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Non-Invasive Glucose Monitoring Device Using Max30102 Sensor

K. Rajasekhar[1,*], M. Yamini Devi[2], B.V.S.N.S. Karthik[2], Ch. E.A.S. Sai[2], N. Hemanth[2]

Abstract

Diabetes mellitus is a chronic metabolic disorder affecting millions globally, requiring continuous blood glucose monitoring to prevent complications such as cardiovascular disease, kidney failure, neuropathy, and retinopathy. Conventional invasive finger-prick techniques result in pain, skin irritation, and an increased risk of infection, which lowers patient compliance, particularly in young patients and the elderly. This paper presents a non-invasive glucose monitoring prototype using the MAX30102 optical biosensor interfaced with the Arduino Uno R3 microcontroller. The design and execution of a non-invasive glucose monitoring prototype utilizing an Arduino Uno R3 microcontroller interfaced with the MAX30102 optical biosensor are presented in this work. The device uses dual-wavelength LEDs—red (660 nm) and infrared (880 nm)—to collect photoplethysmography (PPG) signals from the fingertip. A 12-sample moving average filter is applied to the recorded data to lower noise and enhance signal stability. Afterward, a linear calibration model ($G = 275.862 \times R - 232.103$) is used to precisely measure blood glucose levels. A 16x2 I2C LCD module shows the results in real time. The system captures photoplethysmography (PPG) signals from the fingertip using red (660 nm) and infrared (880 nm) LEDs, processes them with a 12-sample moving average filter and a linear calibration model ($G = 275.862 \times R - 232.103$), and displays the estimated glucose concentration in real time on a 16×2 I2C LCD. Experimental validation on four subjects achieved a mean accuracy of approximately 85.93% compared to a reference invasive glucometer, with individual accuracy ranging from 79.27% to 89.45%. The proposed system demonstrates the feasibility of embedded non-invasive glucose monitoring as a painless, low-cost, portable solution suitable for home-healthcare applications.

Keywords: Non-invasive glucose monitoring, MAX30102, photoplethysmography (PPG), Arduino Uno R3, embedded biomedical systems, diabetes management, optical sensing, I2C communication

***Author for Correspondence**
K. Rajasekhar
E-mail: krsece.bvce@bvcgroup.in

[1]Professor, Department of Electronics and Communication Engineering, BVC Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India
[2]Student, Department of Electronics and Communication Engineering, BVC Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India

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INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder characterized by persistently elevated blood glucose levels due to insufficient insulin production and impaired insulin utilization. According to global health reports, the number of patients with diabetes is increasing rapidly every year, creating a strong demand for reliable, convenient, and continuous glucose monitoring solutions [1]. Maintaining glucose within a healthy range is essential to prevent both short-term complications, including hypoglycemia and hyperglycemia, and long-term sequelae, such as cardiovascular disease, kidney failure, neuropathy, and retinopathy.

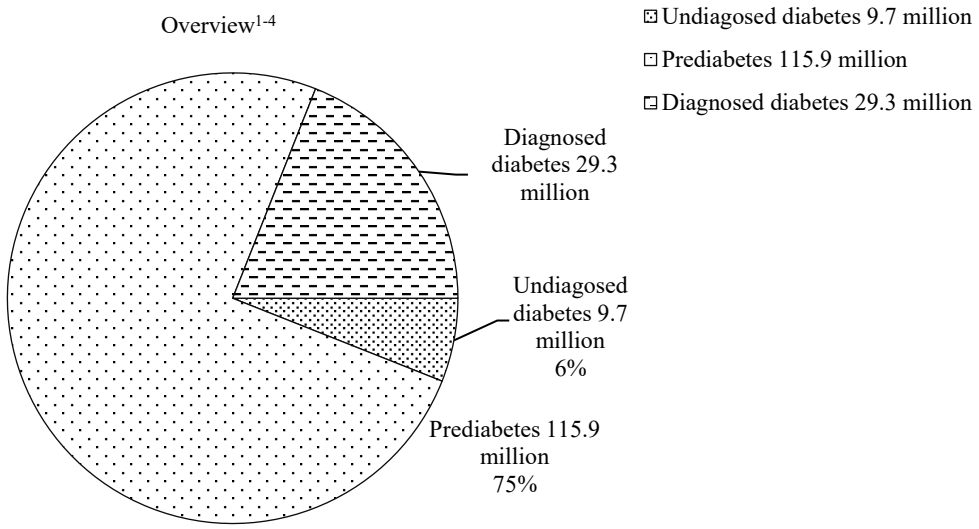

Figure 1. Global prevalence of diabetes (Survey overview).

Traditional glucose monitoring relies on invasive finger-prick blood sampling. Although accurate and widely accepted, these methods cause pain, discomfort, skin irritation, and infection risk, particularly in patients requiring multiple daily measurements [2]. Fear of needles (trypanophobia) affects a significant proportion of patients, especially children and adolescents, making consistent monitoring difficult. In elderly patients, reduced skin elasticity and fragile veins further complicate the process of repeated blood sampling.

Therefore, non-invasive glucose monitoring techniques have attracted significant research interest. Photoplethysmography (PPG), implemented using low-cost optical sensors such as MAX30102, offers a painless alternative by measuring blood volume changes via light absorption at the fingertip [3]. This study presents a compact embedded prototype combining the MAX30102 sensor, Arduino Uno R3 microcontroller, and 16 × 2 I2C LCD to estimate blood glucose in real time without the need for invasive blood extraction, as shown in Figure 1.

RELATED WORK

Non-invasive glucose monitoring has been an active research area for decades. Shinde (2011) proposed an NIR occlusion spectroscopy method and reported promising correlations between optical absorption and glucose concentration [4]. They reviewed several non-invasive monitoring techniques and discussed the trade-offs between accuracy, cost, and portability [5]. An NIR LED-based sensor was developed and demonstrated feasibility for non-invasive estimation under controlled laboratory conditions [3]. The investigation of different measurement sites for NIR-based glucose monitoring provided insights into the effect of skin variability on measurement accuracy [5]. An NIR-embedded hardware platform was further developed, and its practical implementation was validated [6].

While NIR spectroscopy provides wavelength-specific absorption signatures for glucose, PPG-based systems using sensors such as MAX30102 offer significant advantages in terms of cost, size, and ease of embedded integration. The proposed system extends this line of research by implementing a real-time PPG-based glucose estimator on an Arduino platform, targeting home healthcare deployment.

SYSTEM DESIGN AND METHODOLOGY

System Architecture

The proposed system integrates four principal subsystems: (1) the MAX30102 optical biosensor for PPG signal acquisition from the fingertip; (2) the Arduino Uno R3 microcontroller for signal processing and glucose estimation; (3) a 16×2 LCD with an I2C interface for real-time display; and (4) a regulated power supply providing stable 5V and 3.3 V outputs.

The sensor and LCD both communicate with the Arduino via the I2C bus on pins A4 (SDA) and A5 (SCL), minimizing wiring complexity and allowing multiple devices on a single two-wire interface, as shown in Figure 2.

MAX30102 Optical Biosensor

The MAX30102 integrates a red LED (660 nm) and an infrared LED (880 nm) with an 18-bit ADC photodetector in a compact surface-mount package. Key features include a programmable LED current (0–50 mA), configurable sampling rate (50–3200 sps), on-chip ambient light cancellation, and a low-noise analog front end. It interfaces via I2C at 3.3V, making it well-suited for portable biomedical applications. When a finger is placed on the sensor, the pulsatile blood volume changes to modulate the amount of light absorbed by the tissue, producing a characteristic PPG waveform. The ratio of red to infrared absorption is correlated with blood composition, including glucose concentration, through an empirically derived calibration model (Figure 3(a and b)).

Signal Processing and Glucose Estimation Algorithm

Raw IR and red channel values were continuously polled from the MAX30102. The presence of a finger is validated using the threshold condition IR > 50,000 ADC counts; the system remains in the idle state ('Place Finger…') until a stable reading is detected. Once valid, the ratio R = IR_value / Red_value was computed and passed through the linear calibration model:

$$G = a \times R + b \quad (a = 275.862,\ b = -232.103)$$

To reduce noise and motion artifacts, a moving average filter with a window of 12 consecutive samples was applied. The LCD displayed 'Analyzing... Sample N/12' during collection. Once the window is complete, the averaged result is classified as LOW (<70 mg/dL), NORMAL (70–125 mg/dL), or HIGH (>125 mg/dL), and displayed alongside the numeric value. After a 6-second display period, the system resets for the next user.

Circuit Diagram and Interfacing

The MAX30102 SDA and SCL lines were connected to Arduino pins A4 and A5, respectively. The sensor was powered at 3.3V from the Arduino onboard regulator, and the LCD module was powered at 5V. All components share a common ground to maintain a stable reference voltage and prevent I2C communication errors. The Arduino was powered via USB during development or via a 7–12 V DC external adapter for standalone deployment. Proper wiring and voltage levels are critical for stable PPG signal acquisition, as shown in Figure 4.

HARDWARE COMPONENTS

Arduino Uno R3

The Arduino Uno R3, which is based on the ATmega328P microcontroller, serves as the central processing unit. It reads PPG data from the MAX30102 via I2C, applies the filtering and estimation algorithm, and drives an LCD output. It provides 14 digital I/O pins, 6 analog pins, and supports UART, SPI, and I2C communication protocols. In this project, analog pins A4 (SDA) and A5 (SCL) are shared by both the sensor and LCD on the I2C bus, as shown in Figure 5.

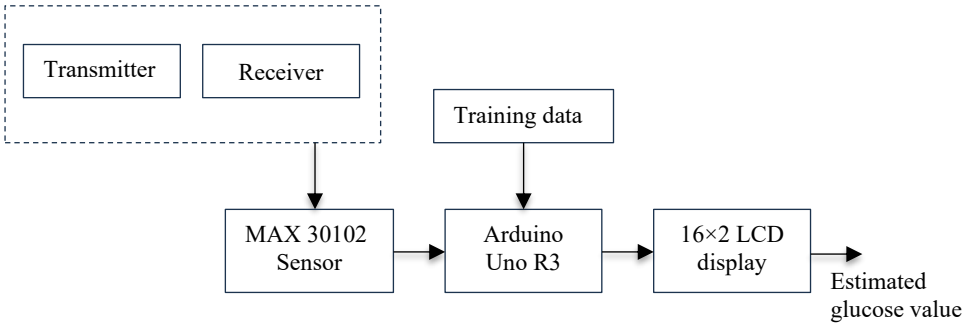

Figure 2. Block diagram of the non-invasive glucose monitoring system.

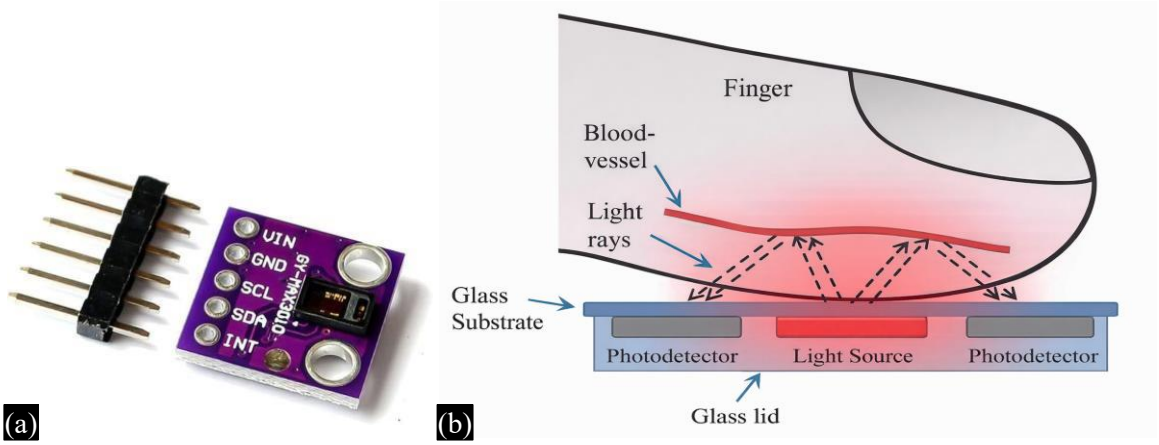

Figure 3. (a) MAX30102 sensor module; (b) MAX30102 working principle.

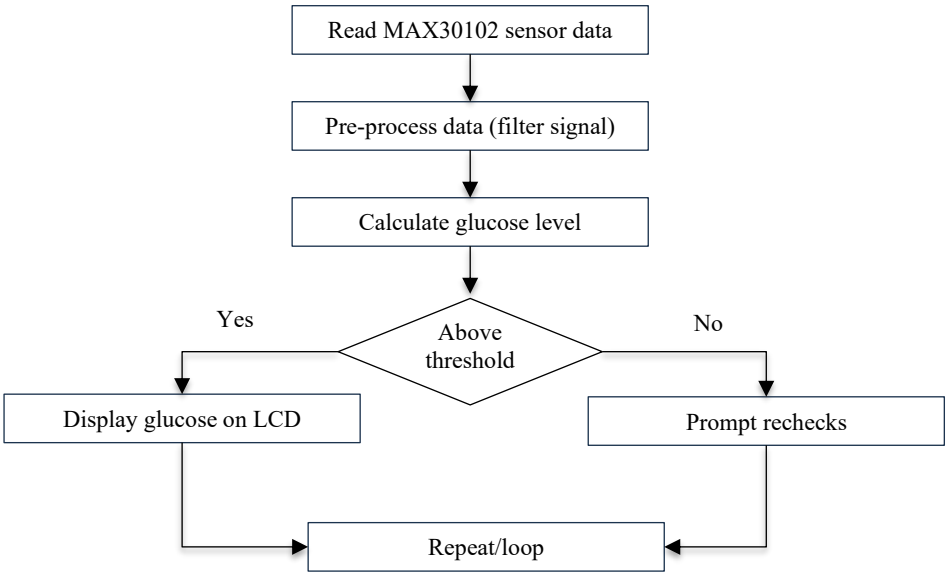

Figure 4. Glucose estimation algorithm flowchart.

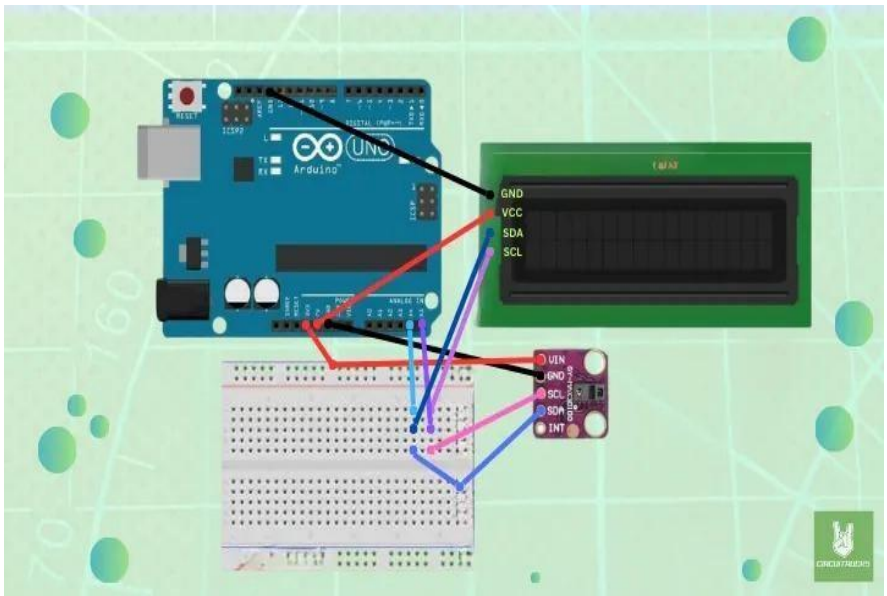

Figure 5. Complete circuit diagram—MAX30102, Arduino Uno R3, and LCD interconnection.

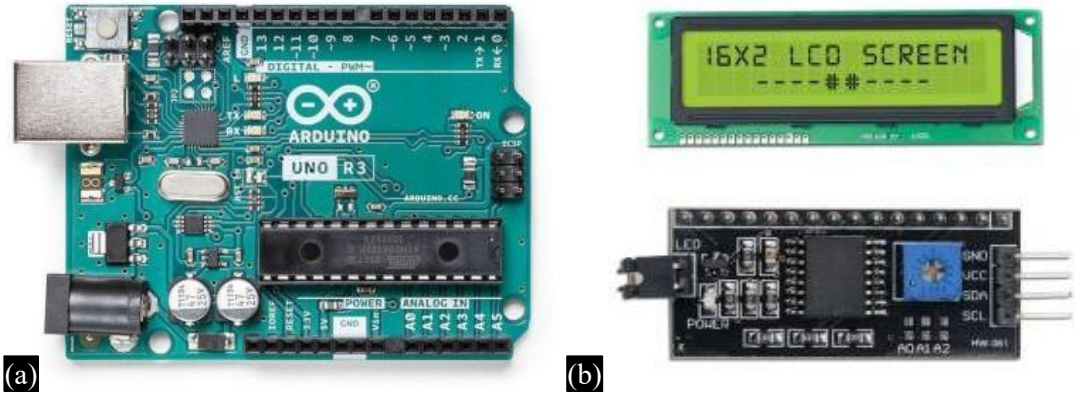

Figure 6. (a) Arduino Uno R3; (b) 16 × 2 LCD with I2C module.

Table 1. Arduino Uno R3 key specifications.

Microcontroller	**ATmega328P @ 16 MHz**
Operating voltage	5V (input: 7–12V via VIN)
Digital I/O/PWM pins	14/6
Analog input pins	6 (A0–A5, 10-bit ADC)
Flash/SRAM/EEPROM	32 KB/2 KB/1 KB
Communication protocols	UART, SPI, I2C (A4-SDA, A5-SCL)

Table 2. MAX30102 sensor key specifications.

ADC resolution	**18-bit**
LED wavelengths	660 nm (red), 880 nm (infrared)
LED current range	0–50 mA (programmable)
Sampling rate	50–3200 samples/second
Communication interface	I2C @ 3.3 V
Operating temperature	−40°C to +85°C

16 × 2 I2C LCD Display

The 16×2 LCD with an I2C backpack module reduces the display interface to two communication lines, sharing the I2C bus with the MAX30102, as shown in Tables 1 and 2. The default I2C address is 0 × 27. The display shows the system status messages, real-time sample progress, and final glucose estimate with health classification. It operates at 5 V from the Arduino's regulated output (Figure 6(a) and (b)).

SOFTWARE SPECIFICATION & IMPLEMENTATION

Arduino IDE and Programming Environment

The Arduino Integrated Development Environment (IDE) was used to write, compile, and upload the embedded C/C++ program to Arduino Uno R3 via USB. The IDE provides a built-in compiler, Serial Monitor for debugging, and supports a large ecosystem of libraries. It is open-source and compatible with Windows, Linux, and macOS.

Libraries Used

- MAX30105.h—Initializes the MAX30102 sensor, configures the LED current, ADC resolution, and sampling rate, and provides getIR() and getRed() polling functions for real-time data acquisition.
- LiquidCrystal_I2C.h—Controls the 16 × 2 LCD via the I2C protocol, reducing the interface to two communication wires (SDA, SCL).
- Wire.h is a Native Arduino I2C library that manages bus arbitration and data framing between the microcontroller and peripheral devices.

Program Flow

In setup(), the sensor and LCD were initialized over I2C. The main loop() function continuously reads the raw IR and red values from the MAX30102. If IR > 50,000, the system computes R = IR/Red, applies the calibration equation G = 275.862×R − 232.103, and stores the result in a circular moving average buffer of 12 samples. The LCD is updated with each iteration, showing sample progress. Once 12 samples are collected, the average glucose value and health status are displayed for 6 s before the system resets. If no finger is detected, the idle message 'Place Finger to start…' is displayed.

EXPERIMENTAL RESULTS AND ANALYSIS

Hardware Setup and LCD Output

The prototype was assembled on a breadboard, and all connections were verified using a multimeter before powering. The Arduino was connected to a PC via USB to enable program upload and Serial Monitor observation. Stable PPG waveform patterns were confirmed in the Serial Monitor before proceeding to full experimental testing. Readings with excessive noise due to finger movement or improper contact were discarded (Figure 7(a) and (b)).

Calibration Data and Accuracy Analysis

Four participants were included in the experimental validation. For each subject, the non-invasive estimate from the proposed system was compared with a simultaneous measurement from a commercially calibrated invasive glucometer, as shown in Figure 8(a) and (b). The results are presented in Tables 3 and 4.

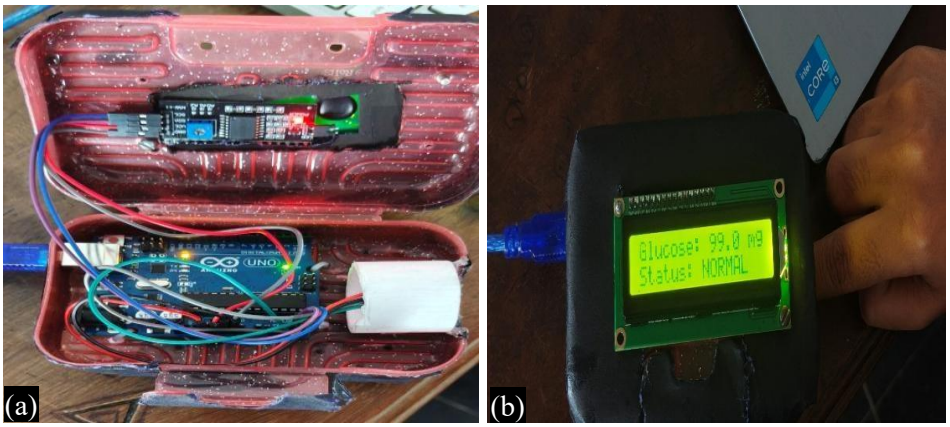

Figure 7. Assembled hardware prototype; (b) Final glucose output on LCD.

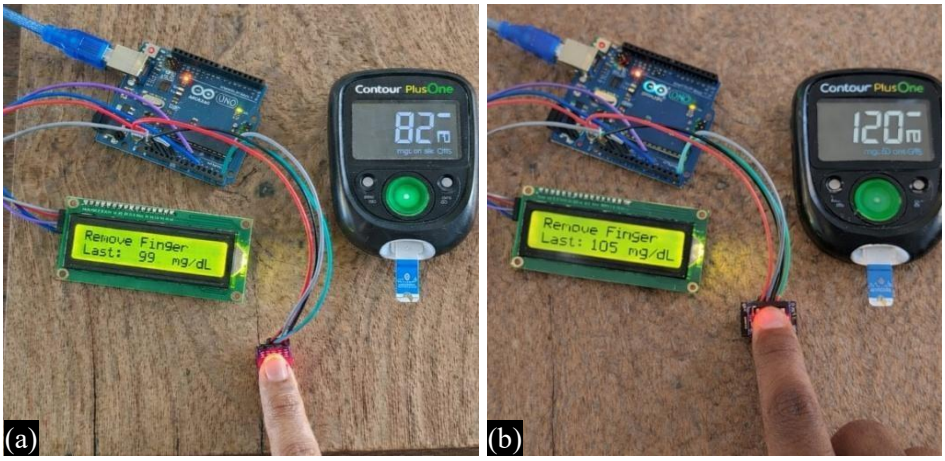

Figure 8. (a) 1st person results; (b) 2nd person result.

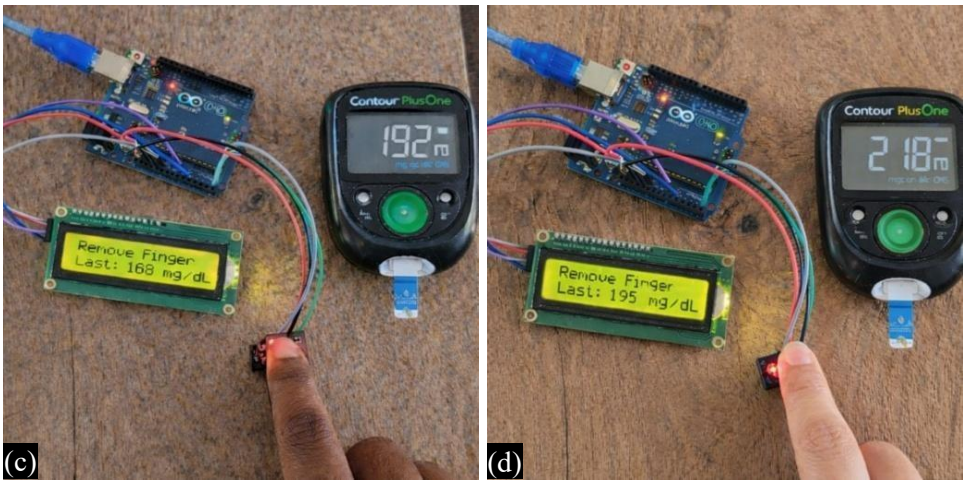

Figure 8. (c) 3rd person results; (d) 4th person result.

Table 3. Calibration data—non-invasive vs. invasive reference values.

Yamini Devi	99	82	+17
Aditya	105	120	−15
Hemanth	168	192	−24
Navya	195	218	−23

Table 4. Accuracy analysis—percentage error and system accuracy.

Yamini Devi	99	82	20.73%	79.27%
Aditya	105	120	12.50%	87.50%
Hemanth	168	192	12.50%	87.50%
Navya	195	218	10.55%	89.45%

ANALYSIS AND DISCUSSION

The system achieved a mean accuracy of 85.93% for all four test subjects. The highest percentage error (20.73%) occurred for the subject with the lowest reference glucose value (82 mg/dL), consistent with the known limitations of linear calibration models at range extremes. At higher glucose concentrations (120–218 mg/dL), the error decreased to a minimum of 10.55%, indicating improved linear model validity in this range (Tables 3 and 4). The 12-sample moving average filter was effective in reducing signal instability caused by motion artifacts and environmental noise. These results are consistent with the PPG-based prototype literature, which typically reports an accuracy in the 80–90% range without advanced machine learning calibration [7, 8]. While the system does not meet the ISO 15197 clinical accuracy standards (±15 mg/dL or ±15% for 95% of readings), it demonstrates meaningful feasibility as a non-invasive monitoring platform for home use, as shown in Figures 8 (c and d).

ADVANTAGES AND APPLICATIONS

Advantages

- *Non-invasive:* glucose estimation without blood extraction is painless and completely free of infection risk.
- *Low-cost:* Uses affordable off-the-shelf components (Arduino Uno R3, MAX30102 sensor module, I2C LCD).
- *Portable and compact:* breadboard/PCB implementation suitable for field and home use without laboratory infrastructure.
- *Real-time output:* Results displayed within seconds via 12-sample averaging with health status classification.

- *Reusable:* No consumables, such as test strips or lancets, are required, reducing recurring costs.
- *Simplified interfacing:* The I2C bus accommodates both the sensor and LCD on two wires, minimizing wiring complexity.

Applications

- Daily self-monitoring is performed in diabetic adults, elderly patients, and pediatric patients who cannot tolerate invasive methods [9].
- Remote and home healthcare settings with limited access to clinical laboratory infrastructure.
- Community health screening camps and diabetes awareness programs for early detection [10].
- Foundational research platform for developing advanced non-invasive biomedical sensing algorithms.
- Wearable glucose monitoring device development using flexible PCB and low-power microcontrollers.

CONCLUSION

This study presents the design, implementation, and experimental validation of a non-invasive blood glucose monitoring device using the MAX30102 optical biosensor and Arduino Uno R3 microcontroller. The system captures PPG signals from the user's fingertip, applies a 12-sample moving average filter and a linear calibration model, and displays the estimated glucose concentration in real time on a 16×2 I2C LCD, entirely without invasive blood extraction. Experimental testing across four subjects yielded a mean system accuracy of approximately 85.93%, confirming the practical feasibility of the proposed method. Although the current prototype does not yet achieve the ISO 15197 clinical accuracy standards, it establishes a robust, low-cost, and portable foundation for further research in non-invasive biomedical monitoring.

Future Enhancement

- Integrate machine learning calibration (SVR, neural networks) on large clinical datasets to approach ISO 15197 accuracy (±15 mg/dL or ±15%).
- Bluetooth (HC-05) or Wi-Fi (ESP8266/ESP32) can be added for wireless data transmission to smartphones and cloud platforms for trend analysis.
- Extend to multi-parameter monitoring: heart rate, SpO_2, and skin temperature, alongside glucose estimation.
- Miniaturized into a wearable wristband using a flexible PCB and a low-power microcontroller (STM32 or nRF52) with clinical validation.

REFERENCES

1. Buda RA, Addi MM. A portable non-invasive blood glucose monitoring device. 2014 IEEE Conference on Biomedical Engineering and Sciences (IECBES), Kuala Lumpur, Malaysia. 2014. p. 964-969. doi:10.1109/IECBES.2014.7047655.
2. So CF, Choi KS, Wong TK, Chung JW. Recent advances in noninvasive glucose monitoring. Med Devices (Auckl). 2012;5:45-52. doi:10.2147/MDER.S28134. PMID:23166457.
3. Yadav J, Rani A, Singh V, Murari BM. Near-infrared LED based non-invasive blood glucose sensor. 2014 International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India. 2014. p. 591-594. doi:10.1109/SPIN.2014.6777023.
4. Chua CD, Gonzales IM, Manzano E, Manzano MC. Design and fabrication of a non-invasive blood glucometer using paired photo-emitter and detector near-infrared LEDs. In: DLSU Research Congress 2014; 2014 Mar 6–8; De La Salle University, Manila, Philippines. Manila (Philippines): De La Salle University; 2014. p. 1-7.
5. Yadav J, Rani A, Singh V, Murari BM. Comparative study of different measurement sites using NIR based non-invasive glucose measurement system. Procedia Comput Sci. 2015;70:469-475. doi:10.1016/j.procs.2015.10.082.
6. Narkhede P, Dhalwar S, Karthikeyan B. NIR based non-invasive blood glucose measurement. Indian J Sci Technol. 2016;9(41):1-7. doi:10.17485/ijst/2016/v9i41/98996.

7. Maier JS, Walker SA, Fantini S, Franceschini MA, Gratton E. Possible correlation between blood glucose concentration and the reduced scattering coefficient of tissues in the near infrared. Opt Lett. 1994;19(24):2062-2064. doi:10.1364/OL.19.002062. PMID:19855740.
8. Babalola AD, Akingbade KF, Ubochi BC. The performance of the STM32 microcontroller and MAX30102 for remote health monitoring device design. J Digit Innov Contemp Res Sci Eng Technol. 2022;10(3):51-68.
9. Shah V. Enabling high-volume, long-term data collection using ultrasound automation. 2024 IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, USA. 2024. p. 1-8. doi:10.1109/ISEC61299.2024.10665183.
10. Freckmann G, Pleus S, Grady M, Setford S, Levy B. Measures of accuracy for continuous glucose monitoring and blood glucose monitoring devices. J Diabetes Sci Technol. 2019;13(3):575-583. doi:10.1177/1932296818812062. PMID:30453761.

