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Non-Invasive Device for Cholesterol, Uric Acid, and Glucose Monitoring: Implementation of Moving Average Filter

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ABSTRACT

Early detection is crucial in preventing diseases caused by high blood glucose, cholesterol, and uric acid levels through routine examinations. However, current testing devices are invasive, uncomfortable, complex, and generate medical waste. Therefore, this study aimed to develop and design a non-invasive measurement tool for these three parameters using the MAX30102 sensor. This research applied the Research and Development (R&D) method using the ADDIE model, adapted to the laboratory testing stage. The infrared values measured by the MAX30102 sensor on the fingertip were converted into mg/dL for blood glucose, cholesterol, and uric acid using a linear regression method to form regression equations. The converted data were then compared with standard devices to assess their accuracy. Additionally, a moving average filter was applied to reduce noise, smooth the signal, and balance the response to data changes. The measurement results were displayed on an OLED screen, a smartphone application for monitoring history and providing health information, and a speaker announcing the result categories. The results of the study showed that the cholesterol measurement accuracy was 89.71%, with an error rate of 10.29%, the uric acid accuracy was 92.98%, with an error rate of 7.02%, and the blood glucose accuracy was 92.64%, with an error rate of 7.36%.

ABSTRAK

Deteksi dini sangat penting untuk mencegah penyakit yang ditimbulkan dari tingginya kadar gula darah, kolesterol, dan asam urat melalui pemeriksaan rutin. Namun, alat pengecekan saat ini bersifat invasive, tidak nyaman, kompleks, dan menghasilkan limbah medis. Sehingga penelitian ini bertujuan untuk mengembangkan dan merancang alat pengukur pada ketiga kadar parameter secara non-invasive dengan sensor MAX30102. Penelitian ini menerapkan R&D dengan model ADDIE yang disesuaikan sampai pengujian laboratorium. Nilai infrared yang diukur oleh sensor MAX30102 pada ujung jari dikonversikan ke dalam bentuk mg/dl pada gula darah, kolesterol dan asam urat dengan metode regresi linier dan membentuk persamaan regresi. Data yang sudah dikonversi akan dibandingkan dengan alat standar untuk dilihat tingkat akurasinya. Selain itu, penulis

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menerapkan moving average filter untuk mengurangi noise, menghaluskan sinyal dan respon perubahan data yang seimbang. Data hasil pengukuran akan ditampilkan pada OLED display, aplikasi smartphone sebagai riwayat monitoring pengukuran dan penyedia informasi kesehatan, serta speaker untuk pembacaan hasil kategori. Berdasarkan hasil penelitian, nilai akurasi kadar kolesterol sebesar 89,71% dengan error 10,29% akurasi asam urat sebesar 92,98% dengan error 7,02% dan akurasi gula darah sebesar 92,64% dengan error 7,36%.

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1. Introduction

Non-communicable diseases (NCDs) are types of diseases that cannot be transmitted from sufferers to others, or which are caused by a person's lifestyle, behavior, and are not caused by viruses or bacteria [1]. Another name for NCDs is degenerative diseases. Health conditions in which organs and tissues deteriorate over time due to changes in body cells, which ultimately affect the function of all organs, are called degenerative diseases. Degenerative diseases increase due to decreased physical activity, eating habits, and lifestyle. [2]. Lifestyle changes like this can cause stroke, coronary heart disease, diabetes, and cancer, which can be caused by various factors such as high blood sugar, cholesterol, and uric acid [3]. The results of the 2018 Basic Health Survey (Riskesdas) showed that non-communicable diseases such as diabetes, hypertension, cancer, stroke, and chronic kidney disease increased compared to the 2013 Riskesdas. These results indicate that this disease is increasing. Diabetes increased from 6.9% to 8.5%, hypertension increased from 25.8% to 34.1%, cancer increased from 1.4% to 1.8%, stroke increased from 7% to 10%, and chronic kidney disease increased from 2% to 3.8%, the prevalence of gout (gout arthritis) in Indonesia reached 11.9% [4].

Based on data from the International Diabetes Federation (IDF) 2021, there are 19.5 million people in Indonesia who have diabetes, making it the fifth largest number of diabetes sufferers in the world. High cholesterol is also a serious health problem in Indonesia, 28% of people in Indonesia have high cholesterol.

One way to prevent degenerative diseases is to conduct an initial examination by checking and maintaining normal cholesterol, uric acid, and blood sugar levels, currently being tested invasively. Invasive methods have drawbacks for patients, such as blood and needle phobia, which makes them uncomfortable and causes fear [5]. This process requires the use of needles for blood sampling, the use of 3 different test strip tools to measure the three levels of these parameters and cannot be monitored digitally through the application and still uses paper manually to store medical records [6]. In addition, invasive testing procedures pollute the environment, are potentially harmful and are difficult to decompose because they produce used syringes, used cotton, used test strips which are included in medical waste [7].

Based on these problems, the author will create a system that can determine the three parameters of levels non-invasively. This system only uses one sensor, namely the MAX30102 sensor which is processed by the NodeMCU ESP8266 microcontroller, then in the sensor reading, signal filtering is carried out using a simple moving average filter to reduce noise, smooth the signal, and a balanced response to changes. This system will also be displayed in the form of an OLED display so that it can be seen directly, there is a speaker to emit a sound reading the category of cholesterol, uric acid, and blood sugar measurement results and is based on the internet of things for monitoring and providing information related to health and diseases from cholesterol, uric acid, and blood sugar which are presented in the form of smartphone applications. In this study, the author developed tool entitled Development of a Non-Invasive Cholesterol, Uric Acid, and Blood Sugar Measuring Tool with the Application of Moving Average Filter. The use of non-invasive tools is expected to be a solution for easy medical devices, can provide a sense of comfort and safety, no phobia and fear to patients without having to take blood samples using syringes and does not produce medical waste that can pollute the environment.

2. Methods

2.1 Simple Linear Regression

Regression analysis is a statistical method used to determine the linear functional relationship between a response variable and a predictor variable. When conducting regression analysis, two types of variables are used: the dependent variable (Y), which is the response, and the independent variable (X), which is the predictor. The predictor variable (X) is the variable that influences or explains another variable (Y), and the variable that is influenced or explained by X is called the response variable (Y) [8]. A simple linear regression equation is shown in

$$y = a + bx \tag{1}$$

In there are variables such as the value of y is the estimated dependent variable, while x is the independent variable, a is the intercept, namely the value of y when x = 0, and b is the slope, namely the average change in y against a change in one unit of x. The coefficients a and b are the regression coefficients, these values can be calculated from equations (2) and (3) [9].

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (nx^2)} \tag{2}$$

$$a = \frac{\Sigma y - b(\Sigma x)}{n} \tag{3}$$

2.2 Moving Average Filter

Moving Average Filter (MAF) is a type of data filtering that can be applied in sensor readings, functioning to strengthen signals and reduce noise to achieve better results. This filter system consists of using the average value of a set of data received over a certain period of time. The MAF filter eliminates deviations in the data, thus only taking data with relevant values [10]. Simple Moving Average (SMA) uses a sliding window to take the average over a certain number of time periods.

$$SMA = \frac{data_1 + data_2 + \cdots + data_n}{M} \tag{4}$$

2.3 Design Concept

The Research and Development (RnD) method or research and development is a type of research used to create products and test their effectiveness so that in creating a product, research is carried out in the form of needs analysis and testing the effectiveness of the product so that it can function in society [11].

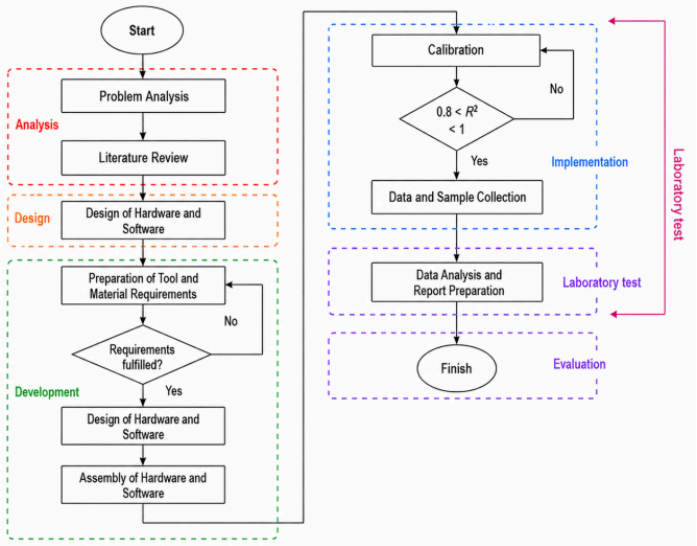

Fig. 1 Research flow chart

In is the ADDIE development model applied in this research which consists of five stages including Analysis, Design, Development, Implementation, and Evaluation. In the Implementation and Evaluation model, there is an adjustment of needs, namely up to laboratory testing.

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2.4 System Design Block Diagram

In the design block diagram there are several parts, namely input, process, output and resource blocks.

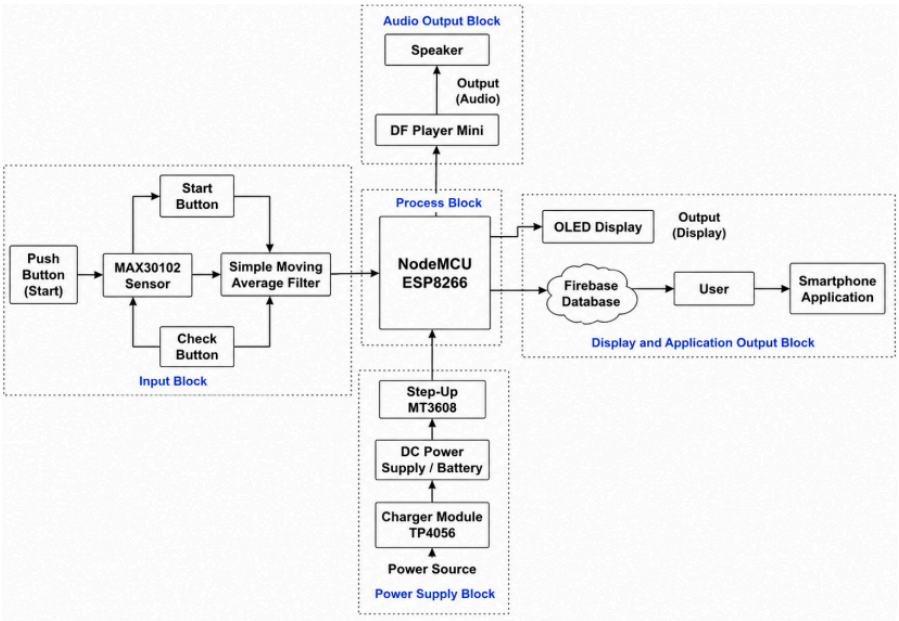


Fig. 2 Block diagram

In the input block section there are fingers, MAX30102 sensors, and start and recheck buttons. Then there is a filter, namely the moving average filter. In the process block section, the ESP8266 microcontroller is used to process IR values to mg/dl units and control input and output. In the output block consisting of an OLED display, speaker, and smartphone application. In the resource block there is a battery, MT3608 step up, and TP4056 charger module.

2.5 Electronic Design

The electronic design of this tool aims to provide an overview or design and connect to each component used, ensure the system can function properly, and facilitate wiring in the circuit. Consists of components such as MAX30102 sensors, ESP8266, Oled display, 2 buttons, DF mini player, mini speaker, battery, TP4056 charger module, and Step up MT3608.

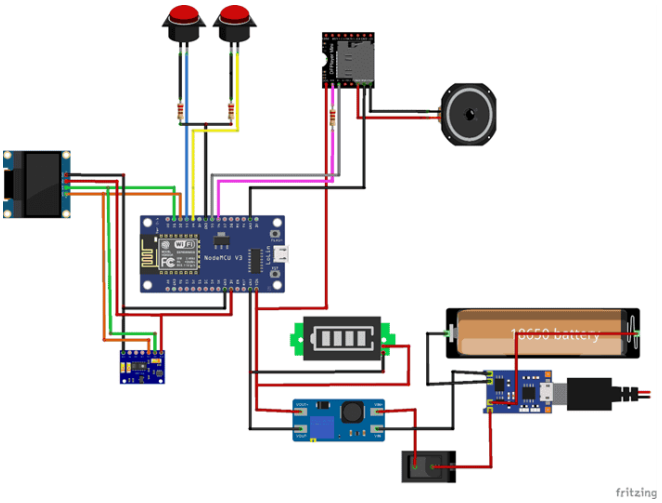
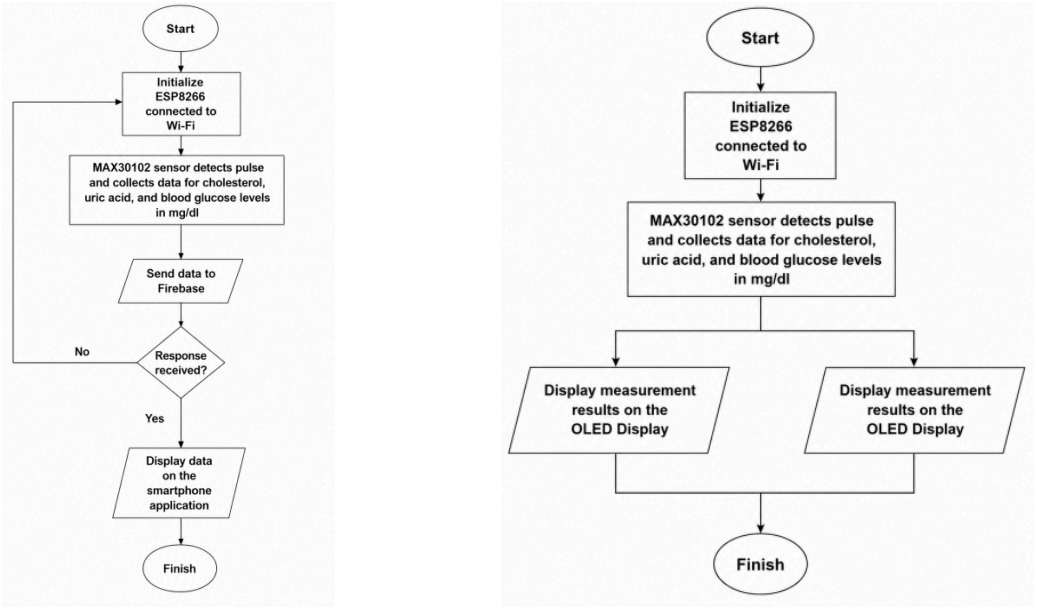


Fig. 3 Electronic design

2.6 NodeMCU ESP8266 Program Design

The program created on the NodeMCU ESP8266 has several main functions, namely reading sensors, processing data, displaying data output results, and WiFi connectivity to send and receive data.



(a) (b)

Fig. 4 (a) Flowchart of ESP8266 design on smartphone application (b) Flowchart of program design on tool prototype

The design of the program on is a design for a smartphone application that begins with the initialization of the esp8226 connected to wifi, then the MAX30102 sensor reads the measurement of the three parameters of levels in mg/dl units then sends the data to firebase which will be displayed on the smartphone application. While on is a program design on the tool prototype that begins when the esp8266 is connected to wifi then the MAX30102 sensor reads the measurement results, then the data results will be displayed on the OLED and emit sound through the speaker for reading the category.

3. Results and Discussion

3.1 Prototype Tool Box and Finger Clip Making Results

The box design measures 12.5cm x 8.5cm with a height of 5cm. Furthermore, the finger clip design is used as a finger placement which contains the MAX30102 sensor, this finger clip functions so that the finger does not easily shift or move, the right finger position, comfort and ease of use.

(a) (b)

Fig. 5 (a) Right view of the tool prototype (b) Left view of the tool prototype

3.2 Moving Average Filter Testing

At the simple moving average filter test stage, it is carried out experimentally by considering the needs. The size of the window size or window size will affect the signal results.

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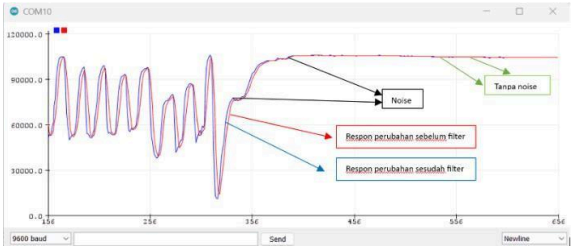

Fig. 6 Signal results with window size 5

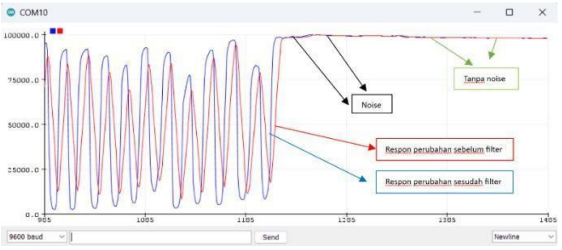

Fig. 7 Signal results with window size 10

Fig. 6 is the result of the signal before being filtered (red) and after being filtered (blue). The signal results have a response that is not so fast in responding to data changes. Then the noise can be reduced and the signal looks smooth. Meanwhile In Figure 7, the response to the change is seen to be delayed, then the noise is seen to be reduced and the signal is smoother. In this study, the author applies a simple moving average filter to reduce noise, smooth the signal, and a balanced data change response. So based on the test results, the author chooses a window size of 5. The filtering process begins with the reading of the MAX30102 sensor in the form of an IR or infrared value. Furthermore, determining the window size 5 means that every time you perform an average calculation, it uses the last data taken from the input.

$$y[5] = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5} \quad (5)$$

```
//SIMPLE MOVING AVERAGE FILTER
SUM = SUM - READINGS[INDEX];       // Kurangi nilai yang akan digantikan dari total
VALUE = particleSensor.getIR();    // Baca nilai sensor
READINGS[INDEX] = VALUE;           // Simpan nilai sensor di dalam array
SUM = SUM + VALUE;                 // Tambahkan nilai baru ke total
INDEX = (INDEX+1) % WINDOW_SIZE;   // Pindah ke indeks berikutnya, lingkupkan dengan WINDOWS_SIZE
AVERAGED = SUM / WINDOW_SIZE;      // Hitung nilai rata-rata
```

Fig. 8 Initialization of MAF program variables

```
//VARIABEL MOVING AVERAGE FILTER
#define WINDOW_SIZE 5       //Jumlah pembacaan yang akan diratakan
int INDEX = 0;              //Indeks saat ini dalam array pembacaan
int VALUE = 0;              //Pembacaan sensor
int SUM = 0;                //Total pembacaan yang disimpan dalam array
int READINGS[WINDOW_SIZE];  //Array untuk menyimpan nilai pembacaan
int AVERAGED = 0;           //Nilai Rata-rata
```

Fig. 9 MAF program formula

Figure 8 and Figure 9 show the variable initialization and the moving average filter application formula that will be entered into the Arduino IDE program. The order of the average divisor can be changed at the window size value. The IR value from the filter result is then used to convert the three parameter levels.

3.3 Tool Calibration

Calibration of the MAX30102 sensor produces an IR value read from the volunteer's left index finger. The value is obtained from the results of reading the level of light absorbed by the blood in the capillaries at the tip of the finger and the flowing blood will absorb different light depending on its oxygen content. The data collection process begins with blood samples taken using a standard Elvasense 3in1 tool, then using a prototype tool on ten random volunteers. The IR value is compared with the three level parameters. Furthermore, the data is plotted in the form of a graph in Microsoft Excel. Then, the equation of the straight line and the coefficient of determination R^2 can be seen with the Treadline feature.

Fig. 10, Fig. 11, and Fig. 12 show the correlation graphs between the average IR values against the three invasive parameters of cholesterol, uric acid, and blood sugar levels. The linear equation obtained for cholesterol y = 0.0024x - 119.45, coefficient of determination R^2 = 0.9886. The equation of the line for uric acid y = 0.0002x - 16.502, with R^2 = 0.9877 and the equation of the straight line for blood sugar y = 0.0025x - 164.12 with R^2 = 0.9597. The calibration results of cholesterol, uric acid, and blood sugar levels produce coefficient determination values that each have a range of 0.8 to 1 so that the coefficient results obtained during calibration show a very strong correlation.

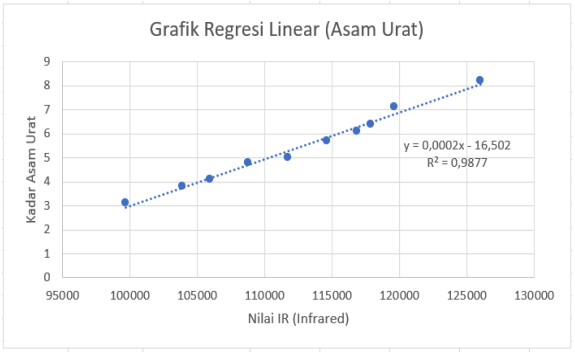

Fig. 10 Linear regression graph of cholesterol compared to IR values

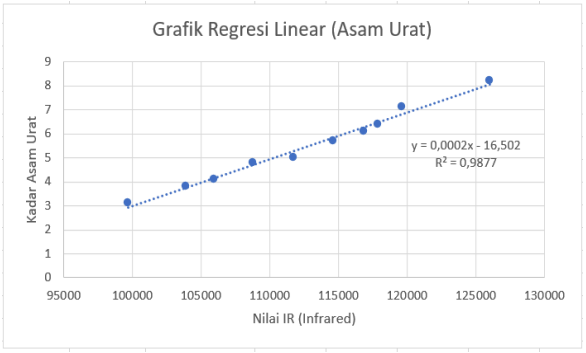

Fig. 11 Linear regression graph of uric acid compared to IR values

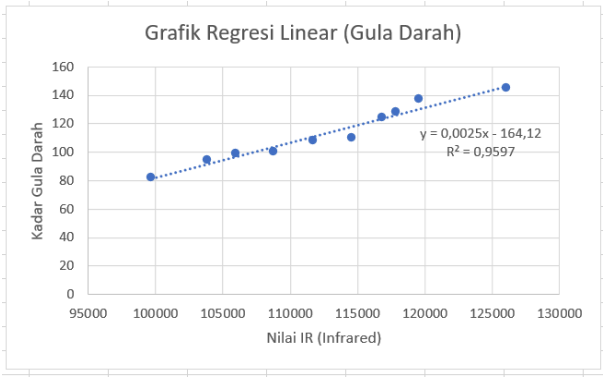

Fig. 12. Linear regression graph of blood sugar compared to IR values

3.4 Precision Testing of Tools

In the precision testing of the prototype of this tool, it was carried out repeatedly 3 times on each volunteer, then the data will be used to calculate the standard deviation, relative error and precision which will be indicators of the precision of the tool.

Table 1. Data from The Results of Precision Testing of The Tool on Cholesterol Levels

Volunter Data			Measurement of the			Average Measurement	Precision Tools (%)
No	Gender	Age	1	2	3		
1	P	52	167	153	158	159	95,55%
2	L	55	150	145	159	151	95,31%
3	P	22	156	141	143	147	94,45%
4	L	20	131	125	123	126	96,70%
5	L	48	129	116	119	121	94,39%
6	P	51	149	151	133	144	93,16%
7	P	22	169	157	155	160	95,28%
8	L	21	142	129	134	135	95,14%
9	P	50	165	150	153	156	94,91%
10	L	20	142	133	138	138	96,72%
11	L	53	122	124	136	127	94,05%
12	L	42	134	127	123	128	95,65%
13	P	45	176	162	164	167	95,47%
14	P	21	153	144	139	145	95,12%
15	P	23	143	133	136	137	96,26%
16	L	25	142	125	127	131	92,93%
17	P	22	128	138	135	134	96,16%
18	L	22	139	125	124	129	93,52%
19	L	22	138	126	129	131	95,23%
20	P	22	135	140	147	141	95,71%
				Average			**95,09%**

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Table 2. Data from The Results of Precision Testing of The Tool on Uric Acid Levels

Volunter Data			Measurement of the			Average Measurement	Tools Precision
No	Gen	Age	1	2	3		
1	P	52	7	6,2	6,5	6,6	93,85%
2	L	55	4,5	4,3	4,2	4,3	96,47%
3	P	22	6	5,4	5,7	5,7	94,74%
4	L	20	3,8	4,3	4	4,0	93,76%
5	L	48	3,8	3,4	3,4	3,5	93,46%
6	P	51	5,9	5,3	5,2	5,5	93,07%
7	P	22	6,5	6,9	6,9	6,8	96,59%
8	L	21	4,4	4,9	4,7	4,7	94,61%
9	P	50	5,9	6,8	6,7	6,5	92,37%
10	L	20	4,7	5,3	5	5,0	94,00%
11	L	53	4	3,9	4,1	4,0	97,50%
12	L	42	4,2	4,3	4,2	4,2	98,64%
13	P	45	7,6	7,3	7,2	7,4	97,17%
14	P	21	5,7	5,3	5,8	5,6	95,28%
15	P	23	4,6	4,9	5,1	4,9	94,83%
16	L	25	6,3	6,5	6,4	6,4	98,44%
17	P	22	4,9	4,5	4.7	4,7	93,98%
18	L	22	3,9	4,4	4,2	4,2	93,96%
19	L	22	4,2	4,5	4.4	4,4	95,12%
20	P	22	5,3	5,5	5,1	5,3	96,23%
				Average			**95,20%**

Table 3. Data from The Results of Precision Testing of The Tool on Blood Sugar Levels

Volunter Data			Measurement of the			Average Measurement	Tools Precision
No	Gen	Age	1	2	3		
1	P	52	122	134	123	126	94,73%
2	L	55	101	93	93	96	95,17%
3	P	22	118	110	112	113	96,33%
4	L	20	93	95	89	92	96,69%
5	L	48	95	82	81	86	90,92%
6	P	51	104	109	118	110	93,57%
7	P	22	126	135	121	127	94,43%
8	L	21	108	100	95	101	93,51%
9	P	50	118	119	133	123	93,20%
10	L	20	99	107	106	104	95,81%
11	L	53	88	95	94	92	95,90%
12	L	42	118	130	122	123	95,05%
13	P	45	130	141	134	135	95,88%
14	P	21	120	109	103	111	92,21%
15	P	23	106	105	99	103	96,34%
16	L	25	101	95	96	97	96,70%
17	P	22	108	96	97	100	93,36%
18	L	22	98	90	94	94	95,74%
19	L	22	100	96	93	96	96,35%
20	P	22	111	104	107	107	96,73%
							94,93 %

Based on the results of the prototype measurement data, the average precision value of cholesterol levels was 95.09%, uric acid was 94.93%, and blood sugar was 95.20%. In cholesterol and blood sugar, the tool is stable because the precision value of the tool is appropriate, namely more than 95% [9]. This means that the measuring tool used is stable and consistent and this tool provides results that are almost always the same in repeated measurements. While in uric acid levels, it shows that the tool tends to provide stable results every time a measurement is taken because it is close to 95%.

3.5 Tool Accuracy Testing

The accuracy testing of the prototype tool was tested by comparing it to a standard measuring tool. Data was collected from 20 volunteers randomly. The data collection process was carried out by taking blood samples using the Elvasense 3in1 standard tool once for all three parameters, followed by data collection using a prototype that had been averaged from 3 measurements. Table 4 is the measurement result on the prototype tool and standard tool.

Table 4. Comparison of Measurement Results on The Prototype Tool and Standard Tool

Prototype Measurement Tool	Standard Tool Measurement

Next, the error calculation, average percentage error, and accuracy level are carried out using Eq. 6, 7, and 8. Then the results are presented in table 5, table 6, table 7.

$$Error = \frac{abs(actual\ value - data\ testing(training\ data))}{actual\ value} \quad (6)$$

$$Average\ error = \frac{\sum_{i=1}^{n} error\ perhitungan}{banyaknya\ data} \quad (7)$$

$$Accuracy = 100\% - \%\ total\ error \quad (8)$$

Table 5. Data on The Results of The Percentage of Error and Accuracy in Cholesterol Levels

No	Tool Standard	*Tool Prototype*	Error (%
1	147	159	8,16
2	182	151	17,03
3	134	147	9,70
4	118	126	6,78
5	163	121	25,77
6	144	144	0,00
7	148	160	8,11
8	129	135	4,65
9	123	156	26,83
10	139	138	0,72
11	126	127	0,79
12	159	128	19,50
13	198	167	15,66
14	140	145	3,57
15	124	137	10,48
16	131	131	0,00
17	154	134	12,99
18	155	129	16,77
19	156	131	16,03
20	138	141	2,17
Average Percentage Error			**10,29**
Accuracy Level			**89,71%**

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Table 6. Data on The Results of The Percentage of Error and Accuracy in Uric Acid Levels

No	Standard Tool	Tool Prototype	Error (%
1	6,2	6,7	8,06
2	4,1	4,3	4,88
3	6,1	5,7	6,56
4	3,8	4	5,26
5	3,1	3,5	12,90
6	7,1	5,5	22,54
7	7,1	6,8	4,23
8	4,7	4,7	0,00
9	6,4	6,5	1,56
10	5	5	0,00
11	3,5	4	14,29
12	4	4,2	5,00
13	6,2	7,4	19,35
14	5,7	5,6	1,75
15	4,8	4,9	2,08
16	7	5,4	22,86
17	4,4	4,7	6,82
18	4,3	4,2	2,33
19	4,4	4,4	0,00
20	5,3	5,3	0,00
Average Percentage Error			**7,02**
Accuracy Level			**92,98%**

Table 7. Data on The Results of The Percentage of Error and Accuracy in Blood Sugar Levels

No	Standard Tool	Tool Prototype	Error (%)
1	128	126	1,56
2	96	96	0,00
3	110	113	2,73
4	95	92	3,16
5	94	86	8,51
6	104	110	5,77
7	124	127	2,42
8	108	101	6,48
9	145	123	15,17
10	99	104	5,05
11	99	92	7,07
12	147	123	16,33
13	137	135	1,46
14	82	111	35,37
15	103	103	0,00
16	100	97	3,00
17	100	100	0,00
18	95	94	1,05
19	102	96	5,88
20	145	107	26,21
Average Percentage Error			**7,36**
Accuracy Level			**92,64%**

Table 5, table 6, and table 7 are the results of the comparison between standard measurements with the prototype of the tool on cholesterol, uric acid, and blood sugar levels obtained from calculations using equations 9, equation 10, equation 11. The accuracy results on cholesterol levels are 89.71% with a percentage error of 10.29%. Then the accuracy results on uric acid levels are 92.98% with a percentage error of 7.02%. Furthermore, the accuracy results on blood sugar levels are 92.64% with a percentage error of 7.36%.

3.6 Smartphone Application

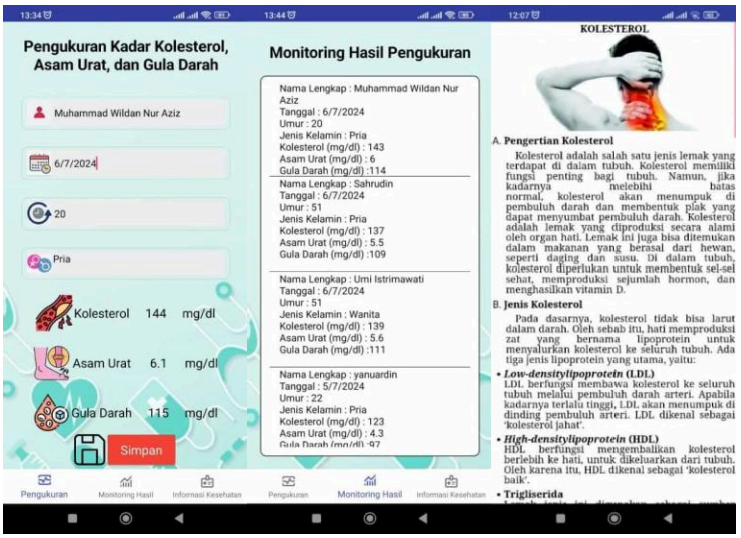

Fig. 13 Display of measurement result monitoring

As shown in Figure 13, users are required to enter their personal information before initiating the measurement. During the measurement process, the results are automatically displayed on the smartphone application. Once the results are displayed, users can save the measurement data by pressing the Save button. The recorded measurement results enable users to monitor their measurement history and may serve as a reference for the early detection of potential health conditions and for determining appropriate follow-up actions. Furthermore, the application provides health-related information, including definitions, causes, prevention and treatment methods, classifications, and other relevant information concerning cholesterol, uric acid, and blood glucose. This feature facilitates users' access to relevant health information and supports a better understanding of these health conditions.

4. Conclusion

The development and manufacture of a non-invasive cholesterol, uric acid, and blood sugar measuring device has been successfully made, functions well, and can be used and the prototype of this tool has the advantages of being easy to use, practical, portable, provides a sense of comfort, safety, and does not produce medical waste and the application of a moving average filter with a window size of 5 can help the sensor reduce noise, smooth the signal, and respond to balanced data changes.

The results of the precision test of the tool are quite stable, namely for cholesterol of 95.09%, uric acid 95.20%, and blood sugar levels of 94.93%. The prototype cannot yet be applied as a standard Health measuring tool because it must have an accuracy of ≥95%. While the prototype of this tool has an accuracy of 89.71% for cholesterol with an error of 10.29%. For uric acid, the accuracy is 92.98% with an error of 7.02% and for blood sugar, the accuracy is 92.64% with an error of 7.36%. However, it has a large enough possibility and prospect to determine the levels of the three parameters. The IoT system and smartphone applications can run well according to their functions, such as monitoring measurement history and providing health information.

Author Contribution:

Muhammad Falah Ar-Rasid: developed the hardware and software system, data collection, data analysis, interpretation of the results, and prepared the initial manuscript. Purno Tri Aji: preparation of the manuscript, and review and revision of the manuscript.

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The authors declare no conflict of interest.

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