Vol. 7, No. 2, August 2025, pp. 231~239, p-ISSN 2685-2381, e-ISSN 2715-2626
http://dx.doi.org/10.28989/avitec.v7i2.3076

Wearable IoT Device for Real-Time Heart Rate and Body Temperature Monitoring

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Article Info

Article history:
Submitted June 23, 2025
Accepted June 28, 2025
Published July 22, 2025

Keywords:
Health monitoring;
heart rate;
Internet of Things (IoT);
wearable device.

ABSTRACT

Heart disease remains one of the primary causes of death worldwide, largely due to sedentary lifestyles and the lack of continuous health monitoring. Many existing wearable health systems fail to provide real-time alerts or offer seamless integration between hardware, cloud platforms, and user interfaces. This study proposes a fully integrated Internet of Things (IoT)-based wearable device for real-time monitoring of heart rate and body temperature. The system utilizes an ESP32 microcontroller combined with MAX30102 and DS18B20 sensors and transmits physiological data via Wi-Fi to the Adafruit IO cloud platform using the MQTT protocol. A custom Android application developed using a low-code environment provides real-time visualization and alert notifications when user-defined thresholds are exceeded. Comparative testing against standard medical devices showed an average error of 1.99% for heart rate and 2.32% for body temperature, demonstrating reliable performance for non-clinical, preventive health monitoring. Unlike previous works, this system offers end-to-end integration, enabling real-time feedback, continuous data access, and user-friendly interaction. Future developments will focus on improving sensor calibration, enhancing ergonomic design, and incorporating advanced features such as historical data tracking and AI-based health alerts.

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1. INTRODUCTION

Monitoring vital signs such as heart rate and body temperature is essential for the early detection of health issues and the assessment of general well-being [1]. These indicators assist healthcare professionals in diagnosing infections, cardiovascular conditions, and metabolic disorders. Early and continuous monitoring significantly improves the effectiveness of preventive care and therapeutic interventions [2]. Cardiovascular disease remains the leading cause of mortality both globally and in Indonesia, often resulting from sedentary lifestyles, poor dietary habits, and chronic psychological stress [3]. Delayed diagnosis can lead to critical events such as heart attacks and strokes [4].

Recent technological developments have facilitated the emergence of mobile platforms and biosensor-based digital health systems that enable real-time physiological monitoring and early diagnosis [5]. The proliferation of Internet of Things (IoT) technology has supported the design of affordable and interconnected health monitoring devices. Wearable systems equipped with cloud connectivity allow for seamless data acquisition, transmission, and visualization [6]. Previous studies have explored the use of IoT in health contexts, including smartwatches, temperature sensors, and ECG-enabled wearables that deliver data to dashboards or mobile applications [7]. These solutions are particularly valuable in remote or underserved areas where access to healthcare professionals may be limited [8].

Despite these advancements, many existing systems suffer from poor integration between hardware and software components [9]. Users are often required to manually interpret data from disjointed platforms that lack real-time synchronization across sensors, microcontrollers, and user interfaces. In addition, most systems do not offer intelligent features such as automated health alerts or abnormal condition detection, limiting their practicality [10]. This poses usability challenges, especially for elderly or nontechnical individuals who benefit most from intuitive and unified systems [11]. Much of the prior research has focused on either hardware prototyping or data transmission without delivering a fully integrated real-time monitoring solution [12].

Although platforms like Blynk and Adafruit IO have been applied for IoT-based data visualization, they typically lack real-time anomaly detection and notification mechanisms [13]. As a result, there is a persistent need for a portable, user-friendly, and fully integrated system capable of independent vital sign monitoring, data visualization, and real-time alerts without manual data handling.

This study addresses that gap by presenting a wearable IoT-based health monitoring device that integrates the ESP32 microcontroller, MAX30102 heart rate sensor, DS18B20 temperature sensor, and an OLED display. The device transmits data in real-time to the Adafruit IO cloud platform and interfaces with a custom Android application for continuous monitoring and automated alert generation. The main contribution of this work is the development of a compact, fully integrated, end-to-end monitoring system specifically designed for elderly or nontechnical users. Unlike previous studies that isolate hardware implementation or focus solely on data transmission, this system provides a user-friendly solution that bridges hardware and software integration with cloud-based analytics and real-time feedback, enhancing early health anomaly detection with minimal user intervention.

2. RESEARCH METHODS

2.1 System Block Diagram Design

The architecture of the wearable health monitoring system is illustrated in the system block diagram as shown in Figure 1. The ESP32-WROOM-32 microcontroller (Espressif Systems, v1.0) receives data from two biomedical sensors: the MAX30102 pulse oximeter and heart rate sensor (Maxim Integrated), and the DS18B20 digital temperature sensor (Maxim Integrated). The collected data are processed and transmitted over Wi-Fi using the MQTT (Message Queuing Telemetry Transport) protocol to the Adafruit IO v2 cloud platform. The MQTT protocol was selected for its lightweight and efficient communication, making it suitable for IoT applications. The transmitted data are visualized in real time through an Android application.

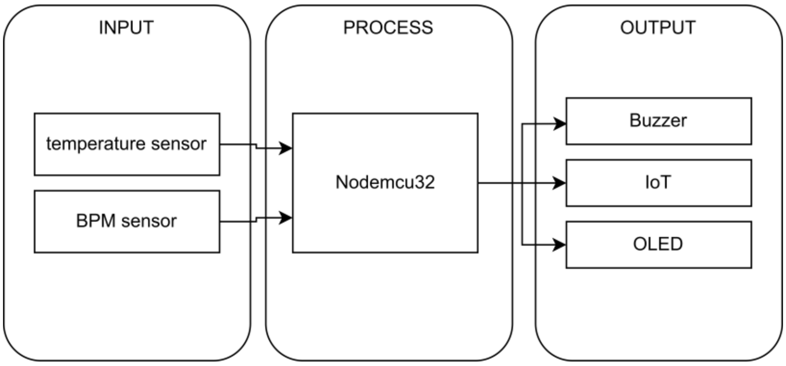

Figure 1. System block diagram of the wearable health monitoring device

2.2 System Circuit Design

The system's electronic circuit was designed to efficiently integrate multiple biosensors with reliable communication protocols while maintaining low power consumption, compactness, and robustness. The core controller of the device is the ESP32-WROOM-32 module, which manages sensor data acquisition, cloud communication, and local feedback display.

Two primary biosensors were incorporated in the circuit: the MAX30102 for pulse rate and blood oxygen saturation (SpO_2), and the DS18B20 for body temperature measurement. The MAX30102 sensor module interfaces with the ESP32 using the I2C communication protocol. In this configuration, the SDA (Serial Data) line is connected to GPIO21 and the SCL (Serial Clock) line is connected to GPIO22 of the ESP32. This standard I2C setup ensures reliable and synchronized data transfer for continuous physiological monitoring.

Meanwhile, the DS18B20 sensor operates using the One-Wire protocol and is connected to GPIO4 of the ESP32. This sensor was selected over alternatives like BME680 due to its superior reliability in direct-contact skin temperature sensing, consistent performance in dynamic environments, and broad compatibility with wearable hardware platforms. Its digital accuracy and minimal calibration requirements make it well-suited for continuous personal health monitoring. All sensors and the ESP32 module receive a stable 3.3V supply regulated by an AMS1117-3.3 voltage regulator. The system is powered by a 3.7V Li-Ion rechargeable battery managed by a TP4056 charging module, which provides overcharge protection and ensures safe energy delivery during operation.

A 128×64 pixel OLED display is connected via I2C, sharing GPIO21 (SDA) and GPIO22 (SCL) with the MAX30102, to provide real-time local feedback. This reduces reliance on smartphone displays. An active buzzer on GPIO18 delivers audible alerts when sensor readings exceed defined thresholds, enhancing user responsiveness. Power to the entire system is supplied by a 3.7V lithium-ion battery managed by a TP4056 charging module, while an AMS1117-3.3V regulator ensures a consistent 3.3V output for the ESP32 and connected sensors. The circuit was first modeled and simulated using Fritzing and Proteus to validate layout accuracy and pin mapping, before being transferred to a custom PCB designed in Eagle CAD. All components were manually soldered using a temperature-controlled iron, and validated using a digital multimeter to confirm voltage outputs and signal continuity. The system circuit schematic can be seen in Figure 2.

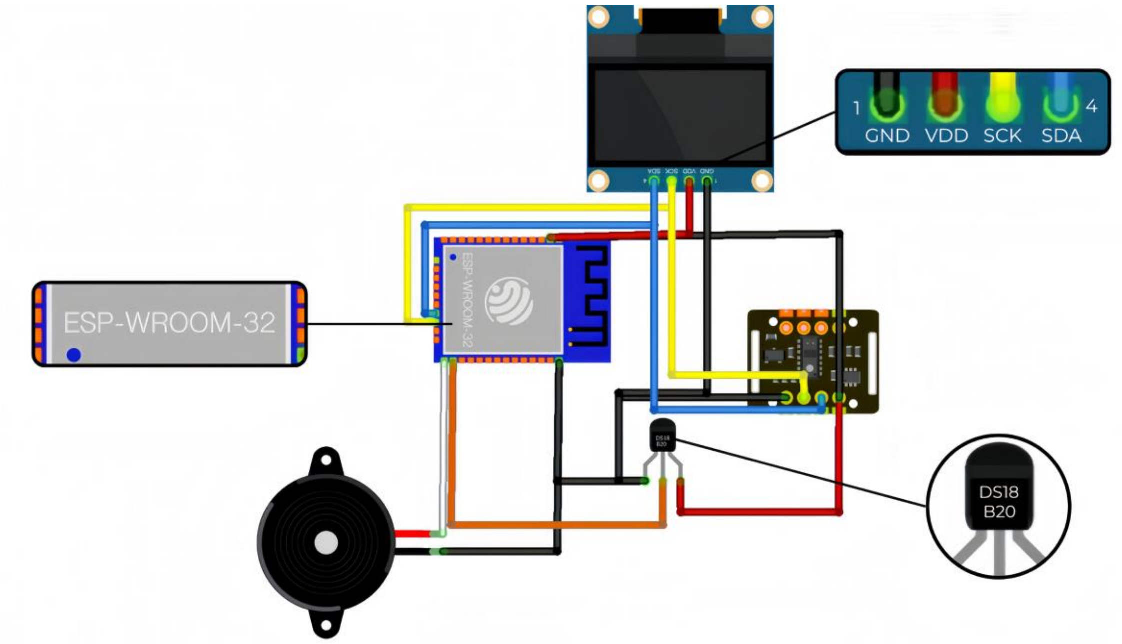

Figure 2. System circuit schematic

2.3 Android Application Design

A custom Android application was developed using MIT App Inventor 2 (v2.60, 2024). The application retrieves sensor data from the Adafruit IO cloud platform via the MQTT protocol. Its interface is intentionally simple and accessible, with large icons and clear indicators designed to accommodate elderly users. The application includes a real-time notification system that alerts users when heart rate or body temperature readings exceed predefined thresholds (above 100 bpm for heart rate or 37.5°C for temperature), enhancing user engagement and safety. The Android application prototype can be seen in Figure 3.

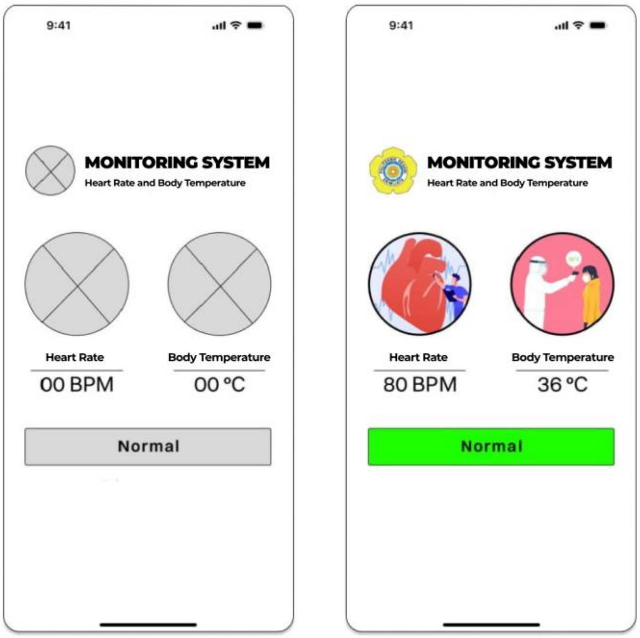

Figure 3. Android application prototype showing real-time heart rate and temperature readings

2.4 Mechanical Design

The physical enclosure of the wearable device was designed using Tinkercad (Autodesk, v2023) and fabricated with a Creality Ender 3 V2 3D printer using Polylactic Acid (PLA) filament. The casing is ergonomically shaped to fit comfortably on the wrist and is optimized for continuous skin contact with the

MAX30102 sensor. The DS18B20 sensor is positioned to accurately capture body temperature without obstruction. The design prioritizes comfort, durability, and suitability for daily wear. The mechanical layout of the device can be seen in Figure 4.

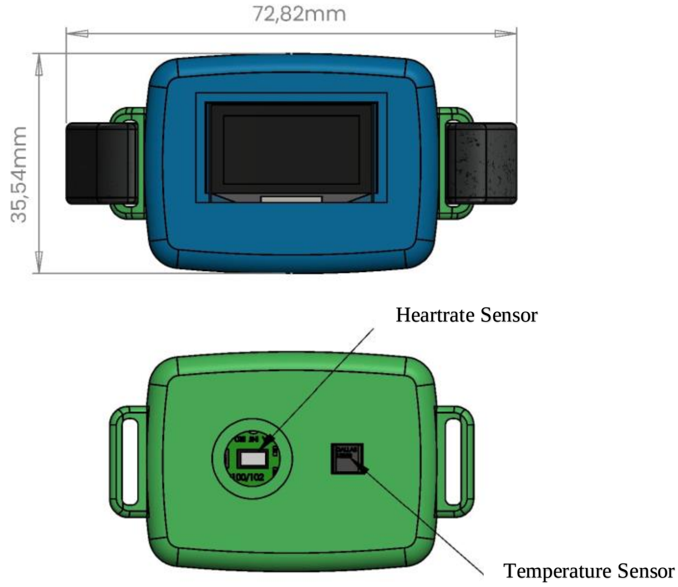

Figure 4. Mechanical layout of the device using PLA-based ergonomic casing

2.5 Device Workflow and Error Analysis

The operational workflow of the wearable health monitoring device is designed to ensure continuous real-time tracking of physiological signals and automatic alerting in response to abnormal conditions. The process begins with the initialization phase, during which the ESP32 microcontroller configures all necessary pins and attempts to establish a Wi-Fi connection to the Adafruit IO cloud platform. A conditional loop is implemented such that if the connection attempt fails, the system reinitiates the configuration process and retries until a stable internet connection is secured. This loop guarantees uninterrupted remote data access and is critical for maintaining consistent communication between the device and the cloud server.

Once connected to the network, the system enters the main monitoring loop. In this phase, the ESP32 sequentially acquires data from the integrated sensors: the MAX30102 for heart rate measurement and the DS18B20 for body temperature sensing. The MAX30102 communicates via the I2C protocol, whereas the DS18B20 uses the One-Wire protocol. The readings are captured at defined time intervals to ensure periodic health tracking while maintaining low power consumption.

Following data acquisition, the system performs a conditional check on the heart rate value. If the measured BPM falls outside the normal predefined thresholds (less than 50 BPM or more than 100 BPM), the system classifies the reading as abnormal. In this case, the ESP32 immediately activates an audible buzzer to alert the user locally and transmits a real-time warning notification through the connected Android application. This notification includes the abnormal value and the parameter affected, allowing for quick response or escalation.

If the heart rate is within acceptable limits, the system proceeds to evaluate the body temperature reading. Similar to the heart rate check, the temperature value is compared against the predefined safe range (typically 35°C to 38°C). Any deviation beyond these boundaries triggers the same dual-response mechanism: local buzzer activation and real-time notification dispatch via the mobile interface.

The system is designed with a continuous loop architecture to ensure ongoing monitoring. After completing one iteration of sensing, evaluation, and notification (if needed), the device pauses for a brief, predefined delay to reduce redundant processing and then restarts the acquisition process. This ensures a balance between responsiveness and energy efficiency.

To validate the accuracy and responsiveness of this workflow, functional testing was conducted under multiple conditions. These include steady-state testing, active movement simulation (walking or hand motion), and forced Wi-Fi disconnection scenarios to test reconnection resilience. The system successfully reconnected autonomously and maintained data transmission with minimal latency. The sensor readings during idle and active states were consistent, confirming the robustness of the workflow logic.

Overall, as shown in Figure 5, the device's workflow is optimized for autonomous operation, requiring no manual user input, and is capable of generating timely health alerts for both local awareness and remote tracking. This operational flow supports the usability needs of non-technical and elderly users by simplifying interaction while maintaining technical reliability.

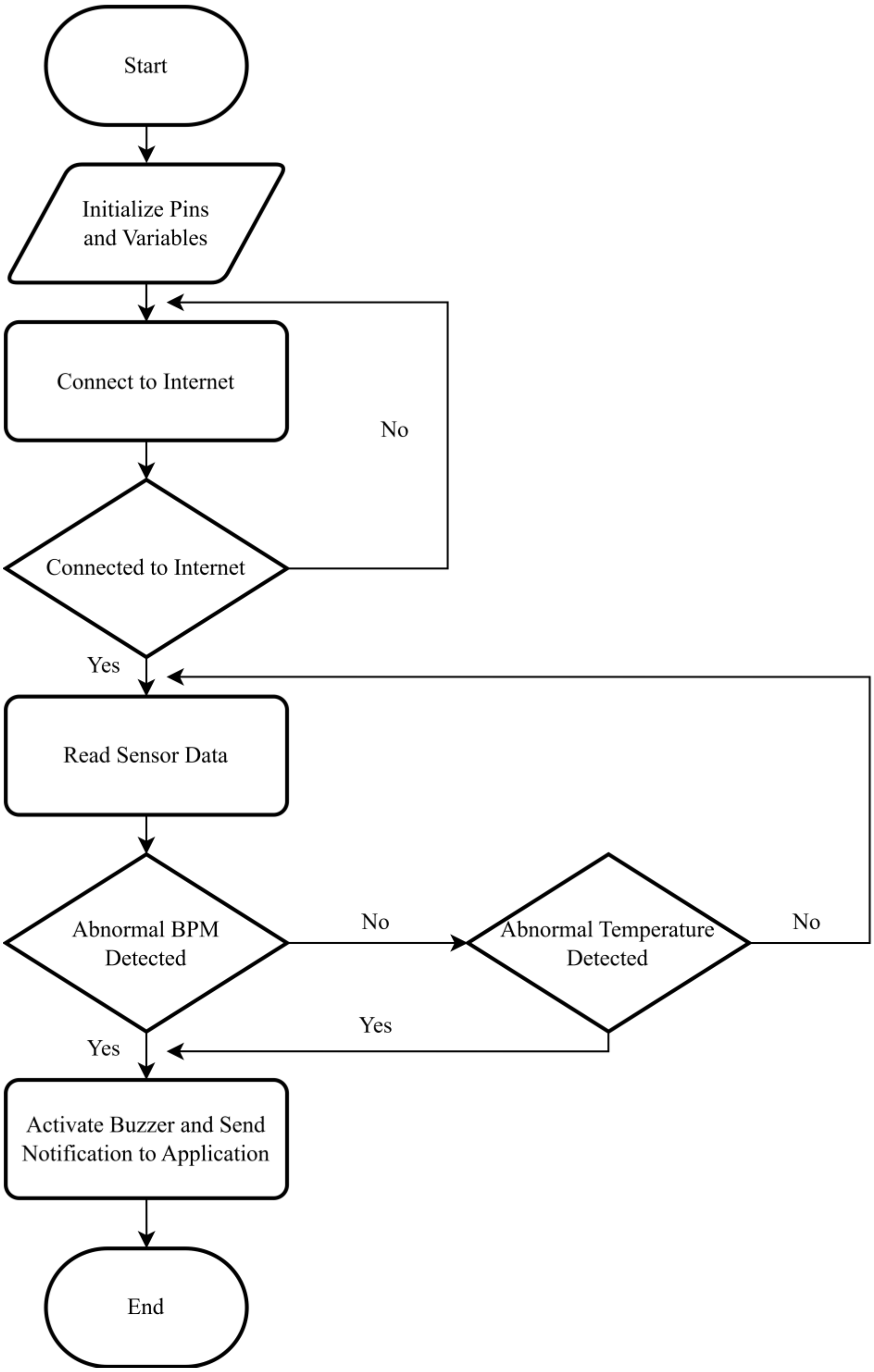

Figure 5. Workflow diagram of the health monitoring device

3. RESULTS AND DISCUSSION

3.1 Research Results

This study presents the design and development of a wearable Internet of Things (IoT)-based device for real-time health monitoring, specifically targeting heart rate and body temperature parameters. The system combines biomedical sensors, wireless communication, and a mobile application to enable continuous, accessible, and user-friendly health tracking. The implementation results include device prototyping, mobile application interface, and performance evaluation through functional and comparative testing.

Compared to earlier systems that relied on offline data storage or lacked alert functionality [1], [2], this device introduces a fully integrated solution that includes real-time data processing, alert generation, cloud-based synchronization, and a mobile interface designed with usability in mind. This integrated approach enhances response time and reliability in non-clinical, preventive healthcare environments.

3.1.1 Wearable Device Prototype Result

The prototype integrates the ESP32-WROOM-32 microcontroller, MAX30102 biosensor, DS18B20 digital temperature sensor, and a 128×64 OLED display. Designed in a compact form factor resembling a smartwatch, the device is powered by a rechargeable lithium battery and operates wirelessly using the MQTT protocol to transmit data to the Adafruit IO cloud platform. This design offers improvements over previous systems by providing both local OLED feedback and real-time remote monitoring, eliminating reliance on wired setups or manual data retrieval. These features increase practicality for continuous use and make the device more suitable for preventive health monitoring [3] as shown in Figure 6.

Figure 6. Wearable device prototype with sensor integration and OLED feedback

3.1.2 Android Smartphone Application User Interface Result

The Android application was developed using MIT App Inventor 2 and is designed to retrieve real-time sensor data from the Adafruit IO cloud platform via the MQTT protocol. Its design prioritizes simplicity and clarity to accommodate both general and elderly users. A key feature is its real-time notification system, which alerts the user through a buzzer and visual warnings when the heart rate or temperature exceeds predefined thresholds. The Application user interface can be seen in Figure 7.

Compared to previous applications built with native Android SDKs or complex libraries [4], this implementation demonstrates the effectiveness of low-code tools in rapidly deploying lightweight, functional mobile interfaces suitable for early-stage prototypes and non-technical users.

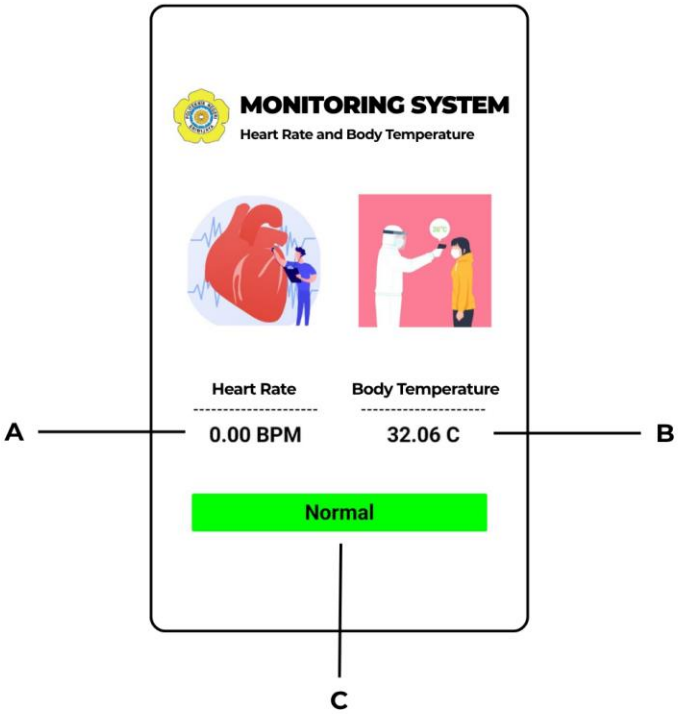

Figure 7. Application user interface on Android smartphone

The application interface is divided into three key sections: (A) heart rate display from the MAX30102 sensor, (B) body temperature display from the DS18B20 sensor, and (C) a status indicator summarizing the user's health condition. The system issues visual and auditory alerts when thresholds are exceeded, ensuring quick interpretation of health data through a simple and accessible layout. The prototype testing with application integration can be seen in Figure 8.

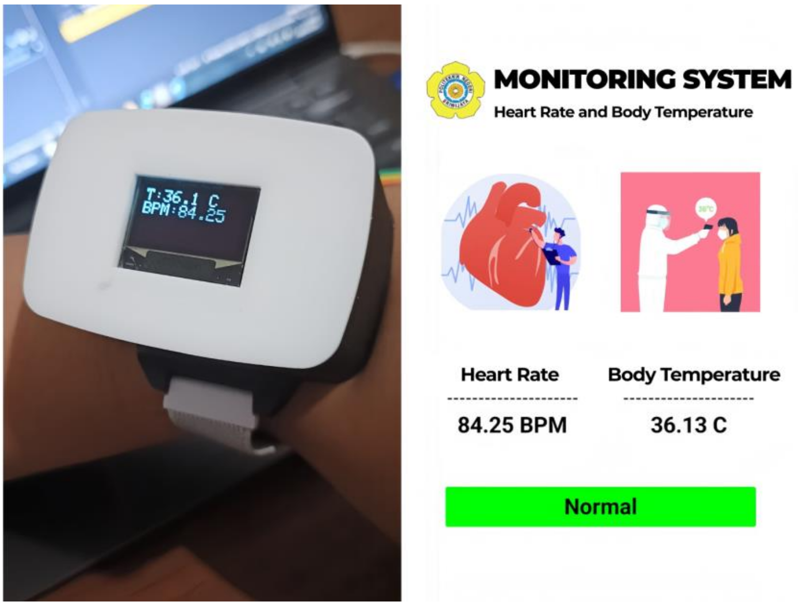

Figure 8. Prototype testing with application integration

3.1.3 Heart Rate Monitoring Test Result

The accuracy of heart rate monitoring was evaluated by comparing the wearable device to a standard pulse oximeter across five test subjects. Table 1 presents the results, showing consistent agreement with the reference device. Error percentages ranged from 1.21% to 2.66%, with an average of 1.99%.

Table 1. Heart rate test results on wearable device and pulse oximeter

No	Test Subject	Wearable Device (BPM)	Pulse Oximeter (BPM)	Difference (BPM)	Error (%)
1	A	84.25	86.25	2.00	2.32%
2	B	81.50	82.50	1.00	1.21%
3	C	78.75	80.75	2.00	2.48%
4	D	76.00	77.00	1.00	1.30%
5	E	73.25	75.25	2.00	2.66%

These results confirm the reliability of the wearable device for heart rate measurement in non-clinical environments. While previous studies using the MAX30102 sensor showed similar accuracy [1], this system adds real-time cloud communication and user alerts, offering a more complete monitoring experience.

3.1.4 Temperature Monitoring Test Result

Temperature accuracy was assessed by comparing the DS18B20 readings with those of a commercial digital infrared thermometer. The results, summarized in Table 2, demonstrate consistent and acceptable accuracy for general health monitoring, with an average error of 2.32%.

Table 2. Body temperature test results on wearable device and digital thermometer

No	Test Subject	Wearable Device (°C)	Digital Thermometer (°C)	Difference (°C)	Error (%)
1	A	36.10	36.70	0.60	1.63%
2	B	36.45	35.20	1.25	3.55%
3	C	36.70	36.10	0.60	1.66%
4	D	36.25	35.50	0.75	2.11%
5	E	36.85	35.90	0.95	2.65%

Despite minor variations, the results support the DS18B20 sensor’s adequacy for non-clinical applications, especially for daily self-monitoring. The system provides stable temperature readings and real-time alerts, improving usability among users who require continuous but non-diagnostic health surveillance.

3.2 Comparison with Previous Studies

This study addresses critical limitations identified in previous research by offering a fully integrated wearable health monitoring system that combines real-time data acquisition, wireless transmission via Wi-Fi, and a user-oriented mobile application.

Akhtar et al. (2020) introduced a heart rate monitoring application, but their solution lacked a wearable component capable of continuous data transmission to a mobile interface [14]. In contrast, the system presented in this study integrates the MAX30102 and DS18B20 sensors within a compact, wearable device that streams real-time physiological data to an Android application, enabling uninterrupted remote monitoring.

Similarly, the method used by Yeh (2020), which involved detrended fluctuation analysis for heart rate variability, was tailored for clinical contexts and required complex signal processing, making it unsuitable for daily, user-friendly home monitoring [15]. Our system offers an accessible alternative that preserves data reliability while eliminating the need for advanced user intervention.

Non-contact monitoring approaches, such as those proposed by Ben Ayed et al. (2021), rely on facial feature extraction and are often susceptible to environmental interference, including lighting conditions and camera quality [16]. The direct-contact sensor strategy employed in our system ensures stable and accurate readings across various usage environments.

In terms of energy efficiency and hardware complexity, Attaoui et al. (2020) relied on ECG-based solutions that demand higher power and intricate circuitry for telemonitoring [17]. Our approach uses photoplethysmography (PPG) via the MAX30102 sensor, offering a compact and low-power alternative that maintains sufficient measurement precision.

Bluetooth-based solutions, such as those explored by Coffen et al. (2020), demonstrate the utility of low-power biosensor rings, however their limited transmission range poses constraints for real-time, long-distance monitoring [18]. Our system overcomes this limitation by using Wi-Fi communication in conjunction with the Adafruit IO cloud platform, providing greater coverage, remote accessibility, and long-term data availability.

Overall, this research contributes a novel and practical solution by effectively bridging gaps in sensor integration, wireless communication, and user interaction. The cohesive deployment of wearable hardware, IoT infrastructure, and mobile applications with real-time alerting capabilities makes the system particularly beneficial for elderly or non-technical users who require dependable and intuitive health technology.

4. CONCLUSION

This study successfully developed a wearable Internet of Things (IoT)-based health monitoring device that integrates the MAX30102 heart rate sensor and the DS18B20 temperature sensor to enable real-time physiological monitoring. Data are transmitted wirelessly via the MQTT protocol to the Adafruit IO cloud platform and visualized through a custom Android application, allowing users to receive immediate alerts when vital signs exceed predefined thresholds. Evaluation results showed an average error of 1.99% for heart rate and 2.32% for body temperature, indicating sufficient reliability for non-clinical preventive use. The main contribution of this work lies in its fully integrated approach, which combines compact hardware, Wi-Fi-based transmission, real-time cloud connectivity, and a mobile interface designed for accessibility and simplicity. This distinguishes the system from previous solutions that were limited in terms of user interaction, communication range, or platform integration. Although the device performs well under test conditions, there is still room for improvement, particularly in enhancing the accuracy of temperature sensing, optimizing the ergonomic design for long-term wear, and expanding the application with features such as historical data tracking, personalized thresholds, and intelligent alert mechanisms using AI. These improvements will support broader adoption and elevate the system's capability as a practical, user-friendly, and autonomous tool for daily health monitoring, especially for elderly or nontechnical individuals.

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