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IoT-Based Insulin Pump Design Analysis Using Flowrate Monitoring

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ABSTRACT The management of diabetes, particularly for individuals requiring insulin therapy, presents significant challenges in ensuring accurate and timely insulin delivery. Traditional insulin pumps often lack the precision and adaptability needed for effective glucose control, leading to potential complications. This study addresses these issues by developing an IoT-based insulin pump that utilizes flowrate monitoring to enhance the accuracy of insulin administration. The research employed the ESP8266 microcontroller for data processing and control, coupled with the SLF3S-0600F liquid flow sensor to monitor insulin flow rates. The Blynk application was utilized for remote monitoring and dose adjustments, allowing users to manage their insulin delivery conveniently via an Android device. The experimental methodology involved conducting five repeated measurements to assess flow rate accuracy, volume delivery, and motor speed. Results indicated that the insulin pump achieved a flow rate measurement error of only 0.0051% at a setting of 1.5 ml/min, while the largest error recorded was 0.0391% at 3 ml/min. Additionally, the volume measurement error was minimal, with the smallest error at a 2 ml setting of 0.016% and the largest at 1 ml with an error of 0.152%. The average motor speed was recorded at 21.22 rpm for auto settings and 49.88 rpm for bolus settings. In conclusion, the developed IoT-based insulin pump demonstrates significant potential for improving diabetes management through precise insulin delivery and real-time monitoring capabilities. The integration of IoT technology not only enhances the accuracy of insulin administration but also provides users with greater flexibility and control over their treatment. This research contributes to the ongoing efforts to innovate diabetes care solutions, ultimately aiming to reduce the risk of long-term complications associated with the disease.

INDEX TERMS Insulin Pump, ESP8266, IoT, Flowrate

I. INTRODUCTION

Diabetes Mellitus can generally be classified into two types. The first type is a condition where people with diabetes mellitus experience problems in the production of the insulin hormone (insulin hormone deficiency), while the second type is a condition where people with diabetes experience problems in utilizing the insulin hormone (insulin hormone immunity) [1]. The International Diabetes Federation (IDF) states that between the two types, the second type is the type of DM that is most frequently experienced by DM sufferers, with approximately the number of people suffering from type two DM reaching 90% of the total population of DM sufferers. However, type two DM is also a type that often shows no symptoms at all until it reaches a chronic point, so the IDF estimates that at least 30-50% of people suffer from type two DM without being diagnosed at all [2][3].

T1DM often occurs in children and adolescents, but can also occur in adults. Lack of insulin results in increasing the concentration of glucose in the blood because without insulin it cannot convert carbohydrates such as sugar, starch, or other foods into energy that can be used by the body[4]. This condition requires lifelong treatment which includes administering insulin via injection or infusion[5].

In the bio-medical field, the most effective treatment method for diabetics is long-term insulin injections, for which open-loop insulin infusion pumps are currently used. Therapy using an insulin pump involves long-acting basal insulin, usually given once or twice daily and bolus insulin given before meals (referred to as multiple daily injections).[6][7]. Insulin pumps have several advantages compared to administering insulin via conventional injection. Some of these include the ability to control blood glucose levels better, reduce the number of insulin injections needed, provide flexibility in eating and exercise schedules, and help minimize the risk of long-term diabetes complications.[8][9].

There are several previous studies that have been carried out in the development of insulin pump devices.Habiburrahman conducted research on a prototype insulin pump injection with an Arduino Uno control panel. In this researchdesigned using an Arduino Uno microcontroller as a control panel (processor), this stepper motor functions to produce regular linear movement with a threaded rod as a linear driver (fluid pusher in the syringe), a 2x16 LCD as a display and a battery as a 12volt DC and 5 volt DC voltage supplier. . This tool is equipped with a timer. Injection uses a real time clock (RTC) module. However, this tool has a drawback, namely that it uses a stepper motor construction which affects the noise level[10].Next, Rahman Hanun et al conducted research entitled Driving and Controlling circuit of Inuslin Pump. In this study, an Atmega microcontroller was used as the control, a dc motor as the piston driver, a keyboard matrix to input the dose and a 16 x 2 LCD to read the results. However, the drawback of this tool is that it only uses one basic pattern (basal) to set the dose [8].

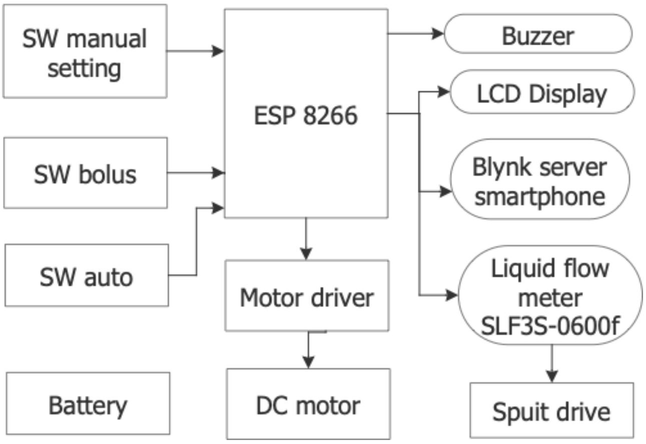


FIGURE 1. Block Diagram

From the literature study that has been carried out, several things have been found that require further research.Controlling the speed of insulin fluid entry uses a stepper motor which has less stable movement and is considered less effective for use as a speed control on this device and its size is quite large, making this device not easy to move.. Next, monitor the flow rate parameters to monitor the flow rate of the drug injected into the patient's body. Therefore, this research will design an insulin pump device with the title "Iot-Based Insulin Pump Design Analysis with Flowrate Monitoring".

The aim of this research ishelps patients suffering from diabetes mellitus get insulin doses according to their needs and helps maintain stable blood sugar levels. The constant speed of the motor allows for consistent and steady delivery of insulin into the body and provides high precision flow, taking into account the right size and power. There is also a flow rate monitoring parameter to monitor the accuracy of the flow rate of the drug injected into the patient's body. This tool is designed to be portable with low voltage and IoT-based dose monitoring that is connected to an Android device.

This research will then use a dc motor to drive the insulin pump and regulate insulin flow, ESP8266 as a data processor and controller and use the SLF3S-0600F sensor for flowrate monitoring.To display the output value on this module, it uses OLED and the Blynk application. By using a DC motor, it is hoped that it can provide stable speed control so that it can help maintain the user's blood sugar levels.

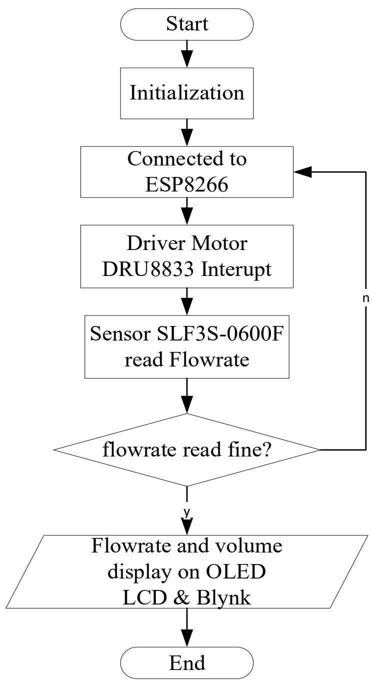


FIGURE 1 Flow diagram

II. MATERIALS ANDMETHOD

This research was conducted at the Surabaya Ministry of Health Polytechnic under the auspices of the Department of Electromedical Technology. Infusion Device Analyzer as a calibrator tool in this research. The research design applied in module development is a pre-experimental design with the After Only Design type. In this design, the researcher observes the results of the treatment, namelymeasure the flow rate of insulin that has been given, and compare the results of the calibrator with the module. This research utilizes the SLF3S-0600F sensor as input to display the flow rate readings that have been previously set. The data collection process is carried out via the SLF3S-0600F flow sensor and the data is processed using the ESP8266 microcontroller. In this study, motor speed and flow rate are the independent variables observed, while the dc motor sensor functions as a driver for the insulin pump and the SLF3S-0600F sensor as a sensor that functions to read flow rate is the dependent variable observed. The role played by the ESP8266 is as a control variable that regulates and controls the process in the module being developed. Thus, this study focuses on developing a system that combines sensor technology, data processing, and microcontroller control to achieve specific goals in regulating and monitoring flow rates in an insulin pump device. FIGURE 1 illustrated system block diagram consisting of 3 main parts: input, process and output. When the power button is pressed the battery will supply voltage to the entire circuit. There are 3 types of setting buttons, namely manual, bolus and auto buttons. After selecting the settings according to your needs and pressing start. Then the controller block will process the input and produce an output in the form of a control signal which will be sent to the dc motor driver. The dc motor driver block functions to control the speed and direction of rotation of the dc motor in the insulin pump. The dc motor block will receive a control signal and convert the control signal into rotational movement in the dc motor, to rotate the screw and this thread moves the syringe pusher piston forward and backward according to the motor rotation. Then the fluid in the reservoir will flow into the hose. The insulin reservoir is a storage place for insulin which will be released by the insulin pump. The buzzer will light up when the injection process is complete. The tool interface in this design is in the form of a button to adjust the dose settings and an OLED to display information on the insulin dose that will be released.

Module flow diagram on FIGURE 2The flow diagram shows that the tool system is carried out in several stages. When the tool is first turned on, it will initialize. Before the process takes place, the microcontroller initializes the program to be executed. After the initialization process is complete, it continues with the process of determining the volume and flowrate settings. There is an auto setting if you want the tool to determine the number of doses to be injected according to the blood sugar data entered, a bolus setting if you want the number of doses injected faster and a manual setting if the user wants to input based on volume and flowrate values. Then press the start button, in this process the motor will move as a fluid propeller. The SLF3S-0600F sensor will read the flow rate value of the dose that has been injected into the user's body. This value will then be processed and displayed on the OLED and Blynk application. Next, an alarm will sound indicating the injection process has been completed.

A. DATA ANALYSIS

This research was carried out by taking measurements using the Infusion Device Analyzer as a calibrator. This research was carried out by measuring the flow rate, injection volume and motor speed. The measurement results will then be compared with the results of standard measuring instruments so that the values produced on the tool made can be accurate according to the original tool. To obtain the accuracy value on the tool module, 5 tests were carried out. After completing the test, an analysis of the results obtained is carried out. From 5 repeated measurements, it is necessary to calculate the average. Equation (1) is used to determine the average measurement value:

$$Rata-rata\left(\overline{X}\right)=\frac{\sum Xi}{n} \quad (1)$$

By using the arithmetic average, which is the number resulting from dividing the total data value by the amount of data in the set, we can produce an average value. The average is the result of dividing the amount of data measured by the total existing data, where x represents the average value, xi is all existing data, and n is the amount of existing data. Standard deviation, on the other hand, is a number that indicates how much variation there is in a set of data or the standard deviation from the mean. Equation (2) can be used to display the error value formula:

$$\%Error=\frac{Xn-(Yn)}{Xn}x100\% \quad (2)$$

where Xn represents the value measured by the calibrator, while the value determined from the design is x. Error (error) is the difference between the average value and the respective data. This research shows that the accuracy value is still within the specified tolerance limits. Equation (3) is used to determine the standard deviation:

$$SD=\sqrt{\frac{\sum_{i=1}^{n}\left(X_i-\overline{X}\right)^2}{(n-1)}} \quad (3)$$

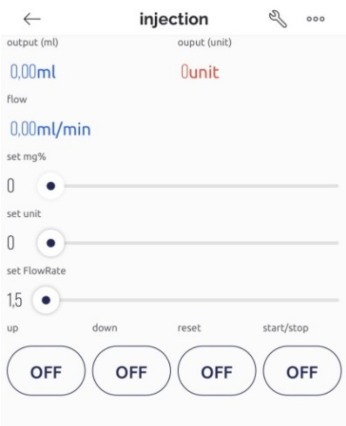
where xi is the percentage of the value in question, x represents the average measurement result, and n indicates the total number of measurements.

III. RESULT

After completing the design of the insulin pump module with flowrate monitoring, the next step is to collect data. The aim of this research is to collect data through measurements that are repeated 5 times on the module using an Infusion Device Analyzer. During the data collection process, measurements were recorded in Microsoft Excel.

FIGURES 2. Tool View

FIGURE 3 displays the electronic circuit of the insulin pump module using several components.In the design of this insulin pump device, there are several parts that are visible on the body of the device. On the front there are three buttons, the up button functions to raise the syringe, the down button functions to bolus and the third button functions to reset the input settings.



FIGURES 3. **Blynk Application Appearance**

FIGURE 4 the design of the Blynk application consists of function buttons. This application functions to replace the button function on the main module. To set the input, you can do it via the Blynk application. Users can administer insulin doses through three settings, namely manual by inputting the dose according to the user's wishes, then setting auto based on blood sugar levels, then the tool will determine the number of doses to be injected automatically according to the blood sugar data received by the tool. Next, there is a bolus button if the user wants the injection process to be faster.

TABLE 1
Average Yield and Flow Rate Error

Settings (ml/min)	Average (ml/min)	Errors (%)	Standard Deviation
1.5	1,508	0.0051	±0.023
2	2,078	0.0388	±0.021
2.5	2,548	0.0193	±0.029
3	3,117	0.0391	±0.196

Based onTable 1.In this study, the aim was to determine the accuracy of the speed of the insulin device in injecting liquid medication. The test results were carried out using a standard infusion device analyzer using a variety of input values for the injection process, namely 1.5, 2, 2.5 and 3 ml/min with a liquid volume of 100 units or 1 ml. The smallest error value was recorded at the 1.5 ml/min setting, namely 0.0051% and the largest error at the 2 ml/min setting, namely 0.0388%. Then, there is the smallest standard deviation value, which is 0.021 at a setting of 2 ml/min and the largest standard deviation is 0.196 at a setting of 3 ml/min.

TABLE 1
Average results and error of volume measurements using IDA manual mode

Settings (ml)	Average (ml)	Error (%)	Standard Deviation
0.5	0.51	0.023	±0.048
1	1.15	0.152	±0.068
1.5	1.56	0.043	±0.092
2	2.03	0.016	±0.169
2.5	2.64	0.056	±0.024
3	3.09	0.029	±0.020

Based onTable 2.In this study, volume data collection aims to determine the accuracy of injecting medicinal fluids. The test result values were carried out using a standard infusion device analyzer with units of ml and a standard reading resolution of 0.01 ml. By using various input values for the injection process, namely 0.5, 1, 1.5, 2, 2.5 and 3ml in manual mode. The smallest error recorded was 0.016% at the 2ml setting and the error was 0.152% at the 1ml setting. Then, there is the smallest standard deviation value, which is 0.048 at the 0.5 ml setting and the largest standard deviation is 0.196 at the 2.5 ml setting.

TABLE 2
Average results and error of volume measurements using IDA bolus mode

Value Conversion (ml)	Blynk		Displays	Average (ml)	Errors (%)	Standard Deviation
	Settings (mg)	Outputs (ml)	Output (ml)			
0.07	138/ 7 units	0.09	0.09	0.0904	0.2920	±.007
0.05	83/ 5 units	0.06	0.06	0.0515	0.2640	±0.008
0.1	223 / 11 units	0.12	0.13	0.1130	0.0273	±0.010
0.15	252/ 15 units	0.16	0.16	0.1538	0.0253	±0.11
0.2	321 / 20 units	0.22	0.22	0.2166	0.0830	±0.011
0.24	500/ 24 units	0.25	0.25	0.2518	0.0492	±0.010
0.16	286 / 16 units	0.19	0.19	0.1782	0.1138	±0.016
0.15	253 / 15 units	0.16	0.16	0.1516	0.0107	±0.012
0.12	241 / 12 units	0.12	0.13	0.1252	0.0433	±0.009
0.05	71 / 5 units	0.06	0.06	0.1278	0.0016	±0.007

Based on Table 3, in this study, volume data collection aims to determine the accuracy of injecting medicinal fluids. The test result values were carried out using a standard infusion device analyzer with units of ml and a standard reading resolution of 0.01 ml. The measurement results of the tool use auto settings with a flowrate of 1.5ml/min. The smallest error value is 0.0016% at the 71mg setting and the largest error is 0.292 at the 138 unit setting. Then, the smallest standard deviation value is 0.007 at the 71mg/5Unit setting and the largest standard deviation is 0.016 at the 286mg/16Unit setting.

TABLE 3.
Motor speed measurement results

Settings	Average yield (rpm)	Standard Deviation
Auto	21.22	±0.349
Bolus	49.88	±0.313

Based on Table 4, In this research, motorbike speed was measured using a standard tachometer with auto and bolus setting modes. The average speed in the auto setting is 21.22 rpm, while the average result from bolus setting measurements is 49.88 rpm. In the program that has been created, PWM is set to 100 and a maximum of 255, with a setting of 255, the motor speed is 49.88 rpm. The smallest standard deviation value is 0.313 in the bolus setting and the largest standard deviation is 0.349 in the auto setting.

TABLE 4
Injection speed measurement results

No	*Settings* (units)	Average (second)	Standard Deviation
1	20	10.306	±0.559
2	40	17.244	±0.716
3	60	28.658	±1,208
4	80	42.148	±0.818
5	100	60.866	±0.845
6	120	69.804	±1,248
7	140	80.764	±0.288
8	160	90.374	±0.738
9	180	110.282	±0.433
10	200	120.442	±0.572
11	220	129.924	±0.610
12	240	140.498	±0.451
13	260	149.922	±0.679
14	280	159.328	±1,295
15	300	178.372	±0.883

Based onTable 5.In this research, data collection aims to determine the speed of injection time. The test results were carried out using a stopwatch using a variety of input values for the injection process, namely 20 to 300 units. Obtained speed data on 100 units in 60.866 seconds, 200 units in 120.442 and 300 units in 178.37. So, it can be concluded that the injection speed is 100 units/minute or 1 ml/minute. Then, the smallest standard deviation is 0.288 at the 140 Unit setting and the largest standard deviation is 1.295 at the 280 Unit setting.

TABLE 5
Data delivery delay measurement results

Distance (cm)	Average (second)	Standard Deviation
20	1,2	±0.047
40	1.28	±0.063
60	1.35	±0.070
80	1.49	±0.073
100	1.69	±0.031
120	1.79	±0.056
140	1.88	±0.042
160	2.02	±0.042
180	2.12	±0.063
200	2.18	±0.091

Based onTable 6.In this research, data collection aims to determine the time delay of the data transmission system between the module and the Blynk application. The smallest average was obtained at a distance of 20 cm, namely 1.2 seconds, and the largest average was obtained at a distance of 200 cm, namely 2.18 seconds. The smallest standard deviation is 0.031 at a distance of 100 cm and the largest standard deviation is 0.091 at a distance of 200 cm. Based on the processed measurement results, it can be analyzed that a low standard deviation indicates that the data tends to gather close to the average value, which can be considered a sign of consistency or stability, but on the contrary, a high standard deviation indicates that the data is more scattered and inconsistent. So, the lower the standard deviation, the better the tool because the measurement or observation results obtained tend to be consistent and do not vary. The standard deviation resulting from variations or fluctuations in data in the measurement results can be a factor in determining the suitability of the tool. In the processThis data collection affects the results of variations in the data obtained, namely the hose connected to the sensor is not correct, resulting in differences in IDA readings with the tool being made. The percentage error in the flow rate variable is caused by several factors, including the movement that occurs between the gears that make up the mechanical insulin pump.

IV. DISCUSSION

The work system in this research, both in circuit and software, runs well. The circuit consisting of the ESP8266 can operate properly. The SLF3S-0600F liquid flow sensor is used to monitor the flow rate which is part of the circuit in this module which works well and has the advantage of being able to read with a resolution of 0.001ml/min. Apart from that, this system is equipped with a buzzer to indicate that the injection process is late. The application used for remote monitoring is Blynk. In carrying out the process of using this application, it depends on the performance of the WiFi or surrounding signal, so on several attempts in various places there was a delay in the input setting process. The influence of the size and placement of the hose in this module is the main factor in the variation in values when collecting data using standard tools. This research has differences compared to previous studies that have been carried out. Researchers emphasize several points in this research, namely monitoring the flow rate which aims to prove that the dose of fluid injected into the patient's body is correct. Then the portable design using a battery and IoT-based dose monitoring connected to an Android device makes this module look minimalist and can be carried by users easily. The implications of realizing the system in this research are the ability to control blood glucose levels better, reduce the number of insulin injections needed, provide flexibility in eating and exercise schedules, and help minimize the risk of long-term diabetes complications.

V. CONCLUSION

Based on the results of research that has been carried out from research methods, data collection and analysis of the results of measuring respiration values, several conclusions can be drawn that An IoT-based insulin pump can be made using ESP8266 and it works through the settings in the blynk application. Output values displayed on the OLED and Blynk Application. Variations in the data obtained are influenced by the hose connected to the sensor which may be inaccurate, resulting in differences in readings and movements that occur between the gears that make up the mechanical insulin pump.

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