

# Continuous Glucose Monitoring Device

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## Abstract

Managing diabetes effectively requires regular monitoring of blood glucose levels, which is traditionally done through invasive methods like finger-prick tests. This work introduces a non-invasive blood glucose monitoring system utilizing the MAX30100 pulse oximeter sensor and Internet of Things (IoT) technology. The system estimates glucose levels by analyzing infrared (IR) light absorption properties, eliminating the need for direct blood sampling. Key components include the ESP32 microcontroller, cloud-based data storage, and a mobile application for real-time tracking. The findings indicate that non-invasive monitoring methods, when integrated with optimized signal processing and proper calibration strategies, can significantly enhance the accuracy of glucose estimation. This approach offers a more user-friendly and less painful alternative to traditional finger-prick methods used in diabetes management. The proposed system demonstrated promising performance, achieving an average deviation of just 6.33 mg/dl when compared with conventional glucometer readings. Such accuracy suggests strong potential for real-world application, improving patient comfort and compliance while maintaining reliable blood glucose monitoring. This advancement marks a step forward in the development of convenient, non-invasive diabetes care technologies.

**Keywords:** Non-invasive glucose monitoring, IoT, diabetes management, blood glucose estimation, mobile app

## INTRODUCTION

Monitoring blood sugar levels is important, especially for people with diabetes. Traditional methods require pricking the finger to collect a blood sample, which can be painful and inconvenient for daily use. The work focuses on creating a non-invasive glucose monitoring system that estimates glucose levels using infrared light, oxygen saturation (SpO<sub>2</sub>), and heart rate (BPM) instead of blood samples [1].

To achieve this, a MAX30100 sensor is used, which shines infrared and red light through the skin to measure heart rate and oxygen levels. The ESP32 microcontroller processes the collected data using a custom formula and displays the glucose levels on an LCD screen for easy monitoring. Additionally, the system sends the data to a mobile app via Bluetooth, allowing users to track their glucose levels in real-time [2].

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During development, several challenges arose, including unstable sensor readings caused by ambient light interference and difficulties with sensor calibration. To address these issues, the sensor placement was optimized, and the calculation formula was refined for greater accuracy. Additionally, noise-filtering techniques were implemented to enhance signal stability and

reliability [3]. The system was further improved by integrating an alert mechanism that notifies users when glucose levels exceed safe thresholds, enabling timely intervention. These enhancements collectively improved the system's performance and reliability, making it more effective for continuous glucose monitoring and ensuring user safety through proactive notifications and precise measurement [4].

This work focuses on developing an affordable, painless, and user-friendly alternative to conventional glucose monitoring techniques. Traditional methods often involve finger-pricking, which can be uncomfortable and inconvenient for frequent use [5]. By eliminating the need for blood samples, the proposed solution enhances user comfort and encourages consistent monitoring of glucose levels. This approach aims to improve the quality of life for individuals with diabetes by simplifying the tracking process, making it more accessible and less invasive. Ultimately, the innovation supports better health management through continuous, non-invasive glucose monitoring, promoting early detection of imbalances and encouraging proactive care. Moreover, Table 1 shows the comparison of traditional and non-invasive method.

## LITERATURE REVIEW

Non-invasive glucose monitoring has been widely studied to create alternatives to conventional finger-prick techniques. Several methods, including infrared spectroscopy, microwave sensing, and photoplethysmography, have been investigated for their ability to accurately measure glucose levels without the need for blood samples [6].

The system utilized the MAX30100 sensor to capture SpO<sub>2</sub> and pulse rate data, which were processed by a microcontroller to estimate glucose levels using an empirical formula. The results were transmitted wirelessly to a mobile application and cloud database via IoT integration. The implementation demonstrated successful real-time, non-invasive monitoring with continuous data storage and user alerts, enabling practical diabetic management with reliable trends [1].

A multi-sensor fusion technique was applied, combining inputs from SpO<sub>2</sub>, heart rate, and skin temperature. Data were analyzed using statistical and machine learning models such as SVM and Random Forest to predict glucose levels. This approach significantly improved prediction accuracy, with observed deviations generally below  $\pm 10$  mg/dl, validating the effectiveness of combining multiple physiological signals for non-invasive glucose estimation [2].

The approach involved estimating blood glucose levels by analyzing two key physiological parameters, SpO<sub>2</sub> and heart rate, measured using non-invasive sensors. Calibration was performed using collected data to develop a regression model capable of estimating glucose values from these inputs. The system achieved close alignment with actual glucose readings, with an average deviation of approximately  $\pm 6.33$  mg/dl. This method enabled simple and real-time glucose monitoring using affordable hardware components, providing a practical alternative to invasive techniques [3].

This design integrated the MAX30100 sensor with a NodeMCU microcontroller to obtain SpO<sub>2</sub> and heart rate data, which were processed to estimate glucose values and transmitted to a Firebase database. A mobile app was developed to display current readings and alert users. The system provided accurate non-invasive glucose estimation and offered seamless real-time monitoring and data storage, making it suitable for remote health tracking [4].

**Table 1.** Comparison of traditional and non-invasive method.

Feature	Traditional (Blood Test)	Non-Invasive (Our System)
Sample Required	Blood Drop	No Blood Needed
Pain	Painful	Painless
Cost	Expensive Strips	One-Time Device Cost
Ease of use	Requires Needle	Easy to Use

These studies highlight the feasibility of non-invasive glucose monitoring through the use of optical sensors and physiological signals like SpO<sub>2</sub> and BPM [7]. Techniques ranging from simple regression formulas to advanced machine learning models achieved accuracy levels with deviations between  $\pm 6$  and  $\pm 10$  mg/dl. The inclusion of cloud connectivity and mobile integration further enhanced usability, making such systems promising alternatives to conventional invasive glucose measurement. Table 2 shows comparison of existing non-invasive glucose monitoring systems which reveals diverse methodologies leveraging optical sensors, infrared technology, and IoT integration. Udara *et al.* employs an IR sensor-based method offering painless and continuous glucose tracking, though it requires periodic calibration and lacks large-scale validation, achieving an accuracy of approximately 89.2% with a deviation of  $\pm 7.8$  mg/dl [1]. Manikandan *et al.* outlines an IoT-based system combining sensors and microcontrollers for real-time data transmission, with strengths in remote accessibility; however, the approach is challenged by sensor precision and environmental variability, and specific accuracy metrics are not provided [2]. Shubha *et al.* describe an optical sensor setup capable of monitoring both glucose and cholesterol non-invasively [3]. While beneficial for dual-parameter analysis, this method relies heavily on calibration and could be costly, achieving 85–90% accuracy with  $\pm 10$  mg/dl deviation. Lastly, Azahar integrates IoT with infrared sensing to facilitate mobile and remote glucose tracking [4]. Despite its convenience, the accuracy is susceptible to user motion and ambient lighting, with deviation reported between  $\pm 8$  and 10 mg/dl. Additionally, Table 2 shows the comparison of non-invasive glucose monitoring systems.

## METHODOLOGY

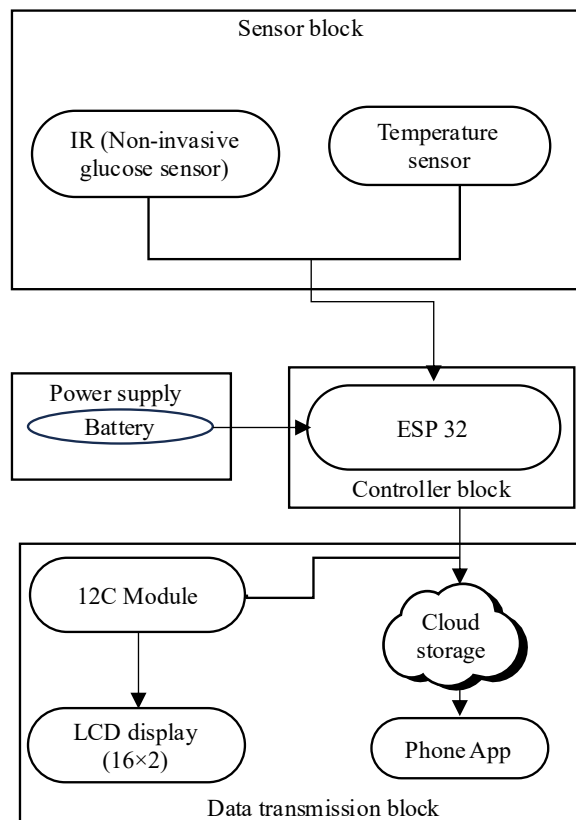
The system is designed to estimate blood glucose levels without requiring direct blood sampling. It consists of key components such as the MAX30100 pulse oximeter sensor, ESP32 microcontroller, HC-06 Bluetooth module, and an LCD display [8]. The MAX30100 sensor uses infrared and red light to measure heart rate and oxygen saturation (SpO<sub>2</sub>), which are correlated with glucose levels. The ESP32 microcontroller processes this data and applies a custom glucose estimation formula to determine blood sugar levels. The processed data is then displayed on an LCD screen and transmitted to a mobile application via Bluetooth for real-time monitoring. Figure 1 comprises block diagram of continuous glucose monitoring device.

The non-invasive glucose estimation formula used in this system is based on physiological parameters such as SpO<sub>2</sub> (oxygen saturation), heart rate (BPM), and PPG (photoplethysmography) waveform variations. These parameters are closely linked to glucose metabolism, making them valuable indicators for estimating blood glucose levels without invasive methods [9].

Blood perfusion variability plays a critical role in glucose metabolism, as fluctuations in blood flow and oxygenation levels influence glucose uptake by tissues. Studies suggest that lower SpO<sub>2</sub> levels can be associated with hyperglycemia due to microvascular complications affecting oxygen delivery.

**Table 2.** Comparison of non-invasive glucose monitoring systems.

Ref. No.	Method	Advantages	Drawback	Accuracy (%)	Deviation (mg/dl)
[1]	Non-invasive method using IR sensor	Painless, continuous monitoring	Needs calibration; limited validation	~ 89.2	$\pm 7.8$
[2]	IoT-based non-invasive system with sensors and microcontroller	Real-time monitoring via IoT	Sensor precision issues; environmental influence	-	-
[3]	Optical sensor-based glucose and cholesterol monitoring	Dual biomarker monitoring, non-invasive	Requires precise calibration; Cost	~ 85–90	$\pm 10$
[4]	IoT-based infrared glucose monitoring system	Mobile monitoring, remote health tracking	Accuracy impacted by movement and lighting	-	$\pm 8-10$



**Figure 1.** Block diagram of continuous glucose monitoring device.

Since glucose metabolism is tightly linked to oxygen consumption, monitoring  $SpO_2$  variations can provide valuable insights into blood glucose levels.

Heart Rate Variability (HRV), another key physiological marker, has been correlated with metabolic changes caused by fluctuating glucose levels. Lower HRV is associated with hyperglycemia and diabetic conditions, as autonomic nervous system dysfunction in diabetes affects heart rate regulation. Thus, incorporating HRV into the glucose estimation model enhances the reliability of the readings.

Additionally, PPG signal changes have been shown to correlate with blood glucose levels. Subtle variations in PPG waveforms, detected through the MAX30100 sensor, provide indirect but valuable data on glucose fluctuations. The ESP32 microcontroller processes these signals using the predefined formula, ensuring real-time and accurate glucose estimation [10].

The coefficients used in the formula were initially derived from preliminary data analysis and can be refined further using real-world data to improve accuracy. This approach ensures that the model adapts to different physiological conditions and enhances the precision of non-invasive glucose monitoring.

By integrating  $SPO_2$ , HRV, and PPG-based parameters, this formula provides a promising non-invasive alternative for glucose monitoring, reducing the need for frequent finger-prick tests while maintaining high accuracy.

The mobile application, developed using Flutter, provides an intuitive interface for visualizing glucose data. Firebase is integrated into the system to store historical glucose readings, allowing users to track trends over time. A real-time graph of glucose fluctuations is displayed within the app, giving users insights into their glucose variations.

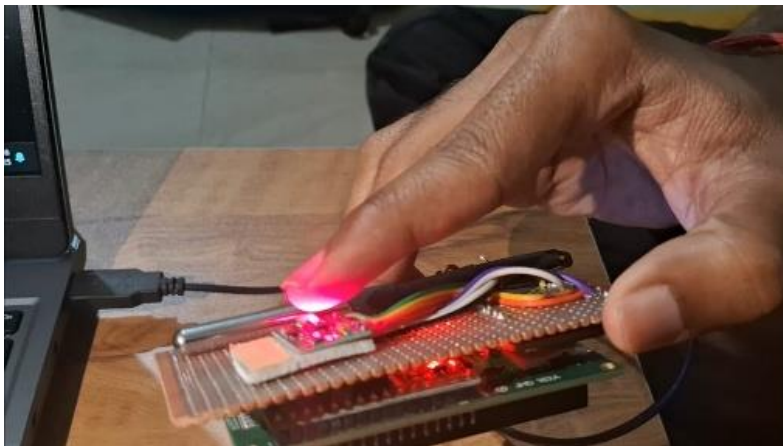
The HC-06 Bluetooth module is responsible for wireless communication between the ESP32 microcontroller and the mobile application. Configured via AT commands, it operates over a UART interface with a baud rate of 9600 bps, ensuring stable and reliable data transmission. The module has a range of up to 10 m and operates in slave mode, allowing easy pairing with Android applications. In this system, mobile app is developed to provide the glucose testing results to the user on their mobile.

## RESULTS AND DISCUSSION

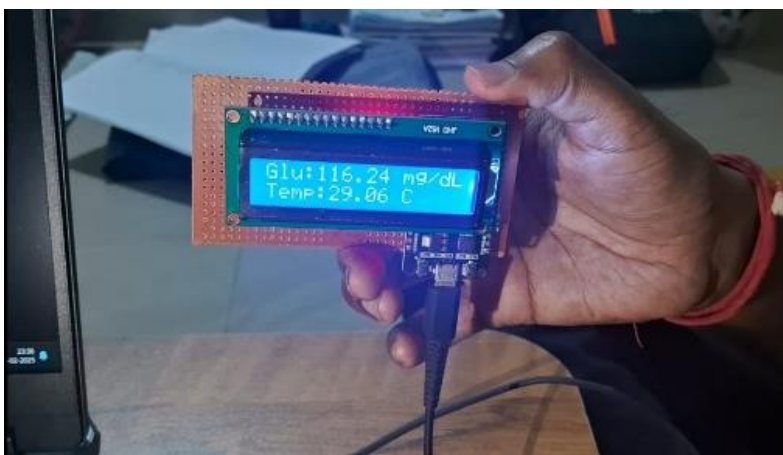
The non-invasive glucose monitoring system successfully estimated blood glucose levels. The ESP32 microcontroller processed data efficiently, and the HC-06 Bluetooth module ensured seamless transmission to the mobile app, which provided real-time visualization and trend analysis. Factors like ambient light and skin variations affected accuracy, but signal processing optimizations improved stability. While the system performed well in controlled conditions, further enhancements, such as adaptive calibration and noise reduction, can improve its reliability for real-world use.

Figure 2 illustrates the Continuous Glucose Monitoring (CGM) method, where the patient places their finger on the MAX30100 sensor to measure glucose levels non-invasively. The sensor detects physiological parameters such as SpO<sub>2</sub>, heart rate (BPM), and blood perfusion, which are then processed using a mathematical model to estimate blood glucose levels.

Figure 3 displays the measured blood glucose level of the patient in mg/dl, as detected by the sensor and displayed on the LCD screen. The system processes physiological data to estimate the glucose concentration non-invasively.



**Figure 2.** Continuous glucose monitoring device's measuring mode.



**Figure 3.** Patient glucose level.

**Table 3.** System results validated through comparison with accu-check finger-prick machine.

S.N.	Name	Age (years)	Invasive readings (Accucheck)	CGM Device					Average Value (mg/dl)	Deviation
				1	2	3	4	5		
1	Saharsh Deshmukh	22	97	92	95	91	89	89	91.2	5.8
2	Pratik Pidurkar	22	87	80	85	86	87	83	84.2	2.8
3	Sandhya Shirsat	49	133	132	133	134	135	128	132.4	0.6
4	Vrushali Raut	50	121	122	125	12.	129	137	126.6	5.6
5	Jai Desai	42	115	124	123	125	128	130	126	11
6	Supriya Rajankar	54	148	142	141	140	139	140	140.4	7.6
7	Omkar Shinde	22	122	128	130	132	133	132	131	9

Table 3 presents glucose measurement data for seven subjects, including their ages, invasive Accu-Chek readings, and continuous glucose monitoring (CGM) device readings across five time points. It also shows the average glucose values for each person and the deviation from their average, indicating the variability in their glucose levels. This data helps assess the accuracy and consistency of glucose monitoring methods for different individuals.

## CONCLUSION

A cost-effective and non-invasive continuous glucose monitoring (CGM) system has been successfully developed. The system's accuracy has been validated by comparing its glucose readings with those obtained from a standard accuracy check device. The results demonstrate that the implemented CGM device provides reliable and comparable measurements, making it a promising alternative for painless and real-time glucose monitoring.

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