IoT-Based Non-Invasive Monitoring of Blood Sugar Levels with Early Warning Mechanism

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This research presents the design and implementation of a non-invasive sugar level monitoring system with an early warning mechanism using embedded systems and Internet of Things (IoT) technologies. The system integrates an Arduino Uno microcontroller with sensors such as the MLX90614 infrared temperature sensor, MAX30102 blood oxygen and heart rate sensor to monitor vital health parameters. The system correlates temperature, blood oxygen levels, heart rate, and glucose levels to provide early warnings for high or low sugar conditions. Experimental results demonstrate the system's accuracy, reliability, and effectiveness in providing real-time health data. Also, this research highlights the potential of non-invasive health monitoring systems in diabetes management and paves the way for future advancements in IoT-based healthcare solutions.

Keywords: Arduino, Internet of Things (IoT), Diabetes management, Non-invasive monitoring, Glucose level detection,

Introduction:

Diabetes is a metabolic condition that entails an increased glucose (blood sugar) level in the blood that is no longer within the normal range. The increase in sugar level can be attributed to inadequate insulin production in blood cells, an improper response of body cells to insulin, or a combination of both. If left unmanaged, diabetes can cause serious complications such as heart failure and blindness. Therefore, regular monitoring of glucose levels is essential for maintaining health. Uncontrolled diabetes can lead to serious complications, including blindness; therefore, regular monitoring of blood glucose is essential. According to the World Health Organization (WHO), approximately 422 million adults were living with diabetes in 2014, and this number is projected to reach about 642 million by 2040 if current trends persist, affecting individuals of all ages, races, and socioeconomic backgrounds. In practice, patients regulate blood glucose through an appropriate diet and, when required, insulin therapy [1][2]. Diabetes affects individuals of all ages, races, and socioeconomic backgrounds, making it a widespread and diverse condition. Complications arising from imbalanced glucose levels in diabetes include strokes, cardiovascular diseases, blindness, chronic kidney failure, and amputations [3]. WHO predicts diabetes as a long-term and non-infectious disease. It is regarded as a significant cause of death in the entire world, and it is anticipated that it will be the fourth or seventh leading cause of death by 2030. Diabetes mellitus, also referred to simply as diabetes, is an autoimmune disorder that is caused by the inability of the body to regulate sugar or glucose levels. If left untreated, persistent diabetes can cause damage and impair the function of various sensitive organs in the body. Insulin, produced by the pancreas, plays a crucial role in regulating and maintaining the balance of sugar (glucose) in the bloodstream. However, it becomes a health challenge when the pancreas produces less insulin than required or the body becomes unable to utilize the produced insulin [4].

Problem Statement:

Diabetes mellitus is a long-term metabolic disorder that requires continuous monitoring of the levels of blood sugar to avoid dangerous complications like cardiovascular disease, kidney failure, blindness, and neuropathy. The traditional methods of glucose monitoring are invasive, somewhat painful, and discomforting. Hence, they tend to hinder frequent practices because frequent visits are expensive and might be painful to some people. Despite some non-invasive solutions being suggested, most of the available solutions were based on single-parameter monitoring, lacked real-time feedback, and could not be used on a large scale because they would be too expensive to be applied in low-resource settings. Hence, it makes the system affordable, reliable, and user-friendly, enabling it to monitor glucose levels in the body and integrate with IoT technologies to provide early advice and remote healthcare assistance, which is urgently necessary.

Literature Review:

Integrating Internet of Things (IoT) technology and embedded systems in health monitoring has received significant attention in recent years, particularly in chronic diseases such as diabetes. Several studies have investigated non-invasive glucose monitoring due to its convenience and the fact that fewer blood samples are taken regularly. Early research on non-invasive glucose monitoring systems primarily focused on optical sensors, with some studies examining the potential of infrared-based sensors for measuring temperature about glucose levels. One such example is the MLX90614 infrared temperature sensor, which offers reliable body temperature measurements that can be correlated with fluctuations in glucose levels [5]. Furthermore, health monitoring devices, including wearable systems developed on microcontroller-based systems such as Arduino, have demonstrated potential in continuously tracking vital health information, including oxygen levels in blood and heartbeat rhythms [6]. These systems can deliver early warnings by simultaneously monitoring multiple health parameters. In addition to temperature sensors, the MAX30102 can measure blood oxygen levels and heart rate, offering a comprehensive solution for real-time health monitoring.

Some studies have illustrated the usefulness of integrating these critical parameters to give the general status of the health of a patient, especially in managing diabetes [7]. The use of multiple sensors in embedded systems has been investigated to ensure greater accuracy and reliability of the monitoring systems. A breakthrough in diabetes treatment and management is the usage of IoT-powered devices that perform real-time analysis of the health condition and provide management. Using IoT solutions, sensor data can be transmitted to the cloud for further analysis, allowing continuous monitoring of glucose levels, heart rate, and blood oxygen levels [8]. Such real-time information sharing can be especially useful in remote patient monitoring so that immediate actions can be taken when either high or low glucose states occur. Additional research has also highlighted the efficacy of IoT systems in monitoring and anticipating the occurrence of diabetes-related complications in their early stages. Health systems based on IoT can offer such flexibility of personal monitoring that patients can monitor their health conditions without the necessity of visiting doctors regularly [9]. In addition, the research indicates that various studies are devoted to the feasibility of IoT and embedded systems integration in delivering early warnings and alerts, which would significantly improve the implementation of diabetes management due to proactive care [10]. Various techniques have been explored for glucose monitoring, including UV spectroscopy, bio-impedance, and RF transmission methods. They developed bio-electrical analysis (BIA), which involves the use of electrodes to exert low-intensity currents on the skin or tissue.

The resultant voltage indicates changes in the dielectric or the size of the target, hence it can detect the chemical compositions or even bio-processes inside the organism [11]. One of the latest methods, capable of being used non-invasively, is the Near Infrared Spectroscopy (NIRS) method, to measure the concentration of glucose in the blood. The alternative methods used to perform a blood glucose test in the laboratory are the reduction method, condensation method, and enzyme method. This technique uses costly photo detectors and spectrometers; hence, it is not cost-efficient to make glucometers using this technique [12]. Spectroscopy is one of the non-invasive ways of measuring glucose levels. When a beam of light passes through a transparent glucose solution in water, the glucose molecules reduce the intensity of specific light frequencies, resulting in a distinct absorption spectrum. Hence, to determine the glucose concentration [13] accurately.

In summary, non-invasive sensors combined with IoT-based glucose monitoring systems hold significant promise for advancing diabetes management. The possibility of observing numerous health parameters in real-time and then getting updates that can save a patient's life can change the world of diabetes management and hopefully increase the chances of positive outcomes and condition prevention.

Objectives:

The primary objectives of this study are:

To design and develop a non-invasive glucose monitoring system with temperature, blood oxygen, heart rate, and glucose sensor supporting an Arduino-alike platform.

To develop an early warning approach that provides real-time warnings when abnormal sugar levels are detected, thereby enabling proactive intervention.

To demonstrate the potential of IoT-enabled healthcare solutions for continuous and remote monitoring, particularly in low-resource environments where accessibility and affordability are critical.

To assess the system's accuracy, reliability, and cost-effectiveness in monitoring several key parameters of the human body.

Novelty Statement:

The originality of the study lies in its combined and comprehensive non-invasive glucose monitoring approach. The proposed system integrates several biosensors (including the MLX90614 IR temperature sensor, MAX30102 blood oxygen and heart rate sensor, and non-invasive glucose sensor) onto a single Arduino-based platform to concurrently measure important health indicators. The system increases the accuracy of detecting abnormal glucose levels by correlating the body temperature, heart rate, and oxygen levels with variations in glucose levels. Additionally, the system is cost-efficient, user-friendly, and particularly suitable for low-resource settings, thereby providing a practical and scalable solution to global diabetes management challenges.

Methodology:

This section presents the design and methodology employed in developing the non-invasive glucose monitoring system. The system integrates hardware components, software algorithms, and IOT connectivity to achieve real-time monitoring and early warning capabilities, as shown in Figure 1.

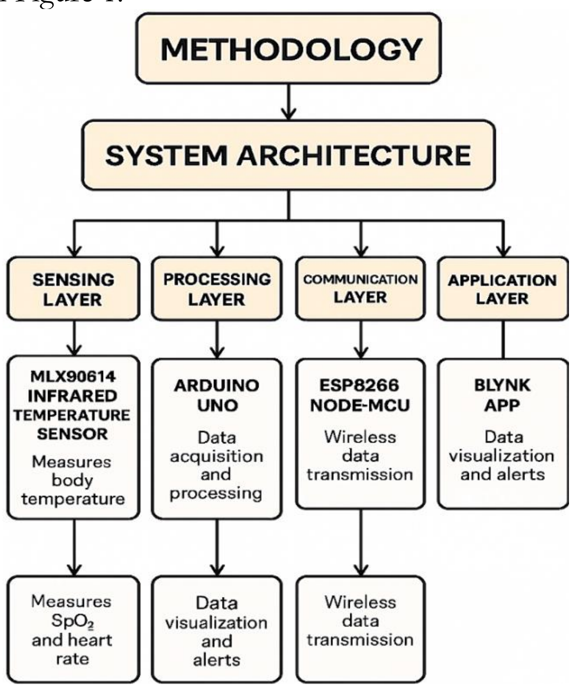

Figure 1. Methodology

System Architecture:

The system architecture is designed to provide a holistic approach to non-invasive glucose monitoring by integrating multiple sensors, a microcontroller, and IOT connectivity. The proposed system architecture is designed with four interconnected layers. The sensing layer incorporates sensors for monitoring glucose, body temperature, blood oxygen saturation, and heart rate. Data collected from these sensors is processed in the processing layer, which is managed by the Arduino Uno microcontroller for acquisition and computation. The processed information is then transferred through the communication layer, where the ESP8266 Node-MCU module enables wireless data transmission. Finally, the application layer provides real-time data visualization and alerts to the user via the Blynk mobile application.

Sensor Integration and Working Principles:

The sensors are integrated with the Arduino Uno to allow data collection and processing. The MLX90614 is used to measure the body temperature by detecting infrared radiation emitted from the skin surface and communicates with the Arduino through the I²C protocol. The MAX30102 sensor, based on photoplethysmography (PPG), is employed to measure blood oxygen saturation (SpO_2) and heart rate by emitting red and infrared light into the skin and examining the reflected signals. Also, a non-invasive glucose sensor is incorporated, which operates optical or electrochemical techniques to estimate glucose levels in interstitial fluid, transmitting data to the Arduino via analog or digital signals. Together, these sensors form a comprehensive system for monitoring vital health parameters in real-time.

System Designing and Setup:

This section integrates an Arduino Uno, and a MAX30102 sensor is used to measure blood oxygen saturation (SpO_2) and heart rate, while the MLX90614 infrared sensor is employed to measure body temperature. The LCD is used to measure and display sugar levels. The MAX30102 and MLX90614 sensors, connected to a breadboard along with other components, capture the user's heartbeats, body temperature, and other vital signs. These signals are then processed by the Arduino Uno, which calculates the beats per minute (BPM). The result is displayed on the LCD screen, providing real-time feedback, as shown in Figure 2.

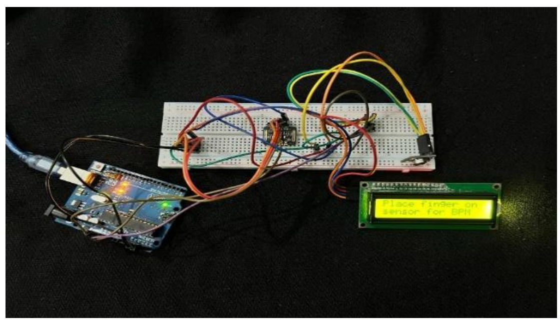

Figure 2. Proposed hardware complete circuit

The sensors were integrated with the Arduino Uno to enable data collection and processing. The MLX90614 infrared sensor measured body temperature by detecting emitted infrared radiation and communicated via I^2C. The MAX30102 (PPG-based) measured SpO_2 and heart rate by emitting red and infrared light and analyzing reflected signals. A non-invasive glucose sensor estimated glucose levels in interstitial fluid using optical or electrochemical methods and provided analog/digital outputs to the microcontroller. These sensors jointly enabled real-time, multi-parameter monitoring.

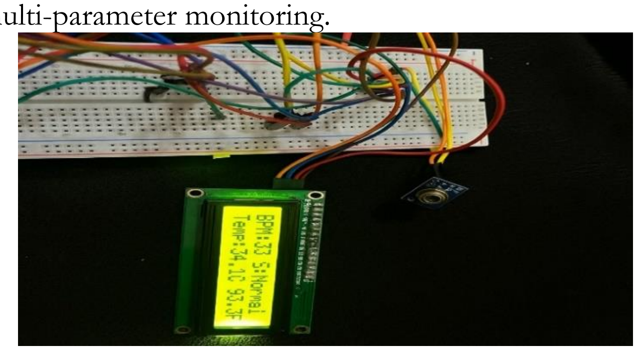

Figure 3. Measuring the Temperature of the Human Body

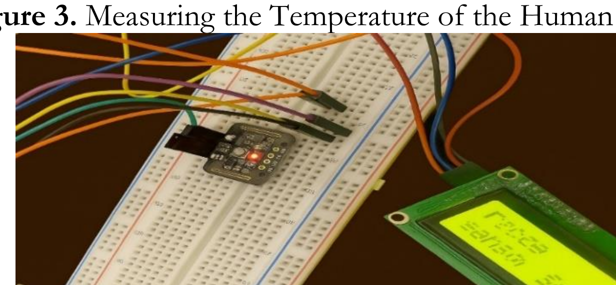

Figure 4. Measuring BPM with SpO_2 Sensor

Proposed System Design:

The proposed system is designed for sugar level monitoring with an early warning system using an Arduino-based platform. Figure 5 presents the flow diagram of the proposed system, illustrating its overall functionality and decision-making process.

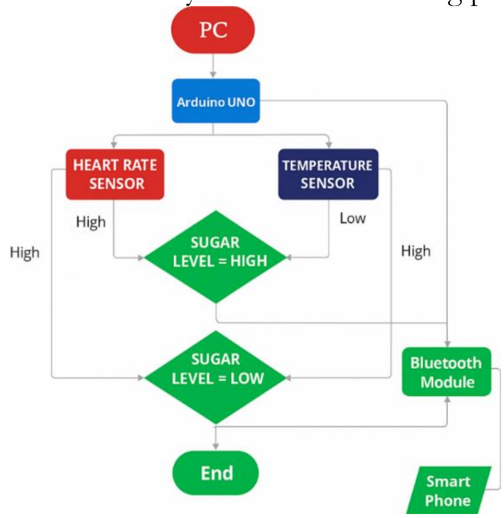

Figure 5. Flow diagram of proposed approach

Input Stage: The system starts with input from two key sensors:

Heart Rate Sensor: Measures the user's pulse rate.

Temperature Sensor: Monitors body temperature.

Processing Unit: The Arduino UNO acts as the central controller, receiving and processing data from both sensors.

Condition Evaluation:

If the heart rate is elevated, the system flags a potential abnormal condition. At the same time, if the temperature is low, it initiates an additional check to assess the sugar level. If both conditions, elevated heart rate and low temperature, are detected as critical, the system infers that the sugar level is elevated.

Sugar Level Evaluation:

When a high sugar level is detected, the system activates an alert mechanism and transmits the data to a Bluetooth module connected to the Arduino UNO.

Alert and Notification:

The Bluetooth module transmits the alert message to the user's smartphone.

If no abnormal conditions are detected (i.e., sugar level is low or normal), the system ends the process with no alert.

Data Logging:

The Arduino UNO is also connected to a PC, which can be used for real-time data logging and future analysis.

Results and Discussion:

Figure 6 depicts an LCD screen that is a representation of real-time health data. The heart rate was measured at 93 BPM, which falls within the normal range, while the body temperature was recorded at 34.9 °C (94.7 °F), below the normal range. These readings can be considered indicative of a monitoring system designed to track key vital health indicators.

The health data are provided in Table 1, a set of essential health indicators gathered with the help of different patients, divided according to their gender. It contains data about body temperature (in Celsius and Fahrenheit), heart rate (in beats per min.), and sugar (low, regular, and high). The temperature ranges from 16.7°C to 42.6°C, indicating a wide range of individuals with varying fever levels and normal body temperatures.

Figure 6. Real-time health monitoring of a patient.

Table 1. Health data of different patients

S. No	GENDER	AGE	TEMPERATURE (°C)	TEMPERATURE (°F)	HEART RATE (BPM)	SUGAR LEVEL
1	MALE	20	36.8	98.2	75	NORMAL
2	FEMALE	21	37.2	99.0	82	NORMAL
3	MALE	23	38.6	101.5	110	LOW
4	FEMALE	25	38.9	102.0	118	LOW
5	MALE	26	39.5	103.1	120	LOW
6	FEMALE	28	40.1	104.2	130	LOW
7	MALE	30	36.5	97.7	72	NORMAL
8	FEMALE	32	37.4	99.3	88	NORMAL
9	MALE	33	39.0	102.2	115	LOW
10	FEMALE	35	39.6	103.3	125	LOW
11	MALE	36	41.0	105.8	140	LOW
12	FEMALE	38	36.9	98.5	80	NORMAL
13	MALE	40	37.1	98.8	85	NORMAL
14	FEMALE	42	39.8	103.6	150	HIGH
15	MALE	43	40.2	104.4	160	HIGH
16	FEMALE	45	36.7	98.1	78	NORMAL
17	MALE	46	37.0	98.6	82	NORMAL
18	FEMALE	48	39.5	103.1	138	HIGH
19	MALE	50	40.0	104.0	145	HIGH
20	FEMALE	52	36.6	97.9	76	NORMAL
21	MALE	53	37.3	99.1	89	NORMAL
22	FEMALE	55	38.8	101.8	120	HIGH
23	MALE	58	39.3	102.7	135	HIGH
24	FEMALE	60	37.0	98.6	80	NORMAL
25	MALE	62	36.5	97.7	70	NORMAL

Discussion:

To assess the feasibility of a non-invasive, IoT-enabled early-warning system that fuses multiple bio-signals, we analyzed 25 patient records containing glucose status (Low/Normal/High), heart rate (BPM), and temperature (°C). Data were acquired on an Arduino-based platform (MLX90614 for temperature; MAX30102 for SpO_2/heart rate) and streamed to the mobile app for real-time visibility and alerts. Furthermore, the evaluation of a non-invasive, IoT-enabled early-warning system was conducted by analyzing 25 patient records, which included glucose status (Low/Normal/High), heart rate (BPM), and temperature (°C). The signals were detected on an Arduino platform (MLX90614 for temperature; MAX30102 for SpO_2/heart rate) and were sent to a mobile app for real-time viewing and alerts. The group distribution, categorized as Low, Normal, and High, as shown in Figure 7, covered both normal and abnormal cases, which helped test the alert logic. The relationship between temperature and heart rate is shown in Figure 8, so temperature alone was not enough to explain heart-rate changes. In contrast, heart rate was higher and more variable in both the Low and High glucose groups than in the Normal group (medians ≈ 115 and 143 BPM vs 83 BPM), as shown in Figure 9. In addition, Table 2 compares our work with existing studies, summarizing methods, monitored parameters, IoT use, cost-effectiveness, limitations, and the advantages of our low-cost, multi-sensor IoT approach.

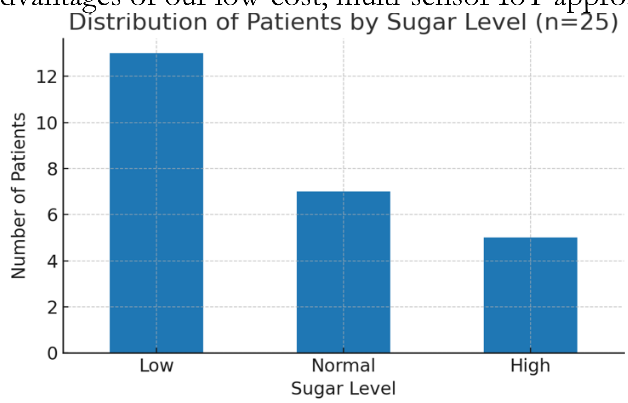

Figure 7. Distribution of patients by sugar level (n = 25).

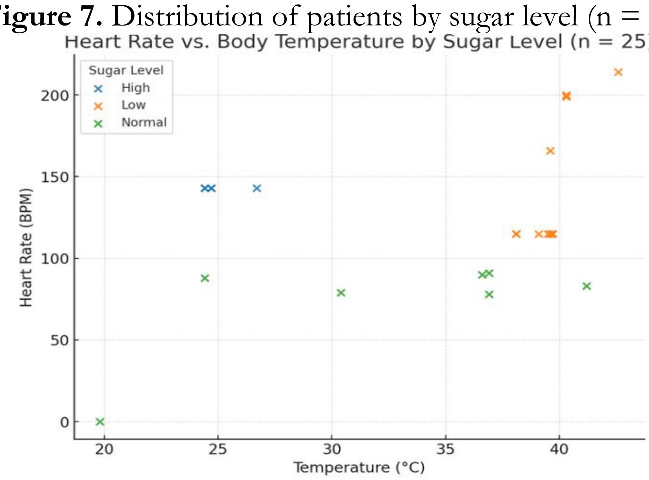

Figure 8. Scatter plot of heart rate vs. body temperature by sugar level (n = 25).

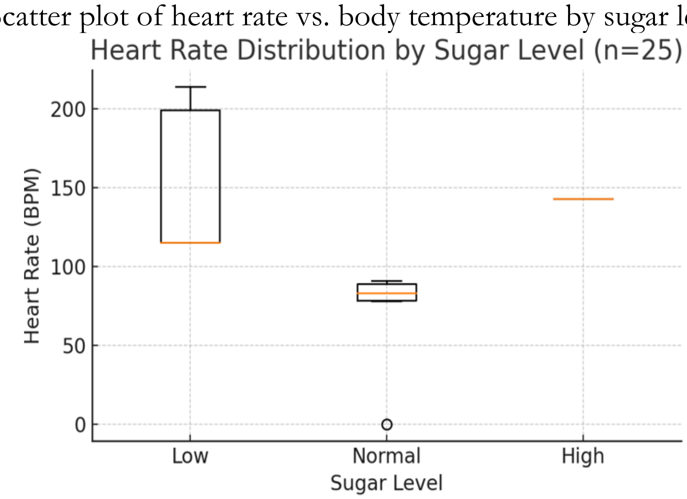

Figure 9. Box plot of heart rate across sugar levels (n = 25).

Table 2. Comparison of Existing Non-Invasive Glucose Monitoring Studies with Proposed System

Study	Method/Technology	Parameters Monitored	IoT Integration	Cost-Effectiveness	Limitations	Proposed System Advantages
[6]	Arduino-based wearable device	Heart rate, SpO_2	No	Moderate	Lacks glucose monitoring	Adds glucose and multi-sensor fusion
[7]	MAX30102 sensor-based system	Heart rate, oxygen	No	Moderate	Single parameter focus	Glucose + temperature integration
[10]	IoT-based glucose sensor	Glucose only	Yes	Low	Lacks reliability under varying conditions	Multi-parameter reliability
[12]	Near-infrared spectroscopy	Glucose only	No	Low (expensive setup)	High cost, bulky	Uses low-cost commercial sensors
[4]	Wearable non-invasive sensor (review)	Glucose (future-oriented)	Limited	Not discussed	Conceptual, no real prototype	Practical IoT-enabled prototype
Proposed System (This Study)	Arduino + MLX90614 + MAX30102 + glucose sensor	Glucose, heart rate, temperature, oxygen	Yes (smartphone alerts via IoT)	High (low-cost design)	Limited dataset size	Multi-sensor fusion, cost-efficient, real-time IoT alerts

Conclusion:

This study developed a non-invasive system to measure sugar levels in individuals, incorporating IoT and an early warning feature that addresses key challenges in diabetes management. Its system offers a comprehensive health monitoring service that is facilitated by glucose, temperature, blood oxygen levels, and heart rate monitoring, which are presented in real time to the individuals. The prototype proved to be incredibly cost-efficient and easy to use, as evidenced by the customer response to this factor. The embedding of IoT technologies ensures that real-time health information is efficiently transferred, enabling proactive intervention in cases of unusual glucose parameters and leading to significant improvements in patient outcomes. The results align with WHO objectives to provide affordable and accessible diabetes management, particularly in low-income countries, and contribute to expanding the knowledge base on IoT-based healthcare practices. Future developments will focus on enhancing sensor accuracy through advanced technologies, including graphene-based sensors and AI-powered calibration.

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