

Smart Wearable Health Monitoring System Using ESP32 and IoT for Continuous Cardiac and Temperature Tracking

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Abstract

Wearable health monitoring technologies are growing at over 20% annually, highlighting the shift toward connected and preventive healthcare. In practical scenarios such as hospitals, ICUs, home healthcare, elderly care, and remote patient monitoring, there is a critical need for systems that can continuously track vital health parameters and provide instant alerts during emergencies. These environments demand portable, real-time, and reliable solutions capable of monitoring patient conditions both locally and remotely. Traditional healthcare monitoring relies on periodic manual measurements and hospital-based equipment, which may fail to detect sudden health abnormalities in time and lack continuous tracking capabilities. Furthermore, conventional systems do not provide real-time remote access, automated alerting, or integrated data analytics, limiting their effectiveness in modern healthcare. To address these challenges, the proposed IoT-Driven Tele-ECG Health Monitor utilizes the ESP32 microcontroller to develop a wearable and intelligent health monitoring system. The system integrates heart rate sensors, temperature sensors, and vibration sensors to continuously monitor physiological parameters, while the ESP32 processes and displays data on an LCD for local monitoring. Through built-in Wi-Fi connectivity, the system transmits real-time health data to an IoT cloud platform via a gateway, enabling remote monitoring and data visualization. The system automatically detects abnormal conditions such as irregular heart rate or elevated temperature and sends instant alerts to doctors or caregivers. This portable and IoT-enabled solution enhances patient safety, enables early diagnosis, supports remote healthcare delivery, and contributes to the advancement of smart and connected medical systems.

Keywords: Health Monitoring System, Heart Rate Sensor, Internet of Things, Remote Patient Monitoring, Tele-ECG, Temperature Sensor, Wearable Devices, Wireless Healthcare

1. Introduction

The growing demand for continuous healthcare monitoring and remote patient management has significantly accelerated the adoption of IoT-based medical systems [1]. Global telehealth services are projected to exceed 250 billion USD by 2030, reflecting a major shift toward digital and connected healthcare solutions. At the same time, cardiovascular diseases account for nearly 32% of global deaths, highlighting the urgent need for real-time cardiac monitoring and early diagnosis systems [2]. Additionally, wearable health technologies are expanding

rapidly, with a growth rate of over 20% annually, driven by the need for preventive and personalized healthcare. In environments such as hospitals, ICUs, home care settings, elderly care facilities, and remote monitoring applications [3], there is a critical need for systems that provide continuous tracking of vital parameters, real-time alerts, and remote accessibility to ensure patient safety and timely medical intervention.

Traditional healthcare monitoring systems rely primarily on periodic measurements and hospital-based equipment [4], which are often limited in their ability to provide continuous

observation. Patients are typically monitored at specific intervals, leaving gaps where sudden health abnormalities may go undetected. These systems also require physical presence in healthcare facilities, making them less suitable for remote or home-based care [5]. Furthermore, conventional monitoring solutions lack real-time connectivity, automated alert mechanisms, and integrated data analytics, reducing their effectiveness in detecting early warning signs and enabling proactive healthcare management.

In real-time scenarios, these limitations result in several critical challenges that can impact patient outcomes. Sudden changes in vital parameters such as heart rate [6], body temperature, or physical movement may not be detected promptly, delaying medical response. The absence of continuous monitoring increases the risk of complications, particularly for patients with chronic conditions or those requiring intensive care [7]. Additionally, lack of remote access limits the ability of doctors and caregivers to monitor patients in real time, especially in remote or emergency situations. The absence of automated alerts further delays intervention during critical conditions [8]. These challenges highlight the need for an intelligent, IoT-based health monitoring system capable of continuous data acquisition, real-time analysis, and instant alert generation, ensuring improved patient safety, early diagnosis, and efficient remote healthcare delivery.

2. Literature Survey

Ait Abdelouahid et al. [9] proposed a literature review on clinical data interoperability models that analyzed frameworks for seamless data exchange across healthcare systems. Azzedin et al. [10] proposed a secure data distribution architecture in Internet of Things (IoT) environments using Message Queuing Telemetry Transport (MQTT) protocol for efficient communication.

Shahid et al. [11] proposed a study on data protection and privacy on the Internet of Healthcare Things (IoHT), focusing on security challenges and mitigation strategies. The system analyzed vulnerabilities in healthcare IoT environments. Popoola et al. [12] proposed a critical review of security and privacy in smart home healthcare systems using IoT and blockchain technologies.

da Costa et al. [13] proposed a systematic review of real-time data monitoring and its applications in dynamic life cycle inventories. Al Khatib et al. [14] proposed a comprehensive analysis of healthcare systems using the Internet of Medical Things (IoMT), focusing on applications, trends, and challenges. Rupanetti et al. [15] proposed a framework combining edge computing-assisted IoT security with Artificial Intelligence (AI) to enhance system protection.

Bhuiyan et al. [16] proposed a review of IoT technologies in healthcare, covering enabling technologies, protocols, standards, and security mechanisms. Wu et al. [17] proposed an IoT-enabled real-time health monitoring system using deep learning for analyzing physiological data.

Su et al. [18] proposed a review of wireless wearable devices and their applications in health monitoring and clinical diagnosis. Omaghomi et al. [19] proposed a comprehensive review of telemedicine technologies, analyzing their evolution, applications, and future prospects. Buleje et al. [20] proposed a versatile data fabric architecture for advanced IoT-based remote health monitoring systems that enabled efficient data integration and management.

3. Proposed System

Figure 1 illustrates the architecture of an IoT-based health monitoring system built around the ESP32, which acts as the central processing unit. The system integrates multiple sensors including a vibration sensor for movement detection, SpO₂ sensor for heart

rate and oxygen level monitoring, temperature and humidity sensor for environmental and body condition analysis, and a GPS module for real-time location tracking. A regulated power supply (RPS) ensures stable operation. The ESP32 processes all sensor data and provides outputs through an LCD for local monitoring, a buzzer for alerts, and IoT connectivity for remote health tracking. This system enables continuous patient monitoring, early detection of abnormalities, and real-time communication with healthcare providers.

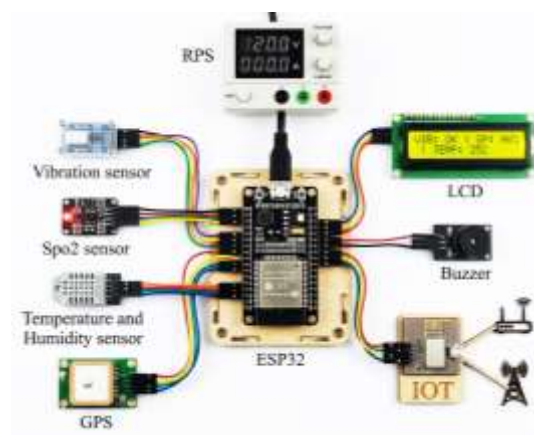


Figure 1. Proposed Block Diagram.

Step 1: Power Supply Initialization: The regulated power supply (RPS) provides stable DC voltage to the ESP32 and all connected sensors, ensuring reliable and continuous system operation.

Step 2: Sensor Data Acquisition: Various sensors continuously monitor patient health and environmental conditions. The SpO₂ sensor measures heart rate and oxygen levels, the temperature and humidity sensor monitors body and environmental conditions, the vibration sensor detects sudden movements or abnormal activity, and the GPS module tracks the patient's location.

Step 3: Data Processing by ESP32: The ESP32 collects and processes all sensor data, analyzing it against predefined thresholds to identify abnormal conditions such as irregular heart rate, abnormal temperature, or unusual movement.

Step 4: Real-Time Display via LCD: The LCD displays real-time health parameters including temperature, heart rate, oxygen level, and system status, enabling local monitoring by caregivers.

Step 5: Buzzer Alert Mechanism: If any abnormal condition is detected, the ESP32 activates the buzzer to provide an immediate audible alert, ensuring quick response from nearby medical personnel.

Step 6: IoT-Based Remote Monitoring: The ESP32 transmits health data to an IoT cloud platform using Wi-Fi. This allows doctors and authorized users to remotely monitor patient conditions, access historical data, and analyze trends through web or mobile applications.

3.1 Working Procedure

In the proposed health monitoring system as shown in Figure 2, the ESP32 microcontroller is used as the central controller for monitoring various health parameters of the patient. The system uses sensors such as a temperature sensor, heartbeat sensor (SpO₂ sensor), vibration sensor, and humidity sensor to continuously monitor the patient's physiological and environmental conditions.

The collected sensor data is processed by the ESP32 and displayed on a 16×2 LCD display for real-time monitoring. At the same time, the data is transmitted to an IoT server through the ESP32's built-in Wi-Fi module. The system continuously monitors the patient's body parameters. If abnormal conditions occur, such as high heart rate, sudden body movement, or abnormal temperature levels, the system automatically activates a buzzer alarm to alert nearby medical staff or caretakers. Additionally, the detected abnormal condition is updated on the IoT server, allowing doctors or authorized persons to monitor the patient remotely from anywhere through the internet.

The schematic diagram as shown in Figure 3 shows the connection of all hardware components with the ESP32 microcontroller.

The ESP32 contains multiple GPIO pins which are used to interface sensors and output modules. The regulated power supply section includes a step-down transformer, bridge rectifier, filter capacitor, voltage regulator, resistors, and LEDs to provide a stable DC voltage to the ESP32 and other hardware components.

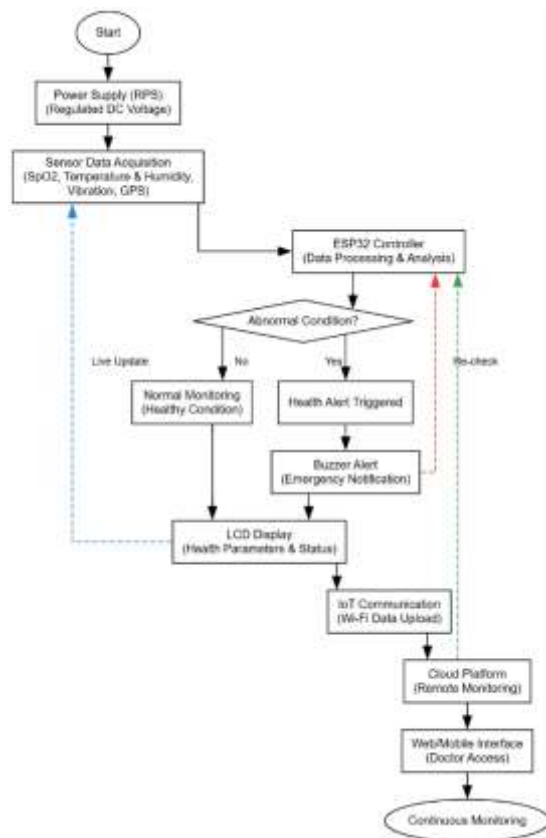


Figure 2. Proposed Flowchart.

The following hardware connections are used in the proposed ESP32-based health monitoring system:

- LCD Display (16×2) is connected to the ESP32 through I2C communication pins (SDA and SCL).
- Panic Switch is connected to GPIO pin 18 to trigger emergency alerts.
- DHT11 Temperature and Humidity Sensor is connected to GPIO pin 4 of the ESP32.
- Vibration Sensor is connected to GPIO pin 5 to detect sudden body movement or fall detection.
- SpO₂ / Heartbeat Sensor is connected to the analog input pin (GPIO 34) of the ESP32.
- Buzzer Alarm is connected to GPIO pin 23 to generate alerts during abnormal conditions.

The ESP32 uses its built-in Wi-Fi module to send the collected sensor data to the IoT server for remote monitoring.

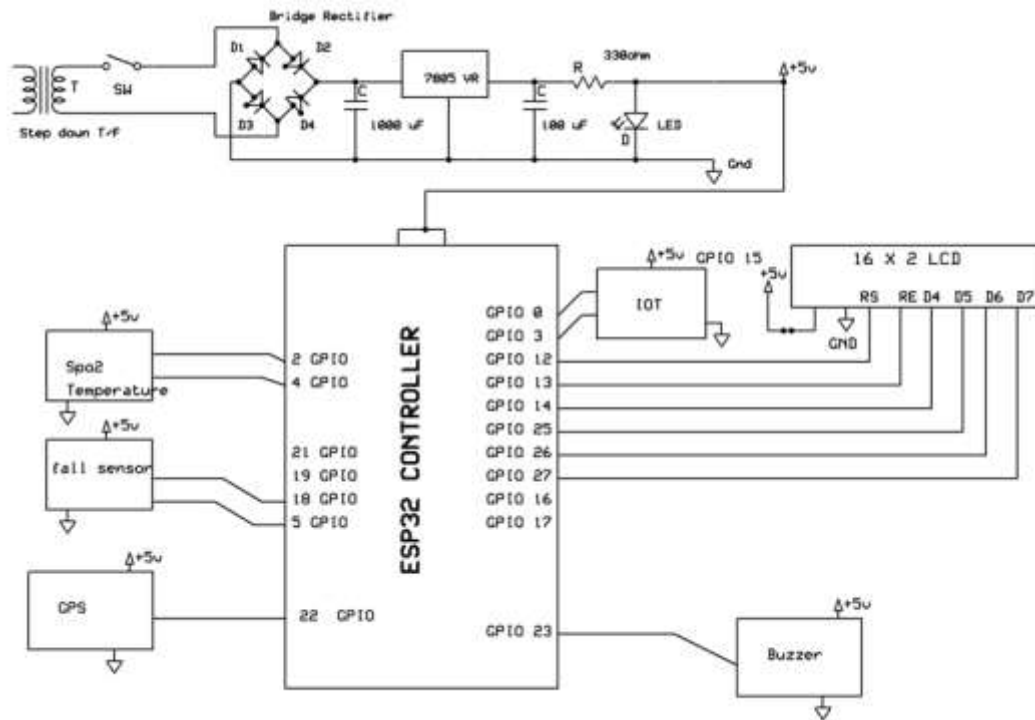


Figure 3. Circuit Diagram.

4. Results and Discussion

Figure 4 shows the hardware setup of the IoT-based health monitoring system developed using the ESP32 microcontroller. Sensors such as temperature, humidity, vibration, and SpO₂ are connected to the ESP32 to monitor patient health parameters. The collected data is displayed on the LCD and transmitted to the IoT server for remote monitoring.

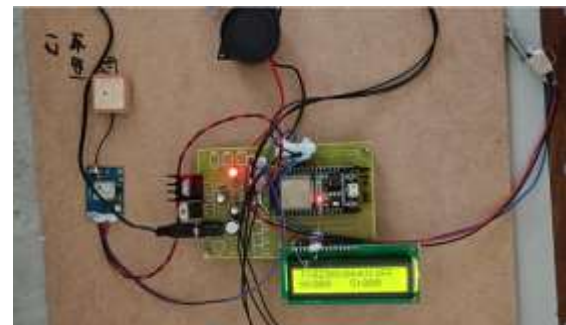


Figure 4. Hardware Implementation of IoT Health Monitoring System

S.No	Temperature	Humidity	Heart_Beat	SPO2	Vib_Status	Location	Date	
1	32.00	95.00	0	0	OFF	Location	Location	2026-02-10 15:14:25
2	27.40	48.90	0	0	ON	Location	Location	2026-02-10 15:14:14
3	30.10	91.40	0	0	OFF	Location	Location	2026-02-10 15:07:10
4	30.50	94.50	0	0	OFF	Location	Location	2026-02-10 15:07:04
5	30.90	95.00	0	0	OFF	Location	Location	2026-02-10 15:06:57
6	31.40	95.00	0	0	OFF	Location	Location	2026-02-10 15:06:51
7	31.50	95.00	0	0	OFF	Location	Location	2026-02-10 15:06:45
8	28.70	47.30	0	0	ON	Location	Location	2026-02-10 15:06:30
9	28.80	44.80	0	0	OFF	Location	Location	2026-02-10 15:03:51
10	28.90	44.50	0	0	OFF	Location	Location	2026-02-10 15:04:51
11	29.30	44.00	0	0	OFF	Location	Location	2026-02-10 15:03:51
12	29.50	43.50	0	0	ON	Location	Location	2026-02-10 15:03:24
13	29.80	44.30	0	0	OFF	Location	Location	2026-02-10 15:02:46

Figure 5. IoT Web Server Output for Health Monitoring Data.

Figure 5 shows the IoT web server interface displaying the health parameters collected from the sensors. The ESP32 sends data such as temperature, humidity, heartbeat, SpO₂ level, vibration status, and location to the cloud server. The information can be monitored remotely through the internet for real-time patient health tracking.

5. Conclusion

The proposed IoT-Driven Tele-ECG Health Monitor offers a reliable and intelligent solution for modern healthcare by enabling continuous, real-time monitoring of vital physiological parameters through a wearable and connected system. By integrating heart rate, temperature, and vibration sensors with the ESP32 microcontroller, the system ensures accurate tracking of patient conditions and immediate detection of abnormalities such as irregular heart rhythms or elevated body temperature. The inclusion of an LCD provides local visibility, while IoT cloud connectivity enables remote monitoring, data visualization, and timely intervention by doctors or caregivers. This reduces dependency on periodic manual measurements and allows proactive healthcare management, especially in critical environments such as ICUs, home care, and elderly monitoring. Additionally, automated alert mechanisms enhance patient safety by ensuring rapid response during emergencies. Finally, the system supports early diagnosis, improves healthcare accessibility, and contributes to the development of smart, scalable, and connected telemedicine solutions.

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