Design and Construction of a Non-Invasive Microcontroller Based Blood Sugar Level Measurement Device

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ABSTRACT

The design of a non-invasive microcontroller-based blood sugar meter is essential for checking blood sugar levels to ensure blood sugar is always within the normal range for people with diabetes mellitus. This non-invasive blood sugar detector uses a photodiode for reading. This study aims to test and validate the performance of this non-invasive blood sugar meter. The method used is Research and Development (R&D) with the ADDIE development model. Data collection is carried out through the main technique, namely direct measurement. The trial was carried out through several stages, namely individual testing, small group testing, and field testing. The trial subjects consisted of individuals with a history of diabetes or prediabetes, as well as healthy volunteers who were willing to participate in the study. In this study, the linear regression method was used to analyze the relationship between the results of the device measurements (independent variables) and actual blood sugar levels (dependent variables) obtained through invasive measurements. The results of the study indicate that this tool successfully functions as an alternative to conventional measurement methods, although the accuracy level still requires improvement with an average accuracy level of 93.45%. The system as a whole has met the functional requirements criteria in terms of the ability to perform measurements, display results via LCD, and transmit data wirelessly. Non-functional requirements such as portability ease have also been met. Comprehensive testing including black box testing and field trials proved that system components can function optimally according to the established technical specifications.

Keywords : Blood sugar, Non-invasive, Photodiode

INTRODUCTION

Nowadays, most people tend to have unhealthy eating habits. Young people, adults, and even toddlers prefer fast food and sweets like donuts, cakes, and packaged sweet drinks to healthy foods. It is also important to improve your lifestyle by consuming nutritious food and exercising regularly. (Lestari et al., 2021). However, when humans consume excessive sugar, insulin resistance increases. Increased insulin resistance prevents the body from processing excess sugar properly. Spikes in blood sugar levels are then inevitable and trigger type 2 diabetes mellitus. Diabetes is a metabolic disorder caused by the inability of the human pancreas to produce insulin normally. Insulin is a type of hormone that controls and processes blood sugar levels in the human body to keep them stable and prevent them from rising. Diabetes is divided into two types: type 1 diabetes and type 2 diabetes. Type 2 diabetes is most common in Indonesia and affects 95% of the world's population (Suyono, nd). In diabetes sufferers, the metabolism of glucose into energy is impaired. This is because the glucose in the blood cannot be entered into the cells, because the amount of insulin is reduced, or the cells are resistant to insulin. So the amount of glucose in the blood continues to increase. (Dr. Apriliana Adhyaksari, Sp.PD, M.Kes, 2019).

The term blood sugar here refers to the level of glucose in the blood. Blood sugar concentration, or serum glucose levels, is tightly regulated in the body. Generally, blood sugar levels are maintained within a threshold of 70 to 150 mg/dl throughout the day. These levels increase after meals and are usually lowest before breakfast. Blood sugar levels are influenced by endogenous and exogenous factors. Endogenous factors, also called humoral factors, include the hormones insulin, glycogen, cholesterol, and receptor systems in muscle and liver cells. Exogenous factors include the type and amount of food consumed and

physical activity⁽Dimas Firmansyah1 et al., 2022)

Checking blood sugar levels also requires a special device called a glucometer. Most blood glucometers typically use either a direct or invasive method of collecting blood samples from the patient. This device works by drawing a blood sample directly from the user with a provided needle, which is absorbed into the blood glucose meter and a blood glucose strip, which causes the enzymes in the blood to react. The strip generates a strong current. The current is connected to the blood glucose meter. Because the current intensity corresponds to the blood glucose level, results can be determined. Identifying vulnerabilities in the use of conventional blood glucose meters that use invasive methods to collect blood samples. This limitation is caused by patient discomfort, which can hinder compliance with initial and routine blood glucose measurements, especially in children (Amanika & S.Kom , M.Kom , 2024).

However, at certain times, people with diabetes are afraid to check their blood sugar levels invasively due to their phobia of blood and needles. Using a syringe when checking blood sugar levels can also cause infections for sufferers, infections occur due to a lack of insulin in people with diabetes mellitus. To eliminate the use of invasive techniques for checking blood sugar levels, it is necessary to design a device that can detect blood sugar levels without harming the body, namely using a non-invasive method. Non-invasive blood sugar detection devices use photodiodes for reading. Readings on this photodiode sensor utilize optical phenomena such as light absorption at a specific wavelength for blood sugar between 750-2500 nm and infrared wavelengths between 750-10000 nm. And then the photodiode sensor will read the voltage fired by the superbright LED and then the voltage obtained is converted into a result in the form of mg / dl units. The superbright LED in this system is used as a light emitter to illuminate the object being analyzed, namely the finger. From the light emitted by the source will pass through the finger before reaching the photodiode. One of them is glucose molecules in the blood. From the factor of these blood sugar molecules, there will be a change in the intensity of the light received by the photodiode. The voltage value received by the photodiode will be processed by the NodeMcu ESP8266 microcontroller then the analog data from the sensor will be converted into digital data, so that the desired results are obtained where the results obtained will be displayed on the LCD.

A system or device that uses a microcontroller as a data processor is called an embedded system or dedicated system. An embedded system is a controller that is embedded in a system or device, while a dedicated system is a system controller that is intended to perform a specific function. A printer, for example, is an embedded system because the microcontroller in it functions as a controller. (Kurniawan Daniel Ade, 2023). This NodeMCU almost has a similar function to an Arduino tool, but its advantage is that it is prioritized as a device that can be connected to the internet. NodeMCU v3 is a third-party development, namely Lolin, which has been claimed to be faster than v2, by improving the faster USB interface. (Saputro & Tuslam , 2022).

This tool show that at the intensity low blood sugar levels more high in blood more dark , so Lots infrared light is absorbed and very little light captured by a photodiode . On the contrary If concentration blood glucose low blood become dilute and infrared rays detected by the photodiode . This is Because when glucose concentration tall meet with ray infrared , glucose the become relax below influence diffraction and disturbances in the dermis of the skin . (Nurmar'atin et al., 2022).

METHOD

This study uses the Research and Development (R&D) type of research. Development research is a research method used to produce a specific product and to test its effectiveness (Sugiono, 2015:407). The ADDIE model consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Shakila, 2020). The reason for choosing the ADDIE development model is that it is simple and systematic in its procedures. This model provides the opportunity for continuous revision and evaluation at each stage or phase, so that the resulting product becomes a valid product. Data collection sources used primary and secondary data sources. This study was conducted in various randomly selected locations to ensure that the results obtained could reflect a wider variety of conditions. This approach aims to increase the validity and generalizability of research findings. The study was conducted over approximately one month, from June 2025 to July 2025.

Data collection was conducted primarily through direct measurement techniques to test the validity of the device by comparing blood sugar measurements obtained from the developed non-invasive device with those from a standard medical reference device, a glucometer. Trials product This aims to collect data that can be used as basis for determining level validity, practicality, and effectiveness tool gauge non-

invasive blood sugar levels based microcontroller. Selection types of data collected in research This focused on assessing validity tools and levels effectiveness its use. Validity data used to measure to what extent the tools are developed give accurate and reliable results trusted compared to with method standards that have been tested in a way clinical .

Types of data collected is data , namely results measurement blood sugar levels use non- invasive devices compared to with results measurement use glucometer standard deviation value or difference between results developed tools and tools reference . While the effectiveness data collected to measure how far the tool This capable give benefits in monitoring blood sugar levels users compared to with method conventional.And reach objective beginning that is effectiveness relieve pain moment checking blood sugar. Types of data collected is the quantity data error measurements that occur compared to with method conventional . With approach this, the result study expected can give comprehensive information about accuracy and effectiveness from developed tools before produced on a larger scale wide .

The trial consisted of several stages: individual testing, small group testing, and field testing. The trial subjects consisted of individuals with a history of diabetes or prediabetes, as well as healthy volunteers willing to participate in the study. The data collection instrument in this study was designed to measure the validity and effectiveness of the microcontroller-based non-invasive blood sugar measurement device. The data analysis technique used linear regression to analyze the relationship between the device measurement results (independent variable) and actual blood sugar levels (dependent variable) obtained through invasive measurements. The purpose of this analysis is to determine the linear relationship pattern between the two variables, determine the level of accuracy of the designed tool consisting of Independent Variable (X): Measurement results of the non-invasive tool (mg/dL) and Dependent Variable (Y): Measurement results of the glucometer tool (mg/dL).

RESULTS AND DISCUSSION
Result

The results of this product trial aimed to ensure that all functions in the non-invasive blood glucose meter operate according to predetermined specifications and provide correct results when used by the user. The results of the product trial in this study are as follows:

- **System Testing**

Testing something system aims to assess whether developed system functioning with okay, check various functionality, as well as documenting possible weaknesses there is . In the testing process system this , the author apply method testing based experiment . Testing implemented to ensure that tool operate with good, like verify proper function or active, testing feature from tool and evaluate it response tool .

Table 1 Test Results System

Input	Function	Output	Information
NodeMCU ESP8266	Processing data	Command data	Succeed
LCD	Showing results / commands microcontroller	Display data on screen	Succeed
Photodiode sensor	Read ADC value	Digital data	Succeed
Superbright LED	Give light	Bright light	Succeed
Push Button	Give order start measurement and reset measurement	Order appear on the LCD	Succeed
ThingSpeak	Displaying the result data measurement online on smartphone	Digital Data	Succeed

From Table 1. Above can concluded that system every component tools that have been designed functioning with good and appropriate with the function of each component tool .

Following is picture appearance tool tool measuring blood sugar levels in a non- invasive manner that appears from front .

Figure 1. Of the Tool Front

Figure 2. LCD Display Image

The following is a display of the Thingspeak test results.

ThingSpeak is an open source platform in the form of a website that provides services for IOT needs and can receive data using HTTP protocol via internet network. ThingSpeak allows manufacturing logging application, application tracker location and network social matter with status updates.(Saputro & Tuslam, 2022)
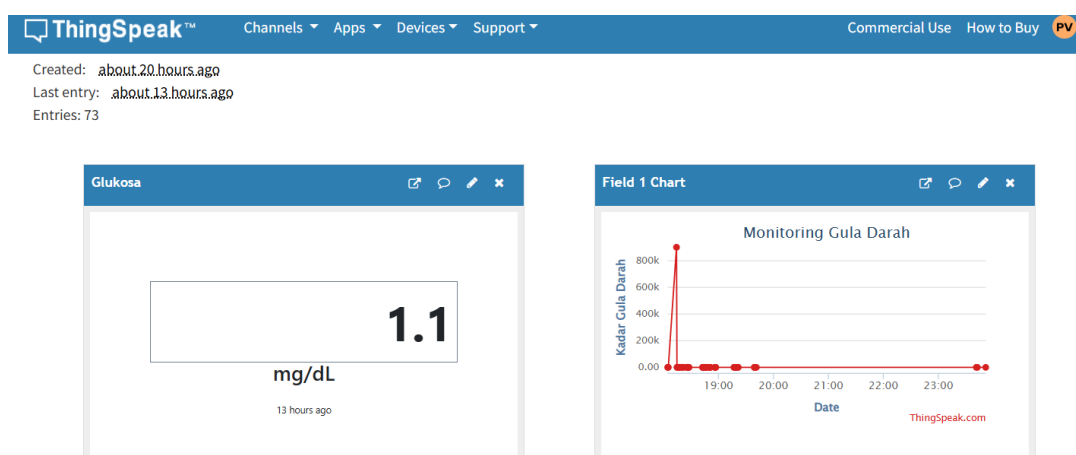

Figure 3. ThingSpeak Test Results Display Image

- **Early Stage Tool Testing**

Testing tools at the stage beginning This is done to obtain output data which will later be used as data used to perform calibration tools for results from measurement tool become more valid. Following is

the result data measurement at the stage beginning .

Table 2 Measurement Result Data Table Early stage

CALIBRATION MEASUREMENT					
NO	NAME	AGE	GENDER (M/F)	ADC VALUE	GLUCOMETER VALUES
1	Luna	17	P	16	181
2	Bian	20	L	17	173
3	Dita	23	P	18	133
4	Zalfa	20	L	18	135
5	Hell you	23	P	19	153
6	Nifzal	16	L	19	119
7	Ambon	22	L	20	104
8	Thunder	15	L	21	107
9	Fabio	15	L	21	107
10	Zilan	15	L	22	98
11	Zahra	19	P	22	73
12	Guide	18	L	23	78
13	Salsa	23	P	25	92
14	Repal	21	L	25	91
15	Samit	15	L	25	92
16	Kiky	41	P	26	97
17	Ayeng	19	L	26	93
18	Nadine	25	P	26	95
19	Yusky	16	L	26	95
20	Najil	16	L	28	88
21	Riky	15	L	30	80

Discussion

Data analysis in research This done to find out percentage error tools that have been designed. From the test data that has been obtained writer process the data using Microsoft Excel to perform calibration with method linear regression that aims look for formula the similarities .
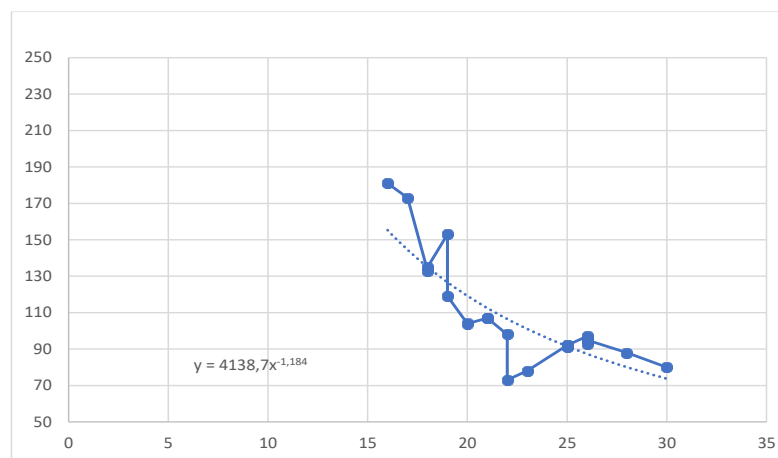

$$y = 4138{,}7x^{-1{,}184}$$

Figure 4. Linear equation calibration

The image above is picture chart comparison mark results from measurement non- invasive devices with tool glucometer .

From the graph on writer get formula equation of the line:

$$y = 4138.7x^{-1.184}$$

Formula the equation of the line above applied to the creation script tool gauge non - invasive sugar levels . The tool has calibrated done testing to find out comparison results measurement from tool non-invasive measurement and glucometer. The following is results the test :

Table 3 Test Result Data After the Tool is Calibrated

VALIDATION			
NO	NAME	NON-INVASIVE	INVASIVE
1	Dita	135.1	133
2	Zara	68.7	73
3	Helmi	155.3	153
4	Gina	78.8	78
5	Luna	182.6	181
6	Kiky	119.2	97
7	Salsa	90.4	92
8	Bian	144.5	173

To know percentage error tool writer use formula :

$$\frac{nilai glukometer - nilai nononnvasif}{nilai glukometer} x 100\%$$

From the formula the can known mark percentage error tool as following :

Table 4 Percentage Data Tool Error

Percentage of Tool Error				
NO	NAME	NON-INVASIVE	INVASIVE	Percentage of Error
1	Dita	135.1	133	1.56%
2	Zara	68.7	73	5.90%
3	Helmi	155.3	153	1.50%
4	Gina	78.8	78	1.02%
5	Luna	182.6	181	1.44%
6	Kiky	119.2	97	22.80%
7	Salsa	90.4	92	1.74%
8	Bian	144.5	173	16.47%
Average				6.55%

From the results calculation percentage error tool can seen in the table above. Value or results from blood sugar measurement non - invasively This No can made into as reference mark blood sugar levels actually. However tool This can made into as estimation tall or low mark blood sugar levels somebody.

Evaluation of results implementation conducted to assess success tool gauge sugar levels non - invasively based microcontroller after implemented and tested on users. Evaluation This covers aspect technical, functional system, satisfaction users, as well as impact to efficiency work and taking decision Functionality evaluation system with results evaluation show that core features namely measurement blood sugar levels without use (non- invasive) needles work with Good and stable. The tool is capable of taking measurements and displaying results in real-time. No critical bugs found during the internal trial period .

Performance evaluation tool with results tool show time fast response in the measurement process. However the tool had time experienced a crash due to connection broken cable during the trial period. the quick overcome with replace old cable with new cable .

Comparison new system with old system

Table 5 Comparison Table New System with Old System

Aspect	Glucometer Tool	Non- invasive tools
1. Time	Waiting 10 seconds to get see results .	The results can be seen in a way real time
2. Comfort	Less comfortable for those who are afraid to needle .	Not required needle so that level comfort more tall .
3. Accuracy	Accurate .	Having percentage accuracy 93.45%
4. Ease of Monitoring	Limited only Can done users themselves.	Can be monitored via smartphone.
5. Ease of Use of Tools	Tend difficult Because there is Lots step .	Easy Because step measurement No Lots .

From the table 5, above can concluded that tool gauge sugar levels non - invasively based designed microcontroller give Lots superiority compared to tools used previously .

The advantages of the system are: accessibility tall allows users to access data from various location and device during connected with the internet, so that makes it easier to monitor when only . Measurement results Can seen in a way realtime . Compared measurement use glucometer that uses needle tool This more comfortable used Because No required needle so that level comfort more height. Measuring tool sugar levels non - invasively based designed microcontroller give ease of use. Tools This only need One step measurement namely put finger in place and press knob so results measurement can direct known.Different with tool glucometers in general that require Lots step like clean finger use alcohol, prepare lancet needle , prepare the measuring strip , and then you can start measurement .

The limitations of the system are: system based IoT , users need a stable internet connection to access it. Limitations network can hinder operational. However This only applies in accessing ThingSpeak.If only want to display enough on the LCD then No required internet connection . System Not yet provide announcement automatic (notification) when stock thinning or moment There is necessary items quick processed . Accuracy level not enough maximum namely only 93.45%. So for the future can done repair with more calibration good. Ensure glucose sensor calibrated with Correct use standard known glucose . Proper calibration can increase accuracy measurement.In addition That need to be done a number of measurement consecutively and taken as an average of the result . This is can help reduce variability in readings . Although tool gauge sugar levels non - invasively based microcontroller own Lots significant advantages compared to manual system, still there is a number of limitations that become notes for future development . With evaluation periodic and development sustainable, system This can improved to be more optimal and adaptive to ongoing needs develop .From the results testing that is carried out, can concluded that system information management inventory this web- based fulfil all over need functional and non-functional that have been specified in the document specifications . All feature main, including recording goods in / out, management inventory, reporting, and management account user, walking with good and appropriate with expectation user. System this also fulfills needs in terms of security and speed data access .

CONCLUSIONS

Based on a series stages analysis, design, implementation, and testing that have been done to tool gauge non- invasive blood sugar levels based microcontroller, can concluded that tool This succeed functioned as alternative replacement method measurement conventional, although with level accuracy that is still need refinement . Test results show tool capable give estimate blood sugar levels with level average accuracy of 93.45%. System in a way overall has fulfil criteria need functional in the form of the ability to carry out measurements , display results via LCD, as well as sending data wirelessly. Non- functional

requirements like portability and convenience usage has also been fulfilled. Testing comprehensive which includes blackbox testing and trials field prove all over component system can functioning optimally according to specification established technical implementation. system This offer a number of superiority operational like efficiency time measurement, ease of monitoring data, as well capability more digital recording accurate compared to manual method .

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