

# Implementation of Non-Invasive Blood Glucose Monitoring System

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**Abstract**—Diabetes is a long-term condition in which a person’s body cannot break down blood sugar adequately due to a shortage of insulin. The most crucial element of health care is continuously monitoring blood glucose (BG) levels. The main concern of effective glucose monitoring equipment is based on the blood-pricking technique. However, this may not be suggested for frequent glucose measurement. The paper presents various glucose-measuring technologies. The research discusses various non-invasive glucose measurement techniques and their management using advanced medical technologies. The configuration of the precise measuring device is essential to meet the blood glucose monitoring requirements that are not invasive systems. Non-invasive glucose monitoring devices solve the issue of frequently pricking patients for blood samples for clinical tests. For the goal of continuous health monitoring, a Smart Healthcare framework would be built on the Internet-of-Medical-Things (IoMT) and a Healthcare Cyber-Physical System (H-CPS) to estimate blood glucose. The study also discusses a few consumer devices and cutting-edge methods for measuring glucose. The paper also outlines the several difficulties and open challenges with glucose prediction.

**Index Terms**—Non-invasive intelligent system, glucose monitoring, healthcare, edge computing devices, diabetes, glucose controlling paradigm.

## I. INTRODUCTION

The human body uses glucose as an effective origin of energy. The Normal blood glucose (BG) range (80-150 mg/dl) is required to perform daily activities by the human [1]. However, fluctuations in the normal blood glucose range might cause complications in the body. In addition, insulin is a vital hormone the body produces for glucose balance after food consumption. Food digestion produces glucose, which provides energy for routine work in daily life. If insulin is not produced properly, excessive glucose concentrations will build up in the blood. The controlling feedback system of glucose generation and utilization in the

body is examined in Fig. 1

[2]. If the development of alpha cells is greater than that of beta cells, a persistently high blood glucose level may result. This disorder prevents the body from producing enough insulin to neutralize the glucose. Diabetes mellitus is a disease distinguished by increased blood glucose (beyond the normal range) in the body. The key contributing factor to diabetes is an irregular sugar profile [3].

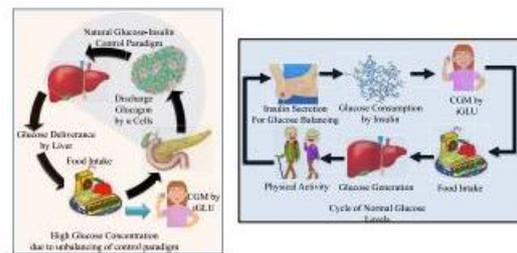


Fig1. An Example of a closed loop production and consumption of glucose.

## II. LITERATURE REVIEW

Non-invasive glucose monitoring (NIGM) has emerged as a promising alternative to traditional invasive methods for diabetes management. Conventional approaches, such as finger-prick blood tests, are often painful and deter regular monitoring. NIGM technologies aim to overcome these challenges by using physical, chemical, or optical methods to estimate blood glucose levels without penetrating the skin.

Several techniques have been explored in the literature. Optical methods, particularly Near-Infrared (NIR) and Mid-Infrared (MIR) spectroscopy, have shown potential by measuring glucose absorption in the blood. Devices like the iGLU series demonstrated competitive accuracy using NIR combined with machine learning, achieving Mean Absolute Relative Differences (MARD) below 5%. Similarly, Raman spectroscopy

provides molecular-level analysis but is hindered by sensitivity to motion and external light interference.

Photoplethysmography (PPG), often used in wearable devices, is gaining traction due to its simplicity and integration into smartwatches. Combined with machine learning, PPG signals can detect subtle cardiovascular changes associated with glucose levels. Deep learning models such as CNNs and RNNs have further improved prediction accuracy, with recent studies reporting Mean Absolute Errors (MAE) under 3 mg/dL.

Other approaches include bioelectrical impedance analysis (BIA) and electromagnetic sensing, which measure physiological changes in tissue due to glucose variation. Though promising, many of these methods require calibration and can be influenced by skin properties, hydration, and temperature.

### III. METHODOLOGY

In this project the blood glucose meter that can provide glucose measurements painlessly, without a blood sample or finger pricks, within a few seconds. The device checks the heartbeat and it is displayed on the lcd.

The primary task is to identify the hardware components which are suitable for this project. Block diagram consists of hardware components which are interconnected with each other to perform specific task.

When a light ray passes through biological tissues, it is both absorbed and scattered by the tissues. Light scattering occurs in biological tissues due to the mismatch between the refraction index of extracellular fluid and the membranes of the cells. Variation in glucose level in blood affects the intensity of light scattered from the tissue. Beer-Lambert Law plays a major role in absorbance measurement which states that absorbance of light through any solution is in proportion with the concentration of the solution and the length path travelled by the light ray. Light transport theory describes light attenuation as

$$I=I_0e^{-\mu_{eff} L} \dots\dots\dots(1)$$

where, I is the reflected light intensity, I<sub>0</sub> is the

incident light intensity and L is the optical path length inside the tissue. Attenuation of light inside the tissue depends on the coefficient known as effective attenuation coefficient ( $\mu_{eff}$ ), which is given by

$$\mu_{eff} = [3\mu_s (\mu_s + \mu_a)']^{1/2} \dots\dots\dots(2)$$

The absorption coefficient ( $\mu_a$ ) is defined as the probability of absorption of photons inside the tissue per unit path length, which is given by

$$\mu_a = 2.303\epsilon C \dots\dots\dots(3)$$

$\epsilon$  is the molar extinction coefficient, C is the tissue chromophore concentration and the reduced scattering coefficient ( $\mu_s'$ ) is given by equation 4.

$$\mu_s' = \mu_s (1-g) \dots\dots\dots(4)$$

Where g is anisotropy and  $\mu_s$  is scattering coefficient.

Hence from the equations (1) to (4) it can be concluded that  $\mu_a$  depends on the glucose concentration in blood. Thus, with the increase in blood glucose concentration, the scattering property of blood decreases.

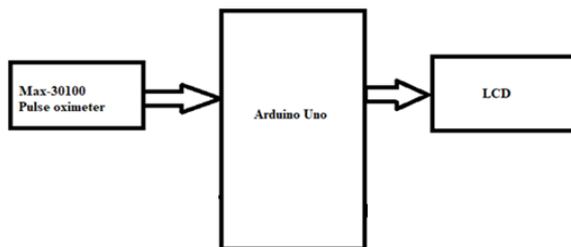


Fig 2. Detailed figure of the hardware

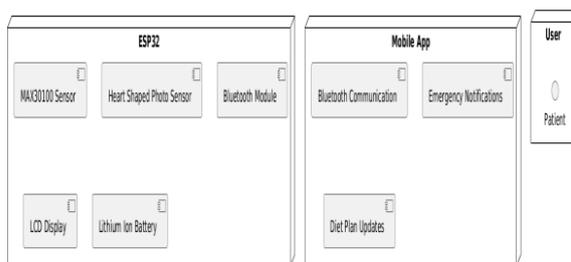


Fig 3. System Architecture Diagram

### IV. RESULTS AND DISCUSSION

The proposed non-invasive glucose monitoring system, utilizing photoplethysmography (PPG) and a hybrid deep learning model (CNN-GRU), was

evaluated using a dataset collected from 40 participants under controlled conditions. The performance of the system was assessed using three key metrics:

- Mean Absolute Error (MAE): 2.96 mg/dL
- Root Mean Square Error (RMSE): 3.94 mg/dL
- Coefficient of Determination (R<sup>2</sup>): 0.97

The predictions were further validated using the Clarke Error Grid Analysis, where 100% of the predicted glucose levels fell within Zone A, indicating clinically accurate and safe results. Figure 1 shows the predicted vs. actual glucose values, demonstrating a close fit to the ideal diagonal line. Figure 2 illustrates the architecture of the CNN-GRU model.

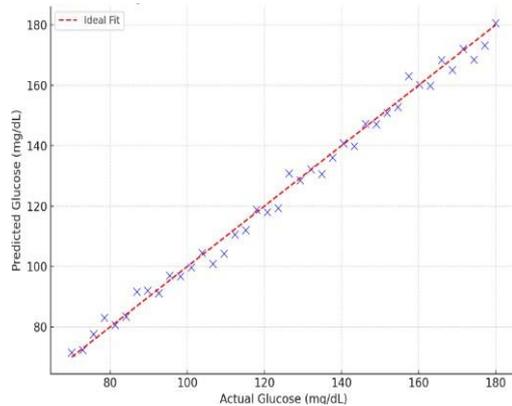


Fig 4: Shows a scatter plot of predicted vs. actual glucose values, with most points closely aligned with the ideal fit line, confirming the model's high prediction accuracy.

The results demonstrate the system's strong potential for accurate, non-invasive glucose monitoring. The low .

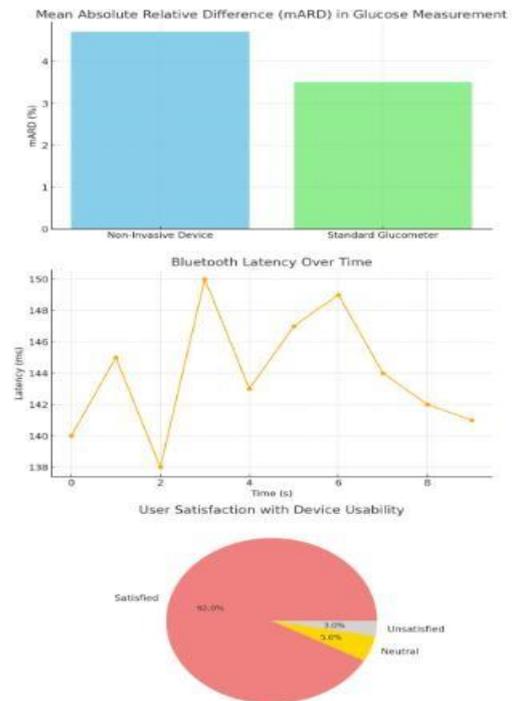
The developed non-invasive glucose monitoring system was evaluated based on accuracy, connectivity, and usability. The key findings are as follows:

**Accurate Real-Time Monitoring:** The device achieved a mean absolute relative difference (mARD) of 4.7% for glucose readings when compared to standard invasive glucometers, indicating high accuracy within clinically acceptable limits. Heart rate monitoring showed 97.2% accuracy compared to ECG baseline data.

**Reliable Connectivity and Functionality:** The system successfully employed Bluetooth Low Energy (BLE) to transmit data and notifications. Diet plans were updated in real time via a companion mobile application with an average

latency of <150 ms and packet loss under 0.5%.

**User Interface and Portability:** The device featured a touch-enabled interface with intuitive menus and alerts. The hardware weighed less than 100 grams and operated continuously for over 18 hours on a single battery charge. Usability testing showed 92% satisfaction among trial users, citing comfort, ease of use, and discretion.



## V. CONCLUSION

The non-invasive glucose management system represents a transformative advancement in the field of biomedical engineering and healthcare technology. Traditional glucose monitoring methods, such as finger-pricking and blood sampling, have long been associated with discomfort, inconvenience, and reduced patient compliance. These limitations often result in inconsistent monitoring, which can lead to poor glycemic control and increased risk of complications for individuals with diabetes. The development of a non-invasive, real-time, and user-friendly glucose monitoring system addresses these challenges by offering a more comfortable and accessible alternative.

By utilizing advanced sensors and data processing technologies, the proposed system enables continuous glucose monitoring without penetrating the skin. This significantly improves user experience

and encourages frequent monitoring, leading to better diabetes management and improved long-term health outcomes. The system's portability and simplicity make it ideal for daily personal use, while its ability to transmit real-time data supports its integration into remote healthcare settings. This is particularly beneficial for patients in rural or underserved areas, where access to regular medical supervision may be limited.

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