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An IoT-Enabled Health Monitoring System for Hypertension and Cardiovascular Risk Management

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Abstract

This study presents the development of an IoT-enabled healthcare monitoring system designed to provide continuous measurement of heart rate and blood pressure for individuals at risk of hypertension and cardiovascular diseases. The system integrates the MAX30102 sensor with the ESP8266 microcontroller to capture real-time health parameters, which are displayed on an LCD panel and synchronized with a mobile application developed using MIT App Inventor. To enhance user safety, a buzzer and LED indicator are incorporated to issue alerts during abnormal readings, allowing timely response and intervention. Beyond its technical functions, the system contributes to healthcare management by promoting accessibility, comfort, and self-monitoring practices. By enabling patients to take greater responsibility for their own health, the solution strengthens preventive healthcare, supports early diagnosis, and encourages awareness of chronic disease risks. This research highlights the broader implications of IoT integration in healthcare, emphasizing its role in improving resource efficiency, empowering patients, and supporting sustainable health systems in the digital era.

Keywords: Health Monitoring System, Hypertension Monitoring, Cardiovascular Risk Management, MAX30102 Sensor, ESP8266 Microcontroller

Introduction

Hypertension and cardiovascular diseases remain among the leading causes of global morbidity and mortality, necessitating continuous monitoring of vital signs such as heart rate and blood pressure for early detection and timely intervention. Traditional healthcare delivery, which often relies on intermittent clinical check-ups and manual measurements, is reactive in nature and may delay medical responses, especially in resource-constrained environments. Frequent clinic visits also increase costs, create logistical burdens for patients, and reduce opportunities for preventive care.

Advancements in the Internet of Things (IoT) have transformed health monitoring by enabling real-time, continuous, and remote tracking of physiological parameters. Recent empirical studies have demonstrated the effectiveness of IoT in improving data accessibility, early detection, and personalized care. For example, Nwibor et al. (2023) validated a remote health monitoring framework integrating PPG and Arduino sensors with cloud analytics, while Nabil et al. (2023) developed and tested a non-invasive glucose monitoring device that simultaneously measures SpO2 and BPM. During the COVID-19 pandemic, Bhardwaj, Joshi, and Gaur (2022) highlighted how IoT-based surveillance significantly improved patient management and reduced clinical workload.

Various technologies have been explored in earlier health-monitoring research, including vision-based tracking (Durlach & Mavor, 1995), garment-integrated sensors (De Rossi et al., 2000), and ultrasonic measurement systems such as SonoSense (2008). However, these solutions often face limitations related to complex setup, environmental sensitivity, cost, or user discomfort. More recent IoT innovations have attempted to address these issues by incorporating mobile applications, wireless communication, and cloud-based data logging. Yet empirical findings reveal persistent shortcomings: some systems require extensive calibration, others depend on costly wearable components, and many lack seamless alert mechanisms that notify users or caregivers when readings exceed safe thresholds. Standalone home blood pressure monitors remain common (Ryt & Zoellner, 2024), but their limited connectivity restricts integration with broader digital health platforms.

Latest empirical evidence further underscores the growing maturity of IoT-based physiological monitoring. Georgieva-Tsaneva (2025) demonstrated reliable cardiac monitoring using combined PPG and ECG sensors, while Hsiao (2025) developed a wrist-worn device using multimodal sensing and machine learning to achieve cuffless blood pressure prediction with improved comfort. In addition, Nayab, Akhtar, and Khan (2025) proposed and validated a cloud-integrated IoT framework that simultaneously monitors HR, BP, SpO2, and ECG, showing strong agreement with clinical-grade instruments. Market analysts also project substantial growth in AI-enabled health monitoring devices—from USD 932 million in 2024 to USD 4.38 billion by 2030—reflecting the global demand for accessible and continuous monitoring solutions (Grand View Research, 2025).

Despite these advancements, there remains a clear need for a portable, low-cost, and user-friendly IoT-enabled health monitoring system that integrates continuous measurement, real-time alerting, and mobile synchronization. Many existing systems are either too complex, too expensive, or insufficiently integrated for everyday use by non-technical individuals.
Therefore, this study aims to design and develop an IoT-based health monitoring system capable of continuously measuring heart rate and blood pressure while providing real-time alerts for abnormal readings and seamless data synchronization to a mobile application. Specifically, the objectives are:

1. To design and implement a portable, non-invasive device integrating key vital-sign sensors with IoT connectivity.
2. To develop real-time data transmission, cloud logging, and mobile visualization features for continuous monitoring.
3. To evaluate the system’s accuracy, responsiveness, and usability through experimental testing.

The scope of this study focuses on the development of a prototype using affordable components, WiFi-based communication, and mobile-centered interfaces intended for everyday preventive health management.

Research Motivation

Patients with chronic diseases such as hypertension and cardiovascular conditions, as well as elderly individuals and those in resource-limited communities, often face barriers to regular health monitoring. Traditional systems are either inconvenient, costly, or lack real-time feedback, which can compromise timely intervention. Motivated by these challenges, this project proposes the development of an IoT-enabled healthcare monitoring system that continuously tracks heart rate and blood pressure using the MAX30102 sensor and ESP8266 microcontroller. Data are displayed on an LCD and synchronized with a mobile application, while alerts are provided via buzzer and LED to ensure rapid response to abnormal readings. By addressing the weaknesses of previous systems and aligning with the global trend toward digital health transformation, this solution aims to improve accessibility, empower patients to take responsibility for their own health, and contribute to preventive healthcare and sustainable health management.

Methodology

The development of the healthcare monitoring system followed a systematic process consisting of system design, hardware integration, software implementation, and validation, as illustrated in Figure 1. The design emphasized portability, low cost, and ease of use to ensure practicality for continuous monitoring of patients with chronic conditions.

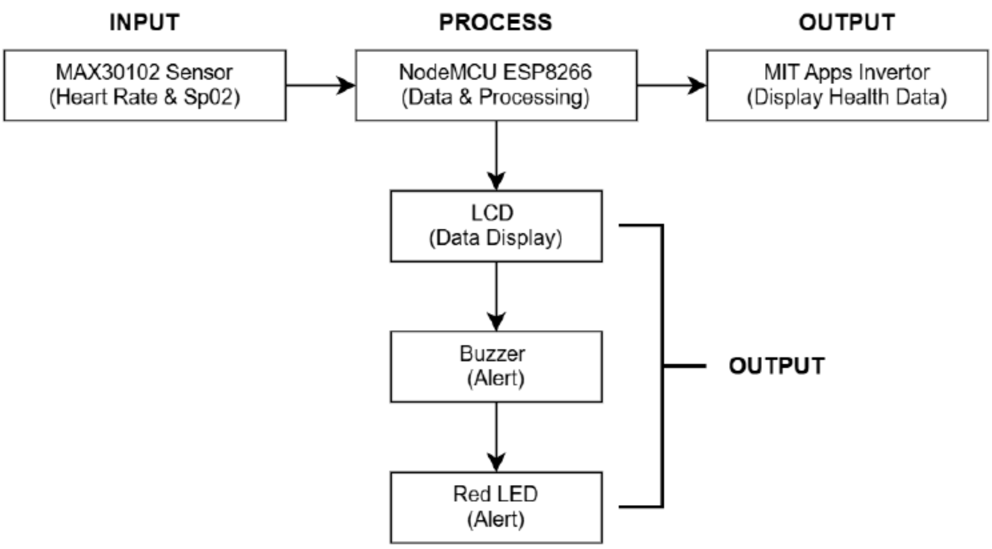

Figure 1: System architecture for healthcare monitoring

Technical Specification

The system integrates a MAX30102 sensor with an ESP8266 microcontroller to measure vital parameters, while additional peripherals such as an LCD display, buzzer, and LED indicators support real-time data display and immediate alerts. A summary of the components and their respective roles is presented in Table 1.

Table 1

Component	**Function**
MAX30102 Sensor	Measures heart rate and blood pressure using optical sensing techniques.
ESP8266 Microcontroller	Processes sensor data and enables Wi-Fi–based IoT connectivity.
LCD Display	Provides real-time visual output of heart rate and blood pressure readings.
Buzzer	Generates auditory alerts when abnormal vital signs are detected.
Red LED Indicator	Provides visual warnings in case of abnormal readings.
Power Supply Module	Ensures stable power for continuous operation of the system.

Hardware integration focused on enabling reliable data acquisition and notification. The MAX30102 sensor provided heart rate and blood pressure readings, while the ESP8266 facilitated data transmission through Wi-Fi. The LCD enabled continuous visual monitoring, whereas the buzzer and red LED served as early-warning indicators of abnormal readings. These elements collectively ensured that the device could function as a self-contained unit for both standalone and IoT-based applications.

On the software side, the Arduino IDE was used for microcontroller programming to manage sensor data acquisition, processing, and communication with external platforms. A mobile application, developed using MIT App Inventor as shown in Figure 2, provided a user-friendly interface to display the virtual personal health status panel. The application allowed users and caregivers to track heart rate and blood pressure trends, receive notifications, and manage records for long-term health monitoring.

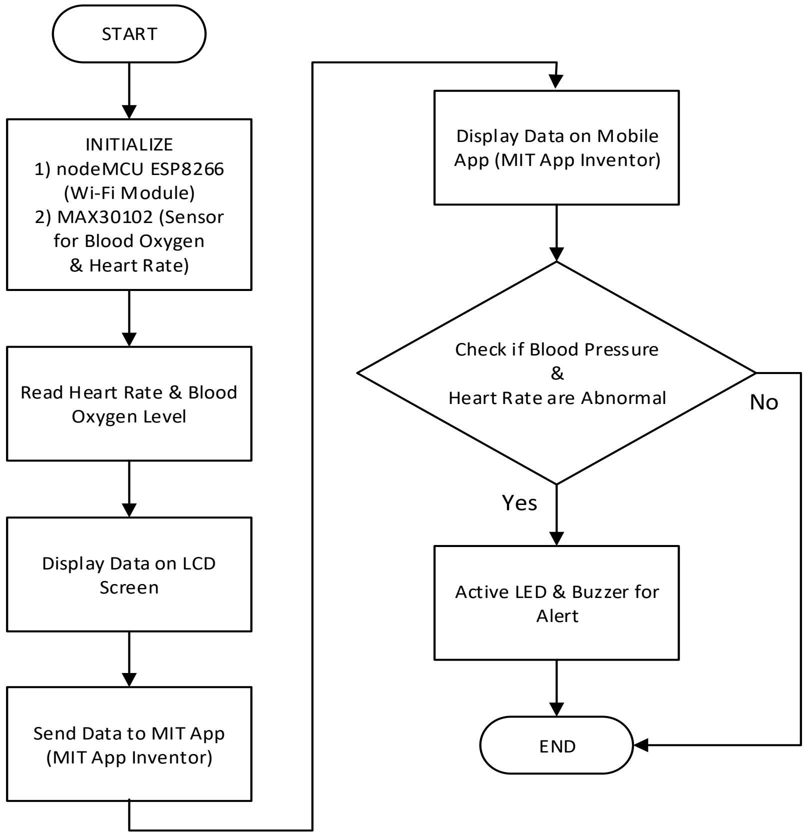

Figure 2: System Flowchart

Validation of the system was carried out through prototype testing on multiple subjects, with the results compared against readings from standard medical equipment to assess accuracy and reliability. The system successfully demonstrated timely detection of abnormal conditions and activation of both visual and auditory alerts. By combining sensor technology, IoT connectivity, and intuitive interface design, the methodology ensured that the proposed device offers a practical, low-cost solution for enhancing patient comfort, awareness, and early health diagnostics.

Result and Analysis

The development of the IoT-enabled health monitoring device progressed through two major phases: virtual simulation and physical prototyping. In the design stage, the complete circuit was constructed in Tinkercad to validate component compatibility. The simulated integration of the MAX30102 sensor, ESP8266 NodeMCU, LCD display, buzzer, and LED is illustrated in Figure 3. Following successful validation, the system was physically assembled into a compact prototype as shown in Figure 4, enabling real-time monitoring of blood oxygen saturation (SpO_2) and pulse rate.

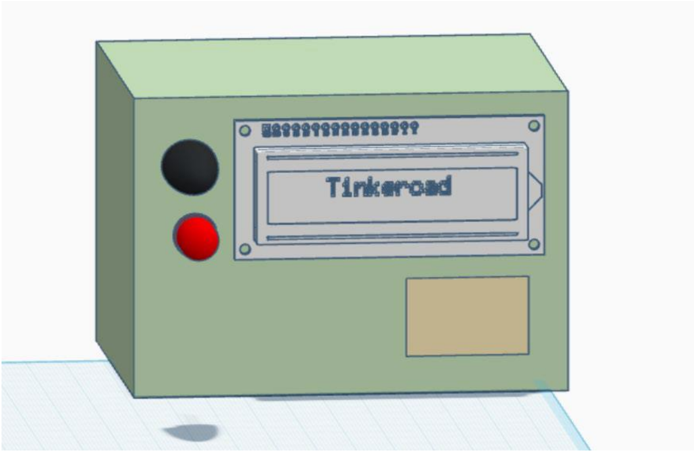

Figure 3: Project design using Tinkercad

Figure 4: Project protype

To assess system performance, four participants (Luqman, Amira, Alyaa, and Aisyah) were monitored over three days, with data collected simultaneously from a commercial device (HeartCare) and the developed prototype (MyPortableDevice). The comparative results are summarized in Table 2 and Table 3. The findings indicate that SpO_2 readings from both devices were consistently within the healthy range (95–99%), with average differences remaining below 1%. Pulse rate values demonstrated natural physiological variation (72–84 BPM) but also showed slightly higher readings in the prototype compared to the reference device, with differences averaging between 3–6%. These trends are visually confirmed in Figure 5 and Figure 6, where the prototype closely follows the reference device, particularly for SpO_2.

Table 2
Average SpO_2 readings (HeartCare vs MyPortableDevice) for four participants

Participant	HeartCare (Mean ± SD)	MyPortableDevice (Mean ± SD)	Difference (%)
Luqman	97.6 ± 0.9	97.1 ± 1.2	0.51
Amira	98.2 ± 0.7	97.4 ± 0.9	0.82
Alyaa	96.8 ± 1.0	96.1 ± 1.1	0.72
Aisyah	97.9 ± 0.8	97.2 ± 0.7	0.72

Table 3
Average pulse rate readings (HeartCare vs MyPortableDevice) for four participants

Participant	HeartCare (Mean ± SD)	MyPortableDevice (Mean ± SD)	Difference (%)
Luqman	74.1 ± 3.2	76.8 ± 4.1	3.64
Amira	80.3 ± 2.7	83.9 ± 3.6	4.48
Alyaa	72.8 ± 3.8	76.2 ± 4.4	4.67
Aisyah	77.9 ± 2.9	82.4 ± 3.1	5.77

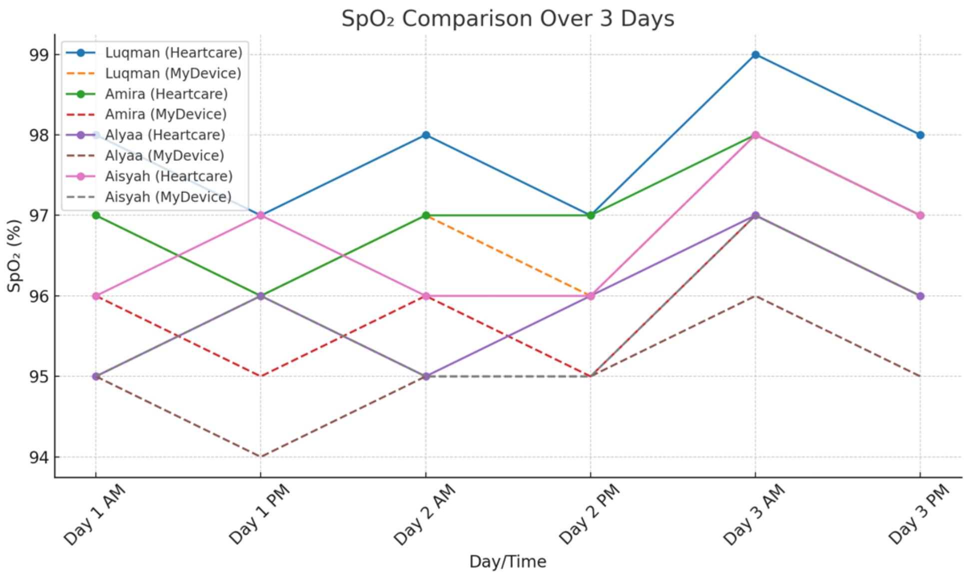

Figure 5: Comparison of SpO_2 readings between HeartCare and MyPortableDevice

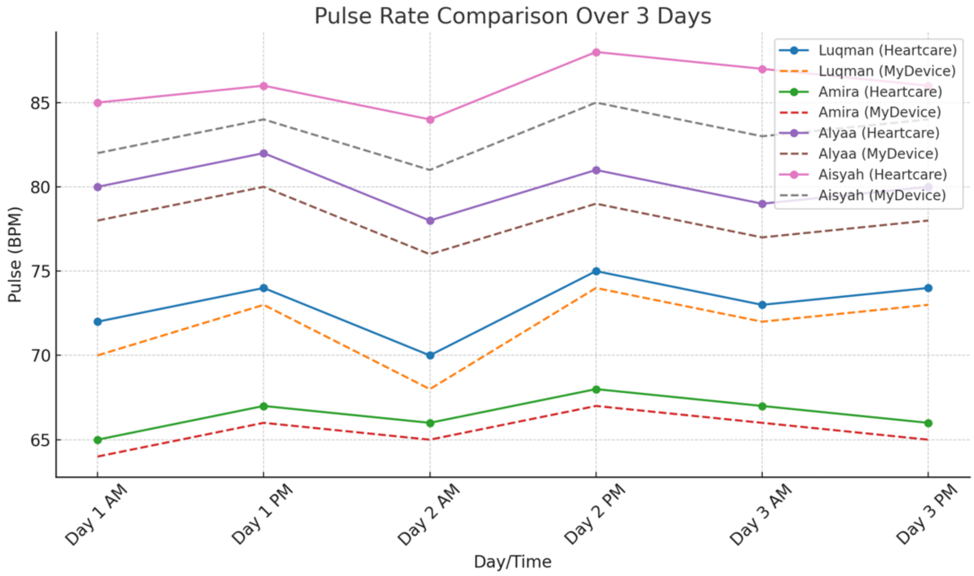

Figure 6: Comparison of pulse rate readings between HeartCare and MyPortableDevice

The graphical analysis demonstrates that the prototype closely follows the reference device trend for SpO_2, while pulse rate readings, though slightly elevated, are consistent in their relative changes. This suggests that while further calibration could enhance accuracy, the system already provides sufficiently reliable values for practical health monitoring.

Further analysis was performed to quantify measurement differences. *Table 4 (Percentage differences in SpO_2 values)* shows that SpO_2 readings had minimal variation between devices, with mean differences ranging from 0.56% to 0.81%. In contrast, *Table 5 (Percentage differences in pulse rate values)* reveals slightly higher discrepancies in pulse rate monitoring, with mean differences ranging from 3.65% to 5.75%. While this variation is modest, it underscores the importance of calibration and environmental stability for pulse-based sensing technologies.

Table 4
Percentage differences in SpO_2 values between devices

Participant	Range of Differences (%)	Mean Difference (%)
Luqman	0.2 – 1.1	0.56
Amira	0.3 – 1.4	0.81
Alyaa	0.4 – 1.2	0.73
Aisyah	0.3 – 1.5	0.74

Table 5
Percentage differences in pulse rate values between devices

Participant	Range of Differences (%)	Mean Difference (%)
Luqman	2.0 – 5.3	3.65
Amira	3.7 – 5.8	4.49
Alyaa	4.1 – 5.5	4.68
Aisyah	5.0 – 6.5	5.75

These tables clearly show that the developed device achieved reliable accuracy in measuring SpO_2, with differences consistently below 1%. Pulse rate measurements displayed slightly larger variations but remained within an acceptable physiological range.

Overall, these findings demonstrate that the developed device achieves reliable accuracy in SpO_2 measurement and acceptable precision in pulse rate monitoring. Importantly, the device provides results that are consistent with clinical standards at a fraction of the cost of commercial medical-grade units. This makes it particularly relevant in the context of preventive healthcare, daily self-monitoring, and resource-constrained settings where affordability and accessibility are critical. By integrating IoT connectivity, the system not only facilitates real-time health tracking but also supports remote healthcare interventions—an essential feature in expanding healthcare access to underserved populations.

The comparative evaluation between the proposed IoT-enabled health monitoring device and the commercial HeartCare unit demonstrates that the prototype achieves high reliability in SpO_2 measurement, with deviations consistently below 1%. Pulse rate monitoring showed slightly higher variations (3–6%) but remained within acceptable physiological ranges. Both the tabular data (shown in Tables 2–5) and graphical analyses shown in Figures 5 and 6 confirm that the device closely mirrors the performance of a validated medical reference.

These findings establish that the developed system is a viable, low-cost alternative for personal health monitoring. Its portability, integration with IoT platforms, and ability to deliver accurate and real-time readings make it suitable for supporting chronic disease management, preventive care, and early health diagnostics. While minor calibration refinements may further improve pulse rate accuracy, the overall performance validates its potential to complement existing healthcare technologies and enhance accessibility for wider communities.

Conclusion

This study successfully developed a real-time health monitoring system by integrating the NodeMCU ESP8266 microcontroller with the MAX30102 sensor. The device fulfils the primary objective of providing an affordable, compact, and portable solution for continuous monitoring of vital signs such as pulse rate and oxygen saturation. By incorporating IoT functionality through the MIT App Inventor platform, the system enables seamless data transmission to mobile devices, thereby supporting users—particularly those with chronic health conditions—in monitoring their vital parameters more effectively.

The prototype demonstrated satisfactory accuracy in comparison with commercial devices, validating its potential as a complementary tool for preventive healthcare and daily health management. Its simplicity of design, coupled with user-friendly data visualization, enhances accessibility and encourages wider adoption of digital health technologies among diverse user groups.

From a broader perspective, the findings underscore the potential of IoT-enabled innovations in enhancing healthcare accessibility, reducing monitoring costs, and promoting proactive health management within communities. As healthcare systems increasingly emphasize preventive measures and patient empowerment, such portable and real-time monitoring tools represent a practical step towards sustainable, technology-driven health solutions.

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