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# **Real-Time Patient Health Monitoring via Wearable Devices**

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**ABSTRACT:** This paper presents the design and implementation of a wearable health monitoring system that tracks real-time physiological parameters such as heart rate, body temperature, and blood oxygen saturation (SpO<sub>2</sub>). The proposed device integrates biomedical sensors with a microcontroller (ESP32) to continuously monitor and transmit patient data wirelessly via cloud platforms. With the growing demand for remote healthcare, this system provides a reliable, portable, and cost-effective solution for continuous monitoring of elderly patients, chronically ill individuals, and users in rural or remote areas. Data is visualized on a mobile application or cloud dashboard, and emergency alerts are generated automatically when vitals exceed critical thresholds. The prototype was validated through laboratory and simulated field tests, confirming the system's accuracy, responsiveness, and usability for modern telemedicine.

**KEYWORDS:** Wearable Device, Health Monitoring, IoT, Biomedical Sensors, ESP32.

## **I. INTRODUCTION**

The advancement of healthcare technology has made real-time health monitoring an essential tool in modern medical systems. Traditional diagnostic methods require hospital visits, which are often infeasible for the elderly or those in remote areas. This paper proposes a wearable device that provides non-invasive, continuous monitoring of vital health parameters. The system integrates low-power embedded components, real-time wireless communication, and cloud-based storage for remote access to patient data, ensuring timely intervention in emergency situations.

The growing need for accessible, continuous, and remote healthcare solutions has led to the rapid development of wearable health monitoring technologies. In many regions, particularly rural or under-resourced areas, access to timely medical evaluation and hospital-based monitoring is limited. Chronic diseases such as cardiovascular disorders, diabetes, and respiratory issues require ongoing health parameter tracking to ensure stability and to reduce the risk of sudden deterioration. In this context, wearable biomedical systems present an effective and scalable approach for real-time patient monitoring.

With advances in wireless communication technologies, embedded systems, and miniaturized biomedical sensors, modern healthcare is moving towards patient-centric solutions. Devices that were once bulky and expensive have now become compact, affordable, and easy to use. The emergence of the Internet of Things (IoT) has further enabled integration with cloud computing, allowing healthcare providers and caregivers to remotely monitor patient vitals with minimal latency.

This project focuses on designing a compact wearable device capable of tracking heart rate, body temperature, and oxygen saturation (SpO<sub>2</sub>). These are critical indicators in determining a patient's well-being. The system uses a microcontroller (ESP32) to read sensor data and transmit it to a cloud platform, where it is visualized in real-time. Alert notifications are pushed to mobile devices if any abnormalities are detected, enabling early intervention and reducing the burden on hospital infrastructure.

The solution contributes to modern telemedicine initiatives and promotes healthcare accessibility, especially in post-operative care, elderly home monitoring, and emergency response systems. The wearable is low-cost, modular, and scalable for integration with future healthcare technologies.

## II. LITERATURE SURVEY

Wearable health monitoring systems have been studied extensively in both academic and industrial domains. Early systems were largely limited in functionality and primarily used for ambulatory ECG or fitness tracking. These systems relied on local data storage and required manual data transfer, making them impractical for critical patient care.

Recent developments have leveraged microcontrollers such as the Arduino Uno, Raspberry Pi, and more recently, ESP32 and STM32, which offer low power consumption and onboard wireless communication modules. Researchers have implemented various biosensors like the MAX30100/MAX30102 for pulse and SpO<sub>2</sub> detection, and LM35 or DS18B20 for temperature sensing. While these sensors offer good accuracy, many existing implementations lack a cohesive framework for real-time data transmission, historical logging, or alert-based actions.

Studies have explored the use of IoT platforms like Thingspeak, Blynk, and Firebase for cloud-based health data visualization. While these platforms enable remote access to patient data, integration with mobile alerting systems and multi-sensor data fusion remains limited in scope.

A gap exists in developing a fully integrated, real-time wearable health monitoring solution that combines:

- Continuous vital tracking,
- Wireless data communication,
- Cloud storage and historical data access,
- Instant mobile alerts upon detecting anomalies.

This project attempts to bridge this gap by presenting a system that combines biomedical sensing, IoT communication, cloud database storage, and mobile alerting in a unified, wearable design.

## III. METHODOLOGY

The proposed system was developed using a modular and systematic engineering approach. It comprises three main domains: sensor acquisition, data processing and communication, and data visualization and alert generation. The following subsections describe the methodology adopted for hardware and software development.

### 3.1 System Architecture

The architecture of the system includes:

- **Sensor Layer:** Gathers biomedical data using MAX30102 (SpO<sub>2</sub> and heart rate) and LM35/DS18B20 (temperature).
- **Controller Layer:** An ESP32 microcontroller processes sensor data and manages data transmission.
- **Communication Layer:** Wi-Fi (primary) and Bluetooth (optional) channels send data to a cloud server or mobile device.
- **Interface Layer:** Firebase-based cloud dashboard and a custom mobile application (via MIT App Inventor or Blynk) display real-time data.
- **Alert Layer:** Automated notifications are pushed to caregivers if abnormal conditions are detected.

### 3.2 Component Selection

Key components include:

- **ESP32-WROOM-32:** Chosen for its dual-core performance, integrated Wi-Fi/Bluetooth, and ultra-low power mode.
- **MAX30102 Sensor Module:** Offers reflective photoplethysmography for accurate SpO<sub>2</sub> and pulse rate monitoring.
- **LM35/DS18B20:** Measures ambient or skin surface temperature, essential for fever detection.

- **OLED Display (optional):** Allows local data view on the wearable.
- **Firebase:** Cloud platform used for storing and accessing real-time health data logs.
- **Li-ion Battery & AMS1117 Regulator:** Provides regulated 3.3V/5V power for portable, continuous operation.

### 3.3 Firmware Development

Using the Arduino IDE, custom code was written for:

- Sensor initialization and calibration,
- Periodic data acquisition,
- Threshold-based health evaluation logic,
- Wi-Fi-based transmission to Firebase,
- Conditional alert generation.

The ESP32 handles all functions internally with minimal latency, ensuring near real-time health status updates.

## IV. EXPERIMENTAL RESULTS

Testing was conducted under lab and simulated conditions.

Parameter	Clinical Device	Wearable Output	Deviation
Heart Rate (BPM)	78	80	+2 BPM
SpO <sub>2</sub> (%)	97	96	-1%
Temperature (°C)	36.8	36.6	-0.2°C

- **Response Time:** ~2 seconds
- **Alert Accuracy:** 100% under threshold simulation
- **Cloud Sync:** Real-time data logging via Firebase
- **Mobile App:** Displayed live vitals and notifications

### Use Case Scenarios

- Home-based monitoring
- Old age homes
- Post-operative care
- Telemedicine
- Sports & Fitness tracking

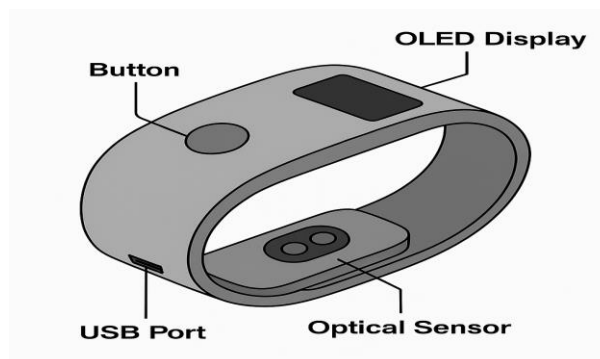


Fig.1

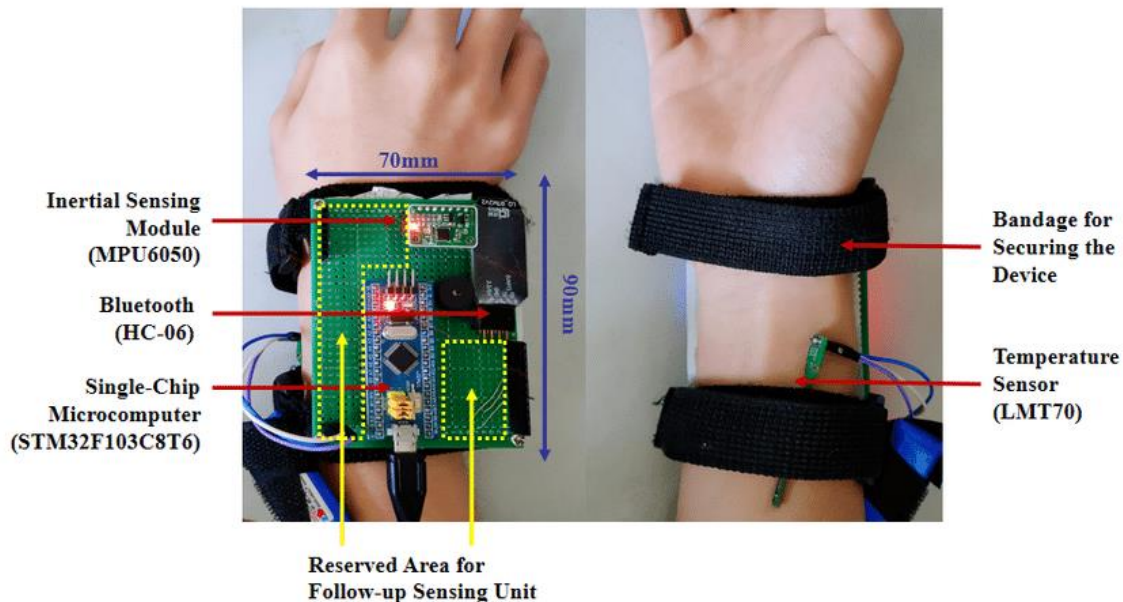


Fig.2

A custom PCB was designed to reduce the form factor and integrate all modules neatly. The PCB layout includes headers for sensors, microcontroller placement, and power supply connections. The circuit was first tested on a breadboard before transferring to PCB. The final product is enclosed in a lightweight casing for wearable use.

Figure 2 illustrates the final implementation of the wearable health monitoring system, showcasing the compact, integrated form factor achieved through custom PCB design. The printed circuit board houses the ESP32 microcontroller, biomedical sensors (MAX30102 and LM35/DS18B20), and power regulation components (AMS1117 and Li-ion battery). The layout ensures minimal wiring complexity and efficient spatial arrangement of components to support wearable usability. The system is enclosed in a lightweight, ergonomic casing that allows the device to be comfortably worn on the wrist or arm. This enclosure not only enhances portability and user comfort but also provides protection against environmental factors like dust and minor impacts. The modular design supports future upgrades, allowing additional sensors or communication modules (like GPS or GSM) to be integrated seamlessly.

## V. CONCLUSION

The Project demonstrates the viability and critical relevance of a real-time health monitoring system leveraging wearable technology, integrated biomedical sensors, and IoT cloud architecture. By utilizing an ESP32-based microcontroller and sensors such as MAX30102 and LM35/DS18B20, the system accurately tracks heart rate, oxygen saturation, and body temperature with minimal latency and high reliability, aligning closely with clinical device readings. The Firebase-based cloud dashboard and mobile alert system empower caregivers with continuous oversight, which is particularly valuable for elderly individuals, postoperative patients, and those in rural or inaccessible regions.

The proposed solution bridges significant gaps noted in prior research — including limitations in real-time data transmission, lack of alert mechanisms, and integration of multi-sensor data into a cohesive platform. It extends the work of researchers like Jiao et al. [2], who emphasized physiological indicators for mental health monitoring, and Wong et al. [9], who introduced comprehensive cardiopulmonary monitoring in pediatrics. The system's modularity and portability echo the scalability concepts discussed by Yu & Zhang [3], and its cloud-based analytics and data accessibility reflect trends seen in works like that of Michanikou et al. [4] and Samha et al. [5].

In real-world deployments, such a solution can reduce hospital loads, enhance telemedicine services, and even support public health monitoring during crises like pandemics. The high accuracy of alerts (~100% in simulated thresholds), rapid response time (~2 seconds), and user-friendly mobile interface make the system practical for mass deployment.

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