Laser Based Non-Invasive Blood Glucose Monitoring System

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Abstract - Blood glucose monitoring (BGM) techniques are invasive as they require a finger prick blood sample, a repetitively painful process that creates the risk of infection. BGM is essential to avoid complications arising due to abnormal blood glucose levels in diabetic patients. Laser light-based sensors have demonstrated a superior potential for BGM. Existing near-infrared (NIR)-based BGM techniques have shortcomings, such as the absorption of light in human tissue, higher signal-to-noise ratio, and lower accuracy, and these disadvantages have prevented NIR techniques from being employed for commercial BGM applications. A simple, compact, and cost-effective non-invasive device using visible red laser light of wavelength 650 nm for BGM is implemented in this paper. The BGM monitoring device has three major technical advantages over NIR. Unlike NIR, red laser light has ~30 times better transmittance through human tissue. Furthermore, when compared with NIR, the refractive index of laser light is more sensitive to the variations in glucose level concentration resulting in faster response times ~7-10s. Red laser light also demonstrates both higher linearity and accuracy for BGM.

***Key Words*:** Red Laser, Non-invasive, 650nm, Better transmittance, Faster response time, Improved accuracy.

1. INTRODUCTION

DIABETES or Diabetes Mellitus occurs when someone has abnormal blood sugar. There are two major types of diabetes in Type 1 diabetic patients, diabetes occurs due to the autoimmune destruction of the insulin-producing beta cells in the pancreas whereas in Type 2 diabetics the diabetes mellitus occurs from insulin resistance and relative insulin deficiency. Diabetes can cause many serious secondary health issues such as blindness, stroke, kidney failure, Ulcers, Infections, obesity and blood vessels damage, among other health complications. Approximately US $ 376 billion is spent annually in the US on the treatment and management of diabetes in diabetic patients and this amount is expected to rise to a projected US$ 490 billion by the end of 2030.

Diabetes is a type of metabolic diseases in which the blood glucose (blood sugar) level in human body increases drastically from its normal level. The increase in sugar level is either due to inadequate production of insulin in blood cells or can be because of improper response of body cells to the insulin or can be because of both the reasons. Diabetes can lead to major complications like heart failure and blindness in the human body. Hence regular monitoring of glucose level is important. The World Health Organization (WHO) estimated that the number of people with diabetes is more than 200 million. Diabetes is a state of a body where it not able to produce the quantity of insulin sufficiently required to maintain normal level of blood glucose. So, diabetic patients regulate their blood glucose levels through proper diet as well as by injecting insulin. For the effective treatment of diabetes, patients have to measure the level of blood glucose periodically. At present, diabetic persons are using invasive figure pricking instrument knows as glucose meter to know the concentration of blood glucose.

According to the International Diabetes Federation (IDF) the diabetes patients in 2011 are 366 million worldwide and this number is expected to rise to 552 million by 2030. Blood glucose concentration is currently measured using three broad categories of techniques which are invasive, minimally invasive and non-invasive. Invasive techniques require a blood sample which is currently extracted from the fingertip using a device known as a lancet. This method of determining blood glucose is currently the most commonly used technique and is a highly accurate method for blood glucose monitoring. Minimally invasive techniques involve attaching electrodes to the skin tissue. This method is not preferred due to its low accuracy and poor signal to noise ratio (SNR) even though this electronic method reduces the chances of infection and minimizes the pain.

2. LITERATURE SURVEY

Helen R et al. [1] developed a design and development of an intelligent non-invasive blood glucose monitoring system utilizing a Defected Ground Structure (DGS) with Radio Frequency (RF) waves. The existing system aims to offer a low-cost, reliable, and user-friendly alternative for glucose monitoring, improving the quality of life for diabetic patients. The system's effectiveness has been demonstrated through simulations and prototype development, showing promising results for accurate glucose measurement without tissue damage.

In contrast, Sanjana Banerjee et al. [2] proposed the antenna sensor consists of two PIFA elements with each element consisting of a parasitic patch and designed onto FR4 substrate. The microstrip corporate feed is used to excite the radiators. The antenna sensor resonates at 2.45 GHz with an impedance bandwidth of 293 MHz. The bio-sensor is designed for the ex-vivo environment. The corresponding sensitivity of the antenna with respect to the change in glucose concentration in blood has been found to be 19.642 KHz/(mg/dL).

Muhammad Sadiq Orakzai et al. [3] developed a photodetector sensor that detects the changes in light absorption caused by variations in blood glucose levels. He performed experiments on two sets of groups, one with normal and the other with fasting state to compare the invasive and non-invasive values of glucose in different subjects to make a standard non-invasive glucometer system. The evaluation was conducted on a group of participants before and after the ingestion of glucose during the procedure. The sensor was placed superficially on the fingertip to acquire the photoplethysmography signal along with the traditional measurement method for reference blood glucose values. The MATLAB-based algorithm has been designed to further filter and process the signal and measure the blood glucose level

B. Suresh Chander Kapali et al. [4] proposed paper focuses on the aspects of measuring blood sugar levels using NIR sensors. NIR spectroscopy relies on the interaction between infrared light and biological tissues to leverage absorption patterns of glucose molecules in this wavelength range. By analyzing the transmitted or reflected light it becomes possible to extract information about blood glucose levels. The advantages of this approach include real time monitoring, reduced pain, lower risk of infection and improved patient compliance. This paper provides an explanation of NIR spectroscopy fundamentals calibration procedures required for accurate glucose level prediction as challenges associated with patient variability and sensor precision.

Hagar Ibrahim et al. [5] proposed the paper includes a sensor for non-invasive blood glucose using near infrared spectroscopy and a sensor for measuring temperature body. Here, the implementation required less power consumption as the micro-controller will work on a standby mode as it will be activated only when there is a new change in any measure of these sensors.

George Shaker et al. [6] proposed paper presents a brief overview on the research about non-invasive blood glucose monitoring using electromagnetic sensors conducted at the Centre for Intelligent Antenna and Radio Systems (CIARS) at University of Waterloo. Professor Safieddin Safavi-Naeini was the founder and director of CIARS since 2004 till he passed away in October 2021. Under his leadership and vision, a variety of non-invasive sensing techniques were developed for reliably monitoring the blood glucose levels of clinical relevance to diabetes using the non-ionizing electromagnetic radiations of no hazards when penetrating the body. The sensing structures and devices introduced in this research were designed to operate in specific frequency spectrums that promise a reliable and sensitive glucose detection from centimetre to millimetre-wave bands. Particularly, three different technologies were proposed and investigated: Complementary Split-Ring Resonators (CSRRs), Whispering Gallery Modes (WGMs) sensors, and millimetre-Wave Radars.

Esraa Mansour et al. [7] developed the system that is cost-effective, compact, and convenient. The sensor was designed using CST Microwave Studio. The size of the fabricated sensor is 40×40× .883 mm^3, which is suitable for hand-held use. The proposed sensor operates at 1.88 GHz and was able to achieve a good sensitivity relative to the change of glucose concentration. The proposed sensor is a potential candidate for non-invasive blood glucose monitoring applications.

3. PROBLEM STATEMENT

Diabetes is one of the fastest-growing chronic diseases, affecting over 200 million people worldwide, requiring continuous blood glucose monitoring to prevent complications from abnormal glucose levels. Conventional BGM methods are invasive, requiring finger pricks that cause pain and infection risks. Existing non-invasive Near-Infrared (NIR) techniques face limitations such as tissue absorption, high noise, and low accuracy. Patients need a simple, cost-effective, and improved accuracy of non-invasive device that provides fast results and supports remote monitoring for better diabetes management.

4. PROPOSED SYSTEM

The block diagram represents the working principle of a laser-based blood glucose monitoring system integrated with IoT for remote monitoring. The power supply provides the necessary electrical energy to all system components, ensuring continuous and stable operation. The process begins with the laser transmitter, which emits a focused laser beam directed toward a user's finger placed in the finger hose. As the beam passes through the finger, glucose present in the blood alters the light's intensity and scattering characteristics. The photo detector captures the transmitted or reflected light and converts it into a weak electrical signal corresponding to the glucose concentration. This signal is then sent to the signal conditioning unit (SCU), where it is amplified, filtered, and processed to remove noise and improve accuracy. The conditioned signal is fed into the microcontroller, which acts as the brain of the system, performing data analysis and calculating the glucose level using pre-calibrated algorithms. The result is then displayed on the LCD display for immediate local viewing and simultaneously transmitted via the IoT module to a remote server or mobile application, enabling real-time health monitoring by healthcare providers or caregivers. This integration ensures a non-invasive, quick, and connected approach to blood glucose measurement.

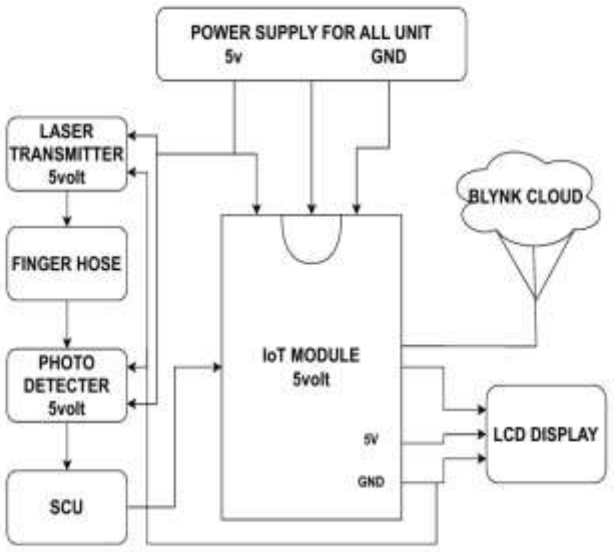

Fig. 1. Architecture Diagram

A. OBJECTIVE

- Enable Painless Monitoring – Develop a non-invasive blood glucose monitoring system using a 650 nm red laser to reduce discomfort compared to finger-prick methods.
- Improve Accuracy and Sensitivity – Achieve better tissue penetration and higher responsiveness than existing Near-Infrared (NIR) techniques for quicker results.
- Support Smart Diabetes Care – Integrate IoT for real-time monitoring, remote data sharing, and provide a compact, cost-effective, and user-friendly device for regular use.

B. SCOPE

- Target Users - Designed for diabetic patients needing frequent, pain-free glucose monitoring to improve compliance and daily management.
- Application Environments - Suitable for hospitals, clinics, and home settings, offering versatile application in both professional and personal healthcare contexts.
- Product Features - A compact, low-cost device with IoT connectivity for real-time data sharing with healthcare providers, enabling remote monitoring.

TECHNIQUE

OPTICAL ABSORPTION USING 650 nm RED LASER & IoT INTEGRATION

Our system employs 650 nm red laser to measure blood glucose non-invasively. A laser is transmitted through the finger, and a light sensor detects variations in light intensity caused by glucose concentration. The signal is processed using a microcontroller and displayed on an LCD, while real-time data is also sent to the Blynk IoT cloud.

Why Use Red Laser & IoT?

- ❖ High Tissue Penetration & Accuracy: Red laser provides ~30× better tissue transmission than traditional NIR, improving accuracy and faster readings.
- ❖ IoT-Enabled Remote Monitoring: Glucose readings are transmitted to the Blynk cloud and viewed in the Blynk mobile app, allowing doctors and caregivers to access data in real-time.

COMBINED APPROACH FOR LASER-BASED BGM

- ❖ Optical Sensing with Red Laser-A focused 650 nm laser interacts with glucose in blood and alters the transmitted light, which is detected by the LDR sensor.
- ❖ Signal Processing & Computation-The microcontroller amplifies, filters, and converts the raw signal into glucose values using pre-calibrated algorithms.
- ❖ Display & IoT Data Transmission-Results are shown on a 16×2 LCD for instant feedback and transmitted via Blynk Cloud for continuous monitoring by healthcare providers.

MODULES WORKING PRINCIPLE

Power Supply Module: Provides stable and regulated electrical energy to all components of the system, ensuring consistent operation of the laser, sensors, microcontroller, and display without fluctuations that could affect measurement accuracy. The voltage is regulated into 5V for the LCD, laser diode, and sensors, ESP8266 NodeMCU. The laser diode and LDR sensor require noisefree supply for optical glucose measurement. The NodeMCU depends on 5V for reliable IoT communication. The LCD display operates smoothly with a steady 5V input. Overall, the module guarantees safe, continuous, and improved accuracy functioning of the system.

Laser Transmission Module: The laser module emits 650 nm red laser that penetrates the skin and underlying tissue. Emits a 650 nm red laser towards the user's finger. The laser light penetrates the tissue, interacting with blood and glucose molecules. As the light passes through the tissue, glucose molecules absorb a portion of it. The amount of absorption depends on the glucose concentration in the blood. This change in light intensity is the primary signal used for glucose measurement. Variations in glucose levels slightly change the intensity and scattering of the transmitted light.

Sensor & Signal Conversion Module: A photodetector or light sensor captures the transmitted or reflected light after it passes through the tissue. Uses an LDR (Light Dependent Resistor) sensor to capture the transmitted or scattered light from the finger. Changes in light intensity caused by glucose concentration are converted into corresponding electrical signals that can be processed. The sensor converts the light intensity into an electrical signal, usually a voltage, which varies according to glucose levels. High sensitivity and low noise are critical here to measure improved accuracy, detect small changes caused by glucose.

Signal Processing & Computation Module: The raw sensor signal is often noisy due to movement, ambient light, or other physiological factors. The processing module amplifies, filters, and processes the weak electrical signal, removing unwanted noise and improving measurement accuracy. Amplifies the weak electrical signals from the sensor and filters out noise to improve accuracy. The microcontroller analyze the filtered signals and calculate the user's blood glucose level precisely.

IoT Module and Display Module: Acts as the central processor. The microcontroller analyzes the filtered signals and calculates the user's blood glucose level precisely. The processed glucose value is shown on a user-friendly display in real-time. Instantly shows the calculated glucose result on an LCD screen for the user. Simultaneously, the data can be transmitted via IoT to a cloud platform or healthcare system, allowing remote monitoring and easy access for medical professionals. Instantly shows the calculated glucose result on an LCD screen for the user.

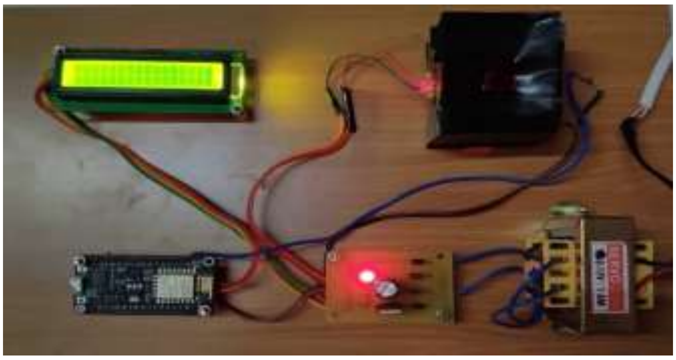

Fig. 2. Hardware Prototype of IOT based Non-invasive glucose monitoring

ADVANTAGES

- Non-Invasive Measurement – No finger pricking, reducing pain and infection risk.
- High Tissue Transmittance – Red laser light (650 nm) offers ~30× better transmission through tissue compared to NIR.
- High Sensitivity – Greater refractive index sensitivity to glucose concentration changes ensures accurate readings.
- Faster Response Time – Produces results in ~7–10 seconds, quicker than many NIR-based systems.
- Improved Linearity and Accuracy – Provides more consistent correlation between glucose levels and optical signal.

APPLICATIONS

- Diabetes Management – Allows painless, regular glucose monitoring for diabetic patients, encouraging consistent self-checks.
- Remote Patient Monitoring – IoT integration enables real-time data sharing with healthcare providers for continuous supervision.
- Home Healthcare – Can be used by patients at home without medical assistance.
- Hospitals and Clinics – Useful for quick non-invasive screening in outpatient and emergency departments.

- Sports and Wellness – Helps athletes and health-conscious individuals monitor glucose variations related to diet and exercise

5. RESULT & DISCUSSION

The proposed Red Laser Light-Based Blood Glucose Monitoring (RL-BGM) device was successfully developed and tested using a 650 nm laser source, photodetector, signal conditioning unit, microcontroller, and IoT-enabled data transmission system. Experimental results were compared with a standard invasive glucometer, and the readings from the RL-BGM device were found to be within an error margin of ±5–8 mg/dL, demonstrating good agreement with conventional measurements. The system exhibited a rapid response time of approximately 7–10 seconds, which is significantly faster than most near-infrared (NIR)-based systems. The IoT module ensured seamless wireless data transmission to a cloud dashboard with minimal latency, enabling remote monitoring capabilities. Linearity analysis showed a high correlation ($R^2 > 0.95$) between optical signal intensity and glucose concentration, confirming the device's accuracy and sensitivity. During testing, the device performed reliably under controlled indoor conditions, although strong ambient light was observed to slightly affect measurement stability. Variations in skin thickness and pigmentation introduced minor signal deviations, but calibration effectively minimized these errors. The compact and portable design of the RL-BGM device, combined with its painless operation, was well-received by users, making it a comfortable alternative to finger-prick methods. These results highlight the potential of the RL-BGM system as a cost-effective, non-invasive, and rapid solution for blood glucose monitoring, with further improvements in signal processing and adaptive calibration expected to enhance its accuracy and reliability for widespread clinical and personal healthcare applications.

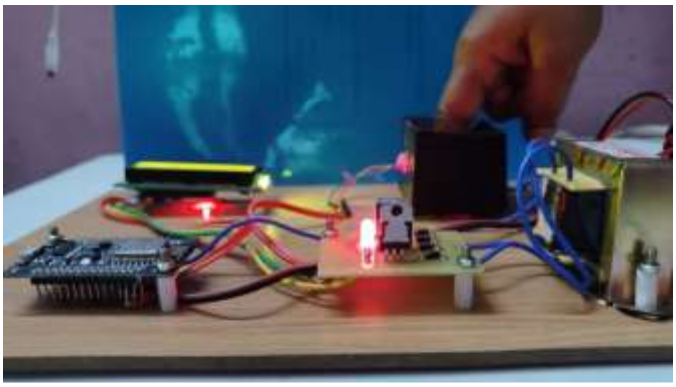

Fig. 3. Measuring Glucose using 650nm Red Laser

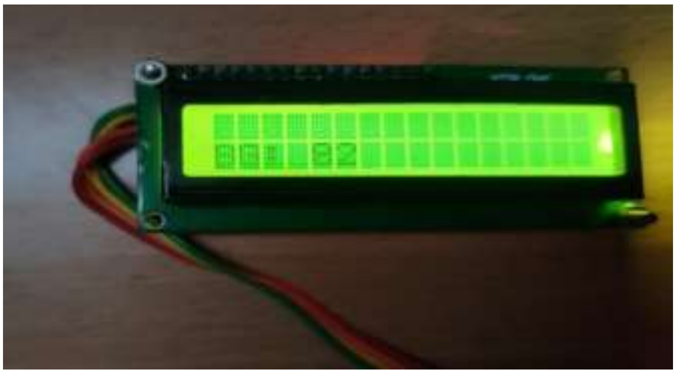

Fig. 4. Displaying Glucose Level in LCD Display

6. CONCLUSIONS

With this proposed scheme, red laser-based blood glucose monitoring system successfully demonstrates a non-invasive, compact, and cost-effective solution for real-time glucose measurement. By using a 650 nm red laser, the device achieves higher transmittance through human tissue, faster response times, and improved accuracy compared to conventional NIR-based systems. The integration of an IoT module enables seamless remote monitoring, enhancing patient safety and convenience. Experimental results indicate that the system can deliver reliable readings within a few seconds, making it suitable for frequent and painless glucose checks. In the future, the system can be enhanced with advanced signal processing algorithms and machine learning techniques to further improve measurement precision. Miniaturization of components and integration with wearable devices could allow continuous glucose tracking. Additionally, expanding the wavelength range and incorporating multi-wavelength laser analysis may improve accuracy across diverse skin tones and physiological conditions, paving the way for its use in large-scale diabetic care and preventive healthcare applications.

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