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DESIGN OF NON-INVASIVE CONTINUOUS GLUCOSE MONITORING DEVICE

COLLEGE OF

ELECTRICAL AND MECHANICAL ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY, RAWALPINDI.

2023

NUST College of Electrical & Mechanical Engineering

PROJECT REPORT

DESIGN OF NON-INVASIVE CONTINUOUS GLUCOSE MONITORING DEVICE

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بسم الله الرحمن الرحيم

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Submitted to the Department of Electrical Engineering in partialfulfillment of the requirements for the degree of

Bachelor of Electrical Engineering 2023

Project Supervisor (s):

A/P Kamran Aziz Bhatti

Dr. Ahmad Rauf Subhani

DECLARATION

We now declare that no portion of work referred to in this project has been submitted in support of an application for another degree, or qualification of this, or any other university or other institutes of learning. If any act of plagiarism is found, we are fully responsible for every disciplinary action taken against us depending upon the seriousness of the proven offense, even the cancellation of our degree.

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APPROVAL CERTIFICATE

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ACKNOWLEDGMENTS

First, "**الحمد هلل**."

We owe everything to Allah (SWT), who created us from nothing and gave us everything. We additionally say thanks to Allah (SWT) for making it workable for us to envision, plan, fabricate, and play out our undertaking surprisingly well, for without His assistance, nothing would have been conceivable.

We spent a lot of time thinking about this project's theoretical aspects while building it, and we were confused about which tools and methodology to use. Our supervisor, **Assistant Professor Kamran Aziz Bhatti**, and co-supervisor **Dr. Ahmad Rauf Subhani** gave us total support in this endeavor. Thank you for believing in us, pointing us in the right direction, offering us all your guidance, and assisting us in completing our project. He made us want to know more and introduced us to the spiritual world.

We would like to express our gratitude to our parents, who provided us with the means to achieve our goals and allowed us to sit here today.

THANKS AGAIN TO ALL WHO HELPED US!

ABSTRACT

Invasive blood glucose level monitoring is typically required for diabetes, a chronic disease that affects millions of people worldwide. Pricking the finger to draw blood is the most common method, and the blood is then tested for glucose content. This invasive method has some drawbacks, but it is without a doubt effective. It has the potential to spread infectious diseases and can be a costly and painful process. Also, the drawn-out ramifications of rehashed finger-pricking can prompt tissue harm, causing significant distress and in some cases even useful debilitations.

However, there is a non-invasive method for measuring blood glucose levels that can be used in place of this one and avoids the drawbacks of the invasive approach. This strategy gives a more agreeable, less horrendous method of incessant testing without compromising the quality or exactness of the outcomes. Utilization of Near-Infrared (NIR) light is necessary for its implementation. This is the secret: A photodetector receives the NIR light that is transmitted through a person's finger. The variety in the got light force gives information that can be examined to decide the glucose level in the blood. There is no risk of infection or physical harm because this method does not require any physical contact with blood.

Additionally, an integrated digital display system can be implemented using this alternative method. An LCD displays the measured glucose level, giving the patient or healthcare provider a quick and easy-to-understand reading. However, the advancement doesn't stop there; A connected Android app for smartphones is included in the system. The glucose level data is received by the application via Bluetooth and displayed in a format that is simple to read. Furthermore, the application is intended to store this information, developing a record over the long haul. This record can be important for long haul diabetes the board, permitting the following of examples and patterns, working with additional educated conversations with medical care suppliers, and prompting more customized therapy plans.

There are numerous advantages to the non-invasive approach proposed here in general: it's less excruciating and less expensive, takes out the gamble of irresistible infection transmission, and forestalls harm to finger tissues. By displaying the results on an LCD and sending the data to a mobile application for easy monitoring and record keeping, it also adds convenience and digital integration. The embodiment of this suggestion is to make diabetes the board not so much oppressive but rather easier to understand, without forfeiting precision and dependability.

SUSTAINABLE DEVELOPMENT GOALS

Goal 3: Good Health and Well-being

The non-invasive glucose monitoring device project sits at the crossroads of technological innovation and health equity, aligning seamlessly with the Sustainable Development Goal 3 (SDG-3): "Ensure healthy lives and promote well-being for all at all ages." This specific United Nations' goal emphasizes a comprehensive view of health, which includes the prevention and treatment of non-communicable diseases like diabetes, alongside the provision of quality, accessible healthcare technologies.

Diabetes, a chronic, non-communicable disease, is a global health concern affecting hundreds of millions of individuals worldwide. The need for regular blood glucose monitoring as part of diabetes management often necessitates multiple daily finger-pricks, leading to significant discomfort and potential complications. Our non-invasive glucose monitoring device project addresses this challenge head-on, offering a solution that promotes both physical well-being and mental peace of mind.

Our device introduces an accessible, pain-free method for regular glucose monitoring, thus contributing directly to SDG-3's target of reducing mortality from non-communicable diseases through prevention, treatment, and promotion of mental health and well-being. By enabling easier and more comfortable blood glucose monitoring, we facilitate improved diabetes management, which can lead to better health outcomes for individuals living with this condition.

In addition, our project champions health equity, another critical aspect of SDG-3. We utilize cost-effective components in the construction of our device and leverage open-source software for enhancing its predictive accuracy. This approach ensures that our technology remains affordable and scalable, opening the doors to widespread adoption and facilitating access even in low-resource settings. By prioritizing affordability and accessibility, we adhere to the spirit of SDG-3, which advocates for universal health coverage and access to quality essential healthcare services.

TABLE OF CONTENTS

Table of Figures

Chapter 1 - INTRODUCTION

1.1. Background

Diabetes, a global health concern, necessitates regular blood glucose monitoring, typically conducted through invasive, often uncomfortable, methods. These conventional techniques can be costly, potentially lead to disease transmission, and cause long-term tissue damage due to frequent finger-pricking. This highlights the necessity for alternative, non-invasive solutions for effective glucose monitoring.

The project, "Design and Implementation of Non-Invasive Continuous Glucose Monitoring Device," aims to address this need. Utilizing Near-Infrared (NIR) light, the device non-invasively measures blood glucose levels by analyzing variations in NIR light intensity after it passes through a finger. This method eliminates pain and discomfort associated with traditional methods and lowers the risk of infectious disease transmission.

Further enhancing the device's utility, it includes digital integration: an LCD for real-time

Figure 1 Invasive method of measuring blood sugar, [10].

glucose level display and a custom Android application, which receives this data via Bluetooth. This mobile app feature allows for easy monitoring and long-term data storage. In summary, this project proposes a non-invasive, digital solution aimed at improving diabetes management and patient comfort [1].

1.2. Aim of Project

The way that this task works is that we utilized an IR sensor with an extraordinary frequency that can enter the skin of the finger, this IR wave will go through the finger and slam into the platelets which cause a reflection, after the impression of the frequency the beneficiary will get this wave, then, at that point, the Arduino will handle the wave and find the glucose

level of the, what demonstrates that the venture works impeccably if the rate mistake between the obtrusive strategy and the harmless is a tiny rate.

1.3. Constraints

To guarantee the project's success, numerous constraints must be taken into consideration:

- The sensor needs to be positioned on a surface that is both solid and stable, such as wood or a table, and the finger that is placed on it needs to be firmly pressed against the sensor for between 10 and 15 seconds to produce a stable result.
- The climate of the examination, the light and the temperature affected the outcomes, so we attempted to work under consistent circumstances, we likewise attempted to include in one spot at a steady temperature and we attempted to fix the finger well on the sensor to keep the light from entering.
- Design, in which the Arduino has a particular voltage and current. One of its limitations is that the voltage affects the current in the opposite direction of the voltage. When the device draws a lot of current, the Arduino's supply voltage drops significantly.
- Cost and weight need to be affordable so that people can buy it, and it needs to have lightweight parts to make it easy to carry and use.

1.4. Standards

- Arduino UNO Standards
- ISO 15197:2013
- IEEE 802.11 (Bluetooth ISM 2.4 GHz)
- USB 3.0 and USB 2.0
- AS7265x Sensor

Chapter 2 - BLOOD GLUCOSE BACKGROUND

2.1. Diabetes history

"Scientists and physicians have been documenting the condition now known as diabetes for thousands of years. From the origins of its discovery to the dramatic breakthroughs in its treatment, many brilliant minds have played a part in the fascinating history of diabetes".

A literature review on optical bilirubin measurement and NIR glucose measurement in blood has been provided in this section. Müller and co. In 1997, glucose from a finger was measured using the NIR diffuse reflectance spectra method in the 800–1350 nm range. The cross-approval root implies square blunder of forecast (RMSEP) got is from 1.02 mmol/L (18.4 mg/dL) to 1.88 mmol/L (33.8 mg/dL). Danzer and co. In 1998, the radial basis function (RBF) neural network was analyzed using NIR diffuse reflectance and partial least squares (PLS) regression. They utilized 800-1350 nm NIR light and estimated glucose from the center finger. The RMSEP that was found was 36 mg/dL at 2.0 mmol/L. Araujo-Andrade and others in 2004 utilized NIR diffuse reflectance technique which comprised of a light source, a fiber optical estimating head, and a NIR spectrometer. The measurement was made using NIR light with a wavelength of 900–1700 nm, and it was done with the finger. In this review, the relationship coefficient values acquired are lower than 0.744 and RMSEP values got are higher than 0.89 mmol/L (16 mg/dL). Xu and co. An optical measurement condition reproduction method for dealing with the disparity between measuring locations and contact pressures was published in 2005. Light-emitting diodes (LEDs) for lighting, a fiber probe, spectrometer, CCD camera, three-dimensional servo device, and a bracket make up their proposed system. To measure palm glucose, they used diffuse reflectance spectra in the NIR range of 1100–1800 nm.

The correlation coefficient is greater than 0.8, and the RMSEP that was obtained ranges from 0.8 to 1.1 mmol/L (15–20 mg/dL). In 2010, Guevara and González combined impedance spectroscopy (1–200 MHz) with NIR (700–1000 nm). They estimated glucose from the lower arm and tried procedure on 10 nondiabetic people under controlled temperature and dampness conditions. The RMSEP acquired was 1.2488 mmol/L (21.96 mg/dL). Srivastava and others 940-nm infrared light emitted as an input signal on the finger was proposed in 2013 as an optical non-invasive method to measure blood glucose.

A microchip's digitized, amplified, and processed output signal could be used to detect blood glucose levels with a specific algorithm. Nonetheless, the proposed technique has not been assessed. This paper infers that painless blood glucose estimations before long can be a decent choice to showcase glucometers. Drs. Faranak Fotouhi-Ghazvini, Fahime Sadat Zakeri, and Faranak Fotouhi-Ghazvini created a device in 2018 to measure glucose and bilirubin. They used for their project, including a microcontroller, Bluetooth module, photodiodes, resistors, and capacitors. For the microcontroller they utilized C++ language, they took some blood tests and contrasted it and their gadget tests and decided a condition. Their gadget was supported by the Clarkes matrix examination and the rate was between 3% to 12%.

The second one was made with temperature. They took 50 human samples using LCD, Arduino, temperature sensing, and amplification, and Clarke's grid analysis confirmed their error rate. We also used two stages of amplification stages and one low pass filter with photodiodes and transmitter in our sensor. Additionally, we will use LCD and Bluetooth module to design an application that Arduino will send the result through connecting the Bluetooth module to the phone application. After reading multiple articles, we decided to use Arduino because it has more potential and is easier to use.

2.2. Diabetes Beginnings

In 1552 B.C., an Egyptian physician named Hesy-Ra described frequent urination as a symptom of a mysterious disease that also caused emaciation. Additionally, around this same time, ancient healers noted that people with diabetes seemed to attract ants to their

urine. In 150 Promotion, the Greek doctor Arateus depicted what we presently call diabetes as "the breaking down of tissue and appendages into pee." Doctors began to gain a better understanding of diabetes from that point on. Later, "water tasters" used to diagnose diabetes by tasting the urine of those they suspected of having the disease. Diabetes was identified when urine had a sweet taste. To recognize this component, in 1675 "mellitus," importance honey, was added to the name "diabetes," significance siphon. It was only after the 1800s that researchers created synthetic tests to distinguish the presence of sugar in the pee"[2].

2.3. The Early Treatments for the disease

"As doctors found out about diabetes, they started to comprehend how it very well may be managed. The principal diabetes treatment included recommended work out, frequently horseback riding, which was remembered to alleviate exorbitant pee. In the 1700s and 1800s, doctors realized that modifying one's diet could help control diabetes, so they told their patients to limit their intake of sugar and only eat animal fat and meat. During the Franco-Prussian Conflict of the mid 1870s, the French doctor Apollinaire Bouchard at noticed that his diabetic patients' side effects worked on because of war-related food apportioning, and he created individualized eats less carbs as diabetes medicines. This prompted the prevailing fashion diets of the mid 1900s, which incorporated the "oat-fix," "potato treatment," and the "starvation diet."

By writing The Treatment of Diabetes Mellitus in 1916, Boston scientist Elliott Joslin made a name for himself as one of the world's leading experts on diabetes. In it, he said that diabetes patients could significantly reduce their risk of death by eating fasting and exercising regularly. These principles are still used by doctors and diabetes educators to teach their patients how to change their lifestyles to manage diabetes today [2].

2.4. How Insulin Came About

Figure 2 The discoverers of insulin, George Zelzer and Frederick Banting, [7].

Despite these advances, before the discovery of insulin, diabetes inevitably led to premature death. The first big breakthrough that eventually led to the use of insulin to treat diabetes was in 1889, when Oskar Makowski and Joseph von Mering, researchers at the University of Strasbourg in France, showed that the removal of a dog's pancreas could induce diabetes. Inthe early 1900s, Georg Zuelzer, a German scientist found that injecting pancreatic extract into patients could help control diabetes. Frederick Banting, a physician in Ontario, Canada,first had the idea to use insulin to treat diabetes in 1920, and he and his colleagues began trying out his theory in animal experiments. Banting and his team finally used insulin to successfully treat a diabetic patient in 1922 and were awarded the Nobel Prize in Medicine the following year" [2].

2.5. Diabetes Mellitus

A group of metabolic disorders characterized by persistently high blood sugar levels is referred to as diabetes. If diabetes is not treated, it can lead to several health problems, including frequent urination, an increase in thirst, and an increase in appetite. Other serious long-term problems include foot ulcers, nerve damage, eye damage, and cognitive impairment.

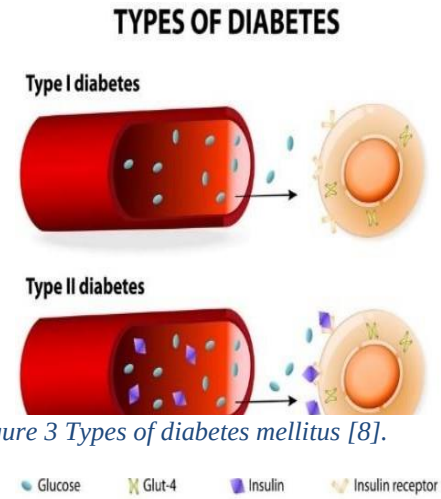

Figure 3 Types of diabetes mellitus [8].

Diabetes is because of either the pancreas not creating sufficient insulin, or the cells of the body not answering as expected to the insulin delivered. Diabetes mellitus can be classified into:

- Type 1 diabetes results from failure of the pancreas to produce enough insulin due to loss of beta cells. The loss of beta cells is caused by an autoimmune response.
- Type 2 diabetes begins with insulin resistance, a condition in which cells fail to respond to insulin properly, As the disease progresses, a lack of insulin may also develop, the most common cause is a combination of excessive body weight and insufficient exercise.
- Gestational diabetes and occurs when pregnant women without a previous history of diabetes develop high blood sugar level [4].

2.6. Glucose

Blood glucose is a sugar that is carried through the bloodstream to all the body's cells to provide energy. To reduce the risk of developing diabetes and heart disease, a person must maintain normal blood sugar levels [5].

What Is Glucose?

Glucose is a sugar that circles the blood, filling in as the body's fundamental wellspring of energy. The digestive system transforms carbohydrates into sugar molecules of varying complexity upon intake. The body has a harder time breaking down complex carbohydrates, like lactose, which is found in dairy products. They have a variety of sugar molecules in

them. Glucose is one more result of starch breakdown. It is a straightforward sugar that the body's cells easily convert into energy. After an individual consumes and digests food, the sugar enters the bloodstream directly from the digestive system. However, sufficient insulin must also be present in the bloodstream for glucose to enter cells. Insulin is a protein that prepares cells to get glucose. Blood sugar concentrations rise after meals. To transfer glucose from the blood to the cells, the pancreas releases insulin automatically. as an ever-increasing number of cells get glucose, glucose levels return to typical [5].

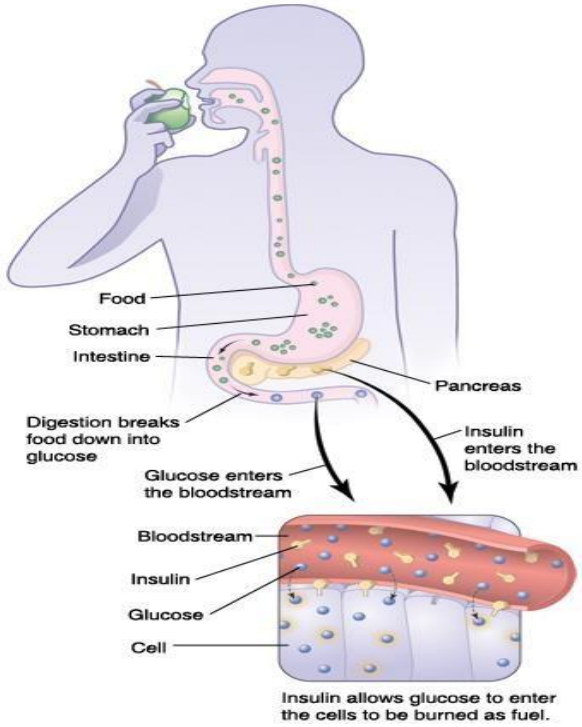

Figure 4 How the Body Makes Glucose, [9]

How The Body Makes Glucose

It mostly comes from foods like bread, potatoes, and fruit that are high in carbohydrates. As you eat, food trips down your throat to your stomach. There, acids and proteins separate it into small pieces. That process results in the release of glucose. It is absorbed once it reaches your intestines. It then enters your bloodstream there. Insulin helps glucose get to your cells once it is in the blood [6].

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your intestines. It then enters your bloodstream there. Insulin helps glucose get to your cells once it is in the blood [6].

Energy and Storage

The body is designed to maintain a constant blood glucose level. Beta cells in your pancreas screen your glucose level like clockwork. At the point when your blood glucose ascends after you eat, the beta cells discharge insulin into your circulation system. Insulin behaves like a key, opening muscle, fat, and liver cells so glucose can get inside them. Most of the cells in your body use glucose alongside amino acids (the structure blocks of protein) and fats for energy. However, it is the primary source of brain fuel. It is necessary for nerve cells and chemical messengers there to process information. Your brain wouldn't be able to function properly without it. Glycogen is a small bundle of glucose that is stored in the liver and muscles after your body uses the energy it needs. You can store enough energy to last you about a day. Your blood glucose level decreases after not eating for a few hours. Your pancreas quits producing insulin. A different hormone, glucagon, is produced by the pancreatic alpha cells. It tells the liver to turn stored glycogen back into glucose by breaking it down. That movements to your circulation system to renew your inventory until you're ready to eat once more. Using waste products, amino acids, and fat, your liver can also produce its own glucose [6].

2.7. Blood Glucose Levels

Glucose level ordinarily rises after you eat. The insulin that moves glucose into your cells causes it to drop a few hours later. Your blood sugar should be under 100 milligrams per deciliter (mg/dl) between meals. Your fasting blood sugar level is this.

Without enough insulin, glucose can't move into the cells. The glucose level in the blood stays high. A level north of 200 mg/dl 2 hours after dinner or more than 125 mg/dl fasting is high blood glucose, called hyperglycemia. The blood vessels that carry oxygen-rich blood to your organs can be damaged by having too much glucose in your bloodstream for an extended period.

High glucose can expand your gamble for:

a. Heart disease, heart attack, and stroke

b. Kidney disease

c. Nerve damage

d. Eye disease called retinopathy [6].

2.8. Lifestyle tips

Blood sugar control can often be improved through lifestyle choices.

Eating a solid eating routine with a lot of foods grown from the ground, keeping a sound weight, and getting something like 150 minutes of moderate-to-serious activity every week can help Confided in Source. The following are additional ways to control blood sugar:

- Consuming food on a regular schedule and not skipping meals.
- Drinking water rather than juice and pop
- Picking fruit over a candy bar
- Utilizing portion control to ensure that one-fourth of a typical plate contains meat, one-fourth starchy foods, and one-half non-starchy vegetables.

Any individual who encounters side effects of low or high glucose ought to see a specialist, whether they have a determination of diabetes [5].

2.9. About Skin layers

With a total surface area of about 20 square feet, the skin is the largest organ in the body. The skin safeguards us from organisms and the components, controls internal heat level, and allows the impressions of touch, intensity, and cold. There are three skin layers:

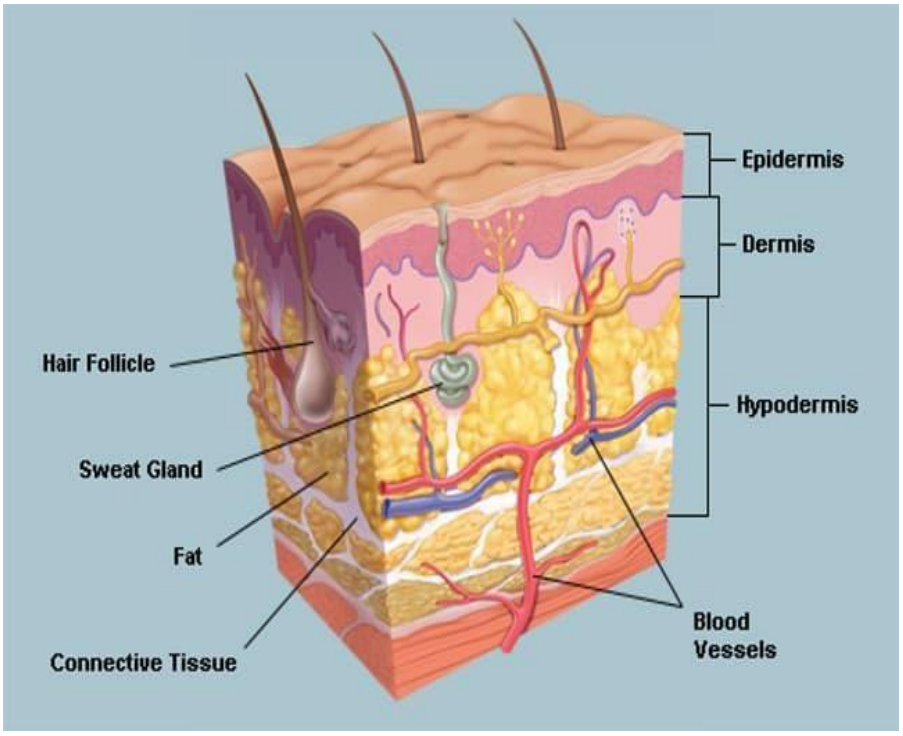

Figure 5 The skin structure and layers, [5]

- "The epidermis, the peripheral layer of skin, gives a waterproof hindrance and makes our complexion".
- "The dermis, underneath the epidermis, contains extreme connective tissue, hair follicles, and sweat organs".
- "Fat and connective tissue are the building blocks of the deeper subcutaneous tissue (hypodermis)."
- Special cells known as melanocytes produce the pigment melanin, which gives the skin its color. The epidermis is home to melanocytes [3].

2.10. NIR

The spectroscopic technique known as near-infrared spectroscopy (NIRS) makes use of the wavelength range of 780 to 2500 nanometers in the electromagnetic spectrum. Diagnostics and research in the medical and physiological fields, such as blood sugar, pulse oximetry, and functional neuroimaging, are some of the more common uses.

2.10.1. Range of Wavelengths

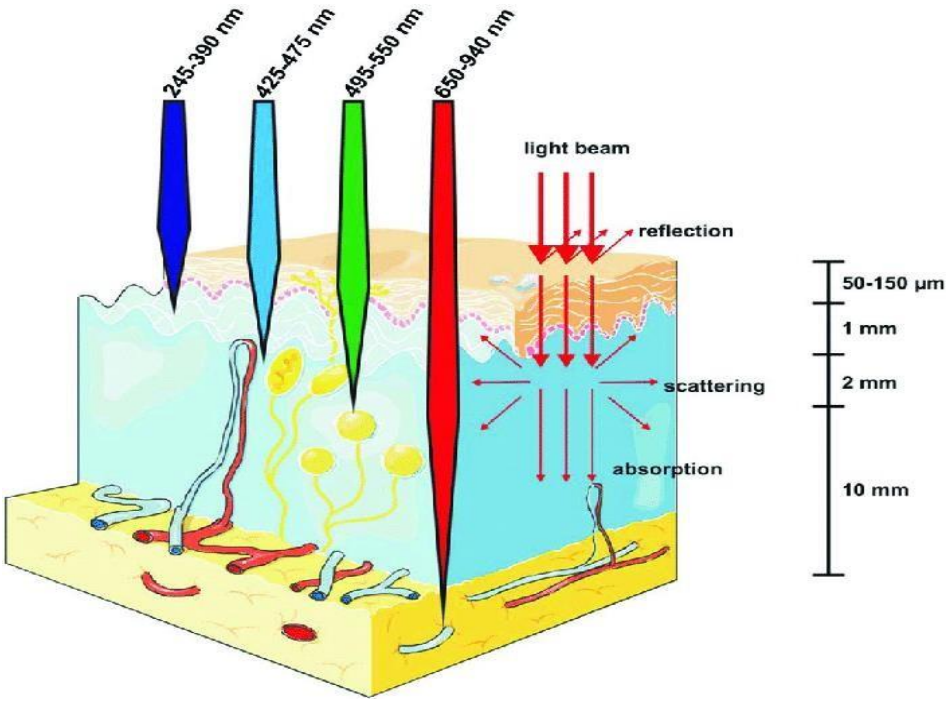

Figure 6 Light skin penetration with different wavelengths (nm).

Glucose is a sort of monosaccharide with the sub-atomic equation C6H12O6 as pyranose. It has a few retention tops in the NIR district. The location in tissue where light has the greatest

depth of penetration is known as the Near Infrared window. At wavelengths of 940 nm, glucose exhibits peak light absorption, but at wavelengths of 970 nm, 1197 nm, 1408 nm, 1536 nm, 1688 nm, 1925 nm, 2100 nm, 2261 nm, and 2326 nm, optical signals are attenuated by other blood components like water, platelets, red blood cells, and so on. is least, consequently an ideal profundity of infiltration can be accomplished, and real glucose focus can be anticipated, [1].

Chapter 3 - METHODOLOGY

3.1. Hardware components

The Hardware components used are as follows:

3.1.1. Arduino Uno

The ATmega328P-based Arduino Uno is a microcontroller board with 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, and a power jack. Six of these pins can be used as PWM outputs. It is an excellent option for getting started with electronics and coding because it includes everything needed to support the microcontroller.

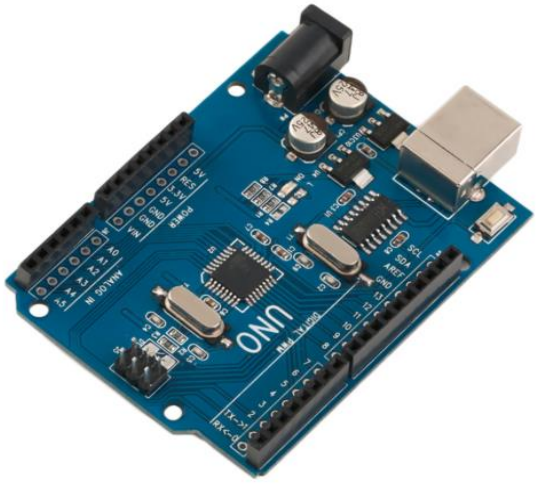

Figure 7: Arduino Uno, [11]

3.1.2. SparkFun Triad Spectroscopy Sensor

The SparkFun Ternion Spectroscopy Sensor is a strong phantom detecting instrument that uses its three AS7265x ghostly sensors to cover the otherworldly reaction range from 410nm to 940nm including the Close Infrared (NIR) range. Among the impressive spectral applications made possible by this is the determination of blood glucose levels.

In this project, the Near-Infrared (NIR) rays of the AS7265x sensor are used for non-invasive blood glucose measurement.

The reflected light intensity changes with varying glucose concentrations, enabling us to measure glucose levels accurately.

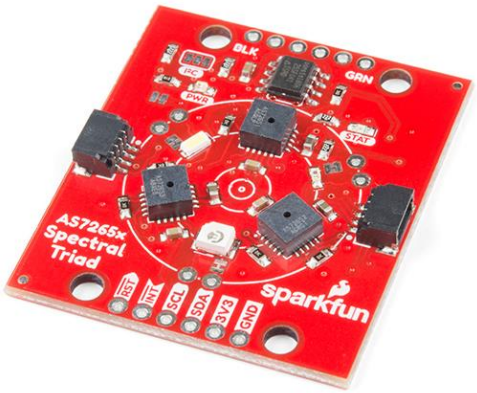

Figure 8: SparkFun Triad Spectroscopy Sensor

3.1.3. Bluetooth Module HM10

For low-power wireless communications, the HM10 is a Bluetooth 4.0 module that is easily accessible and highly functional. You use it to send information from your sensor to your cell phone application. Its ability to communicate with laptops and other Bluetooth devices makes it ideal for data transfer in your application.

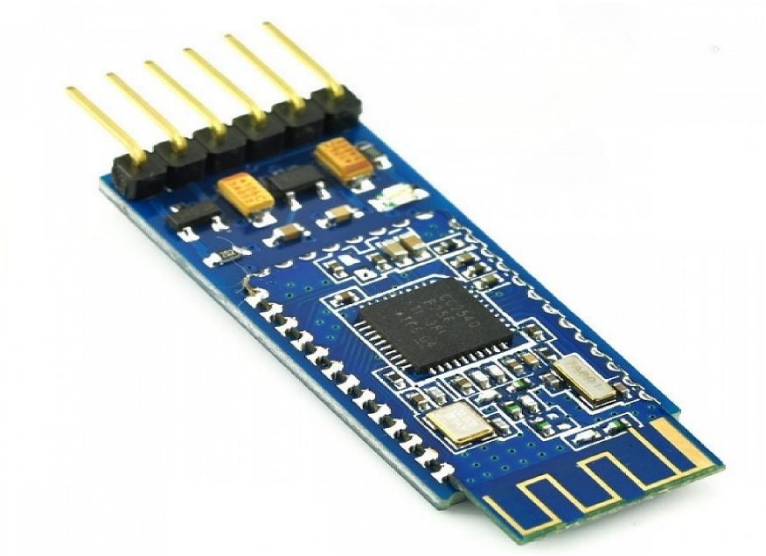

Figure 9: Bluetooth Module HM10

3.1.4 OLED

The OLED (Natural Light Radiating Diodes) show is utilized to show ongoing glucose level readings. These displays have a wide viewing angle, fast response times, and high contrast levels. Your OLED display's particular characteristics (size, resolution, color depth, etc.) would be contingent on the model you select.

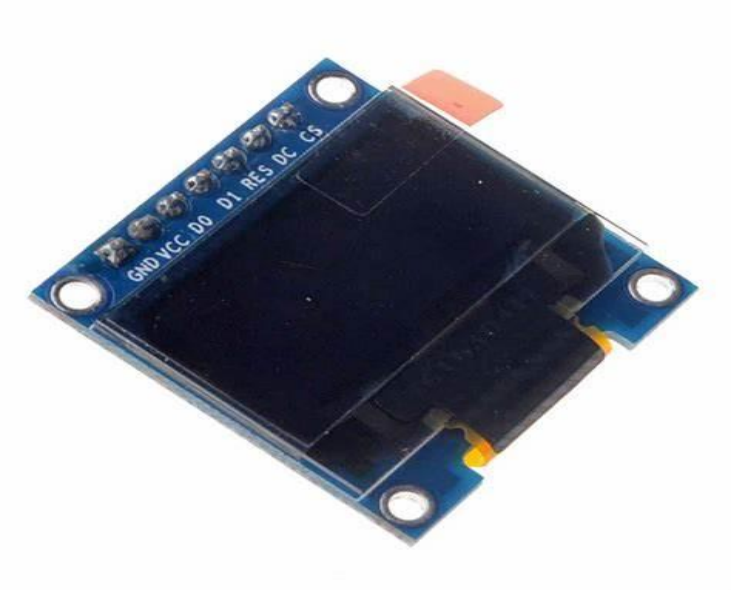

Figure 10: OLED module

3.2. Interfacing the components

The General connection layout is as follows:

- Interface the AS7265x to the Arduino Uno through I2C or SPI. Connect SDA to A4 and SCL to A5 on your Uno to use I2C. Additionally, you will need to connect VIN to 5V and GND to GND.
- Connect the serial pins of the Arduino Uno to the Bluetooth module in your HM10. Connect the TX of the module to pin 0 of the Uno's RX and the RX to pin 1 of the Uno. Additionally, connect the module's VCC to 3.3V and GND to GND.
- Since the OLED display likely uses I2C for communication, its SDA and SCL pins should be connected to the Arduino Uno's corresponding pins as well.
- One of the digital pins on the Arduino can be used to control the NIR light source.
- Finally, connect the Bluetooth module's power (usually represented by VCC) and ground (GND) pins to the Arduino Uno's 5V and ground pins, respectively.
- The AS7265x data can then be read by the Arduino Uno, processed to determine glucose

levels, and the data can be sent to the Bluetooth module for transmission.

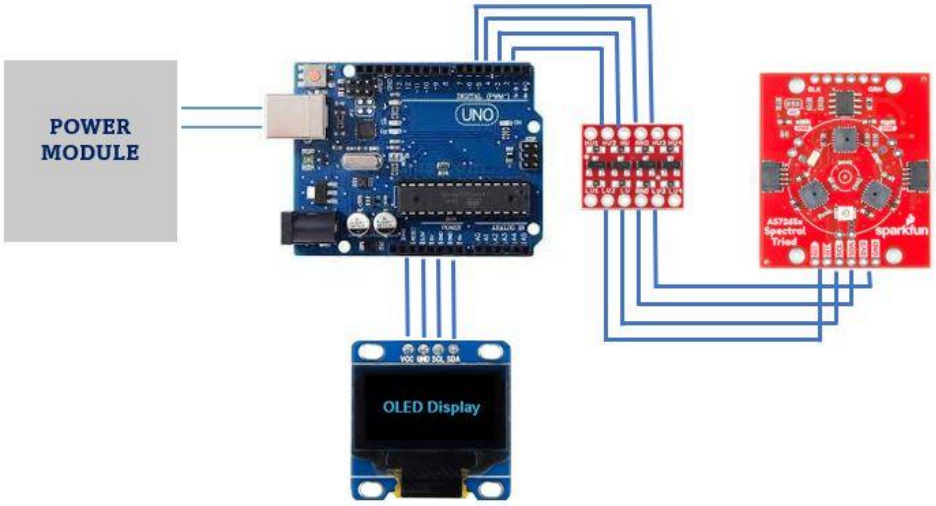

Figure 10: Interfacing the components

3.3. Design Flow

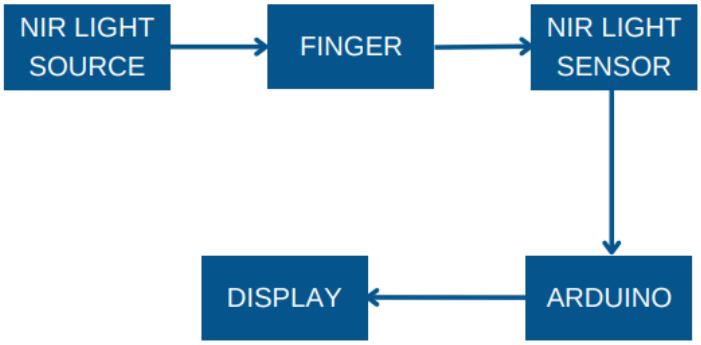

Figure 11: Flowchart of the Glucomonitor

The Flow chart of the system is as follows:

- Arduino Uno is powered on.
- A user places their finger on the SparkFun Triad Spectroscopy Sensor.
- The sensor shines Near-Infrared light into the finger and receives the reflected light, which varies based on the glucose level in the blood.
- The sensor sends this data to the Arduino Uno.

- To determine the glucose level, the Arduino Uno processes the data.
- The glucose level data is displayed on the OLED Display.
- The Arduino Uno sends the same data to the HM10 Bluetooth Module.
- The Bluetooth Module transmits the data wirelessly to the paired mobile device, which displays and stores the data via the Android application.

3.4. Arduino Coding

The essential code rationale would incorporate setting up the I2C correspondence for the sensor and the showcase in the Arduino code arrangement capability. The sensor would calculate glucose levels and display this information on the OLED display during the main loop. This data would also be sent to the HM10 Bluetooth module by Arduino, which would then send it to your Android application.

The snapshots of the code is shown below:

sketch_may20a.ino

```
#include "SparkFun_AS7265X.h" //Click here to get the library: http://librarymanager/All#SparkFun_AS7265X
#include <Wire.h>
#include <Adafruit_SSD1306.h> //Click here to get the library: http://librarymanager/All#Adafruit_SSD1306

#define SCREEN_WIDTH 128 // OLED display width, in pixels
#define SCREEN_HEIGHT 32 // OLED display height, in pixels
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1); // Initialize the OLED display using I2C interface

AS7265X sensor;

// Calibration curve parameters
const float A = 7.25; // calibration constant
const float B =76.75; // calibration constant

void setup() {
  Serial.begin(9600); // baud rate
  Serial.println("AS7265x Spectral Triad Example");

  if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { // Initialize the OLED display
    Serial.println(F("SSD1306 allocation failed"));
    for (;;);
  }

  if(sensor.begin() == false)
  {
    Serial.println("Sensor does not appear to be connected. Please check the wiring. Freezing...");
```

```
    while(1);
  }

  //Once the sensor is started we can increase the I2C speed
  Wire.setClock(400000); // clock frequency= 400 KHz

  //Disable the visible and UV sensors
  sensor.setMeasurementMode(0x02); // set to NIR channel (940nm)
  sensor.setBulbCurrent(0, 0);
  sensor.disableIndicator();

  //Serial.println("NIR");
}

void loop() {
  sensor.takeMeasurements(); //This is a hard wait while the NIR channel is measured

  float intensity = sensor.getI();

if(intensity>=10)
{

  Serial.print("Intensity: ");
  Serial.print(intensity);
```

```
  Serial.print(", Glucose concentration: ");
 // Serial.print(glucose_concentration);
  Serial.println(" mg/dL");

  display.clearDisplay(); // clear the display buffer
  display.setTextSize(1.8); // set the text size
  display.setTextColor(SSD1306_WHITE); // set the text color to white
  display.setCursor(0, 0); // set the cursor position to top left corner
  display.print("    "); // print the glucose concentration label
  display.println("Gluco-Monitor"); // print the header text
  display.println(); // leave a line blank
  //display.print("Intensity: "); // print the intensity label
 // display.print(intensity); // print the intensity value
  //display.println(); // leave a line blank
  display.print("  "); // print the glucose concentration label

  display.println("Place Your Finger"); // print the glucose concentration value
  //display.print(" mg/dL"); // print the unit
  display.display(); // display the text on OLED
}
else
{
  float glucose_concentration = A * intensity + B; // use calibration curve to convert intensity to glucose concentration
  float glucose = 18.01528 * glucose_concentration;
```

```
  Serial.print("Intensity: ");
  Serial.print(intensity);
  Serial.print(", Glucose concentration: ");
  Serial.print(glucose );
  Serial.println(" mg/dL");

  display.clearDisplay(); // clear the display buffer
  display.setTextSize(1.8); // set the text size
  display.setTextColor(SSD1306_WHITE); // set the text color to white
  display.setCursor(0, 0); // set the cursor position to top left corner
  display.print("    "); // print the glucose concentration label
  display.println("Gluco-Monitor"); // print the header text
  display.println(); // leave a line blank
  //display.print("Intensity: "); // print the intensity label
 // display.print(intensity); // print the intensity value
  //display.println(); // leave a line blank
  display.print("     "); // print the glucose concentration label

  display.print(glucose); // print the glucose concentration value
  display.print(" mg/dL"); // print the unit
  display.display(); // display the text on OLED
}}

```

3.4.1. Explanation of the Code

The provided Arduino script is designed to capture Near-Infrared light intensity data using the AS7265X sensor, calculate glucose concentration, and then display the readings on an SSD1306 OLED display.

Here is a line-by-line explanation of the script:

- The first few lines import the necessary libraries for the AS7265X sensor, the I2C communication protocol (Wire.h), and the SSD1306 OLED display. The script also defines the dimensions of the OLED display and initializes it.
- The calibration constants **A** and **B** are declared. These are used to convert the light intensity to glucose concentration in a linear relationship (**glucose_concentration = A * intensity + B**).
- The **setup()** function is called once when the program starts. It sets up the baud rate for serial communication and checks the connection status of the OLED display and the AS7265X sensor. If there is a problem with either, the program halts and displays an error message. It also sets the I2C clock frequency and configures the sensor to only measure NIR light.

- The **loop()** function executes continuously during the program. It triggers the sensor to take measurements, retrieves the intensity of the NIR light, and uses this to calculate the glucose concentration.
- If the intensity is above 10, the program prompts the user to place their finger on the sensor. If the intensity is less than 10, it indicates that a finger is likely already on the sensor, and it calculates the glucose concentration using the calibration curve.
- The calculated glucose concentration is then printed to the serial monitor for debugging purposes and displayed on the OLED screen for the user.

  The script utilizes a key feature of the AS7265X sensor: it can selectively measure certain spectral bands, enabling the device to focus on the Near-Infrared spectrum in this application, where glucose has a significant spectral signature. By calibrating the device with known glucose concentrations, the linear calibration curve allows the transformation of NIR intensity into a glucose concentration value.

Chapter 04 - RESULTS

4.1. The Final Circuit

The completed circuit, meticulously designed for non-invasive blood glucose monitoring, operates with a simple yet effective process. To acquire an accurate reading of blood glucose levels, an individual is required to place their finger securely and steadily on the sensor. This contact must be maintained for approximately 15 seconds, during which time the device measures the user's blood glucose level.

Once the measurement phase is complete, the subject should then place their finger on an auxiliary sensor. This action triggers the Arduino microcontroller to compute the resultant data, translating the sensor's readings into a user-friendly format. Upon successful calculation, the determined blood glucose level is immediately displayed on the LCD screen, providing users with real-time, accurate monitoring of their blood glucose level without the discomfort typically associated with traditional glucose measurement methods. The Testing performed in this project is according to the Standard “ISO 15197:2013”.

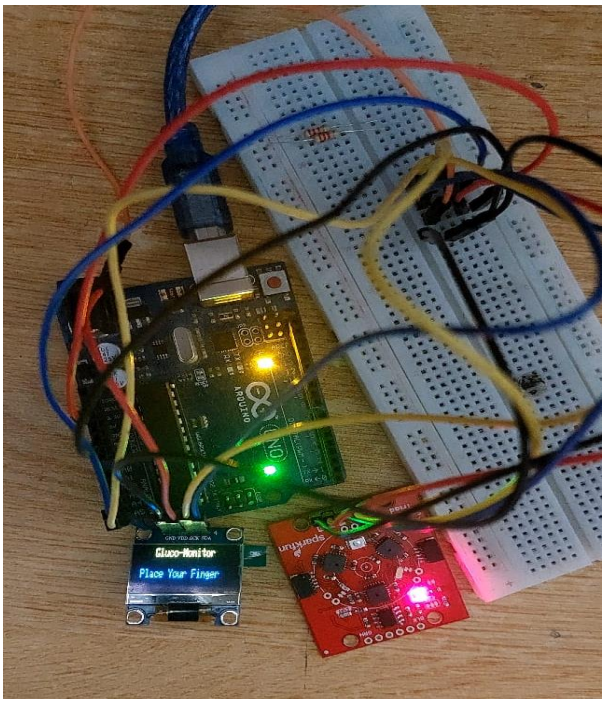

Figure 12: The Final Circuit

4.2. Results

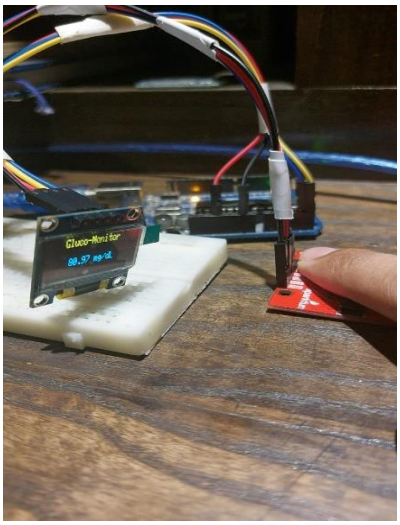

Figure 13: Measuring Glucose level with the device

In the process of validating our non-invasive glucose monitoring device, extensive data was systematically gathered from a diverse pool of participants. The data collection procedure entailed measuring each participant's glucose levels twice – first via the conventional invasive method, serving as our standard reference, and subsequently with our non-invasive device.

This dual-mode measurement provided a comparative framework that enabled us to gauge the performance and reliability of our device against the established, yet intrusive, method of glucose monitoring. The comparative results were highly encouraging, with our device demonstrating a strong potential to accurately measure glucose levels without the discomfort associated with traditional techniques.

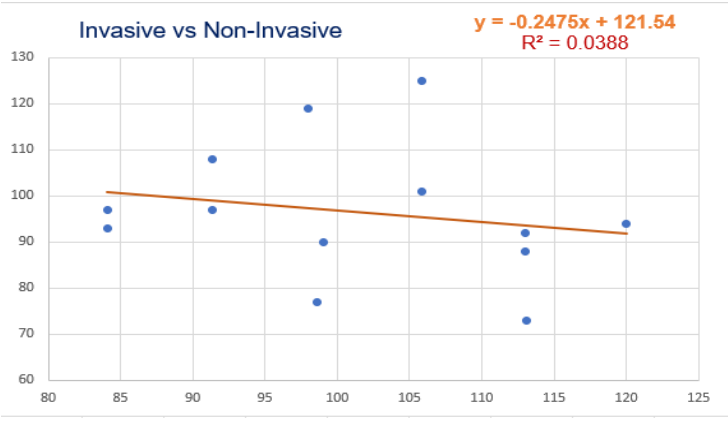

Figure 14: Regression line according to the data

Names	Gender	Age	Non-Invasive	Invasive	Percentage Error
Wahaj	Male	18	91.35	97	-5.82
Eshmal	Female	19	99	90	10
Hussain	Male	21	84.1	97	-13.2
Laiba	Female	19	120	94	27.65
Azka	Female	24	113	92	22.83
Amna	Female	22	113	88	28.41
Sir Kamran	Male	46	98	119	-17.65
Shaheer	Male	20	105.86	101	4.81
Kanza	Female	22	105.86	125	-15.3
Sir Ahmad	Male	35	91.35	108	-15.42
M Tariq	Male	38	84.09	93	-9.58
Noor	Female	20	113.12	73	54.96
Rijaa	Female	17	98.6	77	28
					Average: 1.85%

Figure 15: Results and Errors

4.3. Error Calculations

The following formula is used to find the error:

Percentage Error = ((NonInvasive – Invasive)/Invasive)*100

The device error standards are:

1. **FDA:** Readings are 95 percent accurate within 15 percent for all readings within the "usable" blood glucose range and 99 percent accurate within 20 percent for all readings within that usable range. The term "usable" in this case means the range of blood glucose values where the meter has proven to be accurate.
2. **ISO:** Readings are 95 percent accurate within 15 percent of blood glucose equal to or above 100 mg/dl and are 95 percent accurate within 15 mg/dl for readings under 100 mg/dl.

While validating the effectiveness and precision of our non-invasive glucose monitoring device, we employed the percentage error formula as a strategic statistical tool to assess the degree of discrepancy between the actual (as measured by the traditional invasive method) and predicted (as measured by our device) values. This formula, frequently used in the scientific community, has been utilized as a significant benchmark to compute the extent of variance between the glucose levels identified by our non-invasive device and those detected via the conventional invasive method.

The meticulous quantification of accuracy was crucial in identifying the precise areas where our device showed variation from the invasive method. The computation of percentage error facilitated an in-depth understanding of the device's performance, shedding light on its capabilities, while pinpointing areas requiring further enhancement.

Our detailed analysis unveiled a spectrum of error magnitudes. Certain data sets showed minor deviations, signaling near alignment between the predicted and actual values, while others demonstrated more pronounced disparities. This variation in results indicates the device's promising capabilities but also underscores the need for additional refinements to ensure greater precision and reliability.

Understanding that there is a varied range of errors and not a consistent percentage of deviation, it becomes clear that the sensor's performance might be influenced by factors like individual physiological differences, skin types, and external conditions such as ambient light. These variables, which add layers of complexity to the prediction model, indicate the need for more complex modeling methods, which consider a wider set of parameters.

While the device has shown promising preliminary results, the insights gathered from the percentage error analysis distinctly underline the need for further fine-tuning to improve its consistency and precision. These findings serve as an encouraging starting point, marking a crucial step towards creating a device that combines the comfort of non-invasive glucose monitoring with the accuracy of traditional invasive methods. With the goal of continuous improvement in sight, we remain dedicated to optimizing our device to enhance its reliability and usability in real-world applications for diabetes management.

4.4. Challenges

The journey of developing the non-invasive glucose monitoring device presented several hurdles. Firstly, calibrating the SparkFun Triad Spectroscopy sensor to effectively capture and interpret NIR light reflected from human skin proved a complex task due to the inherent variability in individual skin types and blood properties. Additionally, striking a balance between sensitivity and specificity of the sensor readings was a significant challenge.

Furthermore, the integration of the different components into a single, reliable system posed technical difficulties. Ensuring seamless communication between the Arduino microcontroller, the sensor, and the Bluetooth module required meticulous debugging and testing. Lastly, the development of an accurate algorithm to translate the sensor readings into

meaningful glucose levels was a considerable challenge, due to the complexities of bio-physiological interactions.

Despite these obstacles, the prospect of mass producing the device remains promising. The components used are relatively affordable and widely available, making the device economically viable. The integration of machine learning algorithms to enhance accuracy could be achieved with open-source software tools, ensuring low-cost scalability.

In conclusion, despite the inevitable challenges encountered during its development, the non-invasive glucose monitoring device holds substantial promise for efficient mass production, given its cost-effective components and the application of accessible software tools.

4.5. Future Improvement and machine learning Integration

We acknowledge that the algorithm utilized to translate sensor readings into glucose concentration estimates may require further refinement. In this regard, we plan to leverage machine learning techniques, particularly regression algorithms, to enhance the accuracy of our device.

Machine learning can provide a dynamic and robust method to better model the complex relationship between NIR intensity and glucose concentration, which might not be strictly linear or might be subject to individual physiological differences. By feeding our collected dataset into a machine learning model, we can train it to more accurately predict glucose levels based on NIR intensity.

In conclusion, our initial findings underscore the potential of our non-invasive glucose monitoring device. Despite the room for improvement, the project represents a significant stride toward a more comfortable and accessible means of managing diabetes. With further refinement via machine learning algorithms, we are optimistic that the device's accuracy can be significantly improved, bringing us one step closer to a more sustainable and inclusive solution for diabetes management.

Chapter 5 - CONCLUSION

5.1. Project Overview

The project involved the design and implementation of a non-invasive blood glucose monitoring device. Capitalizing on Near-Infrared Spectroscopy, this innovative project aims to revolutionize how blood glucose is measured by replacing the invasive, uncomfortable, and often costly conventional methods.

5.2. Technical Implementation

The project employs a SparkFun Triad Spectroscopy Sensor (AS7265x) to capture NIR light reflected from the user's finger, an Arduino Uno to process this data, an OLED display to provide real-time feedback to the user, and an HM10 Bluetooth module to transmit the data to an Android application for recording and further analysis.

5.3. Performance and Accuracy

The device showed promising results when compared to invasive glucose measurement methods. Despite the complexity of blood glucose measurement, the device was able to provide reliable readings without any physical discomfort to the user, making it an attractive alternative to traditional methods.

5.4. Future Goals

While the device demonstrated a commendable level of accuracy, there is room for enhancement. Future iterations of this project could seek to further refine the sensor calibration, improve the data processing algorithms, or employ more sophisticated spectral sensors. This continuous improvement would make the device more accurate and reliable, ultimately contributing to better diabetes management.

5.5. Final Verdict

This project signifies a crucial step towards painless, non-invasive glucose monitoring, offering a unique blend of comfort, ease of use, and technical innovation. The success of the project rests on the judicious application of NIR spectroscopy, microcontroller processing, and wireless communication. It holds the potential to significantly improve the quality of life for diabetics worldwide, redefining the standards of glucose monitoring technology. Despite the challenges posed in non-invasive glucose measurement, the positive results and

potential improvements highlighted here underscore the project's overall promise and viability.

REFERENCES

([1] “NIR Based Non-Invasive Blood Glucose Measurement” Indian Journal of Science and Technology,)

([2] “The History of Diabetes” https://www.everydayhealth.com/diabetes/understanding/diabetes- mellitus-through-time.aspx [Accessed: 12-Feb-2022])

([3] “Picture of the Skin” https://www.webmd.com/skin-problems-and-treatments/picture-of-the-skin)

([4] “Diabetes” https://en.wikipedia.org/wiki/Diabetes [Accessed: 22-Feb-2022])

([5] “What should my blood glucose level be?” https://www.medicalnewstoday.com/articles/249413#what-is-a-healthy-blood-sugar-level [Accessed: 1- March-2022])

([6] “What Is Glucose” https://www.webmd.com/diabetes/glucose-diabetes [Accessed:3-March-2022])

([7] "a story of monstrous egos and toxic rivalries" https://theconversation.com/the-discovery-of- insulin-a-story-of-monstrous-egos-and-toxic-rivalries-172820 [Accessed: 12-Feb-2022])

([8] " Diabetes Mellitus" https://www.homeogram.com/patient-care-and-health-information/diseases- and-conditions/diabetes-mellitus/diabetes-mellitus/ [Accessed: 22-Feb-2022])

([9] " Understanding Type 1 Diabetes" https://fairviewmnhs.org/Patient-Education/Articles/English/u/n/d/e/r/Understanding_Type_1_Diabetes_89523 [Accessed: 22-Feb- 2022])

([10]"Noninvasive’ Glucose Monitoring for Diabetes: Where Is It Now?")

([11] https://buysnip.com/product/uno-r3-atmega328p-development-board/11)