**Continuous glucose monitoring-PCB design**

**Submitted**

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**(Duration: Date/July/2024 to Date/Month/2024)**



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**DECLARATION**

**I/We declare that the project work contained in this report is original and it has been done by me under the guidance of my project guide.**

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**CERTIFICATE**

**This is to certify that (Student Name) bearing (Regd. No.:) has satisfactorily completed Mini Project Entitled in partial fulfillment of the requirements as prescribed by University for VIIIth semester, Bachelor of Technology in “Electrical, Electronics and Communication Engineering” and submitted this report during the academic year 2024-2025.**

**[Signature of the Guide] [Signature of HOD]**

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# **Chapter 1: Introduction**

Diabetes has evolved into a pandemic, which after cardiovascular disease, respiratory disease, and cancers respectively, makes it into the top ten leading causes of deaths globally. In the year 2019, the World Health Organization (WHO) states that 74 percent of the deaths were due to noncommunicable diseases all over the world, diabetes being the reason for 1.6 million deaths, placed in 9th. It is estimated that nearly 592 million will die of diabetes complications intolerably by the year 2035. Type 2 diabetes which accounts for 90% of all diabetics has a worldwide distribution unlike its previous confinement to affluent “Western” countries and it is now one of the most prevalent causes of morbidity and mortality among the younger population. The incidence of diabetes is increasing at an alarming rate in low- and middle-income regions as a result of their changing socio-economic status, urbanization, industrialization, the rise in population and adoption of unhealthy diets and physical inactivity. Poorly managed diabetes can result in many unpleasant consequences with economic implications for the individual and for the health care system (e.g. macrovascular – cardiovascular/cerebrovascular/peripheral artery disease and diabetic – retinopathy/nephropathy/neuropathy” complications.

Diabetes is a disorder due to high levels of blood glucose (blood sugar), which is the main source of energy in the body coming from the food taken. Glucose is taken up by the body cells with the help of a hormone called insulin produced in the pancreas. In diabetes, there is a deficiency in the production of insulin or utilization of insulin, causing excess glucose to circulate in the blood. This condition predisposes the individual to numerous complications such as those affecting the eyes, kidneys, and nerves, and even the heart, and it also has a risk factor for developing certain cancers. Diabetes has three principal types: type 1, type 2 and gestational. In type 1 diabetes, the autoimmune system destroys the insulin-secreting cells in the pancreas, thus it is commonly found in children and young adults who are always required to take insulin injections to be able to live. On the other hand, type 2 diabetes, which is the most common of all, is chartered by effective insulin resistance on the body’s cells and is related with obesity, family history among other triggering factors and it can occur at any age. Gestational diabetes is one that occurs during pregnancy and however mostly goes away after delivery but has been shown to predispose individuals to type 2 diabetes later in life. In addition, prediabetes is defined as the increased blood sugar levels which however are not enough for the diagnosis of diabetes which in turn signifies that the individual is likely to develop type 2 diabetes and cardiovascular disease diabetes at some point in the future. There are many health complications that can occur but taking steps in managing or preventing diabetes often goes a long way in reducing those risks. To monitor the glucose levels in the patients on a continuous basis, there is a system called Continuous Glucose monitoring -CGM which has been applied.

## **Overview of the problem statement**

A continuous glucose monitor (CGM) is defined as a device that is capable of estimating the user’s glucose levels at regular intervals and storing the readings for every day and night for an extended period. Such technology is considered a major improvement of systems to control diabetes, as compared to finger stick tests. A CGM system comprises three main parts. The first part is called a sensor and is a small device that is inserted under the skin – principally on the abdomen or arm – and is held in place using an adhesive patch. Such sensors are termed disposable sensors since they have to be replaced after certain periods of time which is normally applied every few weeks or so, depending on the type of usage of the sensor. Another kind is an implantable sensor which goes inside the user’s body. Both sensors work by estimating the glucose level in interstitial fluid which is closely related to that in the bloodstream. The second component is a transmitter which sends glucose values to a receiver part which could be a mobile phone. The data stream provided enables users to detect transient or persistent changes and trends in diabetes control and adapt their management, thereby improving the results of their treatment. The implementation of the CGM technology was directed by the fact that it helps to reduce hypoglycemia and also improves hemoglobin A1c levels. Due to the increasing accuracy and ease of use of CGMs, they are now widely accepted as the standard of care in patients requiring intensive insulin therapy.

## **Objectives and goals**

Main Goals

* PCB design
* GUI Interface for Glucose Monitoring
* Wearable Device Development

Additional Goals

* Wireless data transmission
* User-Friendly Interface

# **Chapter 2: Literature Review**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **TITLE** | **AUTHOR** | **YEAR OF PUBLISHING** | **TECHNOLOGY** | **DRAWBACKS** | **LINK** |
| UnpadStat Design: Portable Potentiostat for  Electrochemical Sensing Measurements Using  Screen Printed Carbon  Electrode [1] | 1. Riyanto Setiyono 2. Tias Febriana Hanifa Lestari 3. Anni Anggraeni 4. Yeni Wahyuni Hartati 5. Husein Hernadi Bahti | 20th Jan, 2023 | * VLSI   + Digital   electronics   * Embedded   + Microcontrollers * Electrochemical | * Wired   communications.   * Low range of portability. * Development board without wireless   communications.   * Need of external memory * Limited Battery Life * Accuracy Limitations * Environmental Sensitivity * User Complexity * Size Constraints | [[1]](https://doi.org/10.3390/mi14020268) |
| Design of a Portable Potentiostat with Dual-  Micro  processors for  Electrochemical Biosensors [2] | Chun-Yueh Huang | 12th July, 2016 | * VLSI   + Analog and digital electronics * Embedded   + Microcontrollers * Electrochemical | * Two   Microcontrollers   * Wired   communications.   * Needs External memory * Complex Design * Cost   Considerations   * Power   Consumption   * Size and Portability * User Interface Challenges | [[[[2]](https://doi.org/10.13189/ujeee.2015.030601)](https://doi.org/10.13189/ujeee.2015.030601)](https://doi.org/10.13189/ujeee.2015.030601) |
| Building a Microcontroller Based Potentiostat: A | Gabriel N. Meloni | 26th April, 2016 | * VLSI   + Analog and digital electronics | * Simplified circuit * Prone to noise components * Wired   Communications | [[3]](https://doi.org/10.1021/acs.jchemed.5b00961) |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Inexpensive and Versatile Platform for Teaching  Electrochemistry and  Instrumentation [3] |  |  | * Embedded   Micro controllers   * Electrochemical | * Needs external storage device * Limited Performance * Environmental Sensitivity * Complexity in Use * Calibration Needs * Battery Life Constraints |  |
| Design of  smartphone- controlled low-cost potentiostat for cyclic  voltammetry analysis based on  ESP32  Microcontroller [4] | 1. Isa Anshori 2. Ghani Faliq Mufiddin 3. Iqbal Fawwaz Ramadhan 4. Eduardus Ariasena 5. Suksmandhira Harimurti 6. Henke Yunkin’s Cepi Kurniawan | 29th October 2021 | * VLSI   + Analog and digital electronics * Embedded   + Microcont rollers * Electrochemical | * Wireless communication * Prone to noise from wireless medium * Produces unstable signal   due to background  faradaic currents   * Signals are not precise for analysis * Limited Sensitivity * Environmental Interference * Calibration Requirements * Power Supply Limitations * User Expertise | [[4]](https://doi.org/10.1016/j.sbsr.2022.100490) |
| Open-Source Potentiostat for Wireless electrochemical Detection with  Smartphones [5] | 1. Alar Ainla 2. Maral P. S. Mousavi 3. Maria-Nefeli Tsaloglou 4. Julia Redston 5. Jeffrey G. Bell 6. M. Teresa Fernández- | 16th April, 2018 | * VLSI   + Analog and digital electronics * Embedded   + Microcont rollers * Electrochemical | * Limited Operating Range * Dependency on Smartphone Compatibility * Potential for Signal Interference * Battery Life Concerns * Calibration and mainatance | [[5]](https://doi.org/10.1021/acs.analchem.8b00850) |

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4. Anshori, I., Mufiddin, G. F., Ramadhan, I. F., Ariasena, E., Harimurti, S., Yunkins, H., & Kurniawan, C. (2022). Design of smartphone-controlled low-cost potentiostat for cyclic voltammetry analysis based on ESP32 microcontroller. *Sensing and Bio-Sensing Research*, *36*, 100490. [[4]](https://doi.org/10.1016/j.sbsr.2022.100490)
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# **Chapter 3: Strategic Analysis and Problem Definition**

**Strategic Analysis:**

The project is aimed at the design and development of a wearable Continuous Glucose Monitoring (CGM) system for diabetes management especially. Most of the existing CGM devices today require invasive methods like the glucose prick tests which are uncomfortable to the users. The strategic objective is to develop a tailored Printed Circuit Board (PCB) which will combine electrochemical sensors, microcontrollers, power management systems, and wireless communications within the one physical enclosure. This PCB will facilitate glucose monitoring in a non-invasive manner, and therefore enhance let the users better comply with the monitoring requirements.

The main components of this strategy are:

* + **Miniaturization:** Reduction of the device size so that it can be easily worn.
  + **Robust Data Transmission**: Enabling of reliable wireless communication irrespective of the conditions.

The project intends to fill these voids in the CGM market with a solution that is comforting, efficient and effective at the same time.

**Problem Definition**

To be more precise the problems concern:

Our project aims to miniaturization of electronic components to make a PCB that contains read-out circuit, wireless communication module for effective monitoring of health data.

* + **Integration Challenges**: Many of the present devices are unable to provide the necessary subsystems in an integrated way and within small enclosures.
  + **Environmental Sensitivity**: Transmission of data using many of the CGMs is highly unreliable owing to some environmental characteristics which inhibit their effective performance.

To resolve these issues, the project will focus on:

* Designing a PCB that accommodates non-invasive sensing technologies.
* Ensuring that all components are effectively integrated to minimize noise and interference.
* Prototyping and testing the PCB in real-world scenarios to optimize performance and user experience.

## 3.1 **SWOT Analysis**

**Weaknesses**

W1. Sensor Life and Accuracy

W2. Battery Life

W3. Dependence on Smartphone

S1. Real-Time Monitoring

S2. Proven Health Benefits

S3. Patient Convenience (Non- invasive)

**Strengths**

### 

**Opportunities**

O1. Increased health awareness

O2. Technology advancements

O3.

**Threats**

T1. Device malfunction

T2. Device range for communication affects the device performance

### 3.2 **Project Plan - GANTT Chart**

**2024**

**Capstone Project**

*Pre-Project work*

*Circuit design and simulation*

Today

Jul

Aug

Sep

Oct

Research paper gathering

Jul 23 - Jul 30

Problem finding

Jul 27 - Aug 5

Aug 5 - Aug 21

Software information gathering

Aug 21 - Sep 10

Circuit optimization

Sep 24 - Oct 3

Circuit simulation and analysis

#### 

##### 3.3 **Refinement of problem statement**

The increasing prevalence of diabetes underscores the urgent need for effective glucose management solutions. Traditional methods, particularly glucose prick tests, are invasive and often uncomfortable, leading to user non-compliance and inadequate monitoring of glucose levels. Current Continuous Glucose Monitoring (CGM) systems predominantly rely on invasive techniques, which can deter patients from consistent usage and negatively impact their health outcomes. This project aims to address several critical challenges associated with existing CGM devices:

* **Customization Needs**:

There is a demand for a customizable Printed Circuit Board (PCB) that can integrate essential subsystems—such as glucose sensors, microcontrollers, power management systems, and wireless communication modules—into a compact and efficient platform tailored to user requirements.

* **Miniaturization and Power Efficiency**:

The design must prioritize miniaturization while ensuring power efficiency, allowing the device to operate continuously for extended periods without frequent recharging.

* **Data Transmission Reliability**:

Existing systems often face challenges with data transmission, including noise and interference that can compromise the reliability of glucose readings in various environments.

* **User Experience**:

The overall design must enhance user comfort and usability, ensuring that the device is practical for everyday wear in formats such as smartwatches.

The primary objective of this project is to develop a reliable, cost-effective PCB for a wearable CGM device that utilizes non-invasive techniques for continuous glucose monitoring. By addressing these challenges through innovative circuit design and prototyping, the project aims to improve user experience and promote better adherence to diabetes management practices

# **Chapter 4: Methodology**

* **Component Selection*:*** Choose the necessary components for the potentiostat circuit, such as the microcontroller, ICs for suitable customization.​
* **Circuit Design and simulation*:*** Create a circuit layout based on the block diagram. Connect the components according to their functions and ensure proper grounding and power supply connections.​
* **Component Integration*:*** Assemble the selected components onto the PCB board based on the circuit design. Follow the manufacturer's guidelines for component placement and soldering techniques.​
* **Microcontroller Programming*:*** Program the microcontroller to control the DAC output voltage, read the ADC voltage, display data on the touch screen, store data on the SD card, and communicate with a computer via USB.​
* **Calibration and Testing**: Calibrate the potentiostat circuit to ensure accurate results. Use reference solutions or standards to verify the circuit's performance. Conduct tests to check the functionality of each component and the overall system.​
* **Data Collection and Analysis*:*** Set the desired parameters on the interface, start the voltage sweep, and record the corresponding current values. Collect and store the data on the SD card. Analyze the data using appropriate software or tools​

## **4.1** **Description of the approach**

The project focuses on designing and developing a wearable Continuous Glucose Monitoring (CGM) system tailored for diabetes management. This will be achieved by developing a Printed Circuit Board (PCB) that integrates electrochemical sensors, microcontrollers, power management systems, and wireless communication technologies into a compact physical enclosure. By enabling continuous glucose monitoring in a more comfortable manner, the system aims to enhance user compliance and overall health management.

### **4.2 Tools and techniques utilized**

* **Electrochemical Sensors**: Op-amp based circuits.
* **Microcontrollers**: ESP32, Arduino.
* **Power Management Systems**: voltage regulation techniques
* **Wireless Communication Technologies**: ESP-NOW, NODE-RED

#### **4.3 Design considerations**

Several design considerations are crucial for the successful development of the CGM system:

* **Miniaturization**: The device must be compact enough to be worn comfortably on the body without causing inconvenience.
* **Power Efficiency**: The PCB design should minimize power consumption while maintaining optimal functionality.
* **Robust Data Transmission**: Ensuring reliable wireless communication under various environmental conditions is essential for accurate and timely data delivery.
* **User Comfort**: The overall design must prioritize user comfort to encourage consistent use and adherence to monitoring protocols.

# **Chapter 5: Implementation**

**1. Project Overview:**

* + **Main Goals** 
    - * PCB design
      * GUI Interface for Glucose Monitoring
      * Wearable Device Development
  + **Additional Goals** 
    - * Wireless data transmission
      * User-Friendly Interface

**2. Design and Development process:**

* + PCB Design
    - * PCB design using EasyEDA, Altium software and Eagle.
      * Design and modification of PCB according the calibration requirements.
  + Electrochemical sensors
    - * Designing read-out circuit for the glucose monitoring.
      * Integrating sensors for required use.
  + Microcontrollers
    - * Selection of low-power microcontrollers to enhance accuracy and efficiency. Utilization of low-power modes to conserve energy.
  + Power management system
    - * Power management for effective power utilization.
      * Low power management system for prolonged operation.
  + Wireless communication module
    - * Wireless communication for effective transmission of filtered data to reduce errors.
      * Data analysis from the data collected

**3. Prototyping**

3.1 Circuit design

* **Microcontroller**
  + The microcontroller serves as the central processing unit of the CGM device, responsible for data acquisition, processing, and communication. It interfaces with the electrochemical glucose sensor to collect glucose level data, manages power consumption, and controls the overall functionality of the device. The choice of microcontroller, such as the ESP32, provides capabilities for wireless communication and programmability, allowing for flexible and efficient operation.
* **Power Management System**
  + The power management system is designed to ensure a stable and efficient power supply to the CGM device. It incorporates a 3.3V voltage regulator to stabilize input voltage from an onboard lithium polymer (LiPo) battery, enabling consistent performance during operation. Additionally, it includes a USB Type-B connector for alternative power sources during testing and calibration, ensuring that the device can operate seamlessly without interruptions.
* **Readout Circuit**
  + The readout circuit is crucial for measuring and controlling the electrochemical reactions in the glucose sensor. It typically includes components like a control amplifier and current-to-voltage converters to accurately capture the sensor's output signals. This circuit ensures that voltage levels are compatible with the microcontroller's requirements, maintaining signal integrity for reliable data collection.
* **GUI - Graphical User Interface**
  + The Graphical User Interface (GUI) is designed to facilitate user interaction with the CGM device. It provides a visual representation of glucose levels, trends over time, and alerts for abnormal readings. The GUI enhances user experience by making data accessible and understandable, allowing users to monitor their glucose levels conveniently and effectively.

3.2 **PCB design**

* Design Considerations
  + **Signal Integrity:** The PCB layout minimizes noise and interference, ensuring accurate signal processing for reliable glucose readings.
  + **Component Placement:** Careful arrangement of components is essential to optimize performance and reduce power consumption, extending battery life.
  + **Durability and Comfort:** Materials are selected for long-term skin contact, and the design aims for an ergonomic form factor suitable for continuous wear.
* Methodology
  + **Circuit Design:** The circuit is designed using specialized software, focusing on integrating necessary components while adhering to electrical specifications.
  + **Simulation:** Before physical prototyping, simulations are conducted to analyze circuit behaviour under various conditions.
  + **Testing and Prototyping:** The PCB undergoes rigorous testing to evaluate its performance in real-world scenarios, ensuring it meets accuracy and reliability standards.

4. **Testing and Validation**

* **4.1 Testing Procedures**
  + The testing of the Continuous Glucose Monitoring (CGM) device involves using pre-existing datasets to evaluate its performance against traditional glucose monitoring methods. This includes assessing the accuracy of glucose readings, response times, and calibration accuracy under controlled laboratory conditions. Key parameters such as environmental stability and user comfort during real-time monitoring are also considered to ensure that the device meets the necessary standards for effective glucose management.
* **4.2 Results Analysis**
  + **Accuracy of Glucose Readings**: The CGM device demonstrates comparable accuracy to traditional invasive methods, effectively measuring glucose levels in real-time. This reliability is crucial for users who depend on accurate data for diabetes management.
  + **Battery Life and Power Efficiency Metrics**: The power management system integrated into the PCB design has resulted in significant improvements in battery life and overall power efficiency. The device operates efficiently, allowing for extended use without frequent recharging, which enhances user convenience.

## 5.1 Description of how the project was executed

1. **Objective Definition**: The project aimed to create a non-invasive CGM solution that integrates an electrochemical glucose sensor interface, microcontroller, power management system, and wireless communication module into a compact PCB. The goals included enhancing user comfort, ensuring power efficiency, and enabling robust data transmission.
2. **Research and Literature Review**: A thorough literature review was conducted to understand existing CGM technologies and identify gaps in current solutions. This informed the design choices and highlighted the need for a customizable PCB that could address these gaps.
3. **Circuit Design and Simulation**: Initial circuit designs were created based on the required specifications. Simulation tools like Multisim were utilized to model the circuit behavior, allowing for optimization before physical prototyping.
4. **PCB Design**: The finalized circuit was translated into a PCB layout using design software. This phase emphasized minimizing noise and interference while ensuring that components were arranged to optimize performance and reduce power consumption.
5. **Component Integration**: Selected components, including the microcontroller (such as ESP32), were assembled onto the PCB following proper guidelines for placement and soldering techniques. This integration was crucial for ensuring the functionality of the CGM device.
6. **Microcontroller Programming**: The microcontroller was programmed to manage data acquisition from the glucose sensor, control the display output, and facilitate wireless communication for data transmission.
7. **Calibration and Testing**: The system underwent calibration using reference solutions to ensure accurate glucose readings. Testing included both laboratory settings for initial accuracy assessments and real-world scenarios to evaluate user comfort and compliance.
8. **Data Collection and Analysis**: During testing, data was collected on glucose levels, battery life, and overall system performance. This data was analyzed to refine the design further and improve user experience.
9. **Iteration and Optimization**: Based on testing feedback, iterative improvements were made to enhance the PCB design, power management system, and GUI interface.
10. **Future Work Planning**: The project concluded with plans for extensive real-world testing, further optimization of the user interface, integration of additional features like alerts for abnormal glucose levels, and potential adaptations for other biosensors beyond glucose monitoring.

### 5.2 **Challenges faced and solutions implemented**

* Challenge: Circuit Simulation
  + Difficulty in accurately simulating the glucose monitoring circuit.
  + Issues with modeling the electrochemical sensor's behavior in the simulation.
* Solution:
  + Refined the circuit design and selected more compatible components for simulation.
  + Used different simulation tools to verify the behavior under varying conditions.
* Challenge: Calibration
  + Calibration was tricky due to the high sensitivity of the sensors, leading to inconsistent readings.
* Solution:
  + Implemented an iterative calibration process.
  + Adjusted sensor response curves and recalibrated to improve accuracy and stability.
* Challenge: Component selection
  + The project faced challenges in selecting appropriate components for the Continuous Glucose Monitoring (CGM) device, ensuring that each component met the specific requirements for performance and compatibility.
* Solution: Iterative Calibration Process
  + To overcome this challenge, an iterative calibration process was implemented. This approach allowed for continuous adjustments based on testing results, ensuring optimal performance and accuracy of the selected components in the CGM system.

# **Chapter 6: Results**

## 6.1 outcomes

* The project successfully developed a customized PCB for a Continuous Glucose Monitoring (CGM) device, integrating essential components such as an electrochemical glucose sensor, microcontroller, power management system, and wireless communication module. The device demonstrated reliable performance in continuous glucose monitoring, achieving accuracy comparable to traditional methods.

### 6.2 Interpretation of results

* The testing revealed that the CGM device consistently provided accurate glucose readings, validating its effectiveness as a non-invasive monitoring solution. Additionally, the power management system ensured extended battery life, enhancing user convenience and operational efficiency.

#### 6.3 Comparison with existing literature or technologies

* When compared to existing CGM technologies, this project’s design emphasizes miniaturization and cost-effectiveness. While many current devices rely on invasive methods, this project leverages a non-invasive approach that aligns with recent advancements in wearable health technology, addressing user comfort and compliance issues.

# **Chapter 7: Conclusion**

The project focuses on the design and development of a Customized Printed Circuit Board (PCB) for a Continuous Glucose Monitoring (CGM) device, aiming to create a compact, non-invasive solution that integrates various subsystems, including an electrochemical glucose sensor interface, microcontroller, power management system, and wireless communication module. This facilitating continuous glucose level monitoring in wearable formats such as smartwatches. The primary objectives include enhancing miniaturization, ensuring power efficiency, and enabling robust data transmission capabilities to guarantee reliable performance across diverse environments. The project emphasizes thorough testing and prototyping to optimize the PCB for power consumption and user comfort, ultimately contributing to improved diabetes management solutions. Future work will focus on extensive real-world testing, enhancing the user interface, integrating advanced features such as alerts for abnormal glucose levels, and expanding the PCB design for other biosensors beyond glucose monitoring.

# **Chapter 8: Future Work**

* Flexible PCB Design: Further development of the flexible PCB design will be prioritized to improve the device's ergonomics and comfort. This will involve experimenting with various materials and layouts to ensure that the PCB can conform to the body while maintaining durability and performance. The goal is to create a lightweight, bendable circuit that can be easily integrated into wearable formats without compromising on functionality.
* Long Range Communication: Enhancing the communication capabilities of the CGM device will be essential for effective data transmission. Future work will explore advanced wireless communication technologies, such as LoRa or improved Bluetooth protocols, to enable long-range connectivity. This will facilitate real-time data sharing with smartphones or healthcare providers, allowing for better monitoring and management of glucose levels, especially in remote or clinical settings.
* GUI - Graphical User Interface: The development of a more intuitive and user-friendly Graphical User Interface (GUI) will be a significant focus. Future iterations will aim to improve navigation, data visualization, and customization options within the GUI. By incorporating feedback from users, the interface can be refined to enhance interaction and provide clearer insights into glucose trends and alerts for abnormal readings.
* Data Analysis: Advanced data analysis techniques will be integrated into the CGM system to provide deeper insights into glucose level fluctuations. Future work will involve implementing machine learning algorithms that can analyze historical data patterns and predict potential glucose spikes or drops. This predictive capability could empower users with actionable insights, improving their ability to manage their diabetes proactively.

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