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RESEARCH ARTICLE

Design of a Non-Invasive Blood Sugar Level Measuring Instrument Using Arduino Nano and MAX30100 Sensor Module

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Abstract: Many electronic technologies are still used in the healthcare field that require a sample of the patient's body to determine the blood sugar level in the patient. Both invasive and non-invasive methods. Invasive methods take blood samples while non-invasive methods use urine samples. For patients who are reluctant to take blood or urine samples to check blood sugar levels, a finger sensor can be used on their fingertips. The purpose of this research is to design an accurate and effective glucose monitoring that is easy for people without fear of needles. This device utilizes Arduino Nano as the main platform and MAX30100 sensor module that is sensitive to glucose molecules in the blood. This research uses the R&D (Research and Development) method and uses the ADDIE approach model. The results of this research show that this device has an average relative error percentage of 5.7%, according to the results of the device comparison test. And the percentage value of the accuracy of this device is 94.3%. On testing the level of feasibility by validators received a final percentage score of 98.3% according to the results of the first validator. This device can be considered "Very Feasible" for use. Results from the second validator showed that the device received a final percentage score of 95%. This device is considered "Very Feasible" for use.

Keywords: blood sugar measurement device, non-invasive medical instrumentation, finger sensor MAX30100, heart rate detection

1 Introduction

The human body needs blood sugar to produce energy for its organs. Blood glucose is a sugar substance that the body receives from food and is converted into calories or energy by the body's cells through the help of the hormone insulin and blood oxygen produced by the pancreas of the human body. Glucose is not only useful as energy, but it is also useful for "fuel" so that the body's organs can work optimally [1]. Insulin functions to regulate the balance of blood sugar levels, but if the intake of glucose / carbohydrates is too much, then insulin is unable to balance blood sugar levels and hyperglycemia occurs. Patients diagnosed with DM require a long treatment therapy to reduce the incidence of complications [2]. The release of oxygen in hemoglobin for red blood cells is an important role played by glucose. It is useful to keep the blood glucose level normal as this can worsen some of the body's health. Many electronic technologies are still used in the health field that require blood or urine samples to determine the glucose level in patients [3]. The blood glucose level usually ranges between 64.8 mg/dL and 104.4 mg/dL in the reference range, which will increase after meals and in the morning, before meals is usually at its lowest level. Besides glucose, blood sugar also contains other sugars such as fructose and galactose. Glucose is a type of blood sugar that is controlled by insulin and pepsin [4].

Dr. Syahidatul Wafa, Sp.PD, Staff of the Endrokin, Metabolic, and Diabetes Division of the Department of Internal Medicine RSCM-FKUI said, diabetes is the cause of all diseases. Complications caused by diabetes include stroke, kidney failure, rupture of blood vessels in the brain, cardiovascular disease, dental and speech problems, and many others [5]. The phenomenon of someone experiencing fear of needles, especially when getting an injection, is very common. Someone who experiences this condition has a term in the health world, namely symptoms of belonephobia / trypanophobia or needle phobia [6]. A total of 27 respondents, 10 respondents or 35.71% stated that they were afraid of needles where a number of reasons were stated including fear of the pain that arose (2 respondents), fear of the after effects of injection (3 respondents), and fear if there was an error in the injection procedure (5 respondents)

[7]. According to Rahmatullah research in 2021, 53% of 83 respondents expressed fear of needles [8]. Diabetes mellitus patients who have uncontrolled blood sugar levels will experience complications, both chronic and acute. Chronic complications such as macroangiopathy, cardiac disorders, stroke, diabetic retinopathy (involving the retina of the eye) and diabetic nephropathy (involving the kidneys) are the most common, but for acute complications, patients are usually unconscious, when blood sugar levels are very high (at KAD 300-600 mg/dL and SHH 600-1200 mg/dL). Regular blood sugar monitoring is very important for patients [9].

According to Tanto and Hustrini (2014) diabetes mellitus characterized by hyperglycemia is one of the risk factors for hypertension [10]. Diabetes mellitus can lead to an increased risk of heart disease and stroke, neuropathy (nerve damage) in the feet that increases foot ulcers, diabetic retinopathy which is one of the main causes of blindness, besides that it can also increase the risk of kidney failure and the risk of death. Based on data from Dr. Cipto Hospital in 2011, the most common complication experienced by diabetic patients is neuropathy, which is 54% followed by retinopathy and proteinuria [11]. One of the complications of diabetic macroangiopathy can occur due to changes in blood sugar levels, high blood sugar will stick to the walls of blood vessels. After that, an oxidation process occurs where blood sugar reacts with proteins from the blood vessel wall which causes AGEs. Advanced Glycosylated Endproducts (AGEs) are substances formed from excess sugar and proteins that bind together. This damages the inner wall of the blood vessels, and attracts saturated fat or cholesterol to the blood vessel wall, resulting in an inflammatory reaction. White blood cells (lekocytes) and blood clotting cells (platelets) as well as other materials coalesce into a clot of plaque, which makes the walls of blood vessels hard, stiff and eventually a blockage that results in changes in blood pressure called hypertension [12]. According to the International Diabetes Federation the number of people suffering from diabetes in Indonesia continues to increase. In 2019 10.7 million people had diabetes. After that in 2021 19.4 million people had diabetes. It is estimated that the number will reach 23.32 million by 2030 [13].

Currently, both invasive and non-invasive methods are used to measure glucose levels in the laboratory. Invasive methods take a blood sample using a lancet and measure it on a glucometer strip. Non-invasive methods require a urine sample and combine it with chemicals until a chemical reaction occurs that can be detected by the device [14]. By taking regular blood sugar measurements and monitoring blood pressure, one can identify early signs of diabetes and take the necessary steps to manage their condition. Early detection also provides an opportunity for individuals to adopt a healthy lifestyle, including a balanced diet and exercise routine, which can help prevent or control diabetes. To reduce the number of diabetes, there is a need for public understanding of Health [15, 16]. While there are some advantages to these popular techniques, there are also disadvantages in that they require more time and space and require human body samples. For people suffering from glucose-related diseases, their blood glucose levels should be checked regularly. For patients who are reluctant to take urine or blood samples for blood sugar measurement, finger stick sensors can be used on their fingertips. The finger sensor detects blood glucose molecules by absorbing two light beams of different wavelengths on the finger. The working principle of this sensor is similar to the Beer-Lambert law [17].

To take one measurement of blood sugar levels at the health center costs around Rp35,000 - hundreds of thousands depending on the tariff at the health center or laboratory. This research not only discusses technological advances, but also how they can positively impact public health. The author seeks to provide solutions that are not only technically innovative but also socially relevant. The authors developed an innovative blood sugar level measurement device based on the latest technology to support routine glucose checks. It utilizes Arduino Nano as the main platform and MAX30100 sensor module that is sensitive to glucose molecules in the blood. The goal is to make accurate and effective glucose monitoring easy for people without the fear of needles. It is hoped that this research will raise awareness of the importance of undergoing regular glucose screening especially for patients who are afraid of needles.

2 Materials and methods

The approach method used in this research is R&D (Research and Development). And using the ADDIE approach model, which includes Analyze, Design, Development, Implementation, and Evaluate [18].

2.1 Analyze

Analysis is a stage for gathering information by conducting literature studies on existing problems. The purpose of collecting information is to gain an understanding of the purpose of making this system and then find the needed for the design of a non-invasive blood sugar level measuring instrument. In the literature study process, researchers analyzed online journals and websites to get an overview of how the system works, as well as the hardware and software requirements needed to make this device.

2.2 Design

The design stage includes the process of designing the device, such as identifying the necessary components, designing the device box, and designing the manual.

2.3 Development

In the development stage, a non-invasive blood sugar measuring instrument was made and then validated. This process includes making hardware and software device using Arduino Nano and MAX30100 sensors, making manuals, and validating tools that are tested by product experts using research instruments.

2.4 Implementation

Implementation is the stage where the non-invasive blood sugar measuring instrument is used for the public. The goal is to find out how accurate the invasive and non-invasive device made by researchers are.

2.5 Evaluate

In this evaluation stage, the performance of the device will be assessed during the validation process by experts and the accuracy results between the invasive and non-invasive device made. The results of the experts' assessment and the comparison of invasive and non-invasive device will show how well the application of the device products made to the feasibility level of the device.

The device design in this research is described in the device planning block in Figure 1.

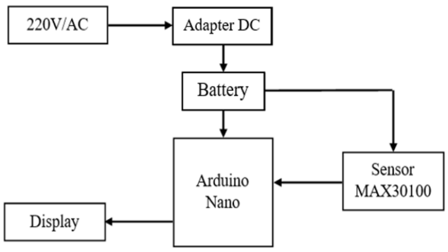

Figure 1 Block Diagram of Non-Invasive Blood Sugar Measurement Device Design

From Figure 1, adapter DC serves as a converter from AC 220V voltage to DC 12V voltage so that it can charge the battery. Battery serves to supply 5 V power to the entire circuit. Arduino Nano useful for processing data received from the MAX30100 sensor, in the form of voltage into digital data to be displayed on the OLED display. Sensor MAX30100 serves as a converter of the patient's blood sugar state by placing one of the fingers on the sensor. Display serves as a display of blood sugar measurement results.

The block diagram above shows how the device works simply. The DC adapter functions as a charger on the battery, then the battery provides voltage to the entire circuit. After that, place the finger to the MAX30100 sensor that has been prepared. The adc value given by the MAX30100 sensor will be sent to the microcontroller and converted into a blood sugar value in the body. This value will be displayed on the display as a result of the blood sugar content in the body.

Before creating a program, a flow chart is made so that the program created can be entered correctly into the Arduino Nano. (Figure 2 and 3)

Flowchart Explanation:
(1) Start: To start doing the experiment;
(2) Program Input: The existing program will start working according to the command that has been given;
(3) Read heart rate through finger: The MAX30100 sensor will read the heart rate and then give the results to Arduino nano;

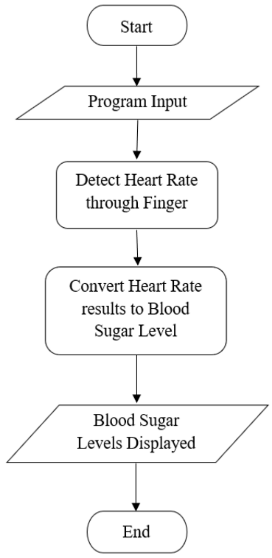

Figure 2 Flowchart of Non-Invasive Blood Sugar Measurement Device

(4) Heart rate conversion: The heart rate value that has been sent by the MAX30100 sensor to the Arduino Nano will be converted through a formula that has been entered into programming through the Arduino Nano;

(5) Blood sugar levels displayed on OLED: The result of converting heart rate to blood sugar level is displayed on the OLED display;

(6) End: To end the experiment.

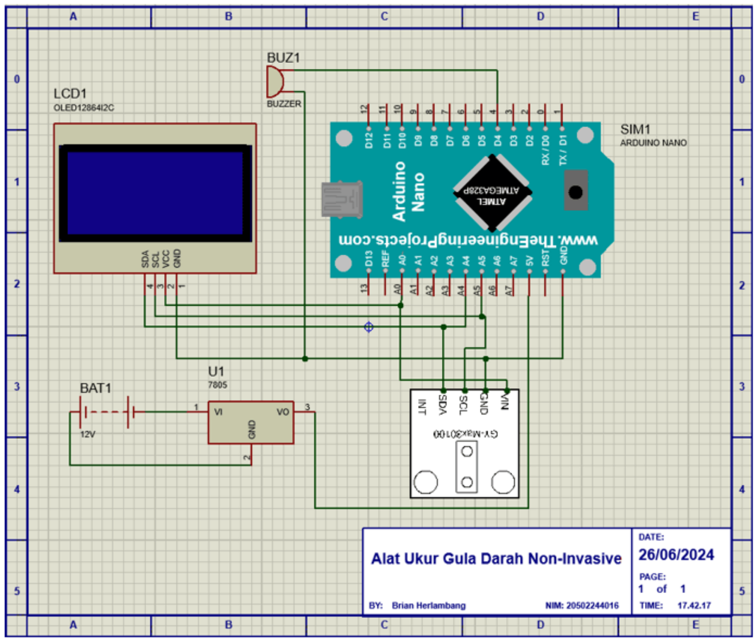

Figure 3 Schematic of Non-Invasive Blood Sugar Measurement Device Circuit

In this research, the data collection technique that can be done is testing done through direct observation by testing blood sugar levels taken from 20 people. This data collection is done by direct observation using invasive devices and non-invasive devices. As well as conducting validation by product experts, this data collection is carried out by direct observation by the validator to assess the feasibility level of the device made. Descriptive statistical data analysis techniques are used in this research to analyze data, provide a description or explanation of the data as a whole, without producing conclusions that can be used in general or for generalization [19].

The first process is the assessment of the product feasibility level score. The following details of the assessment score of the feasibility level of the non-invasive blood sugar level measuring instrument product are in Table 1.

Table 1 Feasibility Level Score

Assessment Score	Rating Category
1	Strongly Disagree
2	Disagree
3	Agree
4	Strongly Agree

After getting an assessment of the feasibility level of the product by the validator, then the percentage of feasibility is calculated by dividing the score obtained divided by the expected score.

$$(\%)\ \text{eligibility} = \frac{\text{score obtained}}{\text{expected score}} \tag{1}$$

After calculating the percentage of feasibility, then the product feasibility assessment is carried out using a rating scale. Table 2 is a detailed description of the rating scale feasibility score.

Table 2 Description Rating Scale Feasibility Score

Percentage Rating Scale	Description
76% - 100%	Very Feasible
51% - 75%	Worth
26% - 50%	Not Feasible
0% - 25%	Very Unfit

The second process is testing the performance of product comparison in this process the author tests the accuracy comparison on the device the author will calculate the average percentage error on the device made using the formula below:

$$(\%)\ \text{error} = \frac{\text{invasive value} - \text{non-invasive value}}{\text{invasive value}} \tag{2}$$

3 Results

3.1 Product validation testing

After the device can function properly (Figure 4). The next process is product validation testing. In the validation process, this device was carried out by 2 product expert lecturers using a questionnaire. The purpose of this device validation testing process is to find out whether its function has met the standards.

Figure 4 Results of a Non-invasive Blood Glucose Meter

Once all devices are tested and functioning properly, they can be considered suitable for use in research. The design of the product, the performance of the product, and the utilization of the product are some of the aspects tested. Table 3 and 4 is an analysis of the results of validation testing from product experts.

Table 3 Score for Product Feasibility by Validator 1

Aspects	Max Score	Validator Score	Avarage	%	Criteria
Product Design	20	20	4	100	Very Feasible
Product Performance	20	19	3.8	95	Very Feasible
Product Utilization	20	20	4	100	Very Feasible
Amount	60	59	3.93	98.3	Very Feasible

Table 4 Score for Product Feasibility by Validator 2

Aspects	Max Score	Validator Score	Avarage	%	Criteria
Product Design	20	17	3.4	85	Very Feasible
Product Performance	20	20	4	100	Very Feasible
Product Utilization	20	20	4	100	Very Feasible
Amount	60	57	3.8	98.3	Very Feasible

3.2 Comparative testing between invasive devices and non-invasive devices

After obtaining the results of the feasibility level of the device assessed by the validator, the next process is comparative testing between invasive devices and non-invasive devices. The author will calculate the average percentage error on the devices made. Table 5 shows the percentage error from the device comparison test results.

Table 5 Average Percentage Error of Non-Invasive Device

Invasive Device (mg/dL)	Non-Invasive Device (mg/dL)	Relative Error Percentage (%)
80	88	10
136	119	12.5
83	79	4.8
83	82	1.2
143	141	1.3
84	82	2.3
97	102	5.1
86	74	13.9
115	105	8.6
144	150	4.1
94	93	1
97	101	4.1
81	85	4.9
94	94	0
111	102	8.1
120	115	4.1
87	82	5.1
143	132	7.6
74	84	13.5
86	85	1.1
Average		113% : 20 = 5.7%
The accuracy percentage of the device is 94.3%		

4 Discussion

In accordance with the data in Table 3, the results of the calculation of the percentage score for the three aspects of the product, namely product design by 100%, product performance by 95%, and product utilization by 100%. This device can be considered "Very Feasible" to use, based on the 98.3% product validation percentage score given by validator 1.

In accordance with the data in Table 4, the results of the calculation of the percentage score for the three aspects of the product, namely product design of 85%, product performance of 100%, and product utilization of 100%. This device can be considered "Very Feasible" to use, based on the 95% product validation percentage score given by validator 2.

From the calculation results listed in Table 5, it can be concluded that this non-invasive blood sugar measuring instrument has an average relative error percentage of 5.7%. And the result for the percentage value of the truth of this device is 94.3%.The research “Design of Non-Invasive Blood Sugar Level Measurement Device Using Arduino Nano and MAX30100 Sensor Module” aims to conduct further analysis of the performance of Non-Invasive Blood Sugar Level Measurement Device Using Arduino Nano and MAX30100 Sensor Module can be assessed from the results of comparative testing between invasive devices and non-invasive devices. The test results are presented in Table 5. This table shows that the non-invasive blood sugar level measuring instrument can work well.

And what is the feasibility level of the Non-Invasive Blood Sugar Level Measurement Device Using Arduino Nano and MAX30100 Sensor Module. To find out the level of feasibility, a validation test was carried out by product experts. The results of the validation are presented in Table 3 and 4. The tables show the overall percentage result by the first validator of 98.3%. Meanwhile, for the second validator, the overall percentage score is 95%. Based on the percentage scores of the two validators, it can be concluded that the Non-Invasive Blood Sugar Level Measurement Device is considered “Very Feasible” to use.

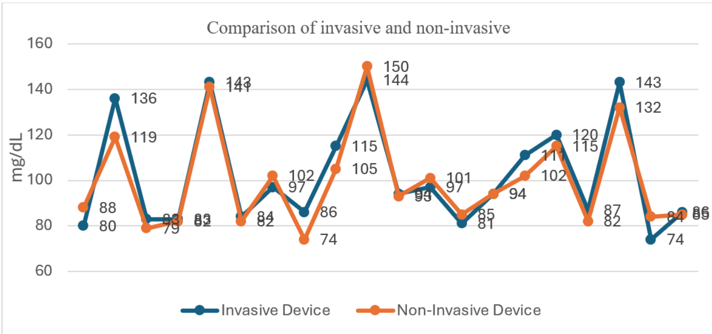

Figure 5 Comparison of Invasive and Non-invasive

From the graph in Figure 5, it can be seen that the difference between invasive device and non-invasive device is not so significant. The least error is when measuring blood sugar levels during fasting time, while when measuring after eating the error is more than during fasting time.

5 Conclusion

The design of a non-invasive system for measuring blood sugar levels can run well. The design consists of designing the device, identifying the components needed, designing the circuit, and programming it into Arduino Nano. The performance of the non-invasive blood sugar level measuring instrument based on the comparison test results listed in Table 5, it can be concluded that this non-invasive blood sugar level measuring instrument has an average relative error percentage of 5.7%. And the result for the percentage value of the truth of this device is 94.3%.

Based on the percentage score on the results of the validation of the feasibility of the device by the two product experts, it shows that the Non-Invasive Blood Sugar Level Measurement Device gets a final percentage score of 98.3% and 95%. Based on this percentage, this Non-Invasive Blood Sugar Level Measurement Device can be considered “Very Feasible” to use.

Conflicts of interest

The authors declare that they have no conflict of interest.

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