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DEVELOPING A NON-INVASIVE INTELLIGENT SYSTEM FOR BLOOD GLUCOSE LEVEL ESTIMATION USING REFLECTIVE OPTICAL SENSORS

Mihaela MARIN, Teodora Alexandra Dobrin, Florin Bogdan MARIN
“Dunarea de Jos” University of Galati, Romania
e-mail: mihaela.marin@ugal.ro

ABSTRACT

This paper introduces a non-invasive system for blood glucose monitoring using a reflective optical sensor (TCRT5000) integrated with an Arduino platform. The system integrates a detection unit equipped with an infrared LED, phototransistor, microcontroller, OLED display, and Bluetooth module-with real-time data visualization and wireless transmission to mobile devices. The TCRT5000 sensor detects light reflectivity changes caused by blood flow, indirectly estimating glucose levels without the discomfort of invasive techniques. Validation was conducted by comparing system readings with a standard glucometer under varied conditions. The system achieved high performance metrics, including 97.14% accuracy, 97.9% precision, 98.59% sensitivity, and 90.91% specificity. Minor variations were observed, attributable to environmental and individual differences. Despite this, the results confirm the device's reliability and usability, making it a promising alternative for frequent and accessible glucose monitoring. Advantages include affordability, ease of use, and adaptability, which are integral to encouraging patient compliance and improving health outcomes. Future developments may incorporate advanced optical sensors such as NIR spectroscopy or Raman technologies, alongside machine learning algorithms, to improve accuracy and extend functionality. The proposed system highlights the potential for non-invasive methods to revolutionize diabetes care in both personal and clinical settings.

KEYWORDS: optical sensors, OLED, Bluetooth module

1. Introduction

Managing diabetes involves continuous blood sugar monitoring, dietary adjustments, regular exercise, and, if necessary, medication or insulin therapy. Advanced tools such as Continuous Glucose Monitoring (CGM) systems and insulin pumps have improved patient outcomes by maintaining stable glucose levels and reducing risks of hyperglycaemia or hypoglycaemia [1-3]. Personalized prevention and monitoring approaches are critical for effective management.

Diabetes complications affect multiple systems, including the eyes, kidneys, nerves, and cardiovascular system [4-7]. Common issues include diabetic retinopathy, nephropathy, neuropathy, and a higher risk of cardiovascular diseases such as myocardial infarction and stroke [8-10]. Preventing these complications requires strict glycaemic control, regular monitoring, a healthy lifestyle, patient education, and access to advanced technologies. Self-management is essential for minimizing vascular complications and premature mortality. Effective self-care combines regular glucose monitoring, adherence to treatment, and lifestyle changes, with personalized guidance improving outcomes [11-14].

Technological advancements have transitioned diabetes monitoring from invasive finger-prick methods to non-invasive CGM systems [15]. These innovations enable real-time glucose monitoring, offering critical insights for treatment adjustments. Devices like Dexcom G4 Platinum [16] and FreeStyle Libre [17] demonstrate high accuracy and user acceptance, revolutionizing diabetes care.

This paper presents the development of an intelligent, non-invasive blood glucose monitoring system using a reflective optical sensor (TCRT5000) integrated with an Arduino platform. The system

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comprises a detection unit with an infrared LED, a phototransistor, a microcontroller, an OLED display, and a Bluetooth module for wireless data transmission to mobile devices.

2. Experimental procedure

This research focuses on developing an intelligent system for non-invasive blood glucose monitoring. As illustrated in the block diagram (Figure 1), the glucose monitoring system comprises a detection unit and a reception unit. The components include: a development board (Arduino), illustrated in Figure 2, an OLED screen (Figure 3), a Bluetooth module (Figure 4), jumper wires (male-female and male-male connectors), breadboard and a reflective optical sensor (TCRT5000).

The detection unit consists of an infrared sensor, a microcontroller, and a Bluetooth transceiver module. The reflective optical sensor is utilized to detect the presence and variations in light reflectivity, which can be influenced by changes in blood flow. However, it does not directly measure blood glucose levels. The reception unit consists of a mobile phone with Bluetooth connectivity. The glucose sensor captures signals related to glucose variations, which are then processed by the microcontroller. The microcontroller performs signal analysis, calculation, and decision-making. It subsequently transmits the glucose level data to: the serial monitor of the Arduino IDE software, the OLED screen, and the Bluetooth module, allowing the connected mobile phone to receive the transmitted data.

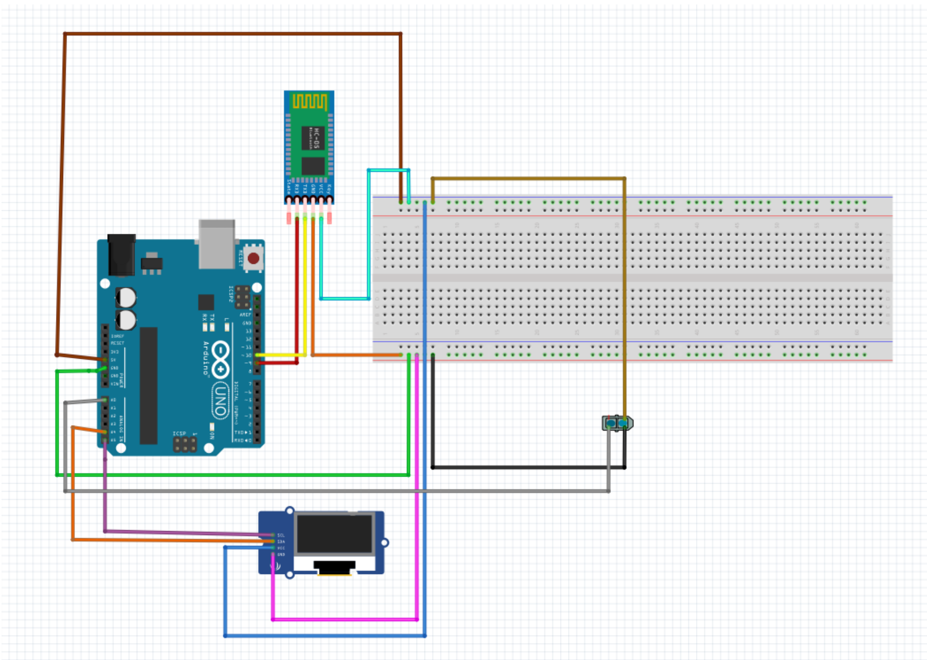
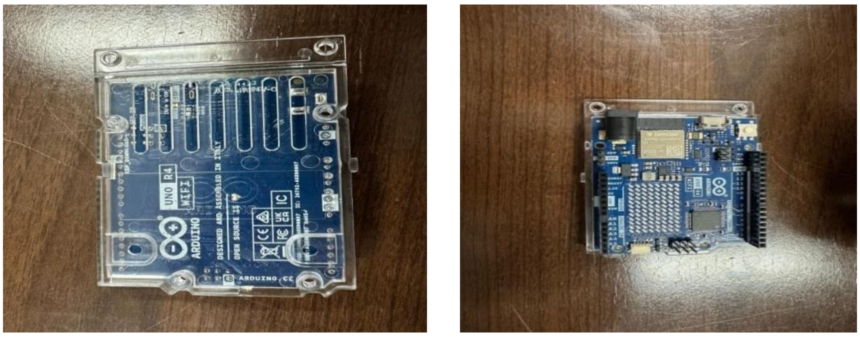


Fig. 1. *Block diagram of the proposed system architecture*



a b

Fig. 2. *Arduino UNO board: a. front side, b. back side*

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OLED (Organic Light Emitting Diode) technology relies on the use of organic polymers as semiconducting materials in light-emitting diodes (LEDs). These materials act like tiny particles "ready" to emit light when electrically stimulated. This innovative approach allows OLEDs to achieve high efficiency, lightweight construction, and the ability to produce flexible and thin displays, making them ideal for modern electronic devices and applications. Figure 4 shows the Bluetooth component.

a b

Fig. 3. *OLED screen: a. front side, b. back side*

a b

Fig. 4. *Bluetooth module: a. front side, b. back side*

The TCRT5000 (Figure 5) is a small yet powerful tool in the world of detection, combining the capabilities of an infrared LED and a phototransistor in a single compact body. This sensor's versatility and efficiency make it an essential component for proximity detection and reflective sensing applications.

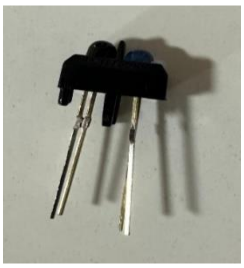

Fig. 5. *TCRT5000 sensor*

Arduino Bluetooth Control (Figure 6) is an application that gives the ability to control the Arduino board (and other similar boards) via Bluetooth, allowing to create custom projects with the new functionalities available in the application.

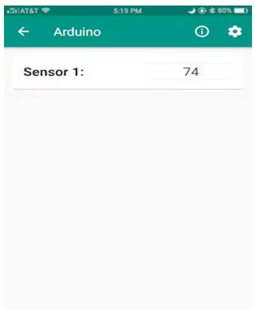

Fig. 6. *Ardutooth App Interface* [18]

To activate the monitoring system using the TCRT5000 sensor and other components, they need to be connected to a development board, such as Arduino. All components are connected to the development board as shown in Figure 7. This setup ensures proper communication between components and allows for efficient data acquisition and processing within the monitoring system.

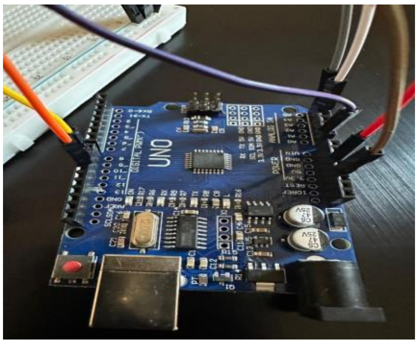

Fig. 7. *Jumper wires connected to Arduino board pins*

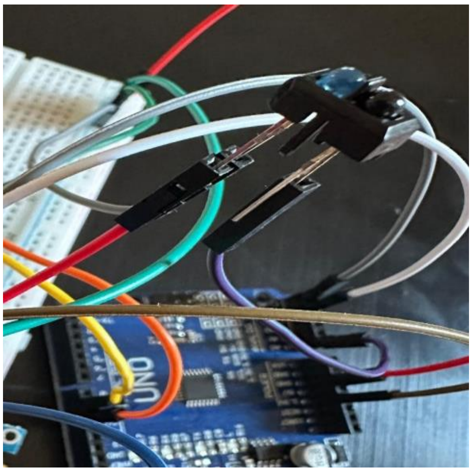

Fig. 8. *Connecting the wires to the TCRT5000 sensor*

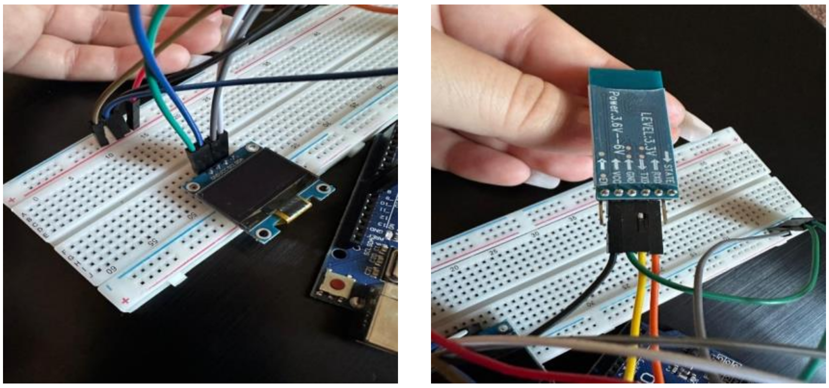

Fig. 9. *Connecting OLED screen and Bluetooth module on Breadboard*

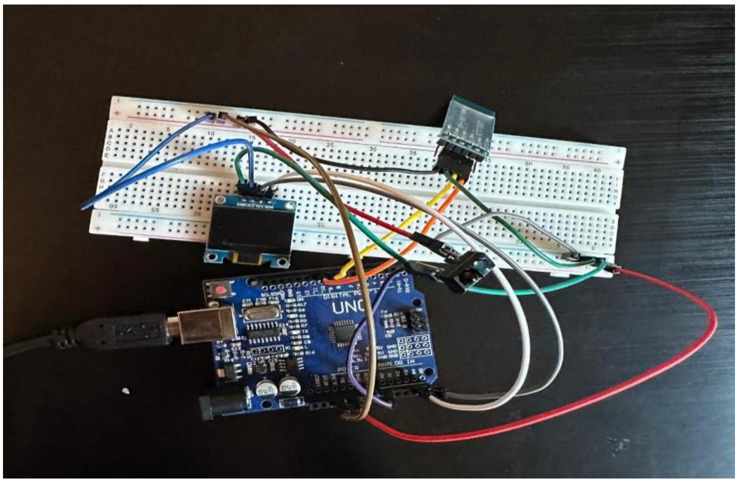

Fig. 10. *The non-invasive intelligent system for blood glucose level estimation*

Once all components are connected, the next step is to link the Arduino board to a laptop using a USB cable. This connection enables both programming and powering the board by launching the Arduino IDE, the data will be displayed on the OLED screen and subsequently transmitted via Bluetooth to the corresponding mobile application (Figure 11).

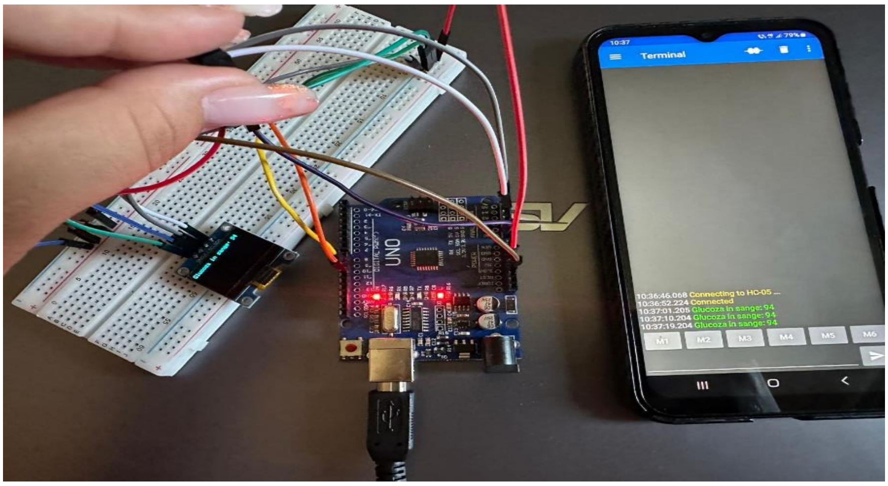

Fig. 11. *Monitoring system - screen and application display*

The TCRT5000 sensor detects any change, and the system successfully updated and transmitted the new values in real-time, both on the OLED screen and to the mobile device. This demonstrates the system's ability to monitor blood glucose fluctuations accurately and in real time.

To validate the accuracy and reliability of blood glucose monitoring device, a rigorous methodology comparing its readings to those of a standard SD glucometer under various conditions and scenarios was employed. By comparing the results from both devices, the accuracy, sensitivity, specificity, and precision of our monitoring system was evaluated. This validation method ensures that the device delivers consistent results aligned with accepted medical standards (Figure 12). After performing ten measurements using both the traditional glucometer method and our new non-invasive approach, we observed differences between the values obtained by the two devices. These results are summarized in the Table 1. The differences can be attributed to several factors: measurement accuracy (differences in the precision of each measurement method), environmental conditions: variations in light, temperature, or other external influences, individual variability due to unique physiological factors of the test subjects. A difference of ±15 mg/dL is considered acceptable for non-invasive glucose monitoring systems according to some standards, such as ISO 15197 [19].

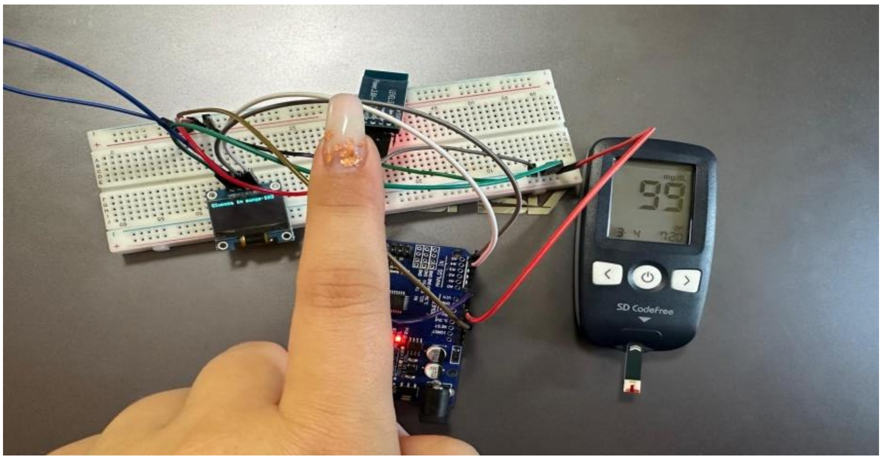

Fig. 12. *Validation of the result with the glucometer*

Table 1. *Comparison between invasive and non-invasive methods*

No.	Blood glucose level (invasive method) mg/dL	Blood glucose level (non-invasive method) mg/dL	Difference
1	98	94	+4
2	100	107	-7
3	93	99	-5
4	115	108	+7
5	99	103	-4
6	91	90	+1
7	92	85	+7
8	102	100	+2
9	105	111	-6
10	94	92	+2

The system's performance metrics are summarized in Table 2, highlighting its strong potential as a reliable monitoring solution.

Table 2. *System Performance Metrics*

Metric	Performance (%)
Accuracy	97.14%
Precision	97.9%
Sensitivity	98.59%
Specificity	90.91%

4. Conclusions

The results indicate that the system accurately estimates blood glucose levels by analysing variations in light intensity reflected by blood flow, as confirmed through tests and evaluations. Utilizing a reflective optical sensor and proper coding on the Arduino board, the device demonstrated reliable performance. Additionally, an Android-based mobile application facilitates data reception and transmission via the HC-05 Bluetooth module, with glucose levels formatted as text messages.

The integration of Bluetooth connectivity ensures seamless data transfer, enhancing ease of use for glucose monitoring and management. The results also highlight the potential for future enhancements, such as replacing the TCRT5000 sensor with advanced optical technologies as NIR spectroscopy or Raman sensors, combined with machine learning algorithms, to improve accuracy and efficiency. This evolution could make the system suitable for continuous patient monitoring in clinical settings.

The non-invasive approach, validated by the obtained results, eliminates the discomfort associated with traditional methods, encouraging frequent usage and better health outcomes. The system's affordability and the flexibility of the Arduino platform further support its adaptability for broader applications and customization to meet specific user requirements.

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