Non-Invasive Blood Glucose Level Monitoring for Enhancement using ML

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Bahrain University
College of Engineering
Electrical and Electronics Engineering Department

Non-Invasive Blood Glucose Level Monitoring for Enhancement using ML

A Senior Design Project (EENG490) Report

Submitted in partial fulfillment of the requirements for the degree of
B.Sc. in Electrical (or Electronics) Engineering

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Starting Date: 11st Feb 2022

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STATEMENT OF AUTHENTICITY

By submitting this senior project report, we declare that:

i. We are aware and fully understand the Plagiarism Policy of the University of Bahrain.

ii. We have not knowingly violated any ethical codes of conduct and our work has taken all ethical issues into consideration.

iii. We confirm that the research that was developed during the senior project course has been original work that adheres to the Plagiarism Policy of the University of Bahrain and has not been submitted for any other course.

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ABSTRACT

Diabetes is a common chronic disease in mostly all countries worldwide. The most used method to measure glucose level in blood is an invasive method which is painful, expensive and danger in spreading infectious diseases. Over a long term, the invasive method results in damage of finger tissues. As an alternative, the non-invasive method can be used which facilitates frequent testing, relieves pain and discomfort caused by frequent finger pricks. A non-invasive method of glucose level measurement is proposed in this paper. The variation in the intensity of NIR light received from the photo detector after passing through the finger is used to determine the glucose level of blood. The measured glucose level is displayed in LCD display and transmitted to the android application which is created in the mobile phone to display and store data via Bluetooth.

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ACRONYMS

IR	infrared radiation
B.C	before Christ
AD	Anno Domini (after Christ)
NIR	Near-infrared
PPG	Photo plethysmography
AC	alternating current
DC	direct current
LCD	liquid crystal display
LED	light-emitting diodes
PC	personal computer
APP	Application
RBF	radial basis function

LIST OF SYMBOLS

µa	absorption coefficient
I	effective optical path length
Mg/dl	Milligrams per deciliter

CHAPTER 1
INTRODUCTION

Diabetes is a type a metabolic Diseases in which the blood glucose (blood sugar) level in human body increases drastically from its normal level. The increase in sugar level is either due to inadequate production of insulin in blood cells or can be because of improper response of body cells to the insulin or can be because of both the reasons. diabetes can lead to major complications like heart failure and blindness in the human body. Hence regular monitoring of glucose level is important. There are more than 200million people with diabetes. Diabetes is a state of a body where it is not able to produce the quantity of insulin sufficiently required to maintain normal level of blood glucose. So, diabetic patients reg up their blood glucose levels through proper diet as well as by injecting insulin. For the effective treatment of diabetes, patients have to measure the level of blood glucose periodically3-5. At present, diabetic persons are using invasive figure breaking instrument knows as glucose meter to know the concentration of blood glucose. In pathology laboratories, glucose is measured by piercing a patient's finger with a lancing needle. Take a small amount of blood sample. Then a blood sample is placed on the strip and inserted in a blood glucose meter. Development of a non-invasive glucose measurement technique would be a boom for a diabetic patient. The major advantage of noninvasive measurement methods is the relief from pain and comfort due to no finger puncturing. The method for glucose measurement like IR spectroscopy is popular from years, but method with a reliable result has not been established yet [1].

Figure 1. No for the invasive method of measuring blood sugar, [22].

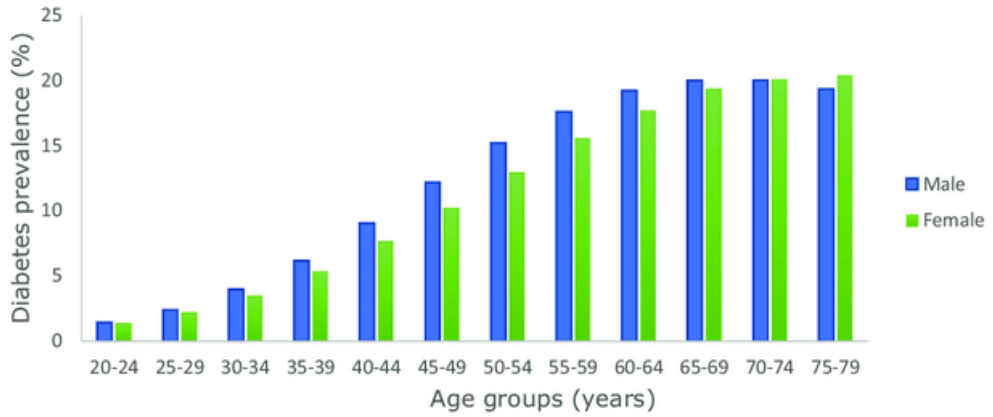


Figure 2: Diabetes prevalence by age and sex in 2019, [18]

1.1 Motivation

"Health organization shows that the amount of people that got diabetes disease in 1980 is 108 million and became 422 million in 2014. Prevalence has been rising more rapidly in low- and middle-income countries than in high-income countries. In Between 2000 and 2016, there was a 5% increase in premature mortality from diabetes. In 2019, diabetes was the ninth leading cause of death with an estimated 1.5 million deaths directly caused by diabetes". After we saw the numbers and the amount of people that suffers from needles and injections, we wanted to help them in having an easy life without the pain of the injunctions whenever they want to measure their blood glucose.

1.2 Aim of the project

The way that this project works is that we used an IR sensor with a special wavelength that can penetrate the skin of the finger, this IR wave will go through the finger and collide with the blood cells which cause a reflection, after the reflection of the wavelength the receiver will receive this wave, then the Arduino will process the wave and find the glucose level of the, what proves that the project works perfectly if the percentage error between the invasive method and the noninvasive is a very small percentage.

1.3 Constraints

The project includes many constraints that must be taken into account to ensure the success of the project:

i. To obtain guaranteed results, the sensor must be placed on a solid and stable surface such as a table or wood, and when placing the finger on the sensor, it must be pressed firmly and firmly, and it must also be pressed for 10-15 seconds to obtain a stable result.

ii. The environment of the experiment, the light and the temperature had an effect on the results, so we tried to work under constant conditions, we also tried to count in one place at a constant temperature and we tried to fix the finger well on the sensor to prevent the light from entering

iii. Design, where the Arduino has a specified amount of current and voltage. One of its Constraints is that the current works with the voltage in reverse, as when the device takes a very large current, this leads to a significant decrease in the voltage in the supply of the Arduino.

iv. Cost and weight, it should have an appropriate cost so that people can buy it and it should contain lightweight components in order to be easy to carry and use.

① Think of the clip thing in our lab

② Usb - rechargable batteries.

1.4 Standards:

i. Arduino UNO Standards.

ii. IEEE 802.11 (Bluetooth ISM 2.4 GHz).

iii. For report departments SP standard template.

iv. 16x2 LCD Module

v. USB 3.0 and USB 2.0.

vi. TCRT5000 IR Sensor

1.5 Report Outline

In this report, we will talk about measuring blood sugar by a non-invasive method. In the second chapter, we will talk about biological aspect We started by talking about diabetes and its history, then we talked about glucose, then the layers of the human skin, then we got acquainted with the rays that penetrate the finger and interact with glucose molecules, and at the end of this section we learned about the method of measuring blood sugar in a non-invasive way. In chapter3 we put our initial work, part aspect, codes and Block diagram of proposed work. In chapter4 we put our final device, our results and error methods. In chapter5 we talked about the discussion and in chapter6 it will be about the conclusion. At the end of the report, we talked about Literature.

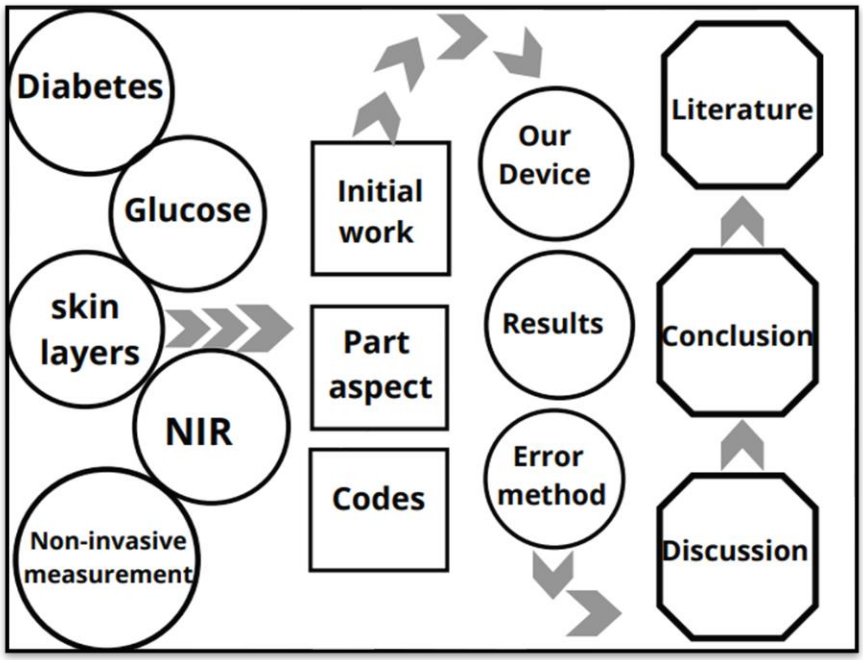


Figure 3: The report outline

CHAPTER 2
BLOOD GLUCOSE BACKGROUND

Biological Aspect

1.6 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".

The Literature

In this section, a literature review on measuring blood glucose using NIR spectroscopy and measuring bilirubin using optical method has been presented. Müller *et al*. in 1997 used NIR diffuse reflectance spectra method in the range of 800–1350 nm to measure glucose from finger. The cross-validation root means square error of prediction (RMSEP) obtained is from 1.02 mmol/L (18.4 mg/dL) to 1.88 mmol/L (33.8 mg/dL). Danzer *et al*. in 1998 used NIR diffuse reflectance with partial least squares (PLS) regression and analysis of radial basis function (RBF) neural network. They used 800–1350 nm NIR light and measured glucose from the middle finger. The RMSEP obtained is 2.0 mmol/L (36 mg/dL). Araujo-Andrade *et al*. in 2004 used NIR diffuse reflectance method which consisted of a light source, a fiber optical measuring head, and an NIR spectrometer. The NIR light with a wavelength of 900–1700 nm was used, and the measurement is carried out from the finger. In this study, the correlation coefficient values obtained are lower than 0.744 and RMSEP values obtained are higher than 0.89 mmol/L (16 mg/dL). Xu *et al*. in 2005 reported an optical measurement condition reproduction technique to deal with the difference in measuring locations and contact pressures. Their proposed system consists of light-emitting diodes (LEDs) for lighting, fibre probe, spectrometer, CCD camera, three-dimensional servo device, and a brocket. They used NIR diffuse reflectance spectra in the range of 1100–1800 nm to measure glucose from palm.

The obtained RMSEP ranges from 0.8 to 1.1 mmol/L (15–20 mg/dL), and the correlation coefficient is greater than 0.8. Guevara and González in 2010 jointed NIR (700–1000 nm) and impedance spectroscopy (1–200 MHz). They measured glucose from the forearm and tested technique on 10 nondiabetic individuals under controlled temperature and humidity conditions. The RMSEP obtained was 1.2488 mmol/L (21.96 mg/dL). Srivastava *et al*. in 2013 proposed an optical non-invasive method to measure the blood glucose by a 940-nm infrared light emitted as the input signal on the finger.

The output signal could be digitized, amplified, and processed in a microchip with a special algorithm designed to detect blood glucose levels. However, the proposed method has not been evaluated. This paper concludes that non-invasive blood glucose measurements soon can be a good alternative to market glucometers. In 2018 three Drs made a device that measure glucose and bilirubin, Dr. Faranak Fotouhi-Ghazvini and Fahime Sadat Zakeri. They used for their project (microcontroller, photodiodes transmitters, resisters, capacitors, LCD, Bluetooth module). For the microcontroller they used C++ language, they took some blood samples and compared it with their device samples and determined an equation. Their device was approved by the Clarkes grid analysis and the percentage was between 3% to 12%.

The second one was made with using temperature, they took 50 human samples by using LCD, Arduino, temp sensing, and amplification, there error rate was also approved from Clarke's grid analysis. So, after reading more than one article we decided to use Arduino because it has more potentials and easier in using it, we also used in our sensor two stages of amplification stages and one low pass filter with photodiodes and transmitter, also we will use LCD and Bluetooth module to design an application that the Arduino will send the result through connecting the Bluetooth module to the phone application.

1.6.1 Diabetes Beginnings

“The first known mention of diabetes symptoms was in 1552 B.C., when Hesy-Ra, an Egyptian physician, documented frequent urination as a symptom of a mysterious disease that also caused emaciation, also around this time, ancient healers noted that ants seemed to be attracted to the urine of people who had this disease. In 150 AD, the Greek physician Arateus described what we now call diabetes as "the melting down of flesh and limbs into urine." From then on, physicians began to gain a better understanding about diabetes. Centuries later, people known as "water tasters" diagnosed diabetes by tasting the urine of people suspected to have it. If urine tasted sweet, diabetes was diagnosed. To acknowledge this feature, in 1675 the word "mellitus," meaning honey, was added to the name "diabetes," meaning siphon. It wasn't until the 1800s that scientists developed chemical tests to detect the presence of sugar in the urine” [2].

1.6.2 The Early Treatments for the disease

“As physicians learned more about diabetes, they began to understand how it could be managed. The first diabetes treatment involved prescribed exercise, often horseback riding, which was thought to relieve excessive urination. In the 1700s and 1800s, physicians began to realize that dietary changes could help manage diabetes, and they advised their patients to do things like eat only the fat and meat of animals or consume large amounts of sugar. During the Franco-Prussian War of the early 1870s,

the French physician Apollinaire Bouchard at noted that his diabetic patients' symptoms improved due to war-related food rationing, and he developed individualized diets as diabetes treatments. This led to the fad diets of the early 1900s, which included the "oat-cure," "potato therapy," and the "starvation diet."

In 1916, Boston scientist Elliott Joslin established himself as one of the world's leading diabetes experts by creating the textbook The Treatment of Diabetes Mellitus, which reported that a fasting diet combined with regular exercise could significantly reduce the risk of death in diabetes patients. Today, doctors and diabetes educators still use these principles when teaching their patients about lifestyle changes for the management of diabetes” [2].

1.6.3 How Insulin Came About

Figure 4: The discoverers of insulin, George Zelzer and Frederick Banting, [19].

“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. In the 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].

1.7 Diabetes Mellitus

Commonly known as diabetes, is a group of metabolic disorders characterized by a high blood sugar level over a prolonged period. Symptoms often include frequent urination, increased thirst and increased appetite, if left untreated, diabetes can cause many health complications, Serious long-term complications include cardiovascular disease, stroke, chronic kidney disease, foot ulcers, damage to the nerves, damage to the eyes and cognitive impairment

Diabetes is due to either the pancreas not producing enough insulin, or the cells of the body not responding properly to the insulin produced. There are three main types of diabetes mellitus:

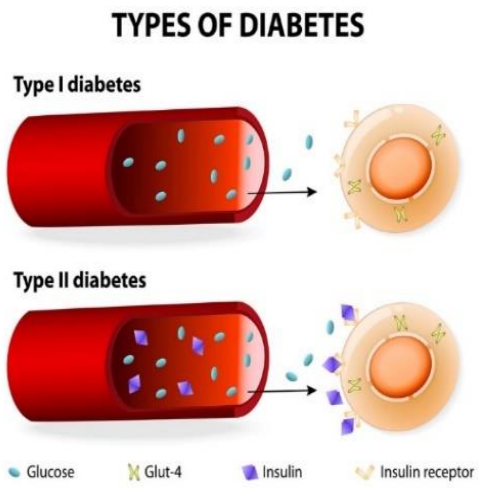


Figure 5: Types of diabetes mellitus [20].

- 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].

1.8 Glucose

Blood glucose is a sugar that the bloodstream carries to all cells in the body to supply energy. A person needs to keep blood sugar levels within a safe range to reduce the risk of diabetes and heart disease [5].

What Is Glucose?

Glucose is a sugar that circulates the blood, serving as the body's main source of energy. When a person takes in carbohydrates, the digestive system processes them into sugar molecules of different complexities. Complex carbohydrates, such as the lactose common in dairy products, are harder for the body to break down. They contain different types of sugar molecule. glucose is another product of carbohydrate breakdown. It is a simple sugar that cells in the body can easily convert to energy. The sugar goes straight from the digestive system into the bloodstream after an individual consumes and digests food.

However, glucose can only enter cells if enough insulin is also circulating in the bloodstream. Insulin is a protein that makes cells ready to receive glucose. After people eat, blood sugar concentrations increase. The pancreas releases insulin automatically to move glucose from the blood to the cells. as more and more cells receive glucose, blood sugar levels return to normal [5].

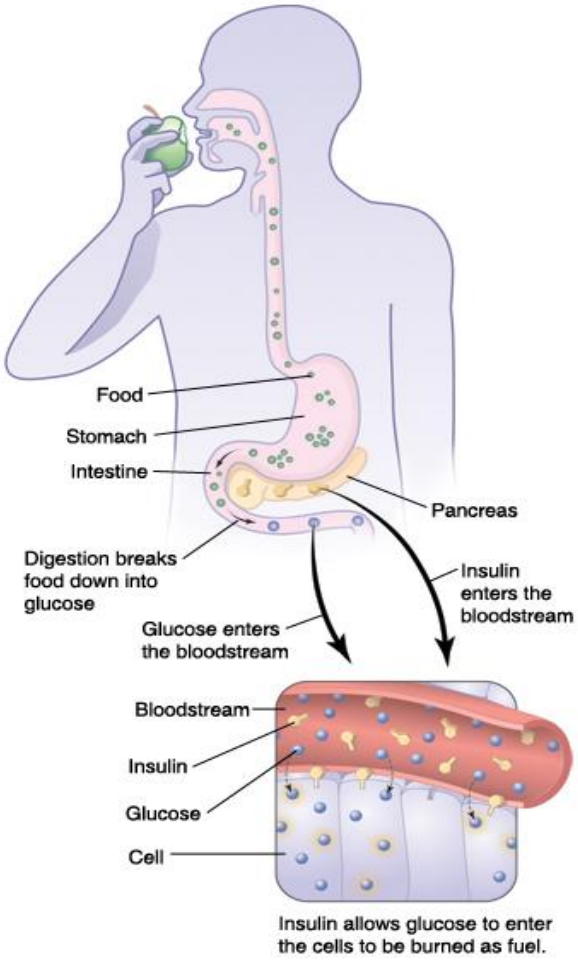


Figure 6: How the Body Makes Glucose, [21]

How The Body Makes Glucose

It mainly comes from foods rich in carbohydrates, like bread, potatoes, and fruit. As you eat, food travels down your esophagus to your stomach. There, acids and enzymes break it down into tiny pieces. During that process, glucose is released. It goes into your intestines where it's absorbed. From there, it passes into your bloodstream. Once in the blood, insulin helps glucose get to your cells [6].

Energy and Storage

Our body is designed to keep the level of glucose in your blood constant. Beta cells in your pancreas monitor your blood sugar level every few seconds. When your blood glucose rises after you eat, the beta cells release insulin into your bloodstream. Insulin acts like a key, unlocking muscle, fat, and liver cells so glucose can get inside them. Most of the cells in your body use glucose along with amino acids (the building blocks of protein) and fats for energy. But it's the main source of fuel for your brain. Nerve cells and chemical messengers there need it to help them process information. Without it, your brain wouldn't be able to work well. after your body has used the energy it needs, the leftover glucose is stored in little bundles called glycogen in the liver and muscles. Your body can store enough to fuel you for about a day. after you haven't eaten for a few hours, your blood glucose level drops. Your pancreas stops churning out insulin. Alpha cells in the pancreas begin to produce a different hormone called glucagon. It signals the liver to break down stored glycogen and turn it back into glucose. That travels to your bloodstream to replenish your supply until you're able to eat again. Your liver can also make its own glucose using a combination of waste products, amino acids, and fat [6].

1.8.1 Blood Glucose Levels

blood sugar level normally rises after you eat. Then it dips a few hours later as insulin moves glucose into your cells. Between meals, your blood sugar should be less than 100 milligrams per deciliter (mg/dl). This is called your fasting blood sugar level.

Without enough insulin, glucose can't move into the cells. The blood glucose level stays high. A level over 200 mg/dl 2 hours after a meal or over 125 mg/dl fasting is high blood glucose, called hyperglycemia.

Too much glucose in your bloodstream for a long period of time can damage the vessels that carry oxygen-rich blood to your organs. High blood sugar can increase your risk for:

a. Heart disease, heart attack, and stroke
b. Kidney disease
c. Nerve damage
d. Eye disease called retinopathy [6].

1.9 Lifestyle tips

Lifestyle choices can often help to control blood sugar.

Eating a healthy diet with plenty of fruit and vegetables, maintaining a healthy weight, and getting at least 150 minutes of moderate-to-intense exercise each week can help Trusted Source. Other tips for controlling blood sugar include:

i. eating at regular times and not skipping meals
ii. drinking water instead of juice and soda
iii. choosing fruit instead of a candy bar
iv. using portion control, so that a typical plate will be one-fourth meat, one-fourth starchy foods, and one-half non-starchy vegetables

Any person who experiences symptoms of low or high blood sugar should see a doctor, whether or not they have a diagnosis of diabetes [5].

1.10About Skin layers

The skin is the largest organ of the body, with a total area of about 20 square feet. The skin protects us from microbes and the elements, helps regulate body temperature, and permits the sensations of touch, heat, and cold. Skin has three layers:

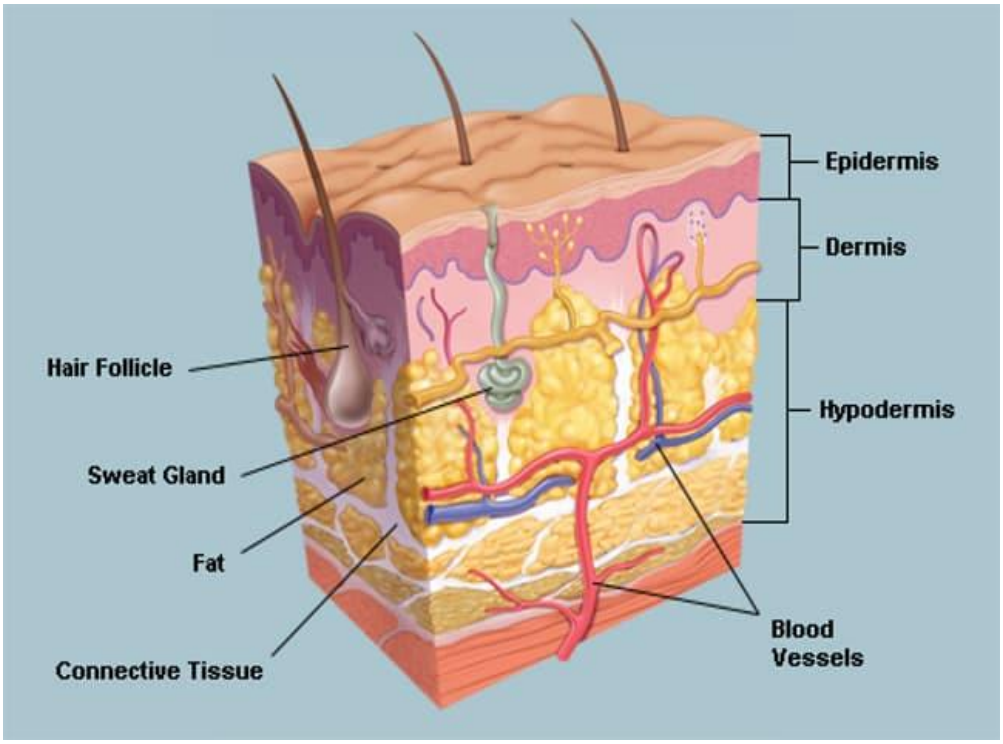


Figure 7: The skin structure and layers, [5].

i. "The epidermis, the outermost layer of skin, provides a waterproof barrier and creates our skin tone".

ii. "The dermis, beneath the epidermis, contains tough connective tissue, hair follicles, and sweat glands".

iii. "The deeper subcutaneous tissue (hypodermis) is made of fat and connective tissue".

The skin's color is created by special cells called melanocytes, which produce the pigment melanin. Melanocytes are in the epidermis [3].

1.11NIR

Near-infrared spectroscopy (NIRS) is a spectroscopic method that uses the near-infrared region of the electromagnetic spectrum (from 780 nm to 2500 nm). Typical applications include medical and physiological diagnostics and research including blood sugar, pulse oximetry, functional neuroimaging, there are also many applications use it.

1.11.1Range of Wavelengths

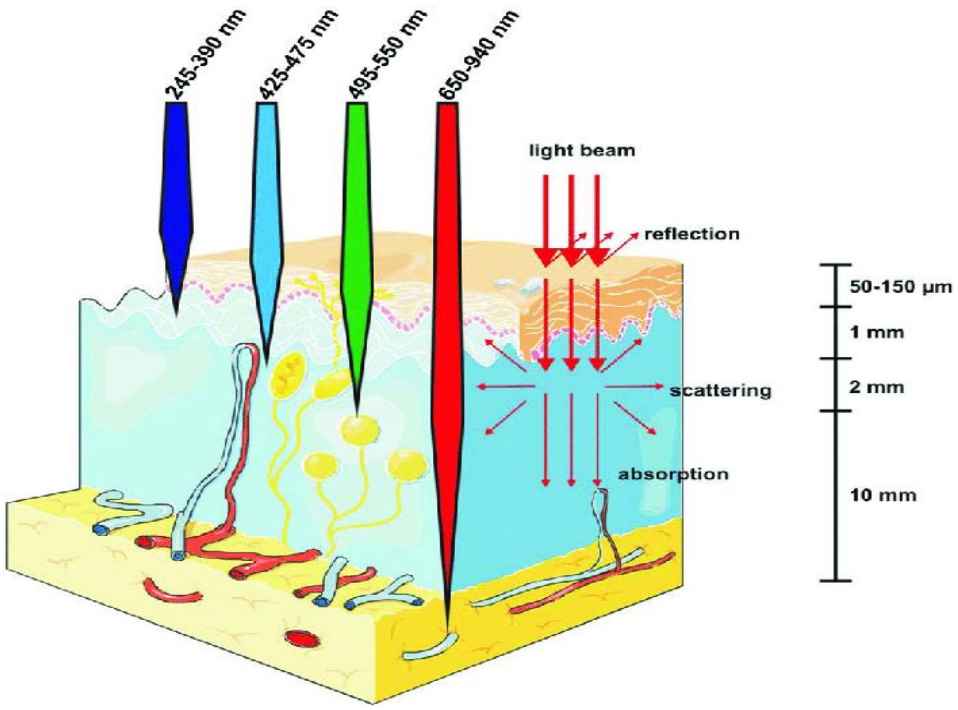


Figure 8: Light skin penetration with different wavelengths (nm).

Glucose is a kind of monosaccharide with the molecular formula $C_6H_{12}O_6$ in the form of pyranose. It has several absorption peaks in the NIR region. where light possesses its maximum penetration depth in tissue is referred as Near Infrared window. Glucose has light absorption peaks at wavelengths of 940 nm, 970 nm, 1197 nm, 1408nm, 1536nm, 1688nm, 1925 nm, 2100nm, 2261nm and 2326nm, but at 940 nm wavelength the attenuation of optical signals by other constituents of the blood like water, platelets, red

blood cells etc. is minimum, hence a desired depth of penetration can be achieved, and actual glucose concentration can be predicted, [1].

1.12 Non- invasive measurement:

1.12.1 Measuring the level of glucose in the blood

Diagnosing systems for blood sugar system are invasive in nature. This procedure is performed by drawing blood through puncturing the skin with a needle and applying it to a chemically active test strip. Another procedure for diagnosing blood sugar is non-invasive method. Some of the existing non-invasive methods are near infrared (NIR) detection, ultrasound and dielectric spectroscopy which do not need any supply of blood for conducting the tests and calculating its result [7].

1.12.2 Photo plethysmography

The skin tissue consists of three layers of which only dermis layer consists of information about blood glucose. infra-red wavelength (780nm to 2500nm) is able to penetrate until the dermis layer, The transmitted IR light will be absorbed by different skin tissues, different molecules in the blood like melanin, keratin, fats, proteins, hormones etc. and the skin pigments. Variations in the volume of blood flow are detected by the (PPG) sensors optically. It records the changes in reflected light intensity from the dermis layer of skin. The light waveform consists of both direct Current (DC) and alternating current (AC) components. The DC component of the PPG waveform corresponds to the optical signal is transmitted or reflected from the tissues during changes in blood volume in this work, reflection photography It is considered to non-invasively determine glucose levels. Here the light passes through the epidermal layer and upon arrival, The light of the dermis is absorbed, scattered, and reflected by glucose molecules. The intensity of light reflected from the dermis layer was examined to predict glucose levels [7].

1.12.3 Principle of Blood Glucose Measurement

When a light ray interacts with human body tissues, it is attenuated by scattering as well as by absorption by the tissues. Due to the mismatch between the refraction index of extracellular fluid and the cell membrane, light scattering occurs in tissues. Refraction index of extracellular fluid varies with the glucose concentration whereas the cellular membrane index is assumed to be remain relatively constant. Beer-Lambert Law plays a major role in absorbance measurement which states that absorbance of light through

any solution is in proportion with the concentration of the solution and the length path travelled by light ray.

more glucose tissue results in less scattering, less optical path length and thus more absorption than before tissues. Due to increased uptake in elevated glucose tissues Reflected light is less intense compared to tissue with lower glucose content [1].

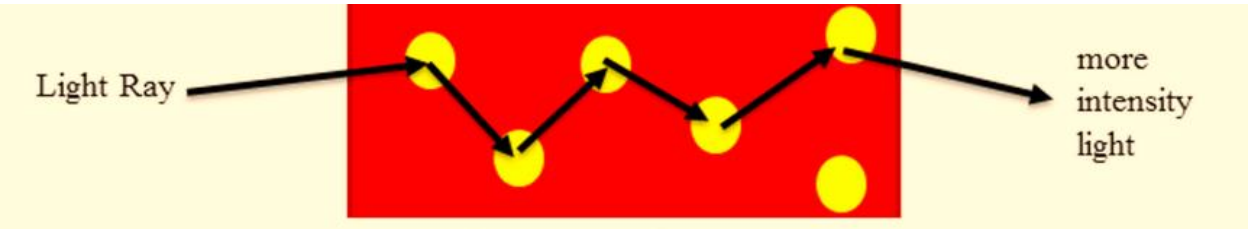


Figure 9: Less glucose tissue, [1].

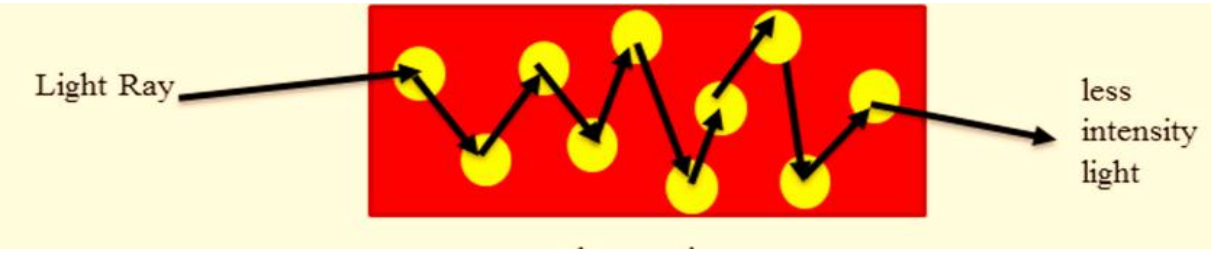


Figure 10: More glucose tissue, [1].

The attenuated light simply due to the absorption of analysts after they pass through tissue is governed by the Beer–Lambert Law, which is expressed as:

$$I = I_0 e^{-i\mu a i}$$

here μa is the absorption coefficient and l are the effective optical path length μa is proportional to εC "cm−1, where ε represents the molar extinction coefficient and C is the molar concentration of the analyte". "μa may increase with an elevated glucose level due to its intrinsic absorption or decrease due to a water displacement effect".

CHAPTER 3

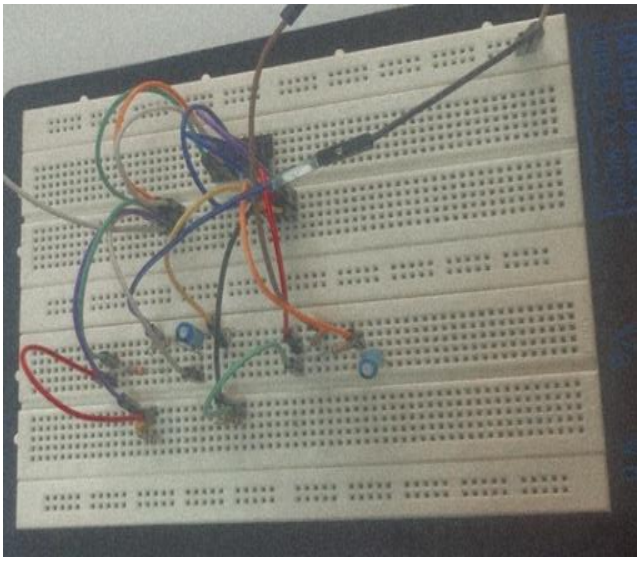
DESIGN AND IMPLEMENTATION

1.13 Background of experiment

To measure blood sugar in a non-invasive way, as we mentioned earlier, the NIR rays penetrate the skin and the rays interact with the finger tissues and glucose concentration and then are reflected, and this reflected light is an electric current and then it is converted into an electric potential. We were looking for a lot of sensors that read the output voltage. Then we compared the results of the effort with the concentration of blood sugar by the gaseous method and extracted the relationship and then finished the design of the device

1.14Initial work

We have tried to make a sensor, circuit that contains an IR transmitter and an IR photodiode receiver, the designed circuit consists of filtering stage and amplification stage.



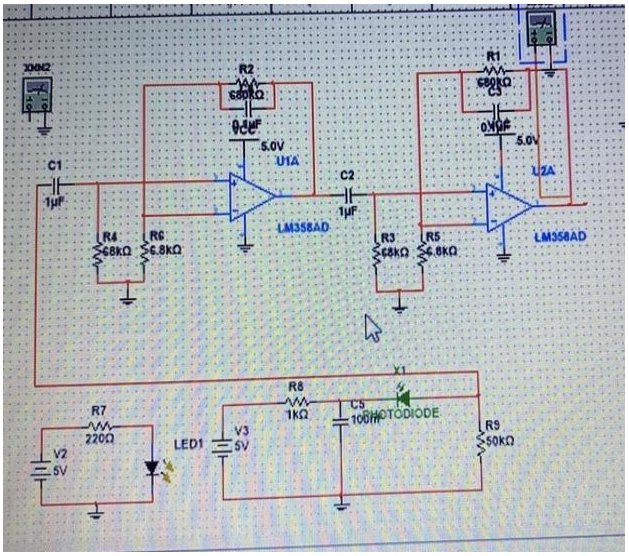


Figure 11 Circuit for first sensor.

Figure 12 Simulation for first circuit.

We finished making the circuit and used an oscilloscope to compare the input with the output and we noticed that there were problems, so we decided to look for another sensor.

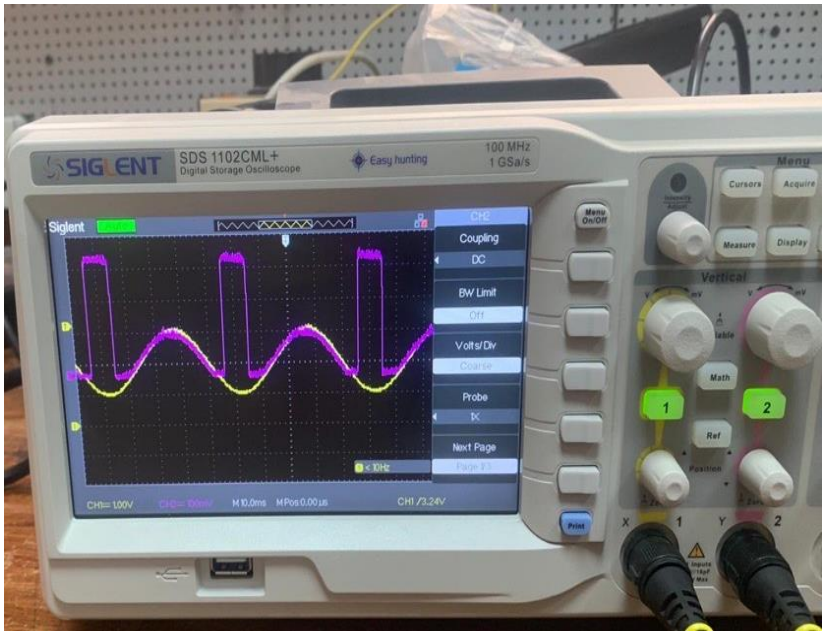


Figure 13 Output for first sensor

1.15 Parts aspect

We choose to use these components and conclude our circuit design upon reading lots of scientific papers and articles that were using different kind of parts, the suitable parts for our project that fulfil the accuracy and low-cost terms, these components are:

i. Arduino
ii. IR transmitter and receiver
iii. LCD
iv. Bluetooth
v. breadboard, power supply, resistors, wires

Parts explanation:

1.15.1Arduino UNO

Figure 14 Arduino component

"Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button". We will connect all the parts with the Arduino which it makes the Arduino the main controller of the whole device.

1.15.2 IR transmitter and receiver

Figure 16: IR transmitter with 940nm wavelength [23]

Figure 15: IR photodiode receiver with spectral range of 840nm-1100nm and a peak wavelength 940nm [24]

We used a sensor that contains the above components which they're 5mm 940nm IR Emitter Transmitter LED Diode Lights, Clear Infrared DC 1.2V with 30mA and 100mW, for the receiver it's a 5mm Photodiode with 840nm to 1100nm spectral density and has 940nm as a peak wavelength, after that the sensor contain an amplifier and current to voltage converter which will convert the conducting current from the transmitter and receiver to voltage, then amplify this voltage.

1.15.3 LCD

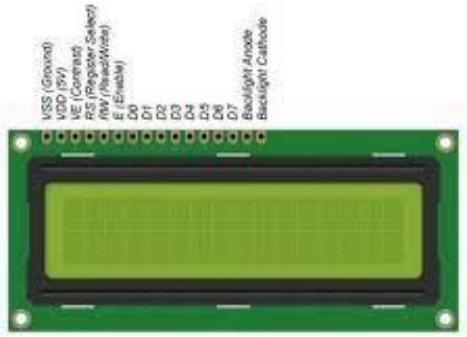


Figure 17: LCD component.

An electronic device that is used to display data and the message is known as LCD 16×2. As the name suggests, it includes 16 Columns & 2 Rows so it can display 32 characters (16×2=32) in total & every character will be made with 5×8 (40) Pixel Dots. This part will be used in this project to display the amount of glucose in the blood and state a comment if its [Low- Medium- High].

1.15.4 Bluetooth [HC-06]

Figure 18: HC_06 Bluetooth module, [25]

The HC-06 is a class 2 slave Bluetooth module designed for transparent wireless serial communication. Once it is paired to a master Bluetooth device such as PC, smart phones and tablet, its operation becomes transparent to the user. All data received through the serial input is immediately transmitted over the air. This module will be used at this project to connect the smart phone to this prototype, which the devise will send a message through the app that's made specially for this project, the message will include the state of glucose if its Low, Medium, or High.

1.16Block diagram of proposed work

The proposed work is based on NIR optical technique. NIR light source of 940 nm wavelength is chosen because it is suitable for measuring blood glucose concentration. The sensing unit consists of NIR emitter and NIR receiver (photodetector) positioned on either side of the measurement site (fingertip). When the NIR light is propagated through the fingertip in which it interacts with the glucose molecule, a part of NIR light gets absorbed depending on the glucose concentration of blood and remaining part is passed through the fingertip. The amount of NIR light passing through the fingertip depends on the amount of blood glucose concentration.

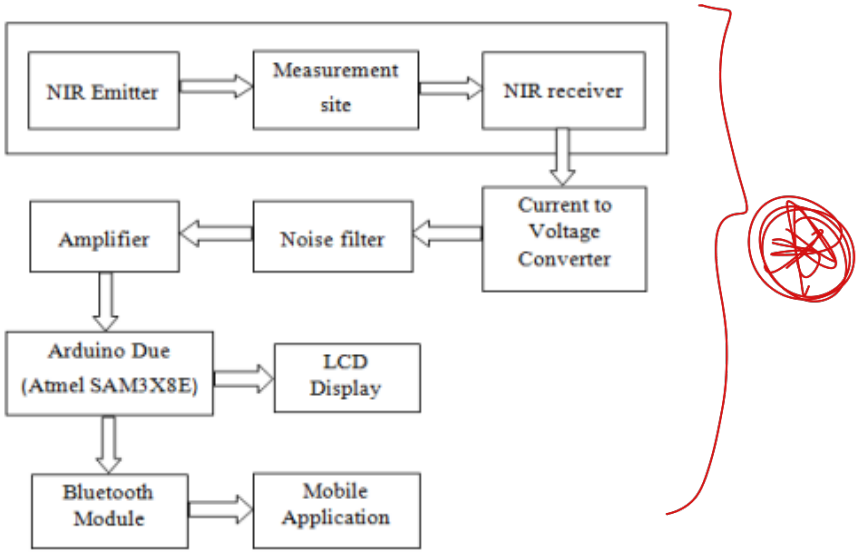


Figure 19:Block diagram of noninvasive glucose concentration measurement system, [9].

The transmitted signal is detected by the photodetector. The output current of the photo detector is converted into voltage signal and then it is filtered and amplified in the sensor. This amplified signal is fed into the Arduino. This signal is processed by using second order regression analysis to predict the blood glucose value and the blood glucose value is displayed on the LCD display. A mobile application (App) is created to view and store the predicted blood glucose value after receiving it via Bluetooth. Atmel communicates to the mobile app via Bluetooth by connecting a Bluetooth module (HC-06) to it. The flow chart of proposed work is shown in the following diagram The circuit diagram of the designed system consists of sensor that do filtering stage and amplification stage. The electrical current obtained from the photo detector is converted into voltage.

1.16.1Additional work

Figure 20: Sensor Max30100 that measures the heart rate and oxygen in blood, [26].

"This sensor turns out, oxygenated blood absorbs more infrared light and passes more red light while deoxygenated blood absorbs red light and passes more infrared light." This is the main function of the of this sensor, it reads the absorption levels for both light sources and stored them in a buffer that can be read via I2C.

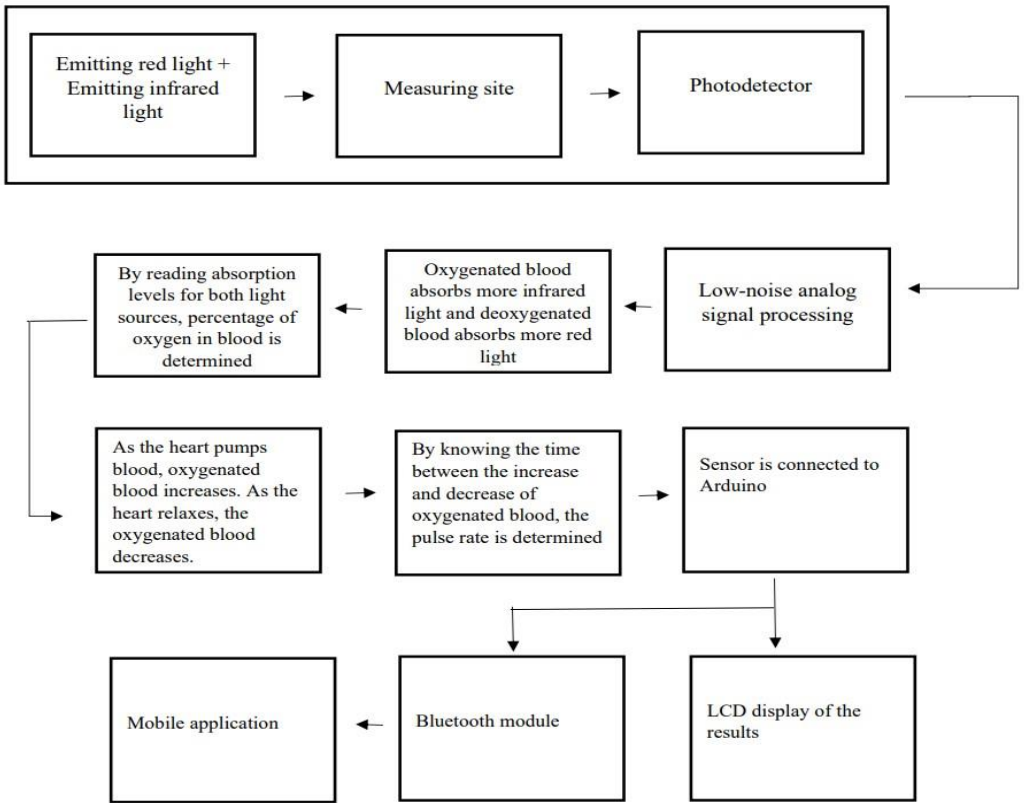


Figure 21: Block diagram for the heart rate and oxygen in blood.

1.17 Beginning of work

We took blood samples from several people by the invasive method, and we measured using the sensor the voltage coming out of the finger and extracted the relationship between them.

Table 1 Analog Voltage and the Glucose Level of Samples

S.NO	Analog voltage (mv)	Glucose Level (mg/dl)
1	1022	240
2	900	220
3	800	200
4	700	180
5	600	160
6	500	140
7	400	120
8	300	100
9	200	90
10	100	80
11	90	70
12	80	60
13	70	50

From the results shown in the table above, and using these results, we extracted the equation that we used and put it in the code to calculate the concentration of sugar in the blood by the non-invasive method.

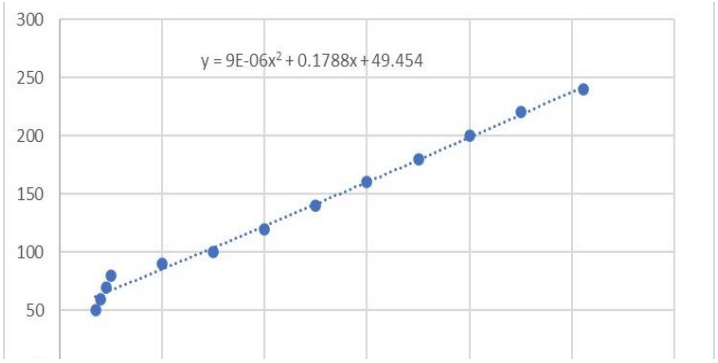


Figure 22: Analog Voltage and the Glucose Level of Samples.

1.18 Flowcharts

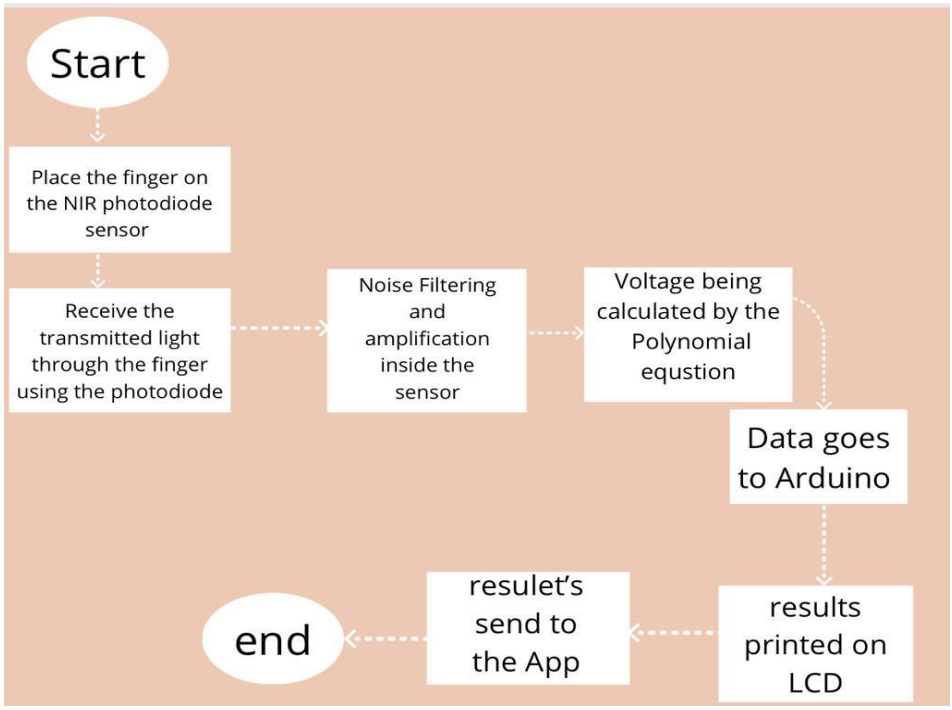


Figure 23: Flowchart for Measuring blood glucose.

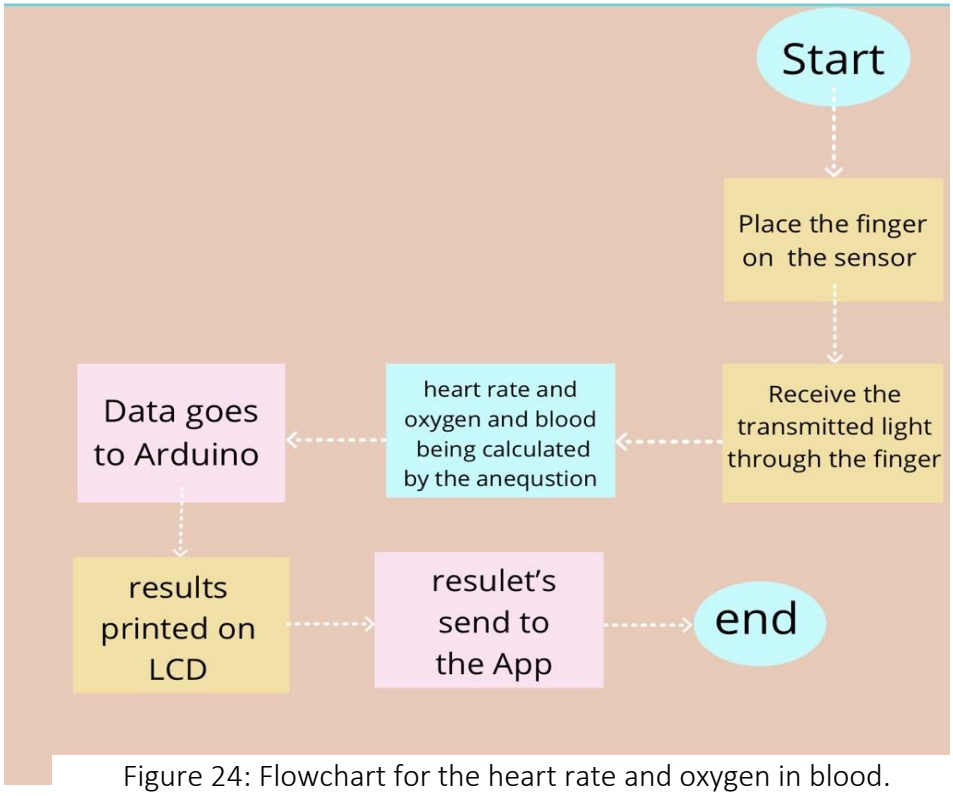


Figure 24: Flowchart for the heart rate and oxygen in blood.

1.19 Coding aspect:

We will need a C++ code (which will be installed in the Arduino microcontroller using the Arduino software) for the following reasons:

a) To input an equation that will be used regularly.

b) We will need code for the output voltage of the photodiode for the Arduino to recognize it as an input and process the data.

c) A code for the LCD screen for the Arduino to recognize it as an output & display result.

```
pox.update();
if (millis() - tsLastReport > REPORTING_PERIOD_MS) {

  lcd.clear();
  lcd.setCursor(0 , 0);
  lcd.print("Heart rate : ");
  lcd.print(pox.getHeartRate());
  lcd.setCursor(0 , 1);
  lcd.print("O2 in blood: ");
  lcd.print(pox.getSpO2());
  lcd.print("%");
  tsLastReport = millis();

  if (pox.getSpO2() >= 96) {
    lcd.setCursor(15 , 1);
    lcd.write(1);
  }
  else if (pox.getSpO2() <= 95 && pox.getSpO2() >= 91) {
    lcd.setCursor(15 , 1);
    lcd.write(2);
  }
  else if (pox.getSpO2() <= 90) {
    lcd.setCursor(15 , 1);
    lcd.write(3);
  }
}
```

Figure 25: The heart rate and oxygen in blood code.

```
void loop()
{
   sensorValue = analogRead(analogInPin);
 //outputValue = map(sensorValue, 0, 1023, 0, 1600);
int  val = (0.000009)*( sensorValue)*( sensorValue)+(0.1788)*( sensorValue)+49.454;
 analogWrite(analogOutPin, outputValue);
// Serial.print("glucose in blood = ");
Serial.println(val);
  lcd.setCursor(0 , 2);
    lcd.print("Blood Sugar: ");
    lcd.print(val);
```

Figure 26: “Blood glucose code”.

1.19.1 Code explanation:

THE GLUCOSE CODE EXPLANATION

First, we included the library that will be used to effectively connect and program the LCD, we also identified the Arduino pins which will be connected to the LCD, and we chose an initial float variable to represent the voltage level that will be processed and the result of processing the input which will represent the glucose level. Second, we identified an analog pin as an input that will be receiving the voltage, and we also informed the program that the LCD will have the capacity to print 16 letters for two rows. Moreover, we used the command "analog read" to read the analog data received which is the voltage level and we set that value to a variable. After that, we substituted the voltage level in the equation which we found earlier by analyzing the data to get the glucose level measurement. Finally, we used "if" command for comparison to determine the if the glucose level is Low, High, or normal and print it on the screen along with calculated result.

THE HEART RATE AND OXYGEN IN BLOOD CODE EXPLANATION

the necessary header files for MAX30100 and 16×2 LCD. As MAX30100 uses the I2C communication protocol were included. In void setup(), we initialized the Serial Communication with a baud rate of 115200, Then test condition for MAX30100 was written. If it is successfully initialized, then we will see "SUCCESS" on the serial terminal; otherwise, it will display "FAILED" wait for infinite time in for loop.Now, the current through the LED was set. By default, the current through the LED is 50mA.the current set in this code through the IR LED is 7. 6mA.The pulse is detected from the sensor by using the setOnBeatDetectedCallback function, which will call the onBeatdetected. In infinite void loop (), function pox.update() updates the sensor reading. Finally, it will print the heart rate in bpm and SpO2 in percentage on a LCD every second.

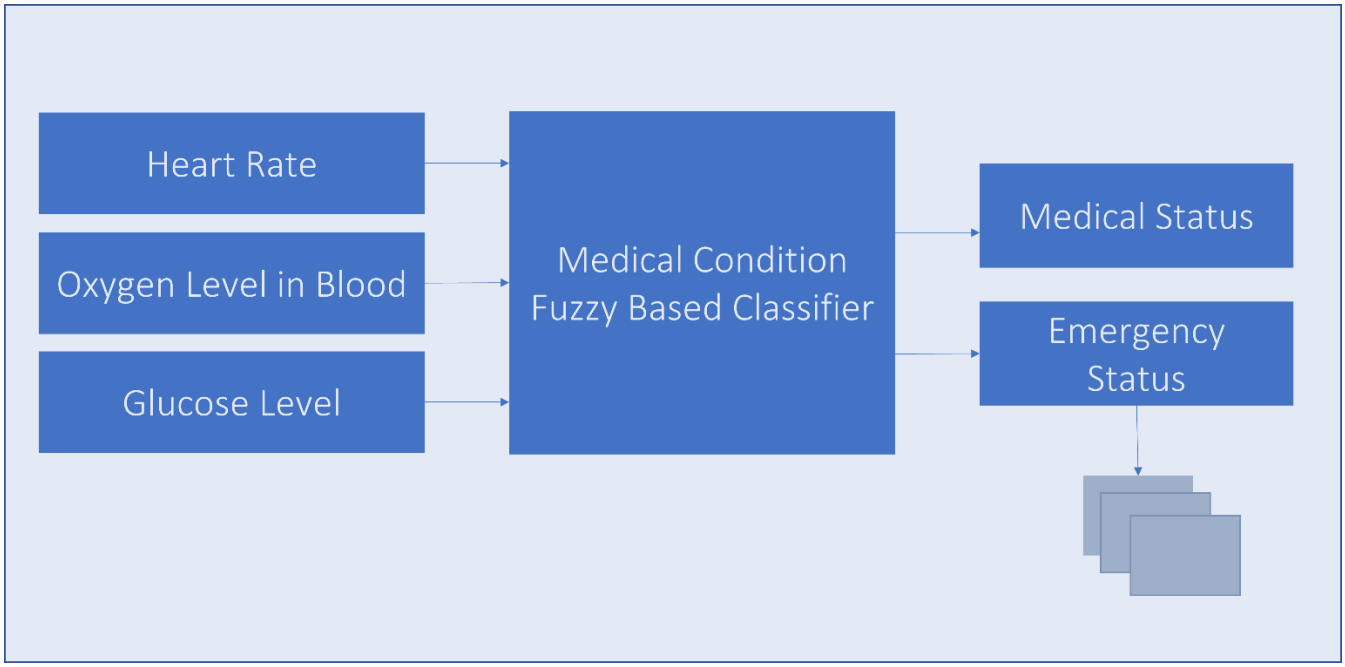


Figure 27: The fuzzy classification system.

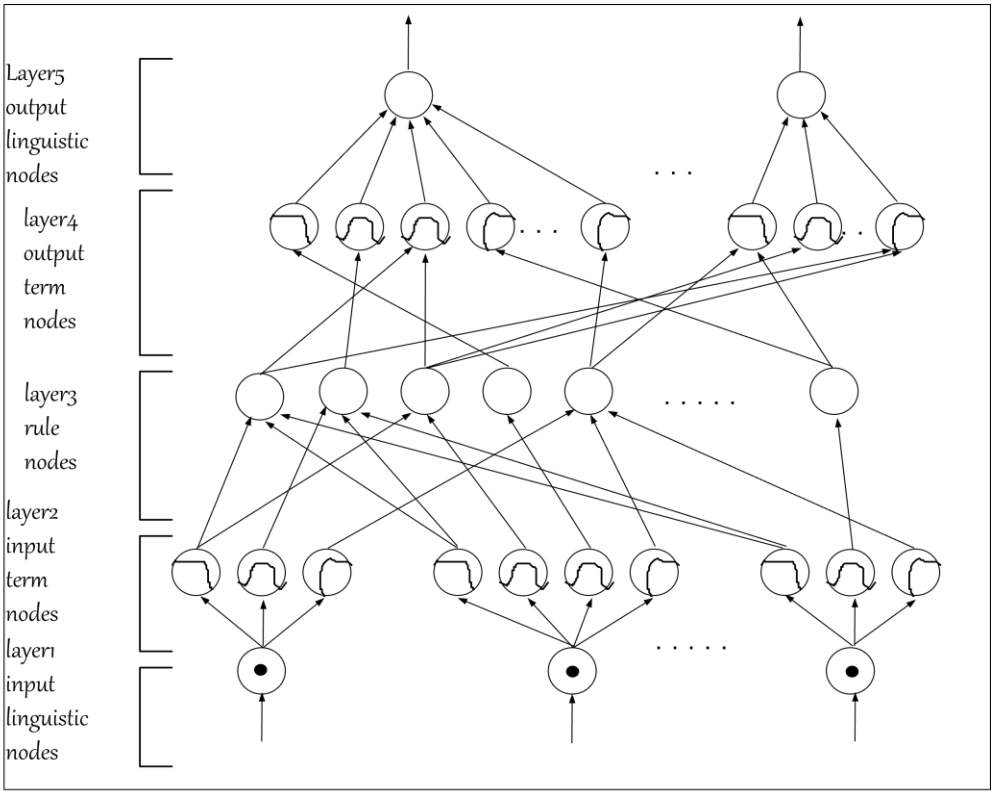


Figure 28: A learning fuzzy classification system.

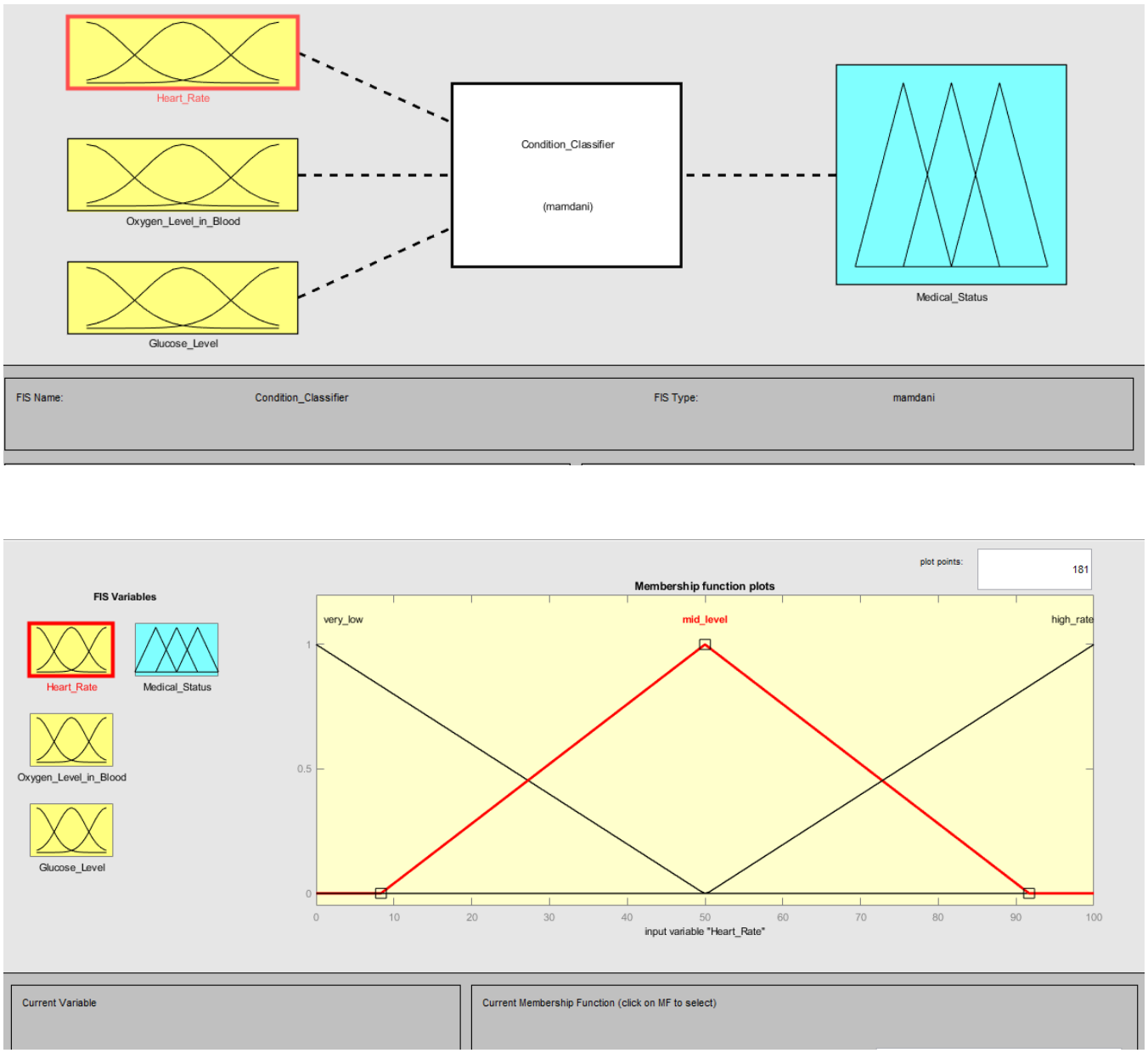


Figure 30: An implemented fuzzy classification system.

CHAPTER 4

RESULTS AND DIFFICULT

The device

This is the final form of the device, to measure sugar without pain in a non-invasive way, you must put your finger on the sensor firmly and firmly for 15 seconds, and we have added the device to measure the percentage of oxygen in the blood and heart rate in the human body, so you only have to put your finger on the other sensor, the Arduino will take over Calculate them all and then the results will be displayed on the LCD screen.

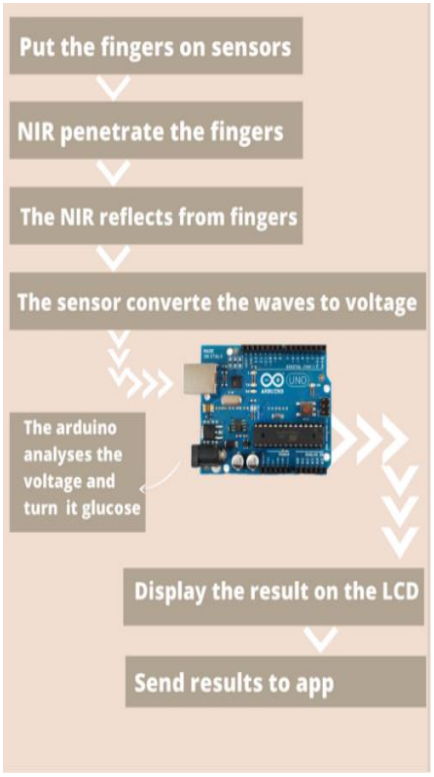


Figure 32: The final look of the device.

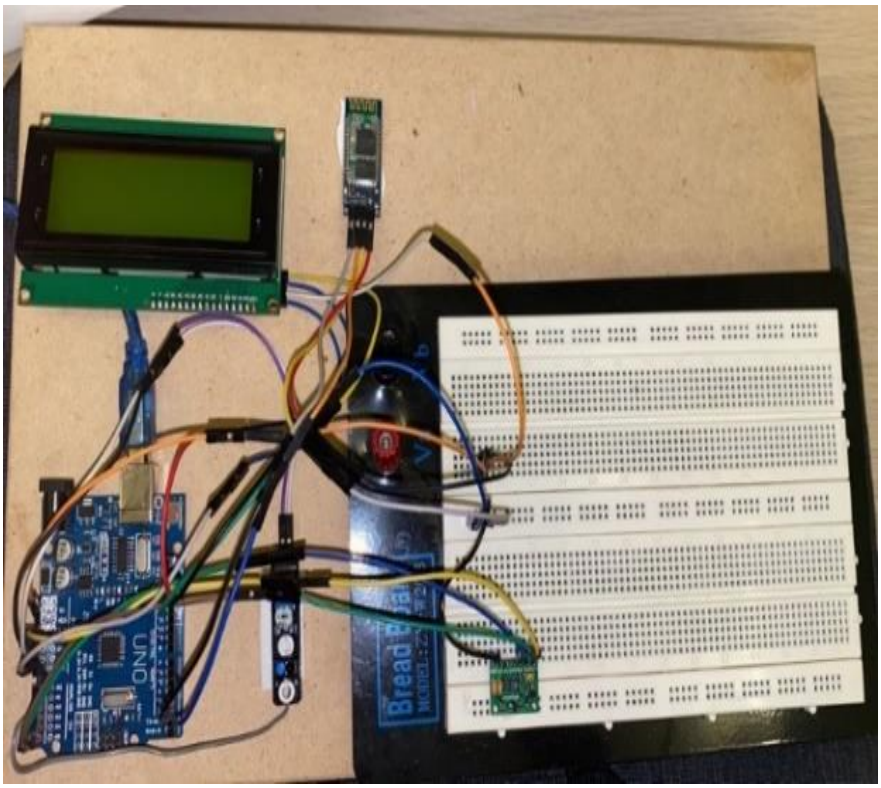


Figure 31: How the device works.

1.20 Results from our device

These are the results we got out of our device and we compered them with those we extracted from the invasive method and we found the difference between them.

Table 2 Difference between invasive and non-invasive

S.NO	Glucose value obtained by invasive method	Glucose value obtained by non-invasive method	Difference	S.NO	Glucose value obtained by invasive method	Glucose value obtained by non-invasive method	Difference
1	97	89	-8	7	103	100	-3
2	119	99	-20	8	150	130	-20
3	95	89	+4	9	115	108	-7
4	100	99	-1	10	90	108	+18
5	101	107	+6	11	200	150	-50
6	99	113	+14	12	79	89	+10

1.21 The methods

The accuracy of this proposed glucose measurement device is measured using two main analysis methods: Clarke Error Grid Analysis and Surveillance Error grid analysis.

1.21.1 Clarke Error Grid Analysis

The Clarke Error Grid shows the differences between a blood glucose predictive measurement and a reference measurement, it also shows the clinical significance of the differences between these values. As observed, the x-axis corresponds to the reference value and the y-axis corresponds to the prediction. The diagonal line shows the prediction value is the same as the reference value. This grid is split into five main zones, Zone A is defined as clinical accuracy while zones C, D, and E are considered clinical error, [10].

ZONE A: Clinically Accurate This zone holds the values that differ from the reference values no more than 20 percent or the values in the hypoglycemic range (<70 mg/dl). According to the literature, values in zone A are considered clinically accurate. These values would lead to clinically correct treatment decisions.

ZONE B: Clinically Acceptable This zone holds values that differs more than 20 percent but would lead to benign or no treatment based on assumptions.

ZONE C: Overcorrecting This zone leads to overcorrecting acceptable BG levels.

ZONE D: Failure to Detect This zone leads to failure to detect and treat errors in BG levels. The actual BG levels are outside of the acceptable levels while the predictions lie within the acceptable range.

ZONE E: Erroneous treatment This zone leads to erroneous treatment because prediction values are opposite to actual BG levels, and treatment would be opposite to what is recommended [10].

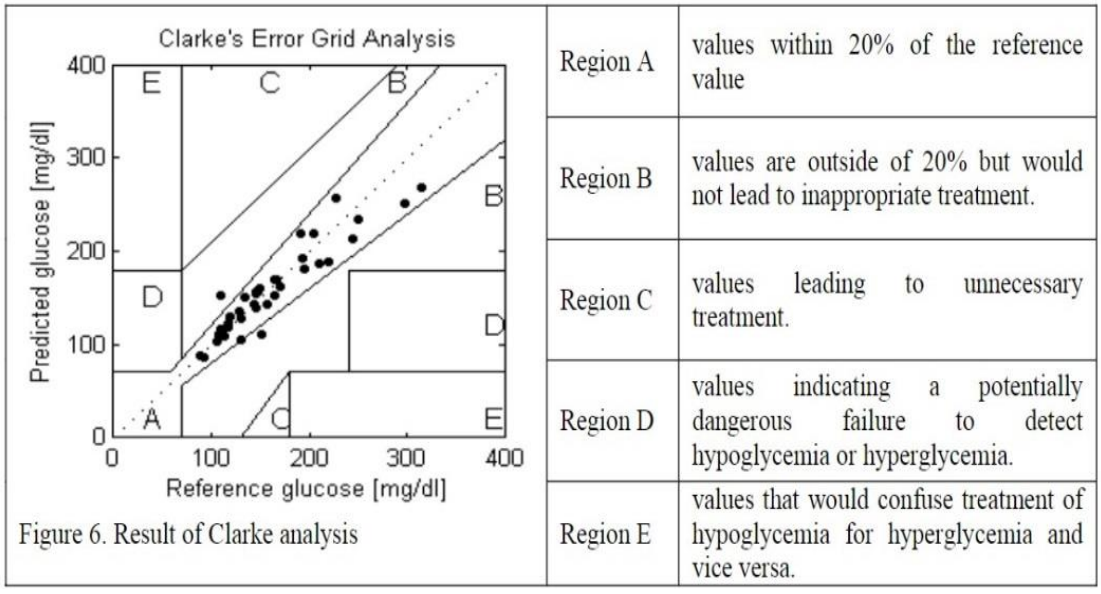


Figure 6. Result of Clarke analysis

Region A	values within 20% of the reference value
Region B	values are outside of 20% but would not lead to inappropriate treatment.
Region C	values leading to unnecessary treatment.
Region D	values indicating a potentially dangerous failure to detect hypoglycemia or hyperglycemia.
Region E	values that would confuse treatment of hypoglycemia for hyperglycemia and vice versa.

Figure 33: Result of Clarke analysis, [9].

As observed, 95% of the values are in region {A} which is considered medically acceptable region for measurement devices, [9].

1.21.2 Surveillance Error grid analysis

The surveillance error grid (SEG) analysis is a tool for analysis and visualization of blood glucose monitoring (BGM) errors, it is mainly used to determine the clinical accuracy and risk range of continuous glucose monitoring device used in intensive care unit. For each data pair of measured and reference glucose, the experts identified the degree of risk associated with an action taken because of a measured BG reading, compared to the action that would have been taken if the reference BG had been known. The degree of risk for hyperglycemia identified by the experts was coded from 0 (none) to 4 (extreme) [11]

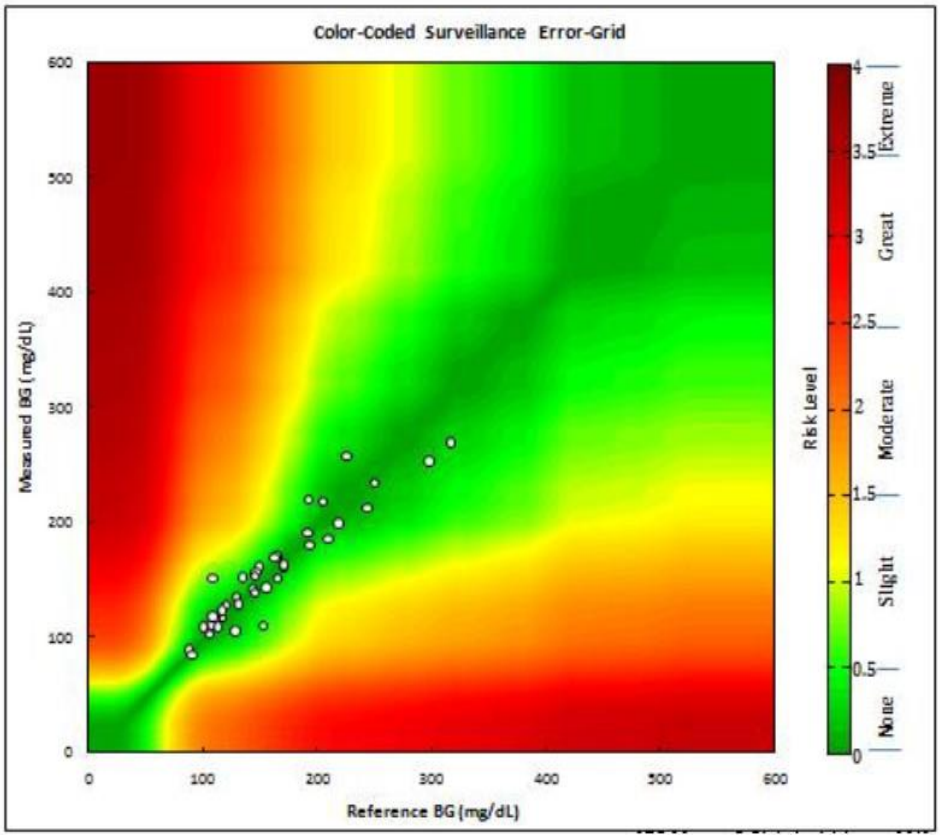


Figure 34: Result of Surveillance Analysis, [9].

The above is our results using the Surveillance Error grid analysis, we notice that the visualization of color-coded accuracy makes it much easier and faster to conclude that the proposed device is acceptable for glucose level monitoring as most of the glucose readings are in dark green zone (no risk) and few glucose readings are in light green zone (slight risk).

1.22 Difficulties

At first, we had a lot of difficulties in how we can design our own circuit, then things started to be clear, the hardest part was ordering some of the components because they weren't available in Bahrain electrical and electronic markets, after the components arrived, we found the coding a little bit challenging, but we've been able to write the perfect coding with some helping from a famous website like GitHub.

We tried to build a whole sensor by our own, but the process was too long and ruff because of the amplification stage and error of the amplification when it multiplied with a high gain. So, after digging more into the subject we found a sensor that's similar to what we wanted to build.

The big challenge was how to obtain the glucose equation by taking the samples from the people, the hard part was stabilizing the sensor and remove everything that affects it so we can take true and correct readings that's without side effects.

We also need to consider these difficulties.

CHAPTER 5

DISCUSSION

1.23 Discussion

After spending time researching, designing, and implementing our glucose level monitoring device. We succeeded in making a device for measuring blood glucose in a non-invasive way Based on the results presented in Table 2, we compared the results of our device with the results of the invasive method of glucose meter and we calculated the differences between the results, the differences between the two devices were very good, but the differences were greater when we measured high blood sugar.

i. What's new in this project?

The new thing in our project is that we were able to measure the heart beats and oxygen in blood beside the blood glucose.

ii. What's new comparing to the other articles, how do you compare your results?

Our project differs than the articles that we read with (simple hardware and application, easy to use and our results are almost in the same error percentage as ours).

iii. What is the project constraining, standards, limits, specifications?

Limitations: are things that effect the sensor reading which make it not efficient and get higher error% they are (light, person skin thin or thick, persons weight)

constrains: The sensor has some constrains which make it in can't read in specific voltage which mean high percentage error in some points.

iv. specifications: easy hardware, parts are available everywhere, low percentage error.

1.24 Total cost of the project

Table 3 Total cost

Device	Amount	Cost (BD)
Arduino uno	1	2.500
sensors	2	0 from uni
wires	2 set of wires	0.700
Bluetooth HC-06	1	2.500
Breadboard	1	0.800
LCD	1	2.000

Total cost = 8.500 BD

CHAPTER 5

CONCLUSION AND FUTURE WORK

To accomplish this project, we read many articles and journals to attempt to design and implement a non-invasive Method for Glucose level monitoring. This method mainly Relies on the NIR light. as we send the wavelength into that finger and measure the reflected amount of the NIR which differs based on the amount of Glucose In the blood. We took samples using the traditional invasive way and our device and found the correlation between both results Using a mathematical equation. This equation is inserted into the Arduino's microcontroller and continuously used to find the glucose level in a non-invasive way. To make sure that our results are accurate and acceptable we used two analyses to find the error percentage and it didn't exceed 20% which makes our device clinically acceptable for usage. This project helped us on how to design, implement and how to bring life to what was once only an idea in our head. we learned a lot of lessons that benefited us as students and will continue to be valuable Information for us as engineers in the near future. As engineers, we are problems-solvers, and we hope to bring to the medical world more designs and solutions that help those who are in need.

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Notes:

- Think of the clip thing in our lab
- typeC to USB, rechargable batteries.
- Get the avg value after getting the signal for like 15-30 seconds. (if we can use a timed push button for 15 seconds it's better.)
- Outputs the values with LEDs for High-Normal-Low sugar levels with a "beep" sound for risky areas.
- Try to develop a simple app to store the data and produce a simple daily, weekly, monthly report. (Then again we need a bluetooth/wifi model)

To make more accurate we can use a high & low threshold to make the result valid.

APPENDIX

Work schedule (Gantt Chart)

Table 4 Work schedule

Task Activity	Sep22-Jun17	18Jun-8Feb	9Feb-2Mar	3Mar-21Mar	22Mar-15Apr	16Apr-12May
Reads articles	■					
Understanding the project		■				
Find the components and read about them			■			
Attempts to build the circuit				■		
Take samples to compete the design					■	
Completion of building the circuit & application						■
Writing the report			■	■	■	■