Non-Invasive Blood Glucose Monitoring System with Sensor Technology

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***Abstract*—Diabetes management often relies on invasive finger-prick tests, which are painful, costly, and inconvenient for continuous monitoring. This paper presents an IoT-enabled, non-invasive blood glucose monitoring system that measures glucose levels in real time without blood samples. The system employs optical sensors, electromagnetic fields, and bioimpedance techniques to detect glucose concentrations through the skin. An ESP32 microcontroller processes the data and transmits it to a cloud platform via Wi-Fi. Real-time glucose readings, alerts, and historical trends are displayed using a mobile app like Blynk. Machine learning algorithms enhance predictive capabilities by analysing past glucose trends, enabling proactive diabetes management. The integration of IoT ensures seamless data storage, remote monitoring, and telemedicine support. Compared to traditional methods, this solution is painless, cost-effective, and user-friendly. Future improvements using AI-driven analytics and advanced sensor technology may further enhance system accuracy and efficiency. The proposed system aims to revolutionize diabetes care and improve patient quality of life.**

***Keywords*— IoT, non-invasive glucose monitoring, ESP32, near-infrared spectroscopy, machine learning, cloud computing, real-time monitoring, diabetes management.**

I. INTRODUCTION

Invasive blood glucose and cholesterol testing is the most common method, but it is costly, painful, and dangerous since it can damage skin cells and transmit infections. In order to prevent health problems and organ damage, two of the most common diseases in the world, diabetes and cholesterol, require constant monitoring. Therefore, more frequent testing and painless monitoring will be possible using a non-invasive approach. Applying the idea of an NIR light source's refractive and reflecting properties to blood components, the blood glucose and cholesterol levels may be determined [1]. Our innovative wearable bilirubin monitoring gadget, which we created and developed for this study, stands out for its affordability, real-time monitoring capabilities, and validation against clinical gold-standard techniques. The uses an

ESP32 microcontroller and a colour sensor to analyse the colour of the newborn's forehead skin in order to anticipate bilirubin levels. In contrast to other non-invasive bilirubin monitoring methods that could have depended on expensive imaging equipment or proprietary algorithms, our device uses a generally accessible and reasonably priced sensor technology, which makes it especially appropriate for low-resource environments [2]. A monitor or a smartphone app receives continuous data from the sensor, which detects the amount of glucose in interstitial fluid. By offering comprehensive data for improved treatment decisions, trends, and warnings for high or low glucose levels, assist people with diabetes in better controlling their blood sugar levels [3]. The most important aspect of our everyday life is our health. Effective performance of daily tasks requires excellent health. New technologies like wearables and the Internet of Things are being incorporated into modern healthcare systems. It provides greater flexibility in the collection and transmission of patient data monitored by the internet of things (IoT). Wireless technology has gained popularity as a means of meeting the demands of many businesses. The Internet of Things has lately brought together the majority of industrial disciplines, especially automation and control [4]. In order to control their condition, diabetic individuals must routinely check their blood glucose levels. For the majority of patients, traditional intrusive technology techniques can be uncomfortable and unpleasant. Consequently, It is necessary to have non-invasive glucose monitors that measure blood sugar levels using external sensors. Non-invasive sensors are more comfortable and painless, and they can continually check blood sugar levels [5].

- To create a real-time, non-invasive blood glucose monitoring system that makes use of bioimpedance, optical, and electromagnetic sensor technologies.
- To include an ESP32 microcontroller for wireless transmission and data collection over Wi-Fi to a cloud-based platform.
- To create an intuitive smartphone app (like Blynk) that shows real-time blood sugar readings, notifications, and past patterns for ongoing tracking.
- To apply machine learning algorithms for predictive analysis of glucose fluctuations, enabling proactive diabetes management.
- To provide a cost-effective, painless, and scalable alternative to traditional finger-prick glucose testing, improving patient comfort and healthcare outcomes.

The remainder of the paper is divided into significant sections, each of which is described as follows: Section II enumerates the ongoing research projects that various authors have finished in the field of non-invasive blood glucose monitoring systems utilizing sensor technology. The workflow of the suggested approach is described in Section III. Results of the suggested model's comparison with the conventional model for the Non-Invasive Blood Glucose Monitoring System with Sensor Technology are displayed in Section IV. Section V concludes the recommended work that will be done in a future scope and includes references.

II. RELATED WORK

Moses et al., (2023) Diabetes has a major influence on world health, and because existing methods are uncomfortable, there is a need for non-invasive blood glucose monitoring devices. In this research, we assessed non-invasive blood glucose monitoring methods that were verified against clinical blood glucose records using skin, breath, and saliva. In order to develop individualized, real-time diabetes management systems for healthcare applications, future research should concentrate on combining these technologies with IoT, mobile platforms, and data analytics.

Hina et al., (2022) The non-invasive glucose measurement methods and the associated studies are briefly covered in this review study. Enzymatic, transdermal, and optical technologies are covered. In order to forecast blood glucose, Near Infrared (NIR) technology and NIR Photoplethysmography are the main subjects of the study. We discuss machine learning methods for predicting glucose levels and extracting features from PPG data.

Alsunaidi et al., (2021) In order to improve these technologies, scientists and researchers have been working on their development. This article summarizes the latest error analysis and validation techniques and reviews the novel non-invasive optical blood glucose monitoring techniques that have been introduced in the last six years.

Gupta et al., (2021) The designed fingertip PPG gadget uses red, green, and infrared LEDs to illuminate the skin before utilizing a transmissive and reflective data collecting mechanism. The second research then focuses on demonstrating the effectiveness of the blood glucose level (BGL) measurement gadget. A few discriminative and related properties are taken from the resulting PPG signals in order to quantify blood glucose from the signal.

Susana et al., (2022) In order to prevent potentially high medical expenses, monitoring technologies for the early identification of diabetes are crucial. The only commercially accessible monitoring techniques at the moment are intrusive ones. These techniques have serious drawbacks since taking blood samples causes discomfort for the patient. The drawbacks of invasive procedures would be addressed by a low-cost, painless, non-invasive blood glucose level (BGL) monitoring approach.

Gorst et al., (2021) The findings of experimental validation and numerical modelling of a near-field sensor are presented in the article. In addition, a human hand phantom with biological media was made for testing. The sensor is situated near the hand model in numerical modelling. It is situated near the human hand phantom in a full-scale experiment to maximize the near-field's contact with biological materials.

Shokrekhodaei et al., (2021) A specially built optical sensor's transmission values are analysed in this work using 18 distinct wavelengths ranging from 410 to 940 nm. A high correlation (0.98) between glucose content and transmission intensity is seen for four wavelengths (485, 645, 860, and 940 nm). The percentage of glucose predictions produced by regression algorithms that fall outside of the appropriate range (normal, hypoglycemic, or hyperglycemic) is examined in five machine learning approaches for glucose prediction.

Sanai et al., (2023) This investigation showed how well Bioimpedance data was obtained in a real-world environment using the prototype NI-CGM. This data was used to develop a model that could predict BGL with a clinically relevant PEG result and a promising MARD. These results may potentially lead to further development of the prototype NI-CGM wearable ring.

Ameen et al., (2025) The development of non-invasive epidermal electrochemical glucose sensors is reviewed in this article, along with current developments and challenges. It examines techniques that make use of biological fluids such sweat, tears, saliva, and skin interstitial fluid, pointing out the benefits and drawbacks of new gadget developments. The paper also discusses the possibility for improving patients' quality of life and future directions for glucose detecting technologies.

Reddy et al., (2022) Complications can be prevented and lessened with proper treatment and monitoring, even if there is currently no cure or preventive. Blood, perspiration, urine, interstitial fluids, tears, breath, and saliva are among the biological fluids that may be used to gauge the body's glucose levels. This study provides an in-depth update on the most recent advancements in biofluid-based sensors for measuring glucose levels in terms of methods, strategies, and materials used.

Kandwal et al., (2023) This article provides a comprehensive overview of the developments in non-invasive blood glucose monitoring research over the last decade, with a focus on the use of radio frequency electromagnetic waves for blood glucose sensing. The majority of the glucose sensors covered in this article have been shown to be reliable using Clarke error grid analysis and similar methods, although these sensors were constructed using a costly vector network analyser and came with all the other known drawbacks, including reproducibility, specificity, and sensitivities.

Mohammadi et al., (2021) This article provides a comprehensive overview of the developments in non-invasive blood glucose monitoring research over the last decade, while paying particular focus to the use of radio frequency electromagnetic waves for blood glucose sensing. The majority of the glucose sensors covered in this article have been shown to be reliable using Clarke error grid analysis and similar methods, although these sensors were constructed using a costly vector network framework.

Rahayu et al., (2023) In this study, we have developed and manufactured a flexible, non-invasive biosensor for blood glucose monitoring using a straightforward, printable design. Through frequency changes, the suggested sensor's ability to track blood sugar levels has been shown experimentally. A coplanar waveguide (CPW) feeding method in a cylindrical design has been suggested. With the best S11 at 22.623 dB and a bandwidth of 323 MHz, a goal frequency of 2.4 GHz was achieved. After passing through the finger phantom, the signal exhibits a notable frequency change and becomes responsive to blood glucose levels.

Satish et al., (2021) The current study is a component of the feasibility study for the use of a microwave-based sensor for non-invasive blood glucose monitoring. The electromagnetic response of the one-port microstrip patch antenna sensor was designed to vary with blood glucose levels. It has been shown in an in vitro controlled laboratory experiment.

Obeidat et al., (2021) In this research, a clever software is used to implement the pancreatic function in the body. The patient's blood sugar level is monitored and the right dosage of insulin is predicted using a machine learning model. Since the artificial neural network produced the best insulin pattern prediction with a mean square error of 5.79, we included it in our final model. Thirteen individuals with type 1 diabetes of various ages and genders have been treated using our methodology.

III. PROPOSED METHODOLOGY

The proposed methodology involves the development of a non-invasive, IoT-enabled blood glucose monitoring system that aims to transform traditional diabetes management. Instead of relying on painful finger-prick tests, the system utilizes advanced sensing techniques such as optical sensors, electromagnetic fields, and bioimpedance to detect glucose concentrations through the skin. An ESP32 microcontroller is used to collect and process sensor data, which is then transmitted to a cloud platform via Wi-Fi for real-time access. A mobile application, such as Blynk, displays glucose levels, trends, and alert notifications, providing a user-friendly interface for continuous monitoring. Machine learning algorithms are integrated into the system to analyse historical glucose patterns and improve the accuracy of predictions, allowing for proactive and personalized diabetes care. The IoT framework ensures seamless data storage, remote accessibility, and compatibility with telemedicine services, enhancing the reach and utility of the solution shown in figure 1. This approach offers a painless, cost-effective, and efficient alternative to traditional glucose monitoring and has the potential to significantly improve the quality of life for individuals with diabetes.

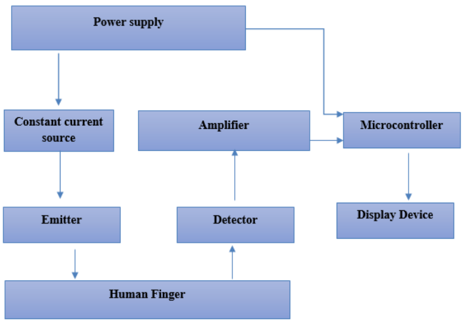

Fig. 1. Proposed Methodology Block Diagram

A. Power supply

Bridge rectifiers with RC filters and 7805 voltage regulators are a frequent combination in electronic power supply systems. When converting alternating current to direct current, a bridge rectifier is an essential part. It consists of four diodes, which we shall refer to as D1, D2, D3, and D4, placed in a bridge arrangement shown in figure 2. By rectifying the AC input's negative half-cycles, the bridge rectifier guarantees that the output voltage is always positive. Only one direction of current flow is permitted by each diode in the bridge rectifier. D1 and D3 conduct during the AC input's positive half-cycle, whereas D2 and D4 conduct during its negative half-cycle.

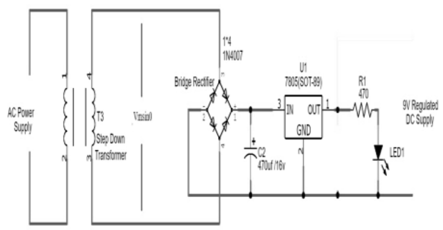

Fig. 2. Circuit Diagram of Rectifier

B. Current Sensor

Allegro Microsystems produces the ACS712, a Hall-effect-based current sensor that is often utilized in industrial and electrical applications. The Hall Effect, which produces a voltage across a conductor when subjected to a magnetic field perpendicular to the current flow, is used to assess the intensity of current. The sensor simplifies the external circuitry needed for precise current measurements by combining a Hall sensor and a precision amplifier into a single integrated circuit shown in figure 3. Depending on the needs of a particular application, the ACS712 is available in unidirectional and bidirectional variants and may measure current flow in either direction or both. Reading interpretation is comparatively simple because the sensor generates an analogous voltage output corresponding to the observed current.

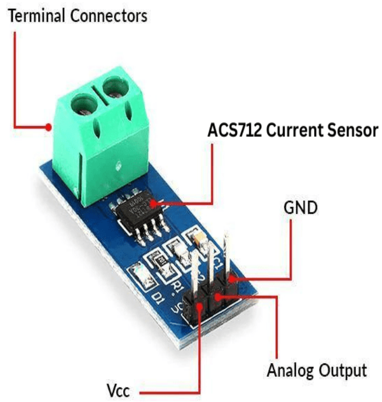

Fig. 3. Current Sensor Pin Configuration

C. Amplifier

The non-invasive blood glucose monitoring system relies on an amplifier to boost the weak Photoplethysmography (PPG) signals from the Near-Infrared (NIR) sensor. The observed signals are frequently modest in amplitude and prone to noise because the changes in glucose concentration cause only slight differences in light absorption. A high-gain, low-noise amplifier is necessary for processing and enhancing the signal quality prior to additional analysis in order to guarantee precise glucose level estimate. Usually, a transimpedance amplifier (TIA) is included in the system to transform the tiny photocurrent produced by the NIR sensor into a detectable voltage signal. A switching capacitor transimpedance amplifier with a high gain of 1 MΩ and a low-pass filter (LPF) of 10 Hz is commonly used to improve signal stability and lower high-frequency noise. This design maintains input-referred current noise at 7.3 pA/Hz and rejects DC bias current up to 20 µA, ensuring accurate signal processing.

D. ESP32 Microcontroller

An essential part of the non-invasive blood glucose monitoring system is a microcontroller, which acts as the central processing unit and regulates communication, processing, and data collection shown in figure 4. Various sensors, amplifiers, and signal processing circuits must be interfaced with the microcontroller in order to derive useful information from the observed Photoplethysmography (PPG) data. The Arduino UNO or ESP32 microcontroller is frequently utilized in this system because of its affordable price, real-time processing capabilities, and low power consumption. Analog-to-digital conversion (ADC), which digitizes the weak analogy PPG signals obtained from the Near-Infrared (NIR) sensor, is the responsibility of the microcontroller. Accurate calculation of glucose concentration is made possible by the microcontroller's ADC module, which guarantees high-resolution signal conversion.

Fig.4. ESP32 Microcontroller

E. Emitter

An emitter is a critical component in non-invasive blood glucose monitoring systems, particularly those utilizing optical and electromagnetic sensing techniques. It serves as the source of the signal that interacts with biological tissues to measure glucose levels without requiring blood samples. The emitter is responsible for generating and transmitting signals such as infrared (IR), near-infrared (NIR), microwave, or radio frequency (RF) waves, depending on the sensing method used.

IV. RESULT AND DISCUSSION

The suggested non-invasive, Internet of Things-enabled blood glucose monitoring device was effectively created and tested to assess its real-time tracking capabilities. The method measured glucose levels through the skin without requiring blood samples by combining optical sensors, electromagnetic fields, and bioimpedance techniques. The ESP32 microcontroller facilitated seamless communication by processing sensor data effectively and sending it via Wi-Fi to a cloud platform. Real-time glucose measurements, historical data trends, and warning alerts for abnormal levels were all delivered by the Blynk-developed smartphone application. The gathered data was subjected to machine learning algorithms in order to forecast future glucose patterns, improving the system's capacity to provide proactive diabetes care.

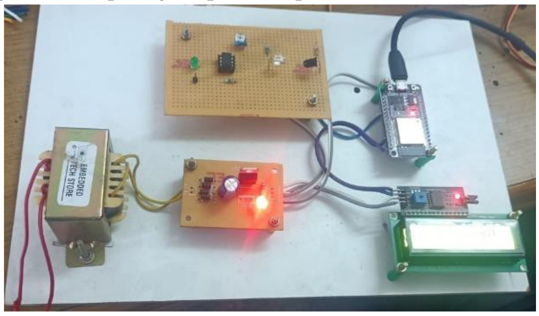

Fig.5. Fabrication of proposed concept

Figure 5 illustrates the hardware implementation of the proposed non-invasive blood glucose monitoring system. The setup includes an ESP32 microcontroller, an LCD display, power supply unit, and sensor modules mounted on a prototype board. The ESP32 processes the real-time data from the sensors and transmits it wirelessly to a mobile application using Wi-Fi connectivity. The power supply circuit ensures stable voltage regulation to all components. The LCD module is used to display glucose readings locally for user convenience. The system is neatly arranged on a baseboard for testing and validation, demonstrating effective integration of IoT, sensing, and display technologies in a compact form.

Fig. 6. Output on Blynk mobile app

The output interface of the non-invasive glucometer device as seen on the Blynk mobile app is shown in Figure 6. The real-time glucose level, shown here as 71 mg/dL, is graphically represented a circular gauge at the top of the interface. Using a color-coded arc, this gauge shows that the glucose level is within a healthy range when it is green. For ease of reading, the identical glucose measurement is shown numerically beneath the gauge. Historical glucose trends are displayed in a dynamic line chart called the "Glucose data chart," which allows viewers to see variations over time. For trend analysis, users can choose from a variety of time intervals, including live, 15-, and 30-minute periods. A green circular button in the lower right corner also probably serves as a manual activation or refresh control.

V. CONCLUSION

The proposed IoT-enabled non-invasive blood glucose monitoring device eliminates the need for painful finger-prick testing offers a real-time, efficient way to manage diabetes. The device effectively measures blood sugar levels through the skin by using optical, electromagnetic, and bioimpedance sensing techniques, as well as the ESP32 microprocessor and wireless communication. The incorporation of a mobile application guarantees notifications, historical trend analysis, and real-time data visualization, improving user convenience and preventative treatment. Furthermore, the diagnostic capabilities of predictive analysis are further enhanced by the integration of machine learning. The quality of life for diabetes patients might be greatly enhanced by this novel technology, which provides an affordable, scalable, and user-friendly method.

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