CHAPTER 3

DEVELOPMENT OF BLOOD GLUCOSE MEASUREMENT WITH IOT APPLICATION

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3.1 INTRODUCTION

Diabetes is an unending health condition at which related to with anomalous large amounts of sugar (glucose) in the blood. Diabetes is majorly occurring when there is absence or insufficient insulin production by the pancreas; hence in other conditions, it is due to the inability of the body to properly utilize the function of the insulin [1]. Diabetes can be categorized into two types, Type 1 and Type 2. Type 1 diabetes usually starts in childhood or young adulthood, whereas type 2 diabetes usually starts in adulthood. In people with type 1 diabetes, the body's immune system attacks and destroys pancreatic cells (Beta cells) that produce insulin. In people with type 2 diabetes, the pancreas is not attacked and usually produces insulin. However, people with type 2 diabetes, for numerous reasons, cannot use the available insulin effectively.

Blood glucose monitors are used to measure the amount of glucose in blood, especially of patients with symptoms or a history of abnormally high or low blood glucose levels. Most commonly, they enable diabetic patients to administer appropriate insulin doses. The availability of home-use glucometers, as opposed to clinical-use equipment, has greatly improved the quality of life of such individuals. However, such monitors require a blood draw through finger pricks for each test, which cause pain and inconvenience. Each test also requires a new test-strip, contributing to the recurring cost of such a device.

3.2 METHODOLOGY

A complete system that utilise infrared technology and effective microcontroller capabilities has been developed to monitor glucose concentrations for health and medical purposes [2]. This device interacts with a subject, usually a human finger, by integrating a 5 mm infrared transmitter and 5 mm photodiode to detect glucose concentration, which is then processed by an ESP32 microcontroller. After processing, the data is sent to the ThingSpeak platform for additional analysis and storage, and it is also shown on an OLED panel for instant feedback. The goal of this creative arrangement is to demonstrate the potential of Internet of Things (IoT) applications in the healthcare industry by offering an effective and real-time means of monitoring glucose concentrations. Figure 3.1 illustrates the overall block diagram of the system. A block diagram is a visual representation of a system that uses simple, labelled blocks representing single or multiple items, entities, or concepts, connected by lines to show relationships between them [3]. The system's general structure and functional connections may be easily understood with the use of block diagram.

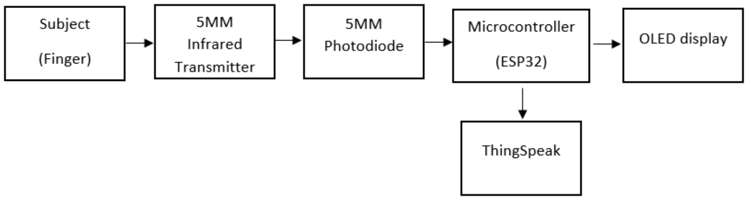

Figure 3.1: Block diagram of the system

A flowchart is a diagram that depicts a process, system or computer algorithm. They are widely used in multiple fields to document, study, and plan, improve and communicate often complex processes in clear, easy-to-understand diagrams [4]. This graphic representation will help to assist a better understanding of the whole workflow, in addition to highlighting how each step is related to the others. This action triggers the subsequent stages of the process. Next, a crucial decision point has been reached, represented by a diamond. The system determines if the sensor has correctly identified the finger. The workflow for this system is shown in Figure 3.2. If the finger is detected, the process advances to the next stage. The sensor value is shown on the OLED upon successful finger detection, and then the data is sent to the ThingSpeak platform if the finger is identified. The data is subsequently transmitted to the ThingSpeak platform, which is intended for a data storage and visualization service. Lastly, the user is advised to realign their finger and the procedure is repeated if the finger is not recognized.

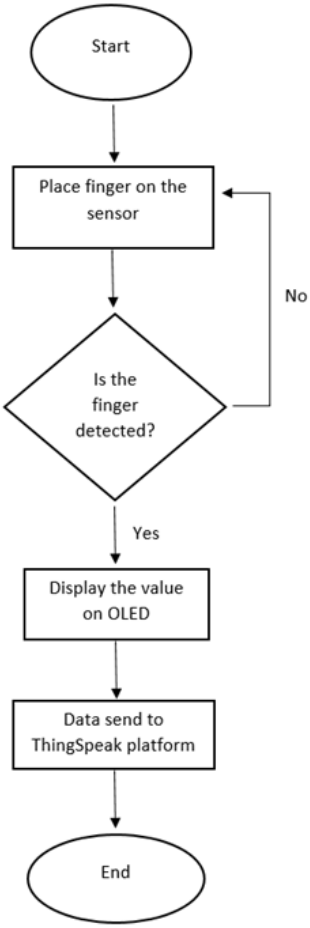

Figure 3.2: Flowchart of the system

3.2.1 DESIGN OF CIRCUIT

Designing a circuit is an important step in the process of creating an electronic device. The purpose for this connection is to emit and detect infrared light between infrared LED and photodiode to take the voltage value for this sensor. The NIR LED used for this proposed project is an infrared LED 5 mm that provides a 940 nm signal wavelength. A signalling photodiode is positioned on the opposite side. The photodiode proposed for this project is a 5 mm photodiode. It typically emits a 940 nm signal. This observant sensor interprets the changing path of the infrared light and converts it into an electrical signal. The reason for using the resistor in this circuit is that resistors are frequently used to restrict the amount of current that passes through parts like LEDs and infrared transmitters. Avoiding excessive current that may damage the LED or other components is crucial. The sensor value proposed on the circuit is 10 kΩ each. Then, the microcontroller proposed in this project is ESP32, the brain of the operation. This microcontroller has capabilities with built-in Wi-Fi and Bluetooth. This is especially helpful for projects that use Bluetooth connections or local Wi-Fi networks for communication.

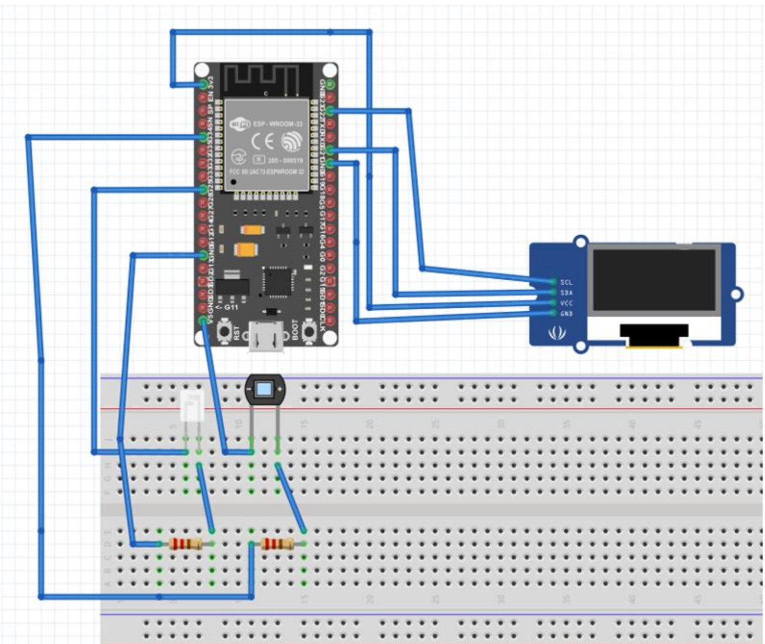

Figure 3.3: Circuit connection for proposed system

3.2.2 ARDUINO IDE SOFTWARE TO GET SENSOR VOLTAGE

The first stage in creating a glucose concentration monitoring system is to interface a sensor with the Arduino IDE in order to identify analogue voltage changes that correspond to different sensor circumstances. Arduino IDE is an open-source software, designed by Arduino.cc and mainly used for writing, compiling & uploading code to almost all Arduino modules. It is an official Arduino software, making code compilation too easy that even a common person with no prior technical knowledge can get their feet wet with the learning process [5]. Create the code setup to observe the analogue voltage from the sensor, observe the serial monitor and also set a threshold for touch and no-touch conditions. Lastly, on the serial monitor, it prints a message showing the voltage value in 'V' and also 'Touch detected!' indicating that a touch or when the finger on the sensor has been detected before continuing the process calibration.

3.2.3 INTERNET OF THINGS (IoT) PLATFORMS USING THINGSPEAK

After processing, the data is shown and sent to the ThingSpeak platform for additional storage and analysis. The goal of this creative setup is to demonstrate the potential of Internet of Things (IoT) applications in the healthcare industry by providing an efficient and real-time technique for monitoring glucose concentrations. ThingSpeak is an IoT analytics platform service that allows to aggregate, visualize and analyses live data streams in the cloud. ThingSpeak provides instant visualizations of data posted by the devices to ThingSpeak [6]. In addition to communicating with other objects and people, these networked gadgets frequently send sensor data to cloud computing and storage services, where it is processed and analyzed to produce valuable insights. To transmit the data reading from ESP32 to ThingSpeak application the apiKey and Channel ID must be same between our coding and ThingSpeak credentials.

3.2.4 LINEAR REGRESSION ANALYSIS USING MATLAB

Based on theory, the prediction of glucose concentration can be calculated by using linear regression analysis. Linear regression is a statistical modelling technique used to describe a continuous response variable as a function of one or more predictor variables. It can help you understand and predict the behavior of complex systems or analyze experimental, financial, and biological data [7]. The data from the experiment result was processed and analyzed and a gradient was constructed based on the data from the experiment. Equation (1) is utilized to predict glucose concentration to get the linear regression analysis using the MATLAB software.

$$y = mx + c \tag{1}$$

where,
y = glucose concentration (mmol/L)
x = voltage reading from sensor
m = gradient of graph
c = y-intercept

The objective of linear regression analysis is to determine which line best fits the data points. To minimise the sum of squared differences between the observed values and the values predicted by the line (the residuals), the slope (m) and y-intercept (c) are chosen. This is often known as the least squares approach. Because it offers a clear, understandable model of the relationship between variables, the formula is frequently used. To quantify the correlation between changes in the independent variable (voltage reading, x) and the dependent variable (glucose concentration, y), linear regression assumes that the relationship between the variables is approximately linear. To get the linear regression analysis, the sample data must be collected based on the value of the sensor that has been collected on the Arduino IDE software. The parameters (m and c) that specify the connection between these variables may be estimated using the linear regression model. The equation may be utilized for predicting glucose concentrations based on new voltage data once these values are determined. Table 3.1 shows the estimated sensor voltage taken from the proposed device and its actual glucometer.

Table 3.1: The estimated sensor voltage taken from the proposed system and its actual glucometer

Participant	Sensor Voltage (V)	Actual Glucometer (mmol/L)
A	2.45	5.5
B	3.91	7.5
C	3.88	6.8
D	3.50	5.8
E	4.00	6.5

3.3 RESULTS AND DISCUSSION

3.3.1 SERIAL MONITOR READING IN ARDUINO IDE SOFTWARE

Figure 3.4 shows the readings on a serial monitor of Arduino IDE software. The result of the model represents two values, which are the voltage reading (V) from the sensor and the glucose concentration (mmol/L). The infrared LED and photodiode is very sensitive to ambient of light. The result for voltage reading show in the serial monitor in Arduino Reading software before calibration process. Sensor sensitivity plays a crucial role in how well it detects the finger and produces an accurate output. So, make sure the hardware is shielded with opaque material so that it can reduce the ambient light from the surroundings.

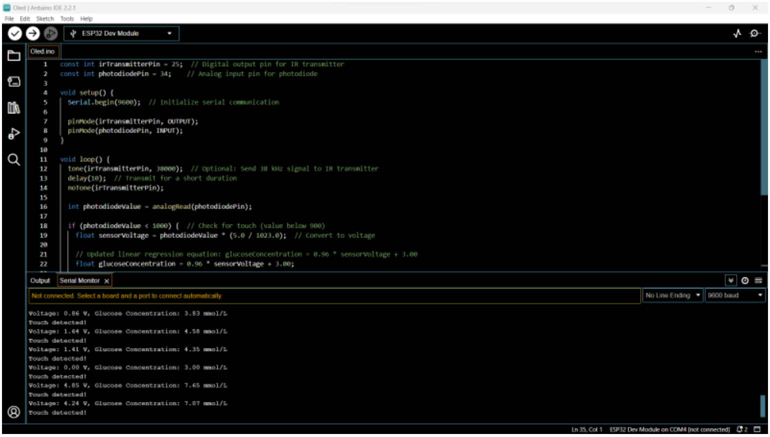

Figure 3.4: Readings on serial monitor of Arduino IDE software

3.3.2 RESULT ON THINGSPEAK CHANNEL

Figure 3.5 the result of glucose concentration in the IoT application that is ThingSpeak. ThingSpeak provides instant visualizations of data posted by your devices or equipment. The output in ThingSpeak is the same as the output in the Arduino IDE serial monitor. It shows unit values for blood glucose in mmol/L. The IoT platform can be viewed on a smartphone and a laptop. ThingSpeak's smooth integration with sensors and microcontrollers is one of its unique qualities. Devices that can send data to ThingSpeak, including ESP32 microcontrollers, can easily transfer data to the platform's cloud servers. This compatibility makes developing IoT applications easier, and developers are free to focus on their devices' features rather than the complexities of data management.

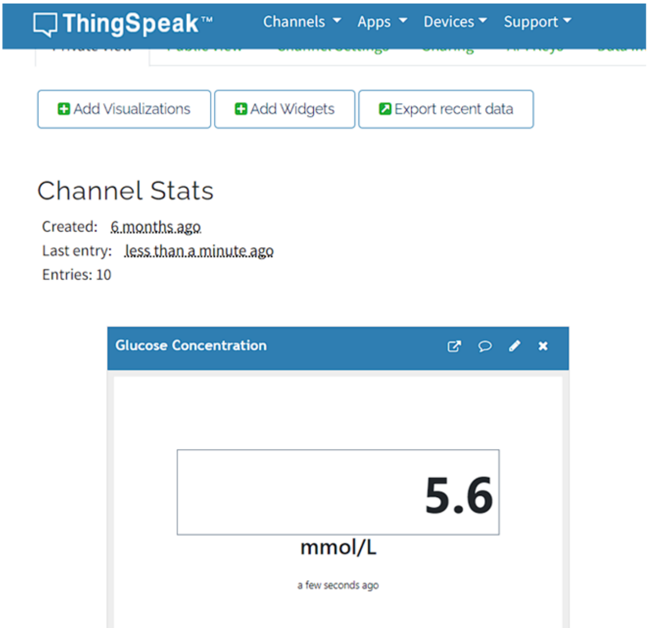

Figure 3.5: The reading value of glucose concentration on ThingSpeak

3.3.3 CALIBRATION RESULT ON MATLAB

The prediction of the glucose concentration is calculated by using the linear regression analysis based on the relationship between the voltage reading and the blood glucose level and sensor voltage. Blood glucose levels were measured from five volunteers using the One Touch Glucometer compared to the voltage output from the project hardware. Next, the relationship between voltage output and One Touch Glucometer reading will be determined using the linear regression analysis in MATLAB.

Figure 3.6 shows the scatter plot of the relationship between voltage readings and glucose concentration, with data points and a regression line. The graph has two labelled axes: “Voltage Reading” on the horizontal axis and “Glucose Concentration” on the vertical axis. Five data points are plotted as blue circles. The five data points are collected based on Table 1.1. Next, the red line drawn diagonally across the data points. This line represents the best fit linear relationship between the voltage readings and glucose concentrations.

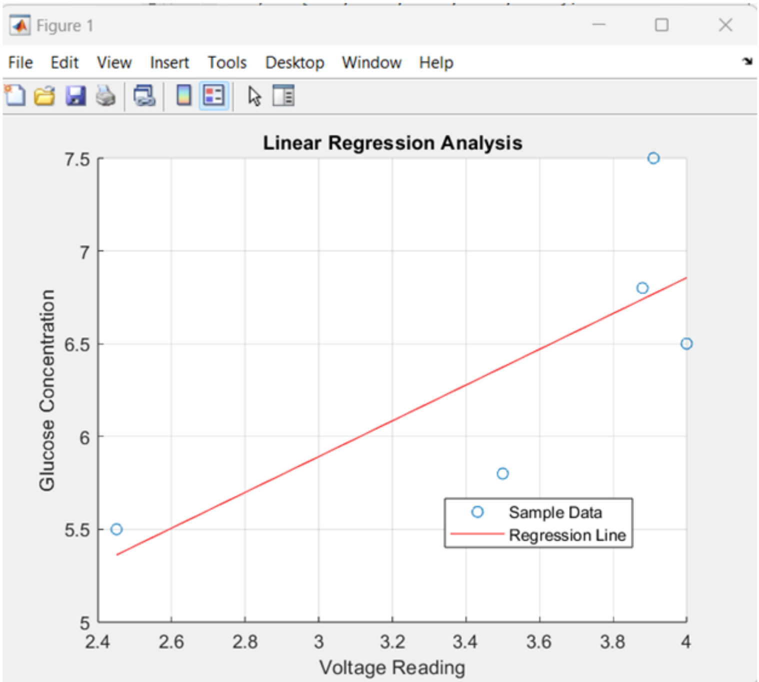

Figure 3.6: Linear regression analysis in MATLAB

After that, the almost straight regression line indicates that the two variables are linearly related. This indicates that constant, proportional changes in the dependent variable are linked to changes in the independent variable. The equation of the regression line is $y = 0.96x + 3.00$. This equation can be used to predict glucose concentration values from the hardware project. The equation of the regression line must be included in the Arduino IDE code to ensure that the sensor readings are accurate. The calibration method might be used specifically for the glucose concentration monitoring project to correlate the sensor's analogue voltage measurements with the actual glucose concentration data.

It is possible to build a link between the sensor's output and the parameter that are seeking to measure in the actual world by using this mapping, which is usually determined through trial and error testing and observation. It makes it possible to adjust for a variety of factors that might cause mistakes, which eventually improves the accuracy and efficiency of the measuring system. Overall, the data points align reasonably well with the regression line, suggesting a moderately good fit of the linear model to the data to get the value the same as the actual glucometer measurement.

3.3.4 COMPARISON BETWEEN PROPOSED HARDWARE AND ACTUAL GLUCOMETER

To assure this result, the comparison will be taken using an actual glucometer according to a person’s BMI, which is categorised as overweight, normal and underweight. The glucose reading will be obtained under three conditions, that is, fasting usually up to 10 hours, 2 hours post-meal and random tests. For the reading, it will be measured based on a person's BMI: overweight is 25 kg/m^2 to 30 kg/m2, normal is 18.5 kg/m^2 to 25 kg/m^2, and underweight is 17 kg/m^2 to 18.5 kg/m^2. The three individuals who participated in the testing were aged 22 to 25.

Based on the theory for the reading of an actual glucometer during a 10-hour fast, glucose readings were consistently less than 6 mmol/L, remained less than 10 mmol/L in random tests, and postprandial readings, obtained two hours after a meal, were consistently less than 8 mmol/L. The purpose of this comparison is to do a comparative analysis (refer to Table 3.2), exploring the domains of development of glucose hardware and non-invasive glucose readings. In this case, examine the values obtained from a development device using non-invasive techniques and compare them to the accuracy standard established by a real glucometer, which serves as the invasive method.

Table 3.2: Error and accuracy for development hardware and actual glucometer

Categories (BMI)	Conditions	Estimated value of glucose hardware (mmol/L)	Invasive value (mmol/L)	Error (%)	Accuracy (%)
Underweight	Fasting up to 10 hours	4.06	4.6	11.7	88.3
	Random tests	4.15	5.1	18.6	81.4
	After 2 hours post-meals	4.79	5.5	12.9	87.1
Normal	Fasting up to 10 hours	5.20	5.3	1.9	98.1
	Random tests	4.04	4.6	12.2	87.8
	After 2 hours post-meals	5.50	6.8	19.1	80.9
Overweight	Fasting up to 10 hours	4.79	5.5	13.0	87.0
	Random tests	6.30	7.5	16.0	84.0
	After 2 hours post-meals	5.70	7.8	27.0	73.0

Based on the reading, the project hardware generally overestimates glucose levels compared to the actual glucometer. The potential reason for overestimation in reading is that the accuracy of the sensors used in the glucose hardware is crucial. If the sensors are less accurate, they may introduce measurement errors. Next, control the serial monitor output when the voltage of the sensor is measured. The code may have faults or loops that enable several print requests to be issued without a required delay, resulting in the simultaneous printing of readings. The other reasons for this overestimated reading are that the development hardware cannot get the same voltage from the same person. This issue can be overcome by first calibrating the sensor using an oscilloscope to determine the high peak of the waveform for a person's finger. Lastly, exploring methods to control hardware buffering or optimizing data transmission in smaller packets can address issues related to simultaneous output.

3.4 CONCLUSION

In conclusion, a development of blood glucose measurement with IOT application using infrared LED and photodiode unfortunately unsuccessful developed in this study. The calibration model of regression line analysis is (y = 0.96x + 3.00) was unsuccessful to determine the glucose-voltage relationship, so the hardware project is overestimates glucose levels by about 2.6 – 2.8 mmol/L. Remember, continuous data collection, analysis, and calibration are essential for refining the accuracy of glucose hardware over time. To improve the accuracy of the sensor reading, the hardware must be shield with opaque material so that it can reduced the ambient light from surroundings because these two components is very sensitive to light also adjust the code structure for serial monitor and can prevent the simultaneous output of reading. This serial monitor output might be one reason that the errors or loops in the code triggering multiple print commands without appropriate delay and may be caused hard to measure suitable voltage for the glucose output in regression line analysis.

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