Non- Invasive Glucometer

For
B. E. Major Project

Submitted in partial fulfillment of the requirements
of the Degree of
Bachelors in Engineering

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B.E. Major Project Approval

Project entitled by **Non-invasive Glucometer** by **Atharva Nayak, Anushka Darure, Avantika Narvekar ,Sudesh Bhagat** is approved for the degree of Bachelor of Engineering.

Examiners

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Internal

2. ____________________
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Date:

Place:

Certificate

This is to certify that **Atharva Nayak, Anushka Darure, Avantika Narvekar, Sudesh Bhagat** have completed the project report on the **Non-invasive Glucometer** satisfactorily in partial fulfilment of the requirements for Bachelor's Degree of Engineering in Electronics and Telecommunication under the guidance of **Mrs. Himali Patel (Assistant Professor)** during the year 2023-2024

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Declaration

We declare that this written submission represents our ideas in our words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misinterpreted or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

A non-invasive glucometer represents a significant breakthrough in diabetes management technology, aiming to revolutionize blood glucose monitoring by obviating the need for the uncomfortable and often painful traditional finger-prick method. This innovative medical device employs cutting-edge technologies such as infrared spectroscopy, optical sensing, or other non-intrusive methodologies to measure blood glucose levels. By leveraging these non-invasive techniques, individuals with diabetes can conveniently and painlessly monitor their blood sugar levels, facilitating a more seamless and frequent monitoring routine.

This device addresses a critical aspect of diabetes care - regular monitoring - by providing a user-friendly and less intrusive alternative. This is particularly vital in encouraging individuals to adhere to their monitoring schedules, enabling proactive management of their diabetes. The elimination of pain and discomfort associated with the traditional finger-prick method not only enhances the quality of life for individuals with diabetes but also potentially leads to more consistent monitoring habits and better glycemic control.

Furthermore, this advancement holds promise for pediatric and geriatric populations, where obtaining blood samples for glucose monitoring can be challenging. By reducing the barriers to monitoring, a non-invasive glucometer has the potential to contribute significantly to improved health outcomes, reduced complications, and overall enhanced well-being for individuals living with diabetes.

Chapter 1

Introduction

Diabetes, a prevalent chronic illness affecting millions globally, presents a formidable challenge to individuals and healthcare systems alike. Characterized by elevated blood sugar levels, diabetes can lead to a range of serious health complications, including cardiovascular disease, kidney failure, blindness, and nerve damage. The key to managing diabetes effectively lies in regular monitoring of blood glucose levels to ensure they remain within a healthy range. However, traditional methods of glucose monitoring often involve invasive procedures, such as finger-pricking to draw blood samples, which can be painful, inconvenient, and discouraging for many individuals.

The discomfort associated with invasive glucometers can have significant implications for diabetes management. Many individuals may avoid monitoring their blood sugar levels as frequently as recommended due to the discomfort and inconvenience of finger-pricking. This reluctance to monitor regularly can result in poor glycaemic control, increasing the risk of complications and undermining efforts to manage the condition effectively. Moreover, the discomfort caused by frequent finger-pricking can impact the quality of life for individuals with diabetes, adding a burden to their daily routine.

Non-invasive glucometer technology represents a breakthrough in diabetes care by offering a painless and convenient alternative to traditional blood glucose monitoring methods. These innovative devices use advanced technologies such as infrared spectroscopy, optical sensing, or thermal sensing to measure glucose levels through the skin, eliminating the need for needles or blood sampling. By removing the discomfort associated with invasive glucometers, non-invasive devices encourage regular and consistent monitoring of blood sugar levels, empowering individuals with diabetes to take control of their health and improve their overall well-being.

Problem Statement

The current method of measuring blood glucose, typically through finger-pricking, poses challenges such as discomfort and infection risks, particularly for diabetic patients requiring frequent monitoring. These issues underscore the necessity for non-invasive, painless, and cost-effective alternatives prioritizing user-friendliness. Such alternatives would facilitate regular monitoring, decreasing infection risks, and enhancing patient comfort. Addressing this need is crucial for enhancing diabetes management and improving health outcomes. Collaboration among healthcare providers, researchers, and technology innovators is essential to develop accessible and efficient solutions empowering patients to manage their conditions effectively. These innovations aim to alleviate patient burdens and contribute to a more streamlined healthcare system focused on enhancing patient well-being and quality of life.

Chapter 2

Literature Survey

A Non-Invasive Blood Glucose Monitoring Device Using Red Laser Light [1] by P.Muhamaduyasic K.M.Gopinath K.Rohini Dr.(Mrs). R. Sukanesh in International Research Journal of Engineering and Technology 2020. This project aims to develop a portable, painless blood glucose monitor using red laser light to measure glucose levels non-invasively. It aims to improve diabetes management, prevent complications like blindness, and provide real-time, accurate glucose readings displayed on an LCD screen, offering continuous monitoring. The results are promising, with low error percentages in comparisons between Invasive and Non-Invasive Glucometers. Only two high-value readings had unacceptable error percentages.

Optical Based Non-Invasive Glucometer with IoT [2] by Saina Sunny1, S.Swapna Kumar in Institute of Electronics and Electrical Engineering in 2021. This paper aims to monitor glucose levels using optical and IoT technologies non-invasively. It employs IR LED and NIR photodiodes based on the Beer-Lambert law for signal processing, and Arduino IDE for system evaluation and analysis. The paper mentions that the project is ongoing, with planned analysis areas including comparing proposed system accuracy, performance, wavelength effects, noise resistance, absorption spectra, and comparisons with invasive sensors.

A Study On Non-Invasive Blood Glucose Meter Providing Glucose Measurements Painlessly, Without a Blood Sample or Finger Pricks. [3] by Dr. S. Sridhar in the International Journal of Innovative Technology and Research in 2020. In this paper, they have developed a non-invasive glucometer kit with the help of Arduino Uno, NIR-LED, Photodetector, MAX30100 pulse oximeter, etc. The receiver will receive the transmitted light from the measurement site through the photodiode with the help of an NIR sensor and photodetector and then it will convert output voltage and photodiode into digital values with the help of inbuilt ADC. They introduced a non-invasive blood glucose meter offering painless, rapid glucose measurements without blood samples or finger pricking. It's adaptable for continuous glucose and blood oxygen monitoring, and storing measurement history.

Breath Acetone Sensors as Non-invasive Health Monitoring Systems [4] by Nader Alizadeh, Hoda Jamalabadi, Farnaz Tavoli in Institute Of Electronics And Electrical Engineering 2021.Breath analysis for non-invasive medical diagnosis, recognizing breath's complex composition with numerous compounds. It identifies VOCs and some inorganic gases as disease biomarkers, emphasizing acetone's role in diabetes diagnosis and management. Creating affordable, portable breath sensors for diabetic acetone detection is crucial in healthcare. The paper addresses sensor challenges, proposes solutions, and highlights breath analysis for real-time disease diagnosis.

Non-Invasive Blood Glucose Measurement Device: Performance analysis of Diffused Reflectance method and Diffuse Transmittance method using Near Infrared Light [5] by Tanvir Raihan Khan, Asif Mostofa and Mrinmoy Dey in International Conference on Electrical, Computer and Communication Engineering (ECCE) 2020.In this paper, a non-invasive blood glucose measuring technique is developed that consists of a Near Infrared LED (940nm) and a photodetector to estimate blood glucose levels. The accuracy of both the diffuse reflectance method and the diffuse transmittance method is compared to see which method is preferable. Also, an app was developed which continuously transfers data from the device to patients' smartphones.

IoT-Based Non-invasive Blood Glucose Monitoring [6] by M. A. Aizat Rahmat, E. L. M. Su,M. Mohd Addi and C. F. Yeong Faculty of Electrical Engineering UTM. The paper introduces GluQo, a non-invasive method for monitoring blood glucose in diabetic patients. It outlines the development of a system using a Near Infrared LED on the fingertip to optically measure and calculate glucose levels based on received light intensity. The study also validates the GluQo prototype by comparing its readings with commercial finger-prick methods. Furthermore, it includes the creation of a GluQo mobile app for doctors and relatives to track patients' glucose levels. The paper confirms a strong correlation between predicted glucose values and sensor voltage signals, validating the reliability of the GluQo system.

Detection of Blood Glucose Level in Humans using Non-Invasive Method-RL BGM [7] by M. Julie Therese, P. Dharanyadevi, A. Devi, C. Kalaiarasy. This paper aims to propose a non-invasive method, specifically the Red Laser (RL) Blood Glucose Monitoring (BGM) technique, for accurately detecting blood glucose levels in the human body and avoiding serious health issues. The paper aims to address the limitations of current BGM techniques, such as invasiveness, pain, risk of infection, and high cost. The experimental results to demonstrate the high accuracy of the proposed RL-BGM method. The paper also compares the accuracy of RL-BGM with other methods, such as Near-Infrared (NIR) and acetone-based BGM, and highlights the superiority of RL-BGM.

An Intelligent Device for Accurate Non-invasive Blood Glucose-Level Monitoring in Smart Healthcare [8] by Prateek Jain, Amit M. Joshi and Saraju P. Mohanty.The aim of the paper is to propose a novel Internet-of-Medical-Things (IoMT) enabled edge device called "Intelligent Glucose Meter" (iGLU) for accurate non-invasive blood glucose-level monitoring in smart healthcare. The device is based on near-infrared (NIR) spectroscopy and a machine learning (ML) model of high accuracy. The proposed device aims to mitigate the inconvenience and risk of blood-related infections associated with invasive approaches like fingertip pricking and laboratory tests. The device has been validated in a hospital setting and the blood glucose values are stored on an IoMT platform for remote monitoring by an endocrinologist. The device is designed to provide precise, painless, low-cost continuous glucose monitoring at the user end and is integrated with IoMT for easy access to the data by caretakers. The device is portable, fast-operated, and easy to use for smart healthcare.

Non-invasive monitoring of glucose level in blood using near-infrared spectroscopy [9] by Anuradha Jadiya, Nikhil Nair, Midhun Nair, and G. Sravani. The paper discusses the challenges of diabetes and the limitations of current glucose monitoring methods, such as fingerstick devices, in terms of infection risks and expenses. The researchers propose a non-invasive glucose monitoring method using Near-Infrared Spectroscopy (NIR) based on the scattering property of glucose. They aim to impinge NIR light on a body part and analyze the reflected light to determine glucose concentration non-invasively. The paper mentions the use of Arduino IDE for acquiring and operating the NIR sensor unit, as well as implementing the system as an IoT device. The mathematical modeling of the device is based on the Beer-Lambert law, which relates absorbance to concentration. The paper presents a working model of the glucose measuring device using IoT and acknowledges the need for more data to improve accuracy. Overall, the paper presents a viable prototype for non-invasive glucose monitoring using NIR spectroscopy and discusses the mathematical modeling based on the Beer-Lambert law. The researchers aim to address the limitations of current glucose monitoring methods and provide a more convenient and accurate solution.

Non-invasive Glucose Sensing Methods

Non-invasive methods [39] studied in recent years for glucose estimation can be grouped according to their technologies. Mainly, they fall into the category of electromagnetic (EM) wave sensing, transdermal, and enzymatic. EM sensing comprehensively defines all the work related to non-ionizing EM radiation, which includes ultraviolet (UV), infrared, microwaves, and the visible light spectrum. It includes Mid-Infrared (MIR), Near-Infrared (NIR), Microwave (MW), Thermal Emission (TE), Photoacoustic, Raman, and Occlusion spectroscopy. Optical Polarimetry (OP) and Optical Coherence Tomography (OCP) also fall into this category. Impedance spectroscopy and electromagnetic sensing are examples of transdermal technology, as they involve sensors being placed on the epidermis layer of human skin tissue. Enzymatic technology comprises non-invasive biological fluids such as saliva and tears for glucose measurements. Figure 1 shows the distribution of non-invasive technologies. Each of these technologies along with its advantages and disadvantages will be discussed in the following subsections

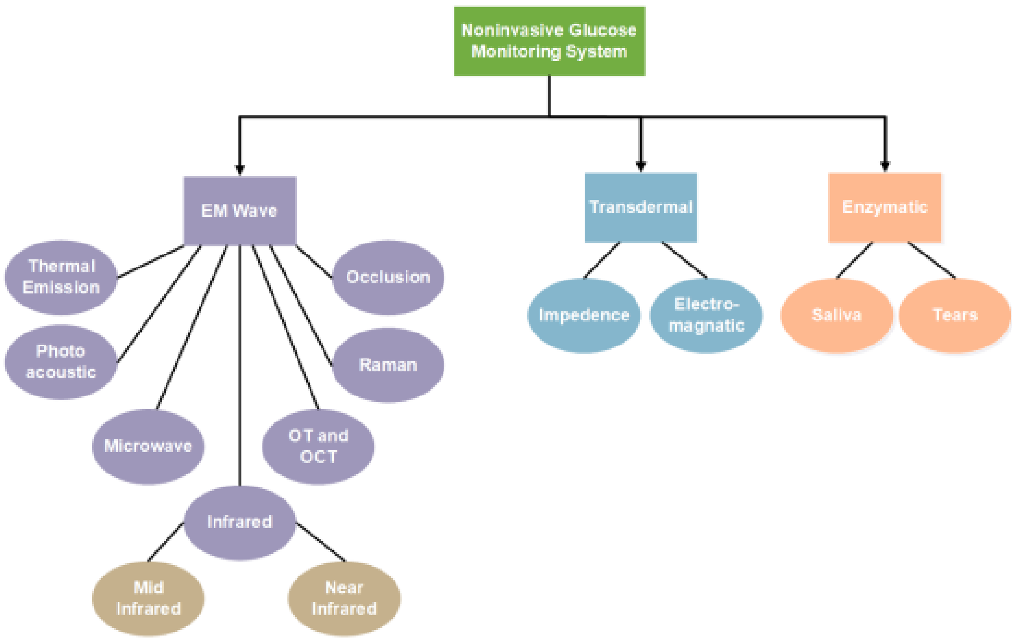

Figure 2.1: Non Invasive Glucose Monitoring System

2.1 Infrared (IR) Spectroscopy

Infrared spectroscopy, or vibrational spectroscopy, is the measurement of how infrared radiations interact with matter. The absorption, emission, and reflection of IR waves are measured and studied to identify functional groups or chemical substances present in matter.

The infrared region of the electromagnetic spectrum is usually divided into three sub-regions, the near-, mid-, and far-infrared, which are named by their relation to the visible spectrum. Figure 2 shows a general diagram of IR spectroscopy. For non-invasive glucose monitoring, mid- and near-infrared regions are more studied, as the penetration reduces with an increase in wavenumber. Both are discussed in the following subsections. Sensors 2022, 22, x FOR PEER REVIEW 3 of 22 and Occlusion spectroscopy. Optical Polarimetry (OP) and Optical Coherence Tomography (OCP) also fall into this category. Impedance spectroscopy and electromagnetic sensing are examples of transdermal technology, as they involve sensors being placed on the epidermis layer of human skin tissue. Enzymatic technology comprises non-invasive biological fluids such as saliva and tears for glucose measurements. Figure 1 shows the distribution of non-invasive technologies. Each of these technologies along with its advantages and disadvantages will be discussed in the following subsections.

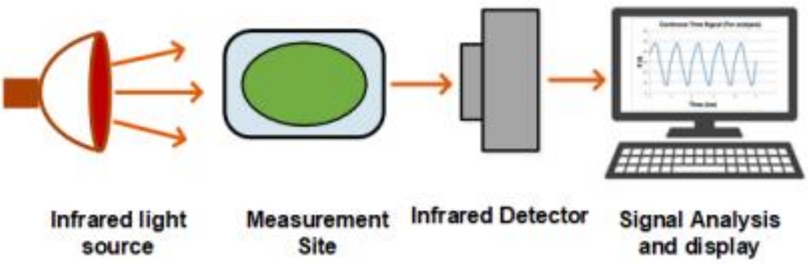

Figure 2.2: Infrared spectroscopy. Infrared spectroscopy

2.1.1 Mid-Infrared (MIR) Spectroscopy

Mid-Infrared waves lie in the region of 2500–25 µm of electromagnetic waves. They use the reflection principle to detect glucose concentration in interstitial fluid (ISF). MIR has sharp response peaks for glucose detection and has low scattering. The main constraint of MIR is that it can only be used in reflectance mode as it has poor penetration in human tissue and cannot determine glucose concentration present in blood vessels. The water content and human tissue affects the reflected light resulting in poor glucose correlation with ISF

2.1.2 Near Infrared (NIR) Spectroscopy

Near-Infrared spectroscopy is an optical method in which scattered, transmitted, or reflected light from the illuminated surface is studied. NIR waves lie in the EM bandwidth of 700–2500 nm. NIR spectroscopy finds its application in numerous fields like medicine, pharmaceutics, food analysis, quality control of chemical products, material sciences, astronomy, and agriculture. It has been investigated for glucose estimation for the last few decades. NIR waves have deeper penetration compared to MIR, so they can easily reach the dermis layer of skin and interact with blood components. Thus, NIR spectrometry can be utilized to estimate glucose levels in the blood.

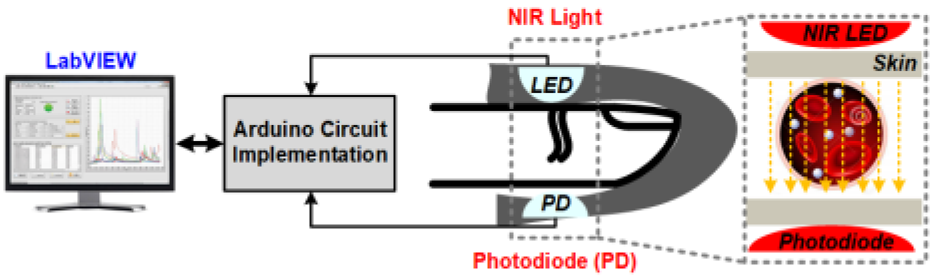

Figure 2.3: A prototype for the NIR spectroscopy using a 940 nm wavelength

This technology is low-cost and simple but suffers from scattering, and the lower bandwidth has a poor correlation with glucose in the blood. Another approach is to acquire PPG signals using NIR waves of specific bandwidths for blood glucose estimation. PPG is an optical technique that detects volumetric changes in blood circulation. The PPG voltage signals are proportional to the quantity of blood flowing through the blood vessels. The changes in blood flow are seen as a waveform. The features obtained from these PPG signals are incorporated into machine learning algorithms to predict BGL. This technique has shown a better correlation with blood glucose.

2.2 Raman Spectroscopy

Raman spectroscopy is based on measuring the scattering of incident monochromatic (laser) light due to the vibrational and rotational motion of particles under study. The change in light wavelength due to scattering (Raman shift) is measured to identify glucose molecules in which vibration modes are linked with carbon, hydrogen, and oxygen bonds. Raman spectroscopy has a sharper spectrum compared with other infrared waves. It is less sensitive to water, ambient light, and temperature changes. The instability of the laser in wavelength and intensity is its major limitation. The intensity of the laser needs to be less to keep it harmless for the human body; therefore, it has a low signal-to-noise ratio (SNR).

2.3 Thermal Emission Spectroscopy (TES)

Thermal Emission Spectroscopy uses the heat radiation principle of the human body in the far-infrared region (8 µm–14 µm). When the body radiates heat, some of it is absorbed by different tissue and molecules, including glucose. The wavelength absorbing most is around 9.4 µm.

Buchert suggested that analysis of radiation can provide information on glucose concentration in blood. Figure 3 shows the setup of Thermal Emission Spectroscopy. Although TES is least sensitive toward scattering compared to other infrared waves, it has several limitations. The radiation intensity also depends upon temperature and measurement site thickness. It has strong water absorption, making accurate and sudden changes in glucose detection difficult.

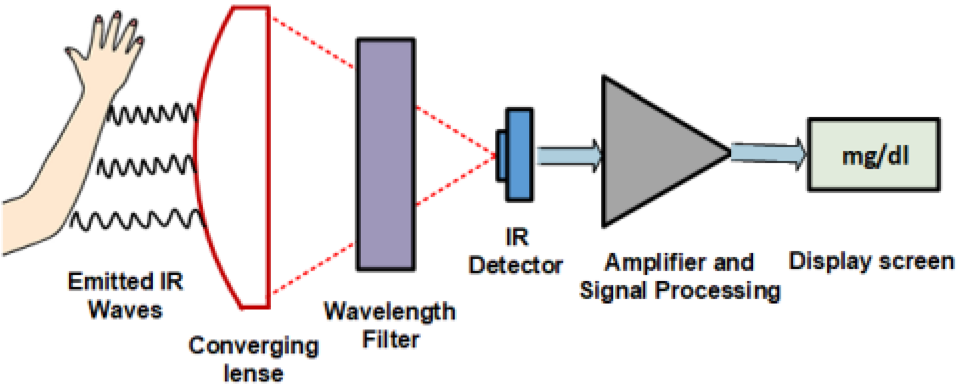

Figure 2.4: Thermal Emission Spectroscopy

2.4 Microwave Spectroscopy (MWS)

Microwaves range from 1 mm to 1 m in the EM wave spectrum. They are widely used in the fields of detection, communication, and medicine. As they can easily penetrate media with a millimetre of thickness, they can penetrate deep in skin tissue, reaching blood vessels in the dermis layer. The reflection, absorption, and transmission theory of microwaves through skin tissues can correlate to the changes in dielectric property, relative permittivity, and conductivity with fluctuating glucose concentrations. Hence, implying these waves can be used to estimate BGL. Figure 4 shows the principle of MWS. The sensor is connected to a vector network analyzer (VNA) which detects changes in amplitude and phase corresponding to changes in the permittivity of the sample, as shown in Figure 4. MWS is sensitive to a small glucose concentration; it can be easily designed and is low cost. Unfortunately, it has poor selectivity, as blood components affect the measurement parameters such as the dielectric constant. MWS is also sensitive to physiological parameters like breathing, sweating, and physical activities.

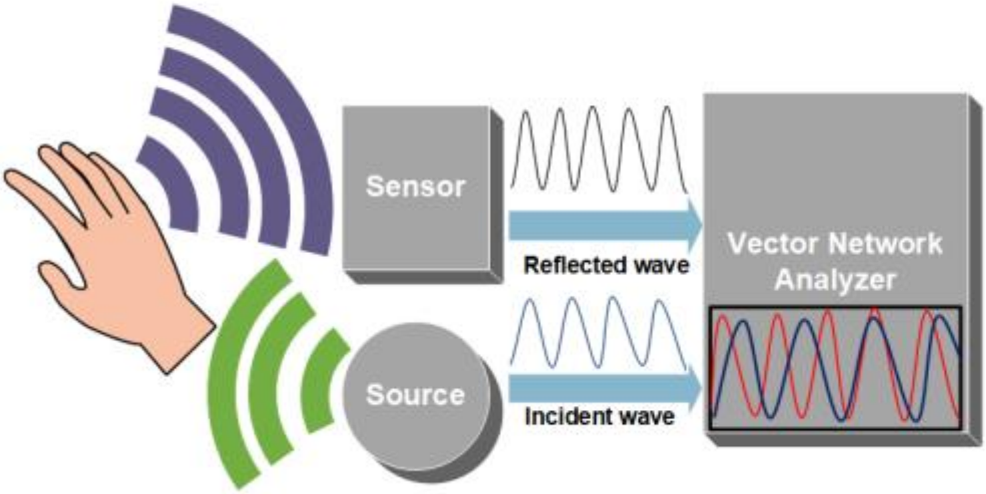

Figure 2.5: Microwave Spectroscopy working principle.

2.5 Metabolic Heat Conformation (MHC)

Metabolic Heat Conformation technology estimates blood glucose by measuring various physiological parameters using multi-wavelength spectroscopy methods along with humidity and temperature sensors. The theory behind this technique is that the amount of glucose and oxygen levels present in the body correlate to the amount of heat produced by the metabolic oxidation of glucose in human cells. The heat emitted from the body as radiation, evaporation, and convention is measured via sensors and spectroscopies. Statistical analysis of the data is performed for glucose estimation. Although the physiological parameter is well-measured in this method, it has less accuracy, as it is susceptible to sweating and environmental conditions such as humidity and temperature variations.

2.6 Photoacoustic Spectroscopy (PAS)

Photoacoustic Spectroscopy exploits the photoacoustic method for glucose estimation. The theory states that if an energy source radiates on the skin surface, it causes thermal expansion at the illuminated site. Due to thermal expansion, acoustic or ultrasound waves are generated and can be detected by pressure sensors. The peak-to-peak variation of the detected signal can be correlated to the glucose level in the blood. This technique is simple and is resistant to water absorption. For excitation sources, a wide range of laser pulses can be utilized, ranging from UV to NIR waves. However, this method is vulnerable to temperature, pressure, and environmental changes. It has a low signal-to-noise ratio and the instrumentation is expensive.

2.7 Occlusion Spectroscopy (OP)

Occlusion spectroscopy is a technique in which scattered light is measured from the pressurized tissue site. The blood flow is restricted for a few seconds at the site by applying pressure. The dynamic changes in blood flow increase the intensity of scattered light. The scattered light is measured to estimate blood glucose concentration. Like other light sources, glucose estimation using OP is affected by physiological factors and ambient light sources.

2.8 Optical Polarimetry (OP)

Optical Polarimetry uses the concept of chiral molecules of glucose to estimate its concentration. Chiral molecules can rotate the polarization plane of the incident light beam at a particular angle. The amount of rotation is dependent upon the optical path length, temperature, wavelength of the incident beam, and concentration of an analyte. OP is unsuitable for skin measurements due to the high scattering of light and other physiological parameters. An aqueous humour of the eye is a suitable analyte for glucose estimation using OP. This technique has high resolution and can measure small changes in aqueous glucose concentration but is sensitive to temperature changes and eye motion. The interferences from other optically active compounds in the eye result in poor specificity of his technique.

2.9 Optical Coherence Tomography (OCT)

Optical Coherence Tomography is an optical imaging technique that can give high-quality 2D images. The signal acquisition method is based on detecting interferometric signals. A low-coherence light source is illuminated on the sample placed in an interferometer. The backscattered light from sample tissue and a reference mirror (inside the interferometer) forms an interferometric signal and is detected by a photodetector. With an increase in glucose concentration present in interstitial fluids, the refractive index also increases. The increase in refractive index decreases the scattering coefficient of illuminated light. Hence, measuring the scattering coefficient indirectly gives the glucose concentration present in the sample [65,66]. This technology has the advantage of good SNR, depth of penetration, and high resolution, but it suffers from tissue inhomogeneity, physiological interferences, and individual motion, resulting in poor selectivity for glucose estimation.

2.10 Bio-Impedance Spectroscopy

Bio-impedance measures the changes in permittivity and conductivity (impedance) through human tissue. The resistance to the flow of electric current through plasma fluid can be correlated to glucose molecules. This is a relatively simple and easy to-implement technique, but the error in measurements increases while sweating. This technique is also sensitive to temperature variation and other physiological conditions.

2.11 Electromagnetic Sensing

Electromagnetic sensing exploits the dielectric properties of blood to estimate glucose concentration. The fluctuation of voltage or current produced due to electromagnetic coupling of inductors indicates the varying concentration of blood glucose molecules. Electromagnetic sensing is specific to the analyte and minimizes the interferences from surroundings, but it is highly sensitive to temperature changes.

2.12 Non-invasive Enzymatic Technology

Non-invasive enzymatic technology includes a technique that involves blood glucose using human fluids such as tears, saliva, and sweat. Ocular technology also falls in this category. It utilizes specially designed contact lenses that determine the glucose present in tears. The saliva in the mouth has also been studied to detect the presence of glucose. The main obstacle in non-invasive enzymatic technology is that these fluids do not necessarily depict glucose values of blood, and, hence, can give a false BGL estimation.

Chapter 3

Project Architecture

This chapter describes the overall architecture of the proposed system. The steps involved in making of the project are described. The block diagram of the proposed system, its description and the significance of every block is discussed. The flow of the code and how it will work in possible scenarios is discussed too.

3.1 Block Diagram:

This block diagram showcases a system designed for remote blood glucose monitoring. Here's a breakdown of its components and how they work together:

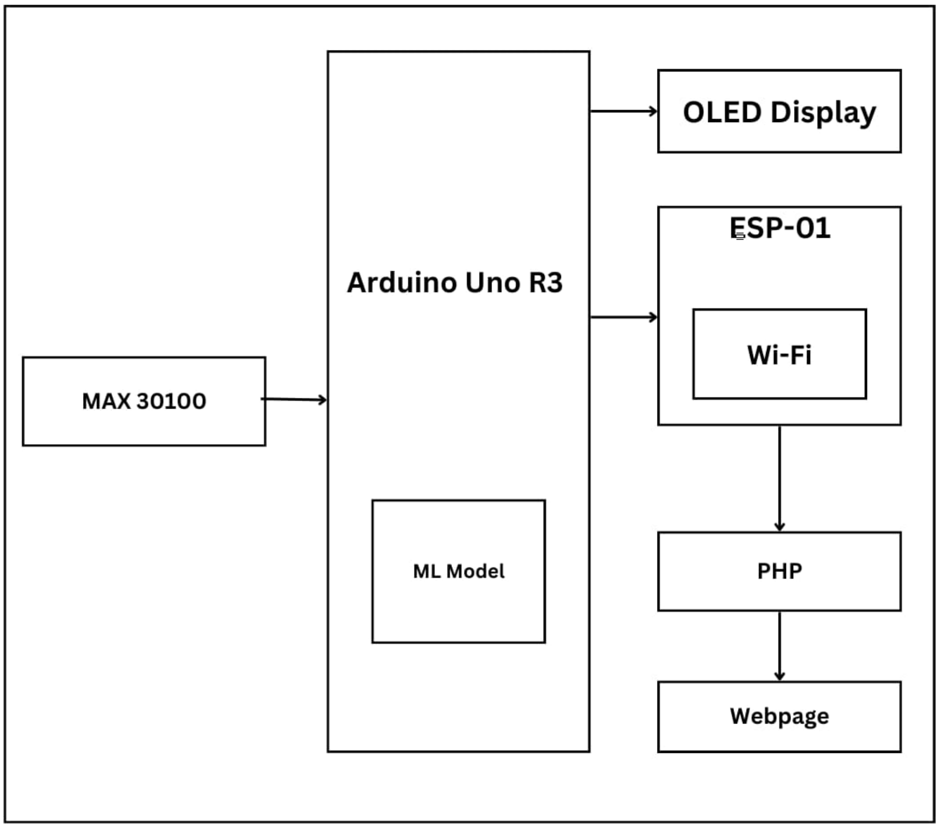

Figure 3.1: Block Diagram

Data Acquisition and Processing: The system relies on the MAX30100 pulse oximeter sensor. Similar to measuring blood oxygen, in this application, it acts as an indirect blood glucose gauge. It emits light through the user's finger and measures the amount absorbed by blood vessels. Variations in blood sugar levels subtly alter this absorption pattern, resulting in raw infrared (IR) readings.

These raw IR readings are then transmitted to the Arduino Uno, a single-board microcontroller. However, the Arduino doesn't directly interpret this data. Instead, it relies on a pre-programmed machine learning (ML) algorithm. This algorithm is the heart of the system, as it's trained on a vast dataset. This dataset likely includes paired data points: raw IR readings from the MAX30100 sensor collected from a group of individuals, along with corresponding blood glucose measurements obtained from traditional blood glucose meters for the same individuals. Through this paired data, the ML algorithm learns the relationship between IR absorption patterns and actual blood glucose levels.

Once trained, the ML algorithm resides on the Arduino Uno. When it receives raw IR readings, it processes them based on the learned relationship. This processing transforms the raw data into a predicted blood glucose value, offering a more user-friendly and informative output compared to the raw IR readings.

Data Transmission and Visualization: While the Arduino excels at processing data, it might lack built-in Wi-Fi connectivity. This is where the ESP01 module comes in. The ESP01 is a microcontroller module specifically designed for Wi-Fi communication. It acts as a communication bridge in this system. It receives the processed blood glucose value (predicted by the ML algorithm) from the Arduino Uno and transmits it wirelessly to a web server using its Wi-Fi functionality.

A PHP script running on a web server acts as the backend for the system. PHP is a popular scripting language often used for web development. The PHP script receives the transmitted blood glucose data from the ESP01 module.

Data Storage and Visualization: The PHP script can potentially store the received blood glucose data in a database on the web server. This database could be MySQL, a popular open-source relational database management system.

The final component is the user interface: a personalized webpage. This webpage would be designed using HTML, CSS, and JavaScript (web development technologies) and connect to the database on the web server. By retrieving the most recent blood glucose value, the webpage can display it in a clear and concise format, potentially accompanied by historical data for trend analysis. This allows for remote monitoring of blood sugar levels, eliminating the need for frequent finger pricking.

3.2 Flowchart:

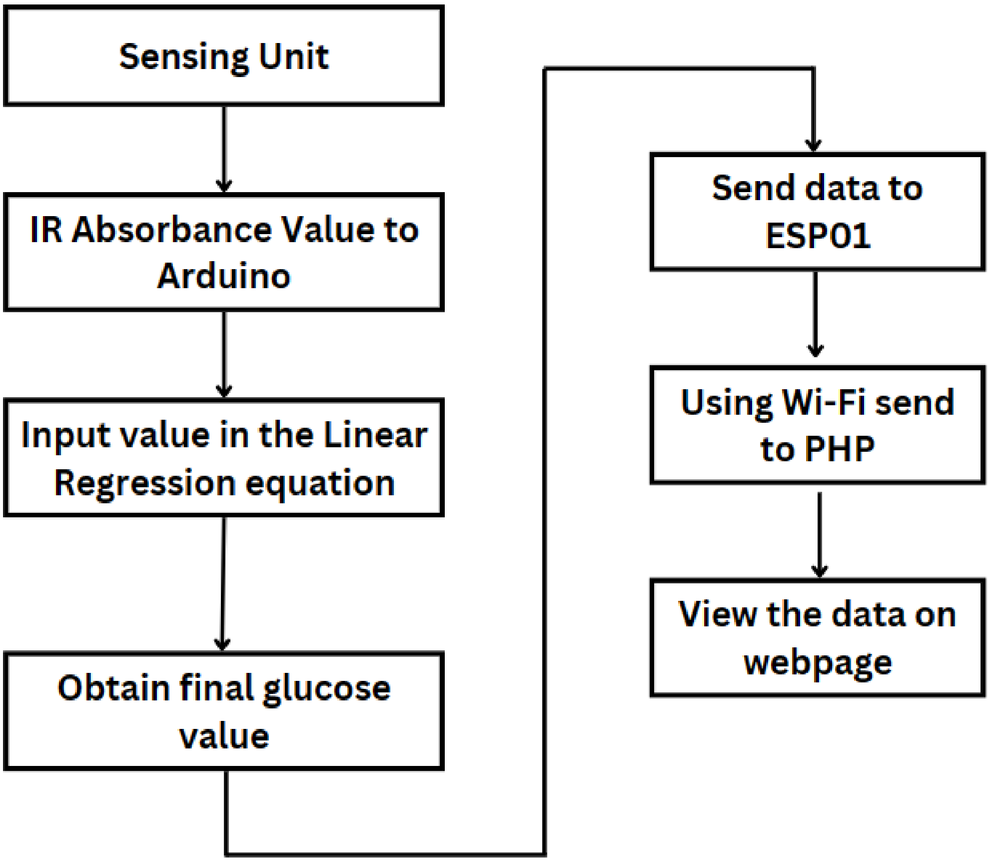

Figure 3.2: Flowchart

The flowchart you sent depicts a process for sending data to a Firebase database, likely from an Arduino or ESP32 microcontroller board. Here's a detailed description of the flowchart:

Start: The process starts with the Arduino or ESP32 acquiring an IR (InfraRed) absorbance value. This value might be from an IR sensor that measures the absorption of infrared light by a substance.

Send data to ESP32: The IR absorbance value is then transmitted from the sensing unit to the Arduino or ESP32 board.

Input value in the Linear Regression equation: The data is processed according to a linear regression equation. As described previously, a linear regression equation establishes a relationship between a dependent variable (y) and one or more independent variables (x). In this case, the equation likely transforms the IR absorbance value into a usable data point.

Using Wi-Fi to send data to a PHP server: The processed data is sent via Wi-Fi to a PHP server.

PHP server receives data: The flowchart shows the PHP server receiving the data from the ESP32 board.

Display data on a webpage using PHP: The data stored on the PHP server can then be accessed and visualized on a webpage using PHP scripting. This involves retrieving data from the PHP server and displaying it in a user-friendly format on the webpage.

End: The process ends after the data is displayed on the webpage.

Chapter 4

Review of Fundamentals

The chapter consists of a brief description of the fundamental components used. The specifications and their use in the system are described. Further the software used is described. These fundamentals all contribute to the project equally.

4.1 Hardware

Sr. No.	Name Of Components	Quantity
1	Microcontroller ESP32	1
2	MAX30100	1
3	OLED display	1
4	Arduino + ESP 01	1
5	Power supply	1

Table 4.1: List of Hardware Components

4.1.1 ESP01 Microcontroller

Figure 4.1: Esp01 Microcontroller

The ESP01 microcontroller is renowned for its versatility and robust features, making it a top choice for IoT applications. Its dual-core Tensilica Xtensa LX6 CPU provides ample processing power while maintaining energy efficiency, ideal for battery-powered devices. Its built-in Wi-Fi and Bluetooth connectivity options allow seamless communication, expanding its utility in interconnected systems.An advantage of the ESP01 is its extensive array of GPIO pins, ADCs, DACs, and hardware interfaces, enabling developers to easily interface with sensors, actuators, and peripheral devices for diverse IoT solutions. Moreover, it prioritizes security with support for secure communication protocols like TLS/SSL and WPA2-Enterprise, ensuring data privacy, crucial in healthcare or industrial IoT deployments.Additionally, the ESP01 's compact form factor, cost-effectiveness, and community support contribute to its widespread adoption. Its small size suits compact devices, and affordability makes it accessible to hobbyists and startups. The vibrant developer community offers resources, tutorials, and libraries for rapid development and troubleshooting.Overall, the ESP01 microcontroller provides a compelling combination of performance, connectivity, and ease of use, making it a versatile platform for IoT development, whether for smart home devices, wearables, or industrial automation systems.

4.1.2 MAX30100

Figure 4.2: MAX30100

The MAX30100 renowned for its exceptional performance and compact size, the MAX30100 stands out as an integrated pulse oximetry and heart-rate sensor module. This cutting-edge device serves as a non-invasive oxygen saturation (SpO2) and heart rate monitor, equipped with an array of photodetectors and LEDs designed to emit and sense light through the skin.

Ideal for wearable fitness and health devices, as well as medical monitoring applications, the MAX30100 boasts low power consumption and seamless integration capabilities. Its versatility makes it a highly desirable option for developers seeking to incorporate precise biometric measurements into their products. Moreover, the MAX30100 is engineered with advanced features such as adaptive gain management and ambient light cancellation, enhancing accuracy and dependability across various environmental conditions. These sophisticated functionalities ensure reliable performance, even in challenging scenarios, further solidifying the MAX30100's reputation as a leading choice in the realm of pulse oximetry and heart-rate monitoring technology.

4.1.3 OLED display

Figure 4.3: OLED Display

The Organic Light-Emitting Diode (OLED) display stands as a monumental breakthrough in screen technology, finding applications in devices ranging from televisions to smartphones. Unlike conventional LCD panels, OLED panels possess the unique ability to generate their own light, resulting in superior visual experiences characterized by higher contrast ratios, deeper blacks, and slimmer form factors. OLED displays are renowned for their vivid colour reproduction, enhancing the viewing experience while demonstrating impressive energy efficiency. This combination of visual excellence and sustainability has cemented OLED technology as a cornerstone of contemporary electronics. Moreover, the adaptability of OLED displays enables creative design solutions, fostering innovation in product form factors and user experiences. Whether in curved screens, flexible displays, or transparent panels, OLED technology offers unparalleled design flexibility, reshaping the consumer electronics market with its cutting-edge functionality and versatility. In summary, OLED displays represent more than just a technological advancement; they embody a convergence of artistry and engineering, delivering immersive visual experiences while driving innovation in design and functionality across various industries.

4.1.4 Arduino with ESP-01

Figure 4.46: Arduino with ESP-01

The integration of an ESP-01 module with an Arduino board marks a revolutionary stride in project adaptability, unlocking a realm of possibilities with the seamless addition of Wi-Fi connectivity. When these components are interconnected and programmed using the Arduino IDE, a vast array of opportunities emerges. These encompass the development of cutting-edge IoT applications and the establishment of intricate remote monitoring systems, empowering users with unprecedented control and accessibility.

By leveraging the Arduino board as the primary processing unit and harnessing the ESP-01 module for Wi-Fi connectivity, this amalgamation presents a versatile and robust platform for crafting interconnected products. Facilitating communication with a diverse range of sensors and actuators, this combined platform fosters experimentation and encourages creativity in the burgeoning field of Internet of Things (IoT) technologies. With this powerful combination, developers and enthusiasts can innovate and iterate, bringing their ideas to life and shaping the future of IoT solutions. Whether it's designing smart home devices, implementing industrial automation systems, or creating wearable gadgets, the ESP-01 module and Arduino board collaboration offers limitless possibilities for exploration and advancement in the realm of connected devices and IoT ecosystems.

4.2 Software

Sr. No.	Name of Software	Online/Offline Compiler
1	Arduino IDE	Both
2	Google Colab	Online
3	Visual studio code	Online
4	PHP	Online

Table 4.2: List of Software Tools Used

4.2 1 Arduino IDE

Figure 4.5: Arduino IDE

The Arduino Integrated Development Environment (IDE) is a software application designed specifically for programming Arduino boards. It offers a straightforward interface for writing, compiling, and uploading code, making it accessible to users with varying levels of programming experience.The IDE features a simple text editor where users can write their code comfortably. With features like syntax highlighting and auto-completion, it facilitates the coding process and helps users avoid common errors. Once the code is written, the IDE's compiler translates it into a format that the Arduino board can understand. One of the key advantages of the Arduino IDE is its user-friendly design. Even those with minimal programming knowledge can navigate the interface and start writing code for their projects. This accessibility has contributed to the widespread popularity of Arduino among hobbyists, students, and professionals alike. Additionally, the IDE includes a serial monitor, allowing users to interact with their Arduino boards in real-time. This feature is invaluable for debugging code and troubleshooting issues as they arise. Overall, the Arduino IDE simplifies the process of programming Arduino boards, making it easier for users to bring their ideas to life.

4.2.2 Jupyter Notebook

Figure 4.6: Jupyter Notebook

Jupyter Notebook is an open-source web application facilitating interactive and collaborative computing, transforming data analysis and scientific computing. Its versatile interface integrates live code, equations, visualizations, and narrative text, fostering exploration and discovery. Supporting multiple programming languages like Python, R, and Julia, it accommodates diverse computational tasks. Notably, its interactive environment allows for immediate code execution, promoting rapid experimentation and model development. Combining code with explanatory text enhances storytelling in data analysis, facilitating effective communication of findings. Additionally, Jupyter Notebook enables seamless document sharing and real-time collaboration among users, enhancing teamwork and driving innovation.

4.2.3 Google Colab

Figure 4.7: Google Colab Notebook

Google Colab, or Google Colaboratory, is a cloud-based platform revolutionizing Jupyter Notebooks' interaction. It provides a seamless web-based environment for creating, running, and sharing interactive notebooks, eliminating local installations and fostering effortless collaboration. With access to CPUs, GPUs, and RAM at no cost, Colab democratizes computational research, empowering users in data science, machine learning, and research tasks. Supporting Python and R, it seamlessly integrates code, visualizations, and text within notebooks. Colab facilitates real-time collaboration with shared notebooks, allowing multiple users to edit and comment simultaneously, enhancing productivity and accelerating research. Overall, Google Colab offers a versatile, accessible, and collaborative platform for interactive data analysis, machine learning, and research, bridging the gap between individuals and computational resources.

4.2.4 Proteus

Figure 4.8: Proteus

Proteus is a powerful suite of design and simulation tools for electrical and electronics engineering, streamlining circuit development. With an intuitive interface and a vast component library, it enables quick circuit assembly and validation through simulation. Notably, it facilitates microcontroller prototyping, integrating popular microcontroller families and IDEs for efficient hardware-software development. Real-time simulation allows users to preemptively address issues, enhancing circuit performance. Moreover, it serves as an educational tool, offering hands-on experience in electronic design. Proteus is indispensable for engineers and students alike, providing a comprehensive platform for designing, testing, and simulating electronic circuits and microcontroller-based systems with confidence and efficiency.

4.2 5 Visual studio code

Figure 7: Visual studio code

Visual Studio Code (VS Code), developed by Microsoft, is a lightweight yet powerful code editor known for its efficiency and flexibility. Its intuitive design and robust features, such as

IntelliSense for smart code completion, enhance productivity and precision. Seamless Git integration simplifies code management and collaboration, while extensive customization options through extensions cater to diverse coding needs. Supporting task running and automation, VS Code streamlines development workflows, saving time and effort. While Visual Studio IDE may offer more enterprise-level features, VS Code's agility and versatility make it a preferred choice among developers for various coding tasks, from small scripts to large-scale applications.

4.2.6 PHP

Figure 4.10: Hypertect Preprocessor(PHP)

PHP (Hypertext Preprocessor) is a fundamental server-side scripting language pivotal in dynamic web development. Executing on the server within HTML, PHP generates dynamic content based on user input, database interactions, and system processes. Its open-source nature and cross-platform compatibility enable seamless integration with various web servers and databases, including MySQL and PostgreSQL. PHP's extensive library support, including frameworks like Laravel and CodeIgniter, accelerates development with pre-built solutions for common tasks. With a low learning curve and simple syntax, PHP is accessible to developers of all levels, facilitating quick web application development and deployment.

Chapter 5

Implementation and Algorithm

In this chapter the working of the system, use case and the timeline for the completion of the project is described. The working describes the technical functioning of the system. The use case defines the usage of the system from the user point of view. The timeline suggests the time taken for completion of the project.

5.1 Working of the Project:

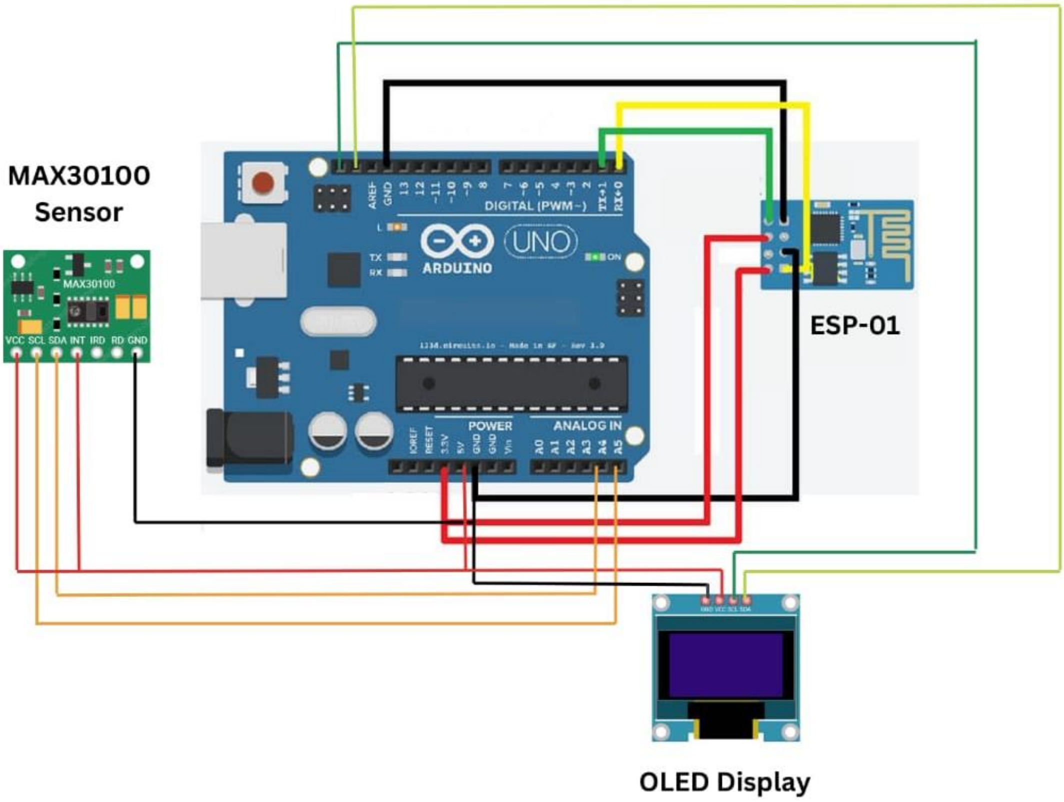

Figure 5.1: Circuit Diagram

The non-invasive glucometer project leverages the MAX30100 sensor, renowned for its non-invasive glucose measurement capabilities using 940nm infrared (IR) light and the reflectance method. The sensor obtains raw IR readings that directly reflect the concentration of glucose molecules in the user's blood. These readings are then processed through a calibrated Linear regression equation within an Arduino microcontroller. This calibration involves training the regression model with a dataset of IR readings and corresponding glucose levels to ensure accurate predictions. The predicted glucose levels are displayed in real time on the device's OLED display, providing users with immediate feedback on their blood glucose levels.

Additionally, the project integrates an ESP01 WiFi module, enabling wireless communication with a PHP server hosted on a webpage. The PHP server receives the glucose level data from the device and presents it in a user-friendly format on the webpage. This integration facilitates remote monitoring and data storage, allowing caregivers and healthcare professionals to access and track glucose level trends over time for better health management decisions. Overall, the project combines advanced sensor technology, intelligent data processing, and wireless connectivity to offer a comprehensive and user-centric solution for non-invasive glucose monitoring and diabetes management.

5.2 Implemented Algorithm

The implemented algorithm section details the use of the Linear regression algorithm to predict glucose levels from raw infrared (IR) readings. The dataset used for training includes a diverse range of IR readings matched with corresponding glucose levels, crucial for ensuring accurate and reliable predictions in our non-invasive glucometer project.

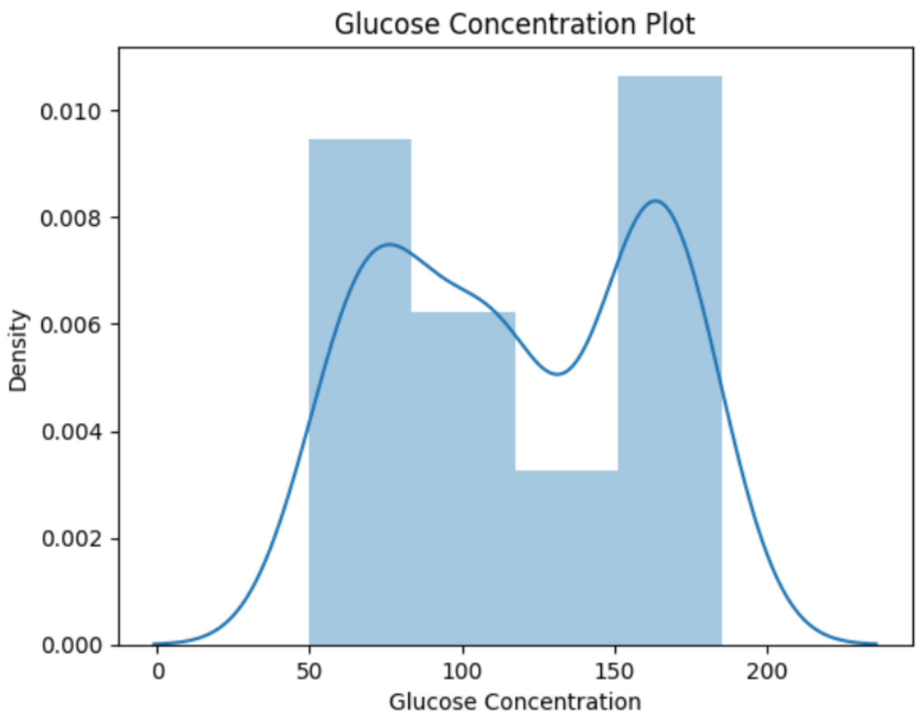

Figure 5.2: Distribution of Glucose Samples in Dataset

The dataset used to train the machine learning (ML) model in our project has been carefully curated to encompass a wide range of glucose levels. Samples are distributed across various ranges of glucose concentration values, ensuring that the ML model is exposed to diverse physiological states and glucose concentration levels during training. This distribution strategy enhances the model's ability to generalize well and accurately predict glucose levels across a spectrum of real-world scenarios.

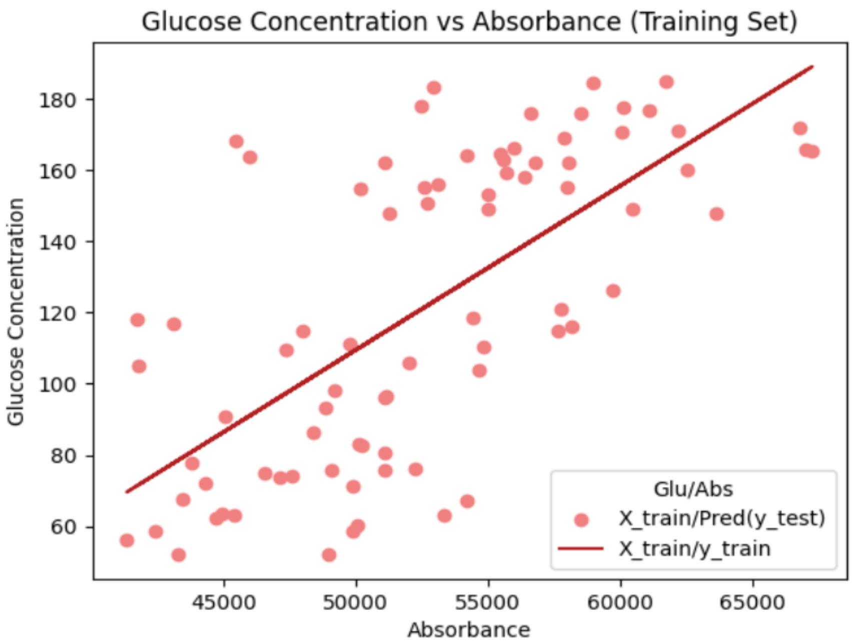

Figure 8: Scatter Plot for Training Set

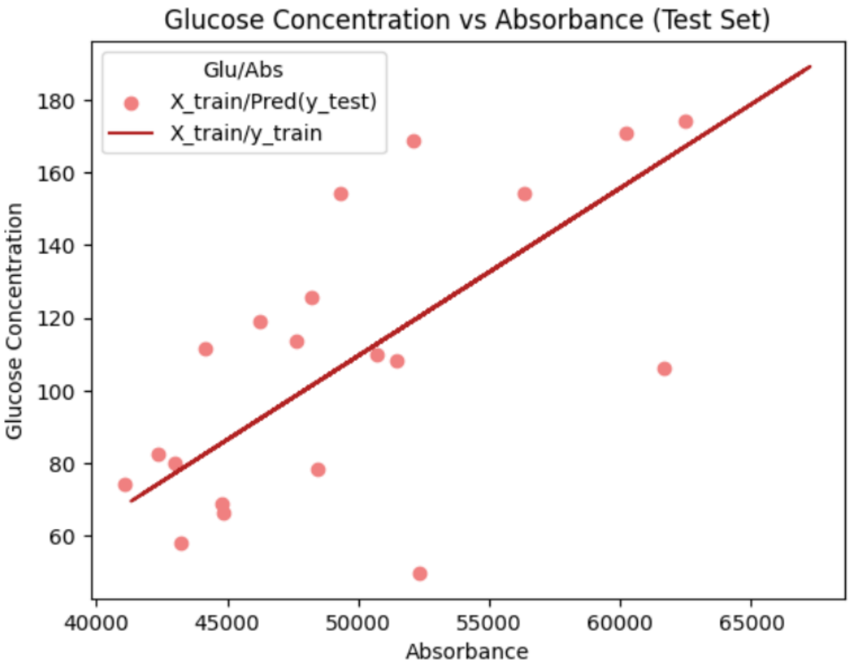

Figure 9: Scatter Plot for Test Set

The above figure presents two scatter plots that evaluate a non-invasive glucometer using a linear regression model. The y-axis in both plots represents blood glucose concentration, likely in milligrams per deciliter (mg/dL). The x-axis of the plot depicts the corresponding light absorption values (possibly in arbitrary units) for the training set.

The presence of two plots allows us to assess the model's performance on both the data used to train it (training set) and unseen data (testing set). Ideally, both plots would exhibit a positive correlation, signifying a rise in light absorption with increasing blood sugar levels. The tightness of the data points around the respective regression lines would also be informative. A tighter cluster in the training set plot suggests good model fitting, while a similar pattern in the testing set plot indicates the model's generalizability to unseen data.

5.3 Use case

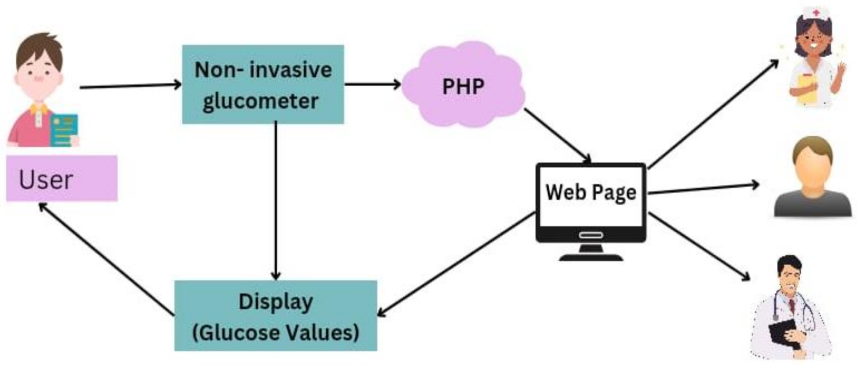

Figure 5.5: Use Case Diagram

This use case diagram offers a glimpse into the core functionality of a non-invasive glucometer. The user, the sole actor in this scenario, interacts with the system, represented by the glucometer itself. The user initiates the process by triggering a "Measure Blood Glucose" action, likely through a button press or following specific device instructions (not shown). The system responds by taking a blood sugar measurement using its internal technology, which remains outside the scope of the diagram. Once the measurement is complete, the glucometer transmits the blood sugar reading wirelessly to a web page for user viewing. This suggests the device might connect to a smartphone app or a separate display unit. The presence of a "PHP" label within the system block might indicate the programming language used to develop the web interface component responsible for displaying the results.

While the specific measurement method employed by the glucometer (e.g., light absorption, electrical signals) isn't shown, this use case diagram emphasizes a user-centric approach to blood sugar monitoring with a non-invasive glucometer. The user initiates the measurement with a simple action, and the device promptly displays the results on a readily accessible web interface, potentially eliminating the need for a separate display unit. This streamlined interaction caters to user convenience and potentially improves adherence to blood sugar monitoring routines. However, it's important to acknowledge that non-invasive glucometers are still under development, and their accuracy might not yet fully match traditional finger-prick blood tests. Further research and development are likely needed to refine the technology and ensure reliable blood sugar readings.

5.4 Timeline of the Project

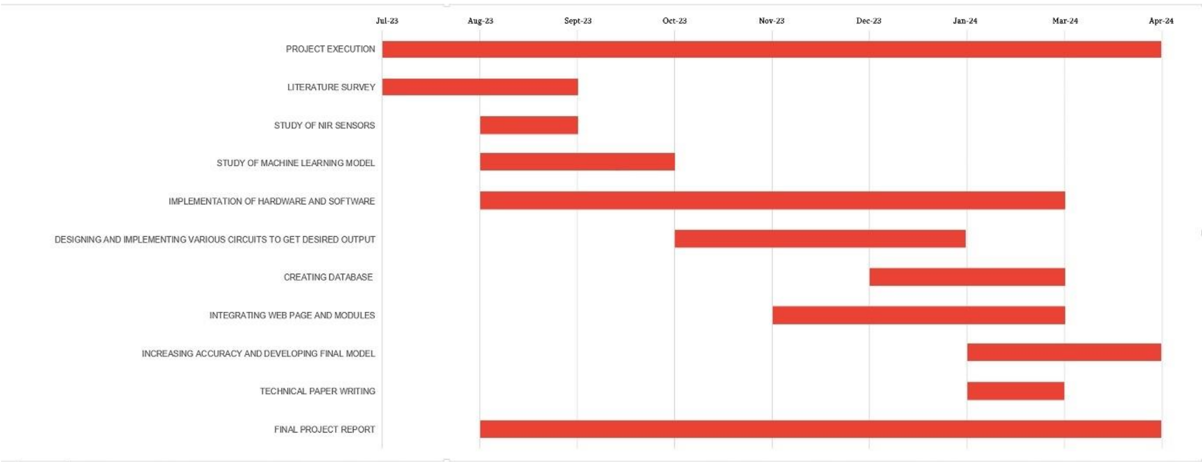

Figure 5.6: Timeline of the project

Chapter 6

Results

6.1 Hardware Experimental Setup

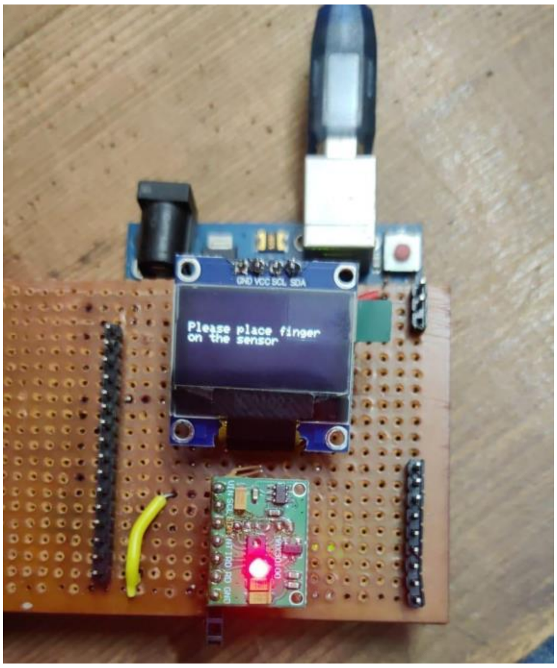

Figure 6.110: Hardware Implementation

The sensing circuit serves as the critical interface between the biological realm of glucose concentration in the blood and the digital domain of data interpretation by the microcontroller. Upon detecting the presence of glucose molecules, it translates this biochemical information into electrical signals, generating a voltage proportional to the concentration of glucose molecules. This raw voltage output undergoes meticulous processing within the conditioning circuit. Here, sophisticated algorithms meticulously filter out extraneous noise inherent in the signal, ensuring accuracy and reliability in the measurement process. Furthermore, the conditioning circuit plays a pivotal role in amplifying the signal to optimal levels, facilitating seamless communication with the microcontroller. By refining the signal and enhancing its fidelity, the conditioning circuit ensures that the microcontroller can accurately interpret the glucose concentration data, enabling precise and timely adjustments in diabetes management strategies. This synergy between the sensing and conditioning circuits lays the foundation for the seamless integration of biological insights with technological innovation, ultimately empowering individuals to effectively monitor and manage their blood glucose levels with confidence and precision.

6.2 Software Setup

Data from Arduino is processed and sent to PHP for real-time storage. A web interface is developed using HTML, CSS, and JavaScript to display data from Firebase, utilizing Chart.js for visualization. Firebase Authentication ensures secure access, while alerts promptly notify users of critical glucose level changes. Additionally, a companion mobile app is available for on-the-go monitoring. Thorough testing is conducted to ensure the accuracy and reliability of the entire system.

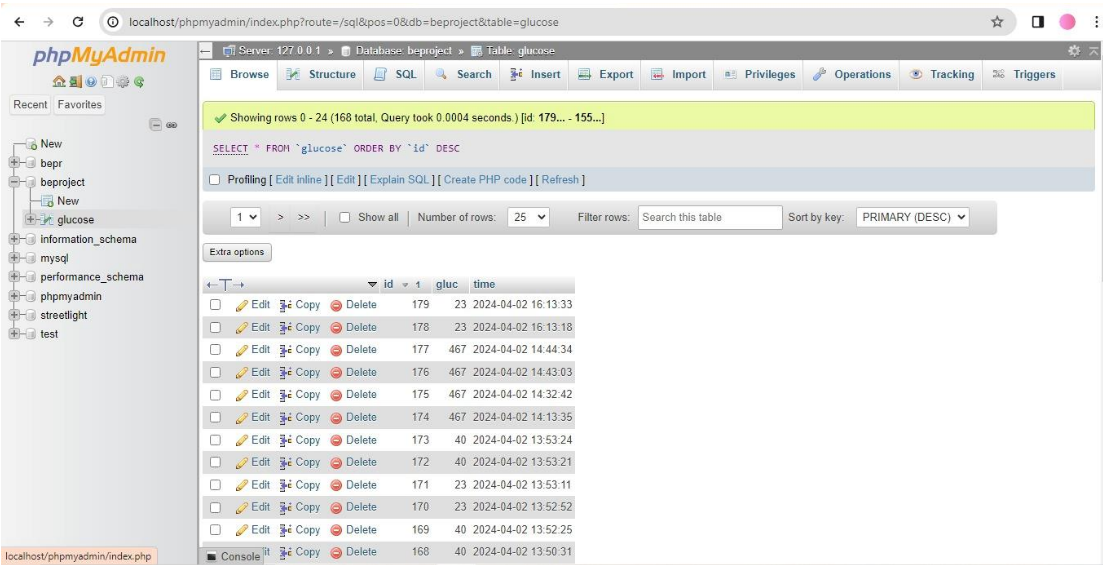

Figure 6.2: PHP Server

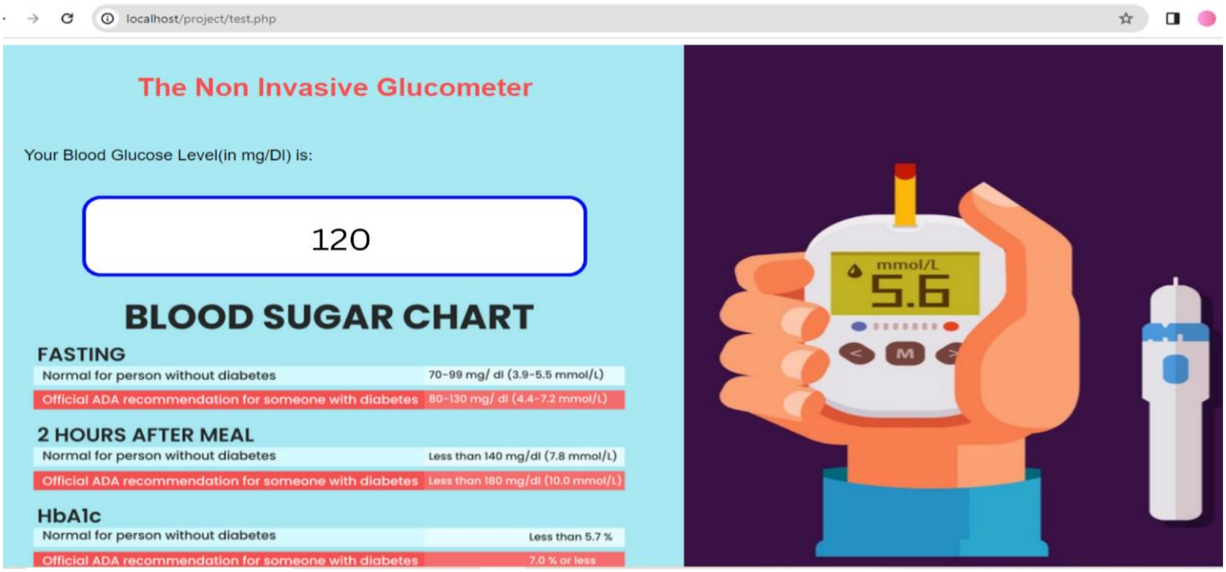

Figure 6.3: Web Page

6.3 Performance Evaluation:

Sr. No	Glucose (mg/dl)	Best Function Calculated Glucose (mg/dl)	Accuracy
1	156	151	97
2	117	116	98
3	145	150	96
4	89	94	95
5	109	129	84
6	130	127	99
7	76	80	95
8	89	96	92
9	67	71	94
10	156	146	90

Table 6.1: Performance Evaluation Table

The table shows the performance evaluation of a sugar analyzer. Ten samples were measured by the analyzer, and the sugar content readings were compared to a reference value, most likely obtained from a laboratory-grade device. The table lists the sample number, the sugar reading from the analyzer (mg/dL), the reference value (mg/dL), and the accuracy of the analyzer reading compared to the reference value. Accuracy is expressed as a percentage. For example, for sample number 1, the analyser reading was 156 mg/dL, the reference value was 151 mg/dL, and the accuracy was 97%. This indicates that the analyser reading was 5 mg/dL higher than the reference value. Overall, the analyzer readings ranged from 67 mg/dL to 145 mg/dL, with accuracies between 84% and 99%. Five out of the ten readings (samples 1, 2, 3, 4, and 6) had an accuracy of 95% or higher.

Chapter 7

Conclusion & Future Scope

7.1 Conclusion

In our pursuit of transforming healthcare practices, especially in diabetes management, we introduce an innovative functional prototype for non-invasive glucose monitoring.

- Introduction of Functional Prototype: We present a functional prototype for non-invasive glucose monitoring, designed to revolutionize healthcare practices, particularly in diabetes management.
- Recorded Accuracy: The Accuracy column in the Performance Evaluation Table demonstrates variability in recorded accuracy percentages.
- Promising Insights: Despite variability, our findings offer promising insights into the feasibility and efficacy of our prototype.
- Validation of Concept: These preliminary results validate the successful translation of theoretical concepts into tangible solutions, affirming the potential of our approach.
- Continuous Improvement: With ongoing refinement and validation, we aim to deliver a cutting-edge solution that empowers individuals with accurate and accessible glucose monitoring capabilities.
- Advancement Towards Personalized Healthcare: Our research represents a significant advancement towards personalized and proactive healthcare, promising improved management and outcomes for individuals living with diabetes.

In summary, our study introduces a functional prototype for non-invasive glucose monitoring, showcasing promising insights into its feasibility and efficacy. Through ongoing refinement and validation, we strive to deliver a cutting-edge solution that enhances personalized healthcare and improves management for individuals with diabetes.

7.2 Shortcomings

In the sphere of non-invasive glucometer projects, achieving accuracy akin to invasive counterparts remains a daunting challenge due to factors like variations in skin type, hydration levels, and body composition, which can introduce complexities impacting glucose readings' precision. Standardizing calibration methods across different devices is crucial to mitigate variations in readings, emphasizing the need for consistent measurement procedures. External factors such as ambient light, temperature fluctuations, and skin substances further complicate accuracy, necessitating robust calibration protocols for precise and dependable glucose measurements. Individual variability in skin characteristics poses another hurdle, necessitating tailoring the technology to accommodate diverse user profiles. Standardizing data processing methods and ensuring precise sensor placement are vital for reliable glucose readings. Overcoming challenges related to motion artifacts during measurement is critical for enhancing accuracy and reliability. Addressing these complexities will bolster the effectiveness of non-invasive glucometer projects in accurately monitoring glucose levels, thereby advancing their potential impact on diabetes management.

7.3 Future Scope:

Looking ahead, the non-invasive glucometer project holds immense potential for further advancements and refinement. Future research efforts could focus on enhancing accuracy through the development of advanced sensor technologies capable of overcoming factors such as skin variability and environmental interference. Additionally, the implementation of machine learning algorithms could enable real-time data analysis and adaptive calibration, further improving measurement precision and reliability. Collaborative initiatives to establish standardized calibration methods and protocols across different non-invasive glucometer devices would be instrumental in ensuring consistency and comparability of glucose readings. Moreover, integrating wireless connectivity features could facilitate seamless data transmission to healthcare providers or mobile applications, enabling remote monitoring and personalized management strategies. Further exploration into novel sensing modalities, such as spectroscopy or bioimpedance, could unlock new possibilities for non-invasive glucose monitoring. Continued innovation and collaboration in the non-invasive glucometer project are essential to realizing its full potential in revolutionizing diabetes management and improving the quality of life for individuals living with diabetes.

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