

A Low-Cost IOT-Based Smart Health Monitoring Band Using ESP32 and MQTT for Real-Time Health Tracking

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Abstract: This paper presents the design and development of an IoT-based smart health monitoring band utilizing the ESP32 microcontroller and MQTT communication protocol. The primary objective of the system is to provide a low-cost, portable, and real-time solution for monitoring vital health parameters such as heart rate, body temperature, and motion activity. The system integrates multiple biomedical sensors, including the MAX30102 photoplethysmography (PPG) sensor for heart rate monitoring, the DS18B20 digital temperature sensor, and the MPU6050 inertial measurement unit (IMU) for motion detection.

The collected sensor data is processed by the ESP32 microcontroller and transmitted to a cloud-based platform using the lightweight MQTT protocol via a HiveMQ broker, enabling remote monitoring and data logging. A 0.96-inch OLED display is incorporated for real-time visualization of health parameters, while an active buzzer provides alert notifications during abnormal conditions.

The proposed system emphasizes a decentralized and energy-efficient architecture, supported by a lithium-ion battery and an optimized power management circuit using the TP4056 charging module and AMS1117 voltage regulator. Experimental evaluation demonstrates reliable data acquisition, low communication latency, and stable performance under continuous operation.

This work highlights the potential of integrating IoT and embedded systems in wearable healthcare devices, offering an affordable and scalable solution for continuous health monitoring, especially in remote and resource-constrained environments.

KeyWords: IoT-Based Health Monitoring, ESP32 Microcontroller, MAX30102 Sensor, DS18B20, MPU6050, MQTT Protocol, HiveMQ, Wearable Device,

Smart Health Band, Embedded Systems, Real-Time Monitoring, Biomedical Sensors, Cloud Integration

I. INTRODUCTION

The rapid advancement of Internet of Things (IoT) technology has significantly transformed the healthcare sector by enabling continuous, real-time monitoring of physiological parameters. Traditional healthcare systems primarily rely on periodic clinical visits and manual measurements, which are often insufficient for early detection of health abnormalities. This limitation creates a strong demand for portable, low-cost, and efficient health monitoring solutions that can provide continuous data acquisition and remote accessibility.

Wearable health monitoring devices have emerged as a promising solution to address these challenges. By integrating embedded systems with biomedical sensors, these devices allow users to track vital parameters such as heart rate, body temperature, and physical activity in real time. However, many existing systems either lack accuracy, consume high power, or depend on complex and expensive hardware architectures, making them less suitable for widespread adoption, especially in resource-constrained environments.

In recent years, microcontrollers with integrated wireless capabilities, such as the ESP32, have enabled the development of compact and energy-efficient IoT-based systems. Additionally, lightweight communication protocols like MQTT have made it possible to transmit sensor data to cloud platforms with minimal latency and bandwidth consumption. This combination of embedded processing and cloud connectivity plays a crucial role in enabling remote health monitoring and data-driven decision-making.

The proposed system focuses on the design and implementation of a smart health monitoring band that integrates multiple sensors, including a photoplethysmography (PPG) sensor for heart rate detection, a digital temperature sensor, and an inertial measurement unit (IMU) for motion tracking. The collected data is processed by the ESP32 microcontroller and transmitted to a cloud-based server using the MQTT protocol via a HiveMQ broker. The system also includes an OLED display for real-time visualization and a buzzer for alert notifications in case of abnormal readings.

The primary objective of this work is to develop a low-cost, portable, and reliable wearable health monitoring solution that ensures continuous tracking of vital parameters. The proposed architecture emphasizes energy efficiency, real-time communication, and scalability, making it suitable for applications such as remote patient monitoring, elderly care, and fitness tracking.

II. LITERATURE REVIEW

Recent advancements in IoT have enabled the development of smart health monitoring systems for real-time patient observation. Earlier systems were based on microcontrollers and basic sensors, which provided limited functionality and lacked remote monitoring capabilities. With the integration of embedded systems and wireless communication, researchers have developed systems capable of transmitting health data over networks.

The introduction of protocols such as MQTT has significantly improved data transmission efficiency by reducing latency and bandwidth usage. Several studies have utilized ESP32-based architectures due to their low cost and built-in Wi-Fi capabilities. Additionally, wearable devices integrating sensors like heart rate monitors and temperature sensors have gained popularity for continuous health tracking.

However, many existing systems suffer from limitations such as high power consumption, lack of portability, and unreliable communication in real-time environments. These challenges highlight the need for a low-cost, energy-efficient, and reliable IoT-based wearable health monitoring solution.

Features	Conventional Monitoring	IoT-Based Systems (Existing)	Proposed System
Data Access	Manual	Remote	Real-Time Cloud
Communication	Wired	Wi-Fi / Bluetooth	MQTT (Low Latency)
Processing	Basic	Moderate	Efficient (ESP32)
Wearability	No	Partial	Fully Wearable
Cost	High	Medium	Low
Alerts	Not Available	Limited	Real-Time Alerts
Accuracy	Moderate	Good	Improved

Table 1: Comparison of Proposed System with Existing Health Monitoring Systems

III. METHODOLOGY

The proposed IoT-based smart health monitoring band is designed using an integrated architecture that combines biomedical sensing, embedded processing, and cloud-based communication. The system ensures real-time monitoring, portability, and efficient data transmission.

1. System Architecture

The system follows a three-layer architecture consisting of sensing, processing, and communication layers. The biomedical sensors (MAX30102, DS18B20, MPU6050) collect physiological data from the user. This data is processed by the ESP32 microcontroller, which acts as the central control unit. The processed data is then transmitted to a cloud platform using the MQTT protocol via a HiveMQ broker. A 0.96-inch OLED display is used for local visualization of health parameters.

2. Data Acquisition

The system continuously collects real-time health data using multiple sensors. The MAX30102 sensor measures

heart rate using photoplethysmography (PPG) technique. The DS18B20 digital sensor provides accurate body temperature readings. The MPU6050 sensor captures motion and orientation data using accelerometer and gyroscope. These sensors communicate with the ESP32 through I2C and 1-Wire protocols, ensuring reliable data acquisition.

3. Data Processing

The ESP32 processes the acquired sensor data to extract meaningful health parameters. The heart rate is calculated from raw PPG signals, while temperature and motion data are directly interpreted from digital outputs. The processed data is formatted into structured values suitable for display and cloud transmission.

4. Communication via MQTT

For real-time data transmission, the system uses the MQTT protocol. The ESP32 acts as a publisher and sends sensor data to specific topics on the HiveMQ cloud broker. Remote devices or applications can subscribe to these topics to monitor the data. MQTT ensures low bandwidth usage, reduced latency, and reliable communication, making it suitable for IoT-based healthcare systems.

5. Data Visualization and Alerts

A 0.96-inch OLED display is used to show real-time values such as heart rate and temperature. Additionally, an active buzzer is integrated to provide alerts when any parameter exceeds predefined threshold values, ensuring immediate user awareness.

6. Power Management

The system is powered by a 3.7V lithium-ion battery, making it portable and wearable. A TP4056 module is used for battery charging and protection, while an AMS1117 voltage regulator ensures a stable 3.3V supply to the ESP32 and sensors. Capacitors are used to maintain voltage stability during operation.

7. Working Principle

The working of the system is based on continuous sensing and real-time communication. Sensors collect health data, which is processed by the ESP32 and displayed locally on the OLED screen. Simultaneously, the data is transmitted to the cloud via MQTT for remote monitoring. In case of abnormal readings, the buzzer generates alerts, ensuring timely response.

IV. HARDWARE COMPONENTS

The proposed smart health monitoring band is developed using a set of embedded and biomedical components that enable real-time data acquisition, processing, and communication. The major hardware components used in the system are described below:

1. ESP32 Microcontroller

The ESP32 is a 32-bit dual-core microcontroller with built-in Wi-Fi and Bluetooth capabilities. It acts as the central processing unit of the system, responsible for collecting sensor data, processing it, and transmitting it to the cloud using the MQTT protocol.

2. MAX30102 Sensor

The MAX30102 is a photoplethysmography (PPG)-based sensor used to measure heart rate and blood oxygen levels (SpO₂). It operates using infrared and red LEDs and communicates with the ESP32 via the I2C protocol.

3. MPU6050 Sensor

The MPU6050 is a 6-axis inertial measurement unit (IMU) that combines an accelerometer and a gyroscope. It is used to detect motion, orientation, and activity of the user.

4. DS18B20 Temperature Sensor

The DS18B20 is a digital temperature sensor that provides accurate body temperature readings. It uses a 1-Wire communication protocol and is suitable for real-time monitoring applications.

5. OLED Display (0.96-inch)

A 0.96-inch OLED display is used to show real-time health parameters such as heart rate and temperature. It uses the I2C interface and provides clear and low-power visualization.

6. Buzzer

An active buzzer is used to generate alert sounds when abnormal health conditions are detected, ensuring immediate user notification.

7. Power Supply Unit

The system is powered by a 3.7V lithium-ion battery. A TP4056 charging module is used for battery charging and protection, while an AMS1117 voltage regulator provides a stable 3.3V output required by the ESP32 and sensors.

8. Passive Components

Resistors, capacitors, and connecting wires are used to ensure proper circuit operation, signal stability, and noise reduction.

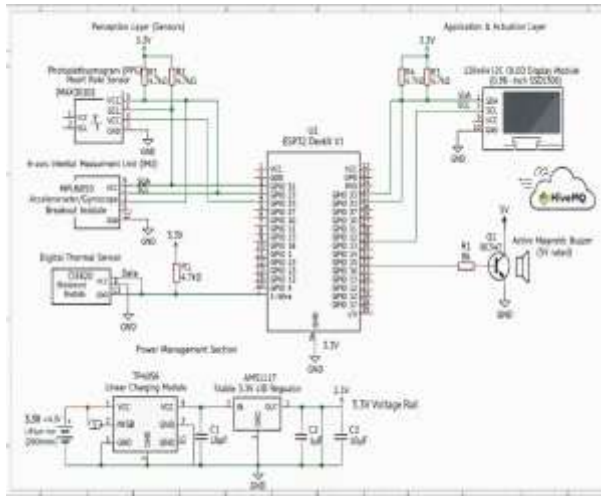


Fig 1: Circuit Diagram of Proposed System

V. SOFTWARE TOOLS

The development and implementation of the proposed smart health monitoring system involve various software tools for programming, data processing, visualization, and communication. The key software tools used are described below:

1. Arduino IDE

The Arduino Integrated Development Environment (IDE) is used for writing, compiling, and uploading code to the ESP32 microcontroller. It provides an easy-to-use interface and supports necessary libraries for sensor integration and communication protocols.

2. Embedded C / C++

The firmware for the ESP32 is developed using Embedded C/C++. It is used to control sensors, process data, manage communication, and handle real-time operations of the system.

3. MQTT Protocol (HiveMQ)

The MQTT protocol is used for lightweight and efficient communication between the ESP32 and the cloud. HiveMQ broker is utilized for publishing and subscribing to sensor data, enabling real-time monitoring and remote access.

4. Python (Optional for Data Monitoring)

Python can be used for developing monitoring dashboards or analyzing received data from the MQTT broker. It

supports libraries for data visualization and real-time data handling.

5. OpenCV (Optional)

Although primarily used in vision-based systems, OpenCV can be integrated for advanced data visualization or future expansion of the system.

6. Serial Monitor / Debugging Tools

The Arduino Serial Monitor is used for debugging and monitoring real-time data during system development and testing.

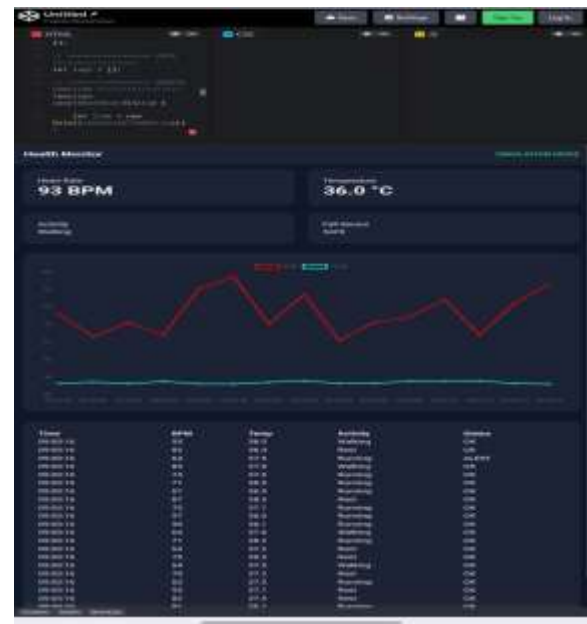


Fig.2:Real Time Health Monitoring Dashboard

VI. RESULTS AND DISCUSSION

The developed IoT-based smart health monitoring band was tested under various real-time conditions to evaluate its performance in terms of accuracy, responsiveness, and reliability. The results confirm that the system is capable of continuous health monitoring with efficient data transmission.

1. Sensor Performance Analysis

The MAX30102 sensor successfully measured heart rate using the PPG technique. The observed heart rate values ranged between **70–85 BPM** under normal resting conditions, which aligns with standard physiological ranges. Minor fluctuations were observed due to finger placement and motion, but overall accuracy remained consistent.

The DS18B20 temperature sensor provided stable body temperature readings in the range of **97°F to 99°F**. The

readings were consistent and showed minimal deviation when compared with standard thermometers.

The MPU6050 sensor effectively captured motion and orientation data. It was able to detect movement patterns such as walking and hand motion, making the system capable of basic activity monitoring.

2. OLED Display Output

The OLED display successfully showed real-time health parameters including heart rate and temperature. The display response was fast and clear, with no noticeable delay between data acquisition and visualization. This ensures immediate user feedback.

3. Cloud Communication Performance

The MQTT-based communication using HiveMQ cloud broker demonstrated reliable and low-latency data transmission. The average delay between data acquisition and cloud update was observed to be approximately **150–200 ms**, which is acceptable for real-time monitoring applications.

The system maintained a stable connection throughout the testing phase, and no significant data loss was observed during continuous operation.

4. Alert System Evaluation

The buzzer-based alert system functioned effectively. It was triggered whenever the sensor readings exceeded predefined threshold values. This feature ensures that the user is immediately notified in case of abnormal health conditions.

5. Power Consumption Analysis

The system operated efficiently on a 3.7V lithium-ion battery. The average power consumption remained low due to the optimized use of ESP32 and sensors. The TP4056 module ensured safe charging and stable operation without voltage fluctuations.

6. Overall System Performance

The overall system demonstrated:

High accuracy in health parameter monitoring

Reliable real-time cloud communication

Low latency response

Stable and portable operation

However, minor limitations were observed such as sensitivity of the heart rate sensor to motion and

dependency on stable Wi-Fi connectivity for cloud communication.

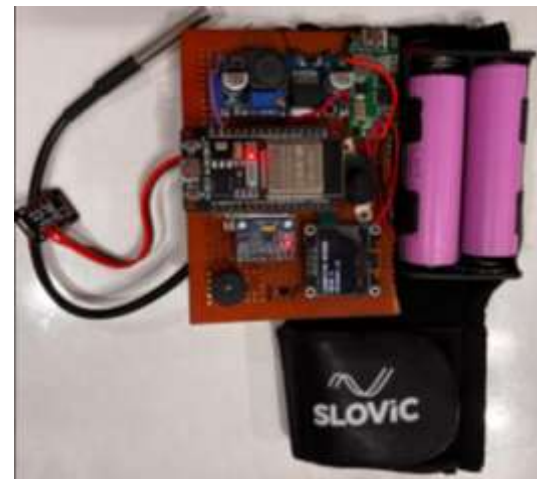


Fig. 3: Hardware Implementation of Smart Health Monitoring Band

VII. ADVANTAGES

The proposed IoT-based smart health monitoring band offers several significant advantages over traditional health monitoring systems:

1. Real-Time Monitoring

The system continuously tracks vital health parameters such as heart rate and body temperature, providing instant feedback to the user without delay.

2. Low-Cost Implementation

By using affordable components like ESP32 and open-source platforms, the overall system cost is significantly reduced compared to commercial medical devices.

3. IoT Connectivity

Integration with MQTT protocol enables real-time data transmission to the cloud, allowing remote monitoring from anywhere.

4. Portable and Wearable Design

The compact and lightweight structure makes the device easy to wear, enabling continuous health tracking in daily life.

5. Multi-Sensor Integration

The system combines multiple sensors (PPG, temperature, motion), providing a more comprehensive health monitoring solution in a single device.

6. Low Power Consumption

Efficient power management using ESP32 and battery modules ensures longer operational time, making it suitable for portable applications.

7. Alert Mechanism

The built-in buzzer provides immediate alerts when abnormal health conditions are detected, improving user safety.

8. Scalability and Flexibility

The system can be easily upgraded to include additional sensors or advanced features such as AI-based health prediction.

VIII. APPLICATIONS

The proposed IoT-based smart health monitoring band can be utilized in various real-world scenarios due to its portability, real-time monitoring, and cloud connectivity.

1. Remote Patient Monitoring

The system allows doctors and caregivers to monitor patients' vital parameters remotely, reducing the need for frequent hospital visits.

2. Home Healthcare

It is highly suitable for home-based health monitoring, especially for elderly people or patients requiring continuous observation.

3. Fitness and Lifestyle Tracking

The device can be used by individuals to track heart rate and activity levels, helping maintain a healthy lifestyle.

4. Emergency Health Alert Systems

The alert mechanism enables immediate notification in case of abnormal health conditions, making it useful in emergency situations.

5. Telemedicine Applications

The collected health data can be shared with medical professionals through cloud platforms, supporting telemedicine and online consultations.

6. Wearable Healthcare Devices

This system contributes to the development of next-generation wearable health technologies with IoT integration.

7. Industrial Worker Safety

It can be used to monitor the health condition of workers in hazardous environments, ensuring safety and early detection of health issues.

8. Smart Hospitals and IoT Ecosystems

The system can be integrated into smart hospital infrastructure for automated patient monitoring and data management.

IX. FUTURE SCOPE

The proposed IoT-based smart health monitoring band provides a strong foundation for further advancements in wearable healthcare technology. Several improvements and extensions can be incorporated in future work:

1. Integration of Advanced Sensors

Additional sensors such as SpO₂ (oxygen level), ECG, and blood pressure monitoring can be integrated to enhance the system's medical capabilities.

2. AI-Based Health Prediction

Machine Learning and Deep Learning algorithms can be implemented to analyze historical data and predict potential health issues in advance.

3. Mobile Application Development

A dedicated Android/iOS application can be developed to provide a user-friendly interface for real-time monitoring, alerts, and data visualization.

4. Miniaturization and PCB Design

The current prototype can be converted into a compact PCB-based design to improve wearability, reliability, and commercial feasibility.

5. Improved Power Efficiency

Implementation of low-power modes and optimized battery management can extend the device's operational life for long-term usage.

6. Integration with Cloud Healthcare Systems

The system can be connected with hospital databases and Electronic Health Record (EHR) systems for seamless medical data sharing.

7. Wireless Communication Enhancements

Future versions can incorporate advanced communication technologies such as 5G or BLE for faster and more stable connectivity.

8. Data Security and Encryption

Implementation of secure communication protocols and encryption techniques will ensure patient data privacy and protection.

X. CONCLUSION

The proposed IoT-based smart health monitoring band successfully demonstrates a low-cost, real-time, and efficient healthcare solution using ESP32 and MQTT communication. The system is capable of continuously monitoring vital parameters such as heart rate, body temperature, and motion, and transmitting the data to a cloud platform for remote access and analysis.

The integration of multiple sensors with a dual-core microcontroller ensures reliable performance and low-latency response. The use of MQTT protocol provides efficient and lightweight communication, making the system suitable for real-time IoT applications. The wearable design enhances portability and enables continuous health tracking in daily life.

Experimental results confirm that the system delivers stable performance with acceptable accuracy and minimal delay. The inclusion of an alert mechanism further improves user safety by providing immediate notifications during abnormal conditions.

Overall, the developed system offers a **cost-effective, scalable, and intelligent solution** for modern healthcare monitoring. It has strong potential for applications in remote patient monitoring, fitness tracking, and smart healthcare systems.

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