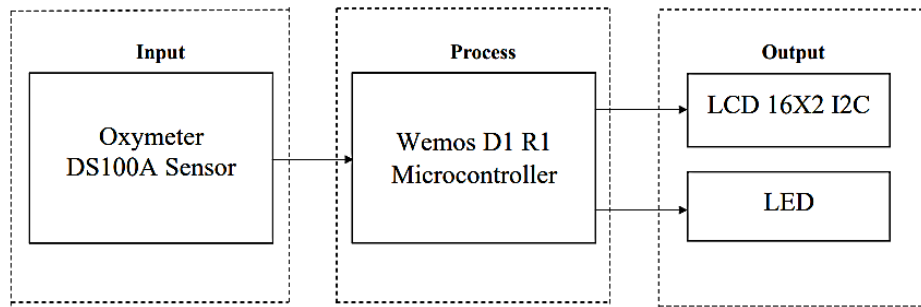


Figure 2. Block diagram system planning

A schematic of all components is shown in **Figure 3**. The pins used on the oximeter sensor are pins 2, 3, 5 and 9 where pin 2 is the infrared anode which is connected to pin D8 on the microcontroller, pin 3 is the red LED anode which is connected to pin D7 on the microcontroller, pin 5 is the photodiode anode which is connected to analog pin A0 on the microcontroller and pin 9 is the photodiode cathode which is connected to ground. Furthermore, the SDA and SCL pins on the LCD are connected to the SDA/D14 and SCL/D15 pins on the microcontroller. The red, yellow, and green LED pins are connected to pins D10, D11, and D12 on the microcontroller. A step-down voltage regulator is used to lower the voltage from 12 V to 5 V on a 12 V power supply, where the V+ pin is connected to the Vin pin on the microcontroller, and V- is connected to ground.

The DS100A Oximeter Sensor is a device used to measure oxygen saturation (SpO_2) non-invasively. Oxygen saturation is defined as a measurement of the amount of oxygen dissolved in the blood, based on the detection of oxyhemoglobin and deoxyhemoglobin (Lopez, 2012).

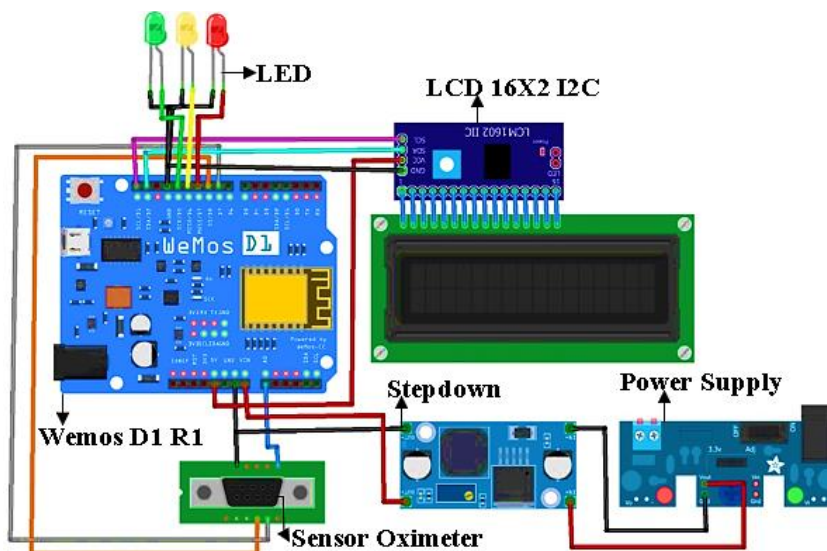


Figure 3. Schematic circuit of the tool

The design of the non-invasive tool is shown in **Figure 4**.

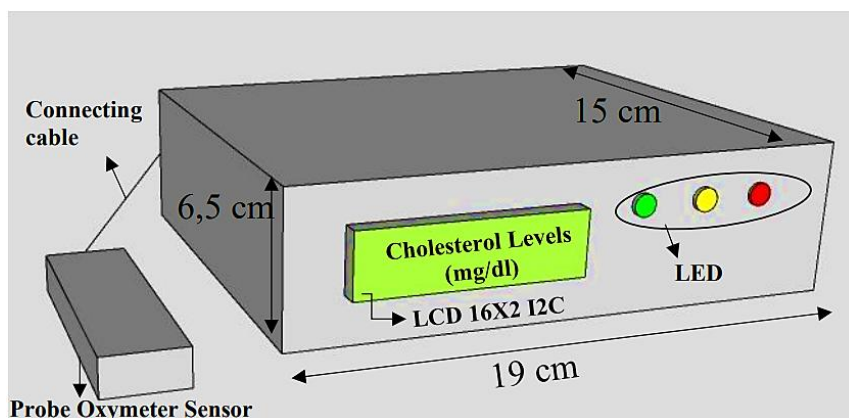
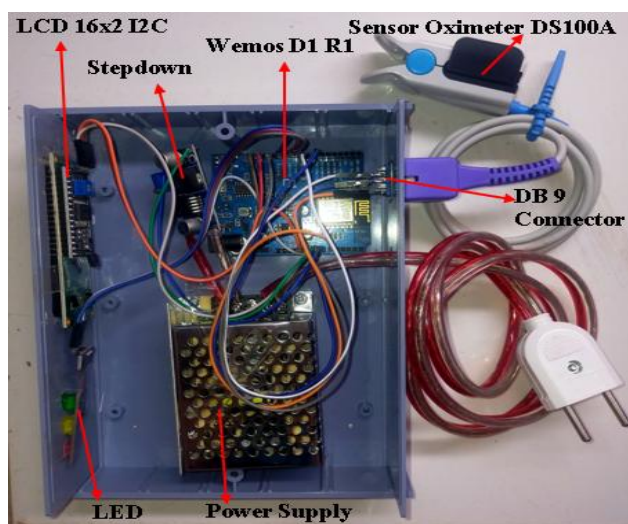


Figure 4. Non-invasive tool design

3. Results and Discussions

3.1 System Design Implementation

The instrumentation system for detecting cholesterol levels has been realized with the result shown in **Figure 5**. This tool utilizes a conjunction box with dimensions of $19 \times 15 \times 6.5$ cm. Before this tool is realized, the Oximeter DS100A Sensor has been calibrated, and the tool has been tested for precision and accuracy.



(a)



(b)

Figure 5. Realization tool: a) Inside look, b) Outside look

Based on **Figure 5**, the working principle of the tool is to utilize the Lambert-Beer law, which states that a beam of light transmitted through a solution will have some of its intensity absorbed by the solution, while the remainder will be transmitted. In this study, the red LED wavelength is 660 nm. The LED light that is on will pass through the finger, which will partially absorb the light, and some will be transmitted and captured by the photodiode, converting it to a voltage value. The condition of the sensor without fingers or obstructions represents the maximum light that the photodiode can detect. When a finger is placed, the intensity of light absorbed by the photodiode decreases to its minimum.

The voltage value is then read by the 10-bit ADC on the microcontroller and converted into an ADC value. The ADC value is then converted to a cholesterol level value using a linear regression equation. The cholesterol value will be displayed on the LCD screen. Then, there are three LEDs, red, yellow, and green, which are used as indicators of cholesterol levels. The red LED will light up if cholesterol is high (≥ 240 mg/dL), the yellow LED will light up if cholesterol is high enough (200-239 mg/dL), and the green LED will light up if cholesterol is at normal levels (≤ 200 mg/dL). A non-invasive tool has been designed to measure cholesterol levels in the blood in the range of 150-240 mg/dL.

3.2 Calibration of the Oximetry DS100A Sensor

This sensor calibration is a test of the sensor's feasibility in achieving results according to the desired indicators, namely accuracy and precision. The sensor calibration stage also aims to determine the light that will be used to convert the ADC value into a cholesterol level value because the red and infrared LEDs on the Oximeter DS100A sensor have different ADC outputs. The calibration phase begins with converting the analog signal into an ADC value. The ADC value is then compared with the output of the invasive device.

After the red and infrared LEDs light up and display the ADC output, the samples are then measured and compared with standard tools or benchmarks, which in this study used an invasive measuring instrument, namely the Easy Touch GCU. The data collection process begins with taking a blood sample using the Easy Touch GCU standard measuring instrument, followed by data collection using the Oximeter DS100A sensor. Calibration was conducted with 20 respondents aged 21-40 years. Prior to the measurement, the respondents had not engaged in strenuous physical activity. The measurement results are obtained using a standard measuring instrument equipped with a sensor.

The DS100A oximeter is shown in **Table 2**.

Table 2. Data calibration of the Oximeter DS100A sensor

No.	Cholesterol Levels Measured Using an Invasive Device (mg/dl)	ADC Measurement for the Red LED	ADC Measurement for the Infrared LED
1.	153	36	34
2.	162	44	41
3.	163	45	44
4.	165	47	45
5.	166	48	46
6.	166	48	46
7.	168	51	49
8.	168	51	50
9.	169	52	51
10.	175	57	60
11.	178	60	64
12.	181	64	67
13.	184	66	70
14.	184	66	70
15.	203	75	80
16.	219	83	86
17.	220	83	85
18.	221	84	87
19.	223	85	88
20.	240	92	94

The data in **Table 2** is then plotted in a graph using Microsoft Excel to display straight-line equations and the coefficient of determination (R^2) using a linear trendline approach. Linear regression is a data analysis technique that predicts unknown data values by using other related and known data values. Mathematically model the unknown or dependent variable and known or independent variable as a linear equation. ADC values with cholesterol levels are entered in the graphs as shown in **Figure 6**.

Figure 6 (a) is a graph of the relationship between the red LED ADC values and cholesterol levels after plotting, so that the value of the regression equation is $y = 1.5226x + 91.226$, and the coefficient of determination (R^2) is 0.9688. **Figure 6(b)** is a graph of the relationship between Infrared ADC values and cholesterol levels, plotted to obtain a regression equation: $y = 1.3285x + 101.91$, with a coefficient of determination (R^2) of 0.9343.

The relationship between the ADC on the red and infrared LEDs and the value of invasive cholesterol levels is directly proportional, meaning that the higher the cholesterol level in the blood, the higher the ADC value, because the blood absorbs less light and more light is transmitted and captured by the photodiode. Conversely, the lower the cholesterol level, the lower the ADC value because the blood absorbs less light, allowing more light to pass through the fingertip and be detected by the photodiode.

The R^2 value, also known as the coefficient of determination, describes how well the independent variable can explain the dependent variable. The coefficient of determination is between 0 and 1, with the condition that the closer to 1, the better. The coefficient of determination for red LEDs yields higher results than that for Infrared. The formula

used to convert the ADC value into a cholesterol level value is the equation for the red LED. The calculated data utilize the equation shown for the red LED in **Table 3**.

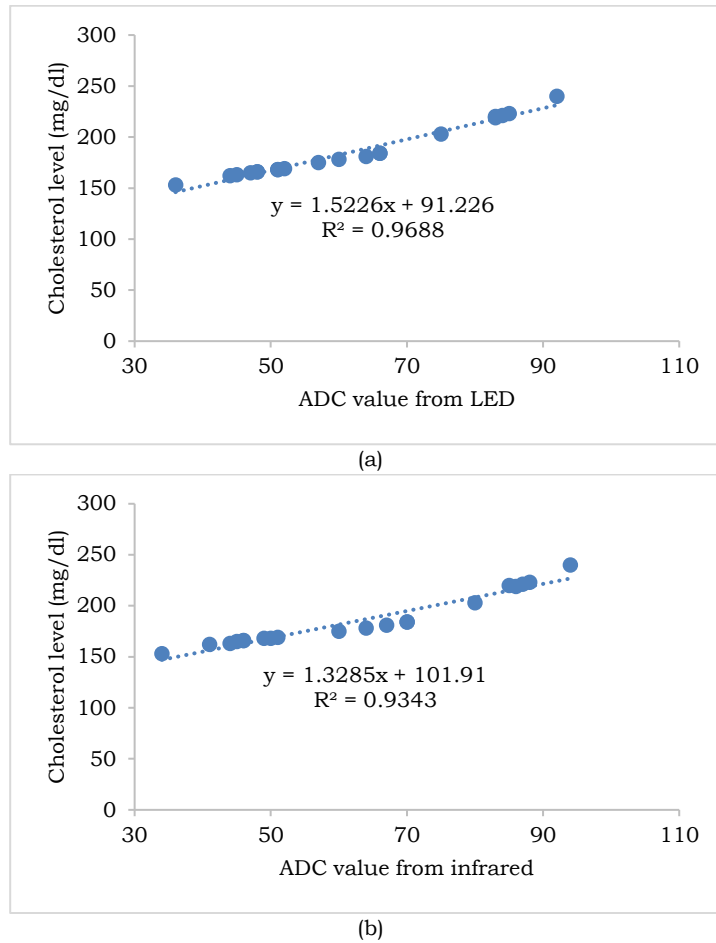


Figure 6. Graph ADC value with invasive value (a) LED (b) Infrared

Table 3. Data after calibration

No.	Cholesterol Levels Measured Using an Invasive Device (mg/dl)	Cholesterol Levels Measured for the Red LED (mg/dl)	Cholesterol Levels Measured for the Infrared LED (mg/dl)
1.	153	146	143
2.	162	158	154
3.	163	160	158
4.	165	163	160
5.	166	164	161
6.	166	164	161
7.	168	169	166
8.	168	169	167
9.	169	170	169
10.	175	178	183
11.	178	183	189
12.	181	189	193
13.	184	192	198
14.	184	192	198
15.	203	205	213
16.	219	218	222
17.	220	218	221
18.	221	219	224
19.	223	221	225
20.	240	231	234
Rata-rata Akurasi (%)		98.02	96.57
Rata-rata Error (%)		1.98	3.43

Based on **Table 3**, the average accuracy values for the red LED and Infrared are 98.02% and 96.57%, respectively, with errors of 1.98% and 3.43%. The value of the coefficient of determination and accuracy for the red LED is better than that of the infrared LED; therefore, the measurement of cholesterol levels on the DS100A Oximeter sensor utilizes light from the red LED.

3.3 Testing of the Non-Invasive Tool

3.3.1 Precision Test

The precision test of the tool aims to see how close the difference in values is when repeated measurements are carried out. At this stage, data collection was repeated five times on a non-invasive device. Furthermore, the data will be used to calculate the standard deviation, which will be an indicator of the tool's precision. The sample used was 10 people. Data precision measurement tools are shown in **Table 4**.

Table 4. Data precision

No.	Measurement (mg/dl)					Average (mg/dl)	Precision (%)
	1	2	3	4	5		
1.	168	169	169	166	170	168	99.10
2.	175	170	172	174	178	174	98.25
3.	193	195	197	197	198	196	98.98
4.	195	193	197	198	195	196	99.00
5.	211	207	207	214	212	210	98.52
6.	211	215	219	210	211	213	98.23
7.	215	212	216	214	217	215	99.10
8.	225	223	222	225	228	225	98.97
9.	231	235	237	231	232	233	98.85
10.	246	249	249	247	247	248	99.46
Precision average (%)							98.85
Error average (%)							1.15

3.3.2 Accuracy Test

Accuracy testing aims to determine the level of measurement error that can occur in a measuring instrument. The accuracy test of the tool was conducted by comparing the prototype of a non-invasive tool with an invasive measuring tool, specifically the Easy Touch GCU. During the data collection process, the subject whose data is being collected should refrain from strenuous physical activity for at least 30 minutes prior to the measurement. The sample used was 10 people. The results of measuring the tool's accuracy are presented in **Table 5**.

Table 5. Data Accuracy

No.	Non Invasive (mg/dl)	Invasive (mg/dl)	Error (%)	Accuracy (%)
1.	168	160	5,25	94,75
2.	174	185	6,05	93,95
3.	196	195	0,51	99,49
4.	196	196	0,20	99,80
5.	210	200	5,10	94,90
6.	213	204	4,51	95,49
7.	215	217	1,01	98,99
8.	225	226	0,62	99,38
9.	233	238	2,02	97,98
10.	248	256	3,28	96,72
Rata-rata (%)			2,86	97,14

Based on **Table 5**, an average accuracy value of 97.14% is obtained, and an average error value is 2.86%. This accuracy is higher than that reported by Marhaendrajaya *et al.* (2017). After analysis, several factors are identified as affecting the error rate of the measurement data. One factor that influences the error value is the respondent's finger thickness, which significantly impacts the results of non-invasive measurement tools. Therefore, an analysis of the relationship between finger thickness and cholesterol levels was conducted using a non-invasive device. Finger thickness measurement data, along with cholesterol levels, are shown in **Table 6**.

Table 6. Data finger thick

No.	Non Invasive (mg/dl)	Finger thick (cm)
1.	168	1.40
2.	174	1.20
3.	196	1.20
4.	196	1.10
5.	210	1.25
6.	213	1.20
7.	215	1.00
8.	225	1.00
9.	233	0.90
10.	248	0.80

The data in **Table 6** is then plotted in a graph to see the relationship between finger thickness and cholesterol levels. The graph of the relationship between finger thickness and cholesterol levels is shown in **Figure 7**.

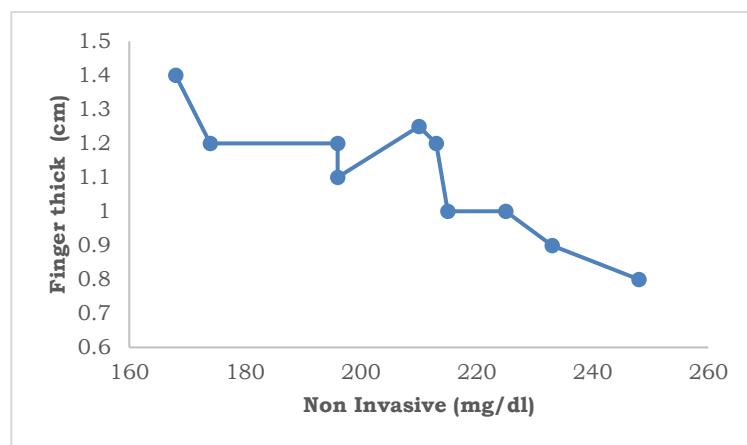


Figure 7. Graph the relationship between finger thickness and cholesterol value

Based on **Figure 7**, finger thickness affects the accuracy of cholesterol level measurements. The relationship between sample finger thickness and cholesterol values is inversely proportional.

4. Conclusion

The realization of a non-invasive tool with the Oxymeter DS100A Sensor based on the Wemos D1 R1 microcontroller. The non-invasive tool can be used to detect total cholesterol levels in the blood with a range of 150-240 mg/dl. The measuring instrument of non-invasive measurement has an accuracy value of 94.14% with an error value of 2.86%. The non-invasive tool cannot be used in accordance with standard tools because the error value exceeds the accuracy threshold for medical devices.

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