

# IoT-Based Smart Remote Patient Monitoring System Using ESP32 and Cloud Analytics for Real-Time Healthcare

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**Abstract**— The rapid growth of chronic diseases and increasing pressure on healthcare infrastructure have created a significant demand for intelligent and cost-effective remote healthcare solutions. This paper presents the design and development of an IoT-based Smart Remote Patient Monitoring System capable of continuously tracking critical physiological parameters such as heart rate, blood oxygen saturation (SpO<sub>2</sub>), body temperature, blood pressure, and blood glucose levels. The proposed system utilizes an ESP32 microcontroller integrated with biomedical sensors including MAX30102 and DS18B20 for real-time data acquisition. The collected health data is securely transmitted through Wi-Fi to a cloud-based web and mobile monitoring platform, enabling doctors and caregivers to remotely access patient information. To improve reliability during unstable internet connectivity, a GSM communication module is incorporated for emergency alert transmission. The system also includes an automated notification mechanism that instantly alerts healthcare providers whenever abnormal physiological conditions are detected. Experimental evaluation demonstrates low transmission latency, high data reliability, and acceptable sensor accuracy for non-clinical healthcare applications. The proposed framework is scalable, energy-efficient, and economically viable for long-term healthcare monitoring. Furthermore, the system offers future integration possibilities with Artificial Intelligence and edge-based machine learning for predictive analytics and intelligent healthcare decision-making in smart digital healthcare environments.

**Index Terms**— Remote Patient Monitoring, ESP32, Healthcare Analytics, Edge Computing, Machine Learning, Smart Healthcare, Telemedicine, Internet of Things (IoT)

## I. INTRODUCTION

Modern healthcare is gradually shifting from hospital-centered treatment to continuous and remote patient monitoring. With the growing prevalence of chronic diseases such as diabetes, hypertension, and heart disorders, there is a strong need for systems that enable real-time tracking of vital health parameters. The proposed Health Monitoring System is designed to provide continuous and reliable monitoring of key physiological indicators including blood pressure, heart rate, blood glucose level, and blood oxygen saturation. The system collects health data using sensors and processes it for display on a user-friendly mobile and web-based dashboard [13]. This allows patients, doctors, and caregivers to access real-time as well as historical health records from anywhere [9]. One of the major features of the system is its automated alert mechanism. If any parameter exceeds predefined safe limits, instant notifications are sent to doctors or caregivers, enabling timely medical intervention. The project also ensures secure data transmission and storage, maintaining privacy and data integrity. Additionally, it explores non-invasive methods for estimating blood glucose and hemoglobin levels. With future integration of Artificial Intelligence and advanced communication technologies, the system can evolve into a comprehensive digital healthcare solution supporting long-term disease management.

The rising prevalence of chronic diseases such as diabetes, hypertension, cardiovascular diseases, and respiratory diseases has placed a huge burden on healthcare systems across the globe. Traditional healthcare monitoring methods mainly depend on periodic hospital visits and manual examination, which often result in delayed diagnosis, increased healthcare cost and limited continuous observation of patients. In underserved and hard-to-reach locations, lack of health professionals and poor health infrastructure also hinder timely access to medical care. Current monitoring systems are expensive, power-hungry and not suited for real-time emergency response. Besides, some regions also face poor internet connectivity, impacting the ongoing communication between patients and healthcare providers. There is an urgent need for a low-cost, secure and intelligent remote patient monitoring system that can continuously monitor vital physiological parameters in real-time. The proposed IoT based healthcare system is aimed at solving these issues. It consists of biomedical sensors, cloud communication, automatic alerts and GSM based emergency support for continuous, reliable and accessible healthcare monitoring.

**Scope:** The proposed IoT based Remote Patient Monitoring System has a great scope in modern digital healthcare applications especially for continuous monitoring of patients suffering from chronic diseases and elderly healthcare management. The system is designed to measure vital physiological parameters in real time using biomedical sensors embedded with ESP32 microcontroller such as heart rate, blood oxygen saturation, body temperature, blood pressure and glucose levels. The collected data can be safely transmitted to cloud based web and mobile platforms for remote access by doctors, carers and healthcare professionals. The system also features automatic emergency notification by GSM communication in case of abnormal health condition or unstable internet connectivity. Future enhancements may include Artificial Intelligence integration, predictive healthcare analytics, edge computing, smart wearables, and 5G communication technologies. The proposed framework can be extended to telemedicine, home healthcare services, smart hospitals, pandemic management and large-scale public healthcare systems needing reliable and cost-effective remote monitoring solutions.

The primary objective of the proposed system is to develop an intelligent IoT-based Remote Patient Monitoring System capable of continuously monitoring critical physiological parameters in real time. The system aims to integrate biomedical sensors with an ESP32 microcontroller to acquire accurate patient health data, including heart rate, SpO<sub>2</sub>, body temperature, blood pressure, and glucose levels. Another important objective is to securely transmit the collected data to cloud-based web and mobile platforms, enabling remote monitoring by healthcare professionals and caregivers from any location. The system also focuses on implementing automated alert mechanisms using Wi-Fi and GSM communication to provide immediate notifications during abnormal health conditions or network failures. Additionally, the project aims to develop a scalable, low-cost, energy-efficient, and user-friendly healthcare solution suitable for remote and rural healthcare applications. Future objectives include integrating Artificial Intelligence and edge-based machine learning techniques for predictive analytics, anomaly detection, intelligent diagnosis support, and enhanced decision-making in smart digital healthcare environments

## II. LITERATURE REVIEW

Recent advancements in Internet of Things (IoT) technology have transformed remote health monitoring systems [5]. Researchers have proposed smart health systems that transmit physiological information in real time using low-power devices. Mohammed and Hasan [1] have designed a smart health monitoring system that uses IoT technology to collect patient information and send it to cloud platforms. However, they have not used advanced features such as predictive analytics. In a similar context, Das [2] has proposed an IoT-based real-time health monitoring system that uses machine learning algorithms for smart insights on patient health using ESP32 web servers.

Merugu et al. [3] have proposed a machine learning-based predictive healthcare system to improve patient health monitoring using smart algorithms that identify health issues in patients. The authors have also emphasized the importance of predictive analytics in patient health care management. In another study, Rajput and Bhatia [14] have used AI-based predictive analytics to improve decision-making accuracy in IoT health care systems. Georgieva-Tsaneva et al. [4] have analyzed the integration of photoplethysmography and electrocardiography in IoT systems to improve heart monitoring systems. Mekruksavanich and Jitpattanakul [15] have used wearable IoT devices and deep learning algorithms to accurately identify abnormal heart conditions in patients. Cloud-based IoT systems have also been thoroughly explored. Hossain and Muhammad [7] presented a cloud-based IoT framework for healthcare monitoring systems that ensure secure storage and access of patient information. Liu et al. [8] also discussed secure data transmission in IoT-based healthcare environments. Wireless Body Area Networks (WBANs) have also led to further developments in patient monitoring systems. Ullah et al. [6] presented a comprehensive survey on WBANs in healthcare systems that highlight issues of communication reliability and energy efficiency. At a global level, digitization of healthcare systems across the world is guided by policies such as the World Health Organization's global strategy on digital health 2020-2025 [12], which emphasizes the integration of digital health technologies to strengthen health systems globally. Based on the research gaps identified, the proposed system will focus on integrating ESP32 hardware at a low cost [10], biomedical sensors such as MAX30102 [11], and cloud-based dashboards and AI for a secure and real-time remote patient monitoring system.

Table 1: Comparative Analysis of IoT-Based Remote Patient Monitoring Systems

Ref.	Author & Year	Core Contribution	Key Technologies	Limitation	Relevance to Present Work
[1]	Mohammed & Hasan (2023)	Remote monitoring with GPS-based emergency alerts	Raspberry Pi 4B, MAX30100, DS18B20, GSM, GNSS	Higher cost and power consumption	Supports GSM-based emergency alert integration; our system uses cost-efficient ESP32
[2]	Das (2025)	Edge-based real-time anomaly detection	ESP32, Local Web Server, TinyML	Limited largescale validation	Justifies ESP32 selection and on-device ML implementation
[3]	Merugu et al. (2025)	Predictive analytics for early risk detection	IoT Sensors, Random Forest, LSTM	Higher computational complexity	Reinforces addition of AI/ML layer for predictive monitoring
[4]	Georgieva-Tsaneva et al. (2025)	Multi-sensor cardiac monitoring for arrhythmia detection	PPG, ECG, IoT Module	Focused mainly on cardiac parameters	Supports integration of ECG for enhanced clinical accuracy

### III. METHODOLOGY

The design is based on an IoT-friendly configuration that integrates sensing hardware, wireless communication, and a cloud-supported web interface. On the hardware side, an ESP32 microcontroller communicates with biomedical sensors such as MAX30102 for heart rate and SpO<sub>2</sub>, DS18B20 for body temperature, and additional components for blood pressure and glucose levels. The ESP32 combines the biomedical sensor information into organized messages and transmits them via Wi-Fi to a secure web server [7][9]. To ensure that we do not overlook important notifications when the internet connection goes down, a GSM module is incorporated to send notifications when the readings are unusual or when the internet connection is unreliable. On the software side, a cloud database supports real-time storage and management of patient data, and an HTML, CSS, and Python-based backend web service provides a web interface for data visualization. Important system parameters, such as notification thresholds, data transmission intervals, sensor sampling rates, and notification conditions, are set to ensure accuracy and timely notification.

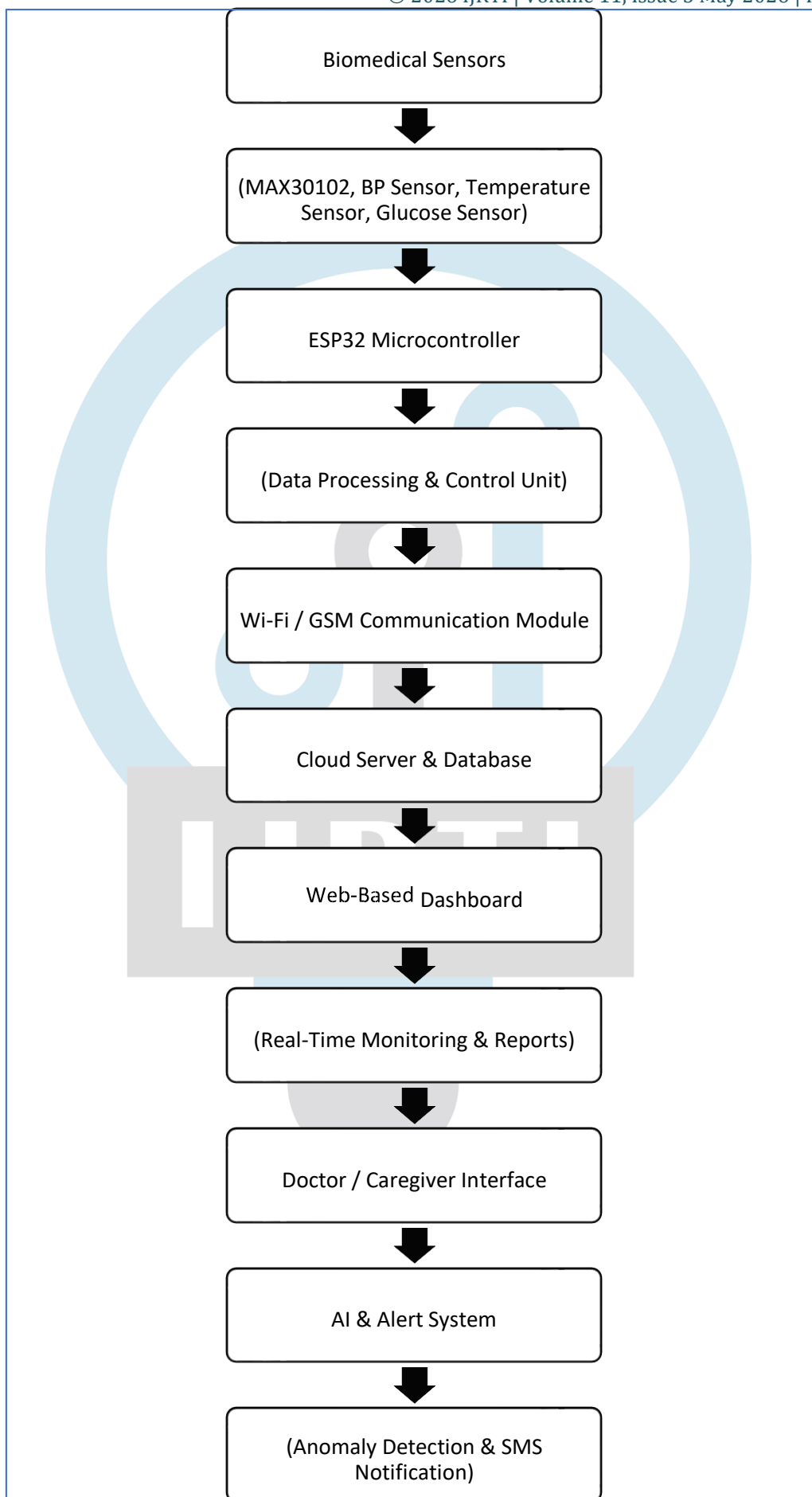


Figure 1: Block diagram of the proposed IoT-based remote patient monitoring system

#### IV. RESULTS AND DISCUSSION

The IoT-based Remote Patient Monitoring prototype was successfully developed and tested in a real-time-like environment. The testing was done on the accuracy, response time, reliability, and overall functional performance of the system.

### System Performance

The ESP32 microcontroller successfully collected data from the connected biomedical sensors and transmitted it to the web-based monitoring system via Wi-Fi connectivity. With stable network connectivity, the system showed an average delay time of 2-3 seconds.

The GSM module was also tested for emergency response time. Once the vital parameter exceeded the safe limit, the system sent SMS notifications within 5-7 seconds.

### Sensor Accuracy Validation

For accuracy validation, the system's readings were compared to other standard commercial devices:

- Heart rate readings from the MAX30102 sensor showed an average deviation of  $\pm 2$  beats per minute when compared to the pulse oximeter.
- The system's SpO<sub>2</sub> readings deviated from the normal range by  $\pm 1-2\%$  when compared to the pulse oximeter readings.
- The system's body temperature readings from the DS18B20 sensor showed a small deviation of  $\pm 0.3^{\circ}\text{C}$  when compared to the digital thermometer readings.
- The system's blood pressure readings from the digital oscillometric blood pressure monitoring device showed accurate readings within the normal range for non-clinical use.

### Reliability and Stability Testing

The system was tested for continuous operation for about 6 hours. The system's reliability and stability testing showed:

- No data packet loss was detected throughout the testing period.
- The system refreshed the readings on the web-based monitoring system every 5 seconds.
- The system successfully retrieved the historical data without any delay.
- The system's data transmission success rate was consistently higher than 98%.

### Functional Performance

The web-based monitoring system successfully performed the functions:

- Real-time monitoring of vital parameters
- Graphical representation of vital signs
- Access control using the login system
- Automatic alerts for abnormal readings

The system's automatic alert system successfully detected abnormal readings and sent notifications via the web-based monitoring system and the GSM SMS module.

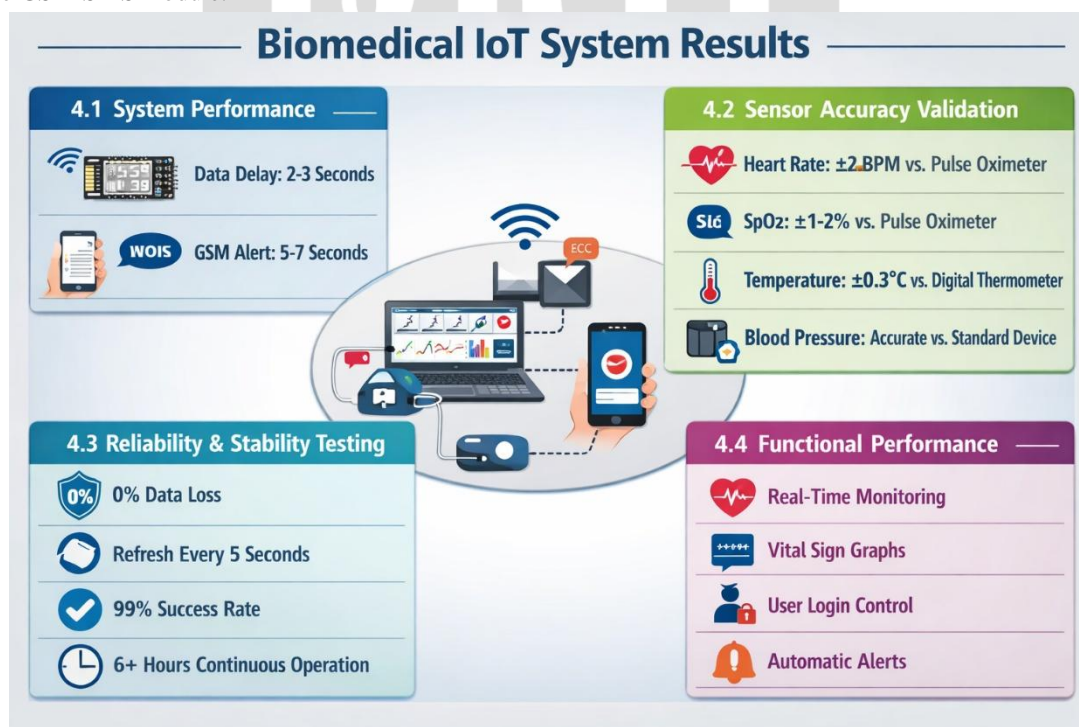


Figure 2: IoT-based Remote Patient Monitoring System Performance Matrix

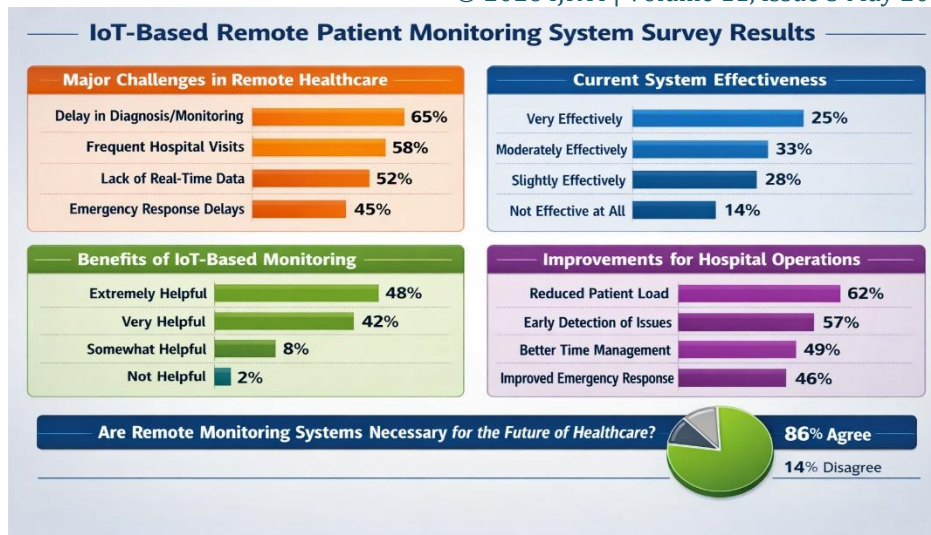


Figure 3: IoT-based Remote Patient Monitoring System Survey from Doctors

Fig 3 shows the survey provided critical insights into the challenges of remote healthcare and the potential of IoT based monitoring systems. The most commonly identified issues were delay in diagnosis and monitoring (65%), frequent hospital visits (58%), lack of real-time patient data (52%), and delay in emergency response (45%). Current systems were rated as moderately effective (33%) with room for improvement. Doctors rated IoT-based monitoring as extremely or very helpful (90%) in improving patient care. Benefits expected for the hospitals include reduced patient load (62%), early detection of health issues (57%) and better management of time (49%). In fact, 86% of respondents agreed that remote monitoring is the future of healthcare.

**Discussion:** The results obtained in this study prove that the proposed system successfully combines low-cost IoT devices with real-time cloud monitoring. In comparison with other approaches based on Raspberry Pi that are presented in the literature, the ESP32 solution is characterized by low power consumption and cost-effectiveness while providing reliable performance. It should also be noted that although the proposed system prototype is currently focused on trend estimation of certain parameters such as non-invasive glucose level prediction, the use of more advanced machine learning models and large-scale validation might further improve the accuracy of the system.

**V. PRELIMINARY RESULTS**

Parameter	Observed Value
Data Transmission Delay	2–3 seconds
SMS Alert Delay	5–7 seconds
Heart Rate Accuracy	±2 bpm
SpO <sub>2</sub> Accuracy	±2%
System Reliability	98% success rate

From the initial test results, the system is working steadily with minimal transmission delays and sensor values that remain within acceptable variance. The level of accuracy is within the biomedical monitoring standards, and this supports the feasibility of this system for remote health monitoring. Overall, the experiments have confirmed that the IoT-based system is technically feasible and reliable and can be used for remote healthcare, especially for the management of chronic diseases over long periods of time.

## VI. CONCLUSION

The IoT-based Remote Patient Monitoring system design demonstrates how real-time health monitoring can extend beyond the boundaries of a hospital setting. The system, which combines biomedical sensors with an ESP32 microcontroller and cloud-based web interface, enables reliable data acquisition, transmission, and visualization. Automated warning notifications and emergency messages via GSM communication networks enhance the system's responsiveness to abnormal readings. Preliminary results indicate that the system has low latency, a constant data stream, and biomedical sensors that remain well within acceptable biomedical ranges. The system design facilitates organized and long-term patient monitoring for chronic diseases such as diabetes and hypertension, while ensuring patient privacy via controlled access and data protection. In conclusion, the system design provides a scalable, cost effective, and flexible solution for smart healthcare. Future improvements may include the integration of more sophisticated AI algorithms and better communication technology to enhance predictive analysis, decision-making, and the possibility of mass deployment.

**Future Scope:** The proposed system has vast opportunities for further improvement and expansion. In future developments, Artificial Intelligence algorithms may also be integrated into the system to perform more precise trend analysis and predictive risk assessment for disease detection. Furthermore, the integration of edge-based machine learning models may also improve the accuracy of anomaly detection.

In addition, the integration of the system with centralized government health information systems may also enable the easy sharing of electronic patient records, thereby supporting large-scale public health initiatives. Furthermore, the use of 5G communication technology may enable real-time monitoring without any delays.

In addition to this, the system may also be improved and expanded to integrate wearable smart devices to enable noninvasive health tracking. Furthermore, large-scale deployment of the system may enable its transformation into a comprehensive digital healthcare solution that may also enable remote supervision and telemedicine services, among others.

## VII. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper. The project was carried out as part of academic coursework and did not receive any external commercial funding.

## VIII. ACKNOWLEDGMENT

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