# Wireless Body Area Network-Based Smart Healthcare Monitoring Using IoT

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***ABSTRACT***

Continuous observation of patient health has become more practical with the widespread adoption of Internet of Things (IoT) technologies. This work presents a Wireless Body Area Network (WBAN)-based monitoring system designed to collect and transmit multiple physiological signals in real time. The system integrates electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), and motion sensing through an accelerometer, enabling a broader assessment of patient condition. Instead of handling all operations within a single controller, the design separates data acquisition and communication tasks. An Arduino unit performs signal sampling and basic preprocessing, while a NodeMCU (ESP8266) module manages wireless transmission to a cloud platform. Communication between the two modules is achieved using a UART interface, which allows each component to operate independently without causing processing delays. Experimental observations indicate that the system maintains consistent performance during continuous operation. An average delay of approximately 1.8 seconds and a packet delivery ratio close to 98.6% were achieved, demonstrating the system's reliability for remote health monitoring applications. The proposed WBAN-based architecture offers a scalable, low-cost solution for real-time patient surveillance, with potential applications in home care, elderly monitoring, and post-operative recovery.

**Index Terms:** Wireless Body Area Network, IoT Healthcare, Arduino, NodeMCU, ECG, EEG, EMG, Fall Detection, Remote Monitoring, ESP8266.

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## I. INTRODUCTION

Healthcare monitoring is gradually moving beyond tradi- tional hospital environments toward continuous observation in everyday settings. This shift is largely supported by IoT technologies, which make it possible to collect and transmit physiological data without requiring the patient to remain in a clinical facility.

Wireless Body Area Networks (WBANs) are central to this transition. By placing compact sensors on the human body, it becomes possible to capture vital signals such as cardiac activity, neural responses, muscle activity, and movement pat- terns. These signals can then be forwarded to remote systems, where they are stored, visualized, and analyzed.

Many existing implementations focus on a single physiological parameter. For example, ECG-based systems are commonly used for cardiac monitoring, while accelerometer- based designs are often used for fall detection. Although such systems are useful in specific cases, they provide only a limited perspective on the patient's condition. In practical scenarios,multiple physiological processes often interact, making multi- sensor monitoring more meaningful.

However, integrating several sensors introduces additional challenges. As more data is collected, the system must handle increased processing and communication demands. When a single microcontroller is used for both sensing and transmis- sion, delays may occur due to resource limitations. This can affect reliability, especially during continuous monitoring.

To address this issue, the present work adopts a dual- controller approach. The Arduino is responsible for acquir- ing and preparing sensor data, while the NodeMCU handles communication with the cloud. By separating these tasks, the system avoids unnecessary processing conflicts and maintains stable operation even when multiple signals are involved.

### A. Motivation

There is a growing need for healthcare solutions that are not only effective but also accessible. In many regions, especially rural areas, continuous monitoring facilities are limited. A system that is low-cost, easy to deploy, and capable of remote operation can help bridge this gap.

### B. *Problem Statement*

Designing a WBAN system that can manage multiple phys- iological signals while maintaining low latency, reliable com- munication, and efficient energy usage remains a significant challenge. In particular, avoiding performance degradation due to overlapping processing tasks is essential.

### C. *Contribution*

The main contributions of this work include:

- A dual-controller WBAN architecture that separates sens- ing and communication tasks
- Integration of multiple physiological sensors (ECG, EEG, EMG, and motion detection)
- A lightweight UART-based communication mechanism between processing units
- Experimental evaluation based on latency, packet delivery ratio, and power consumption

## II. Related Work

Wireless Body Area Networks (WBANs) have been widely explored as a foundation for continuous healthcare monitoring systems. Early research in this area primarily focused on the design of low-power wearable sensors and reliable short-range communication techniques. These studies established the feasi- bility of collecting physiological data directly from the human body while maintaining acceptable energy consumption.

With the integration of Internet of Things (IoT) technolo- gies, attention gradually shifted toward remote accessibility and cloud-based monitoring. Systems capable of transmitting real-time physiological data to cloud platforms made it possi- ble to observe patient conditions beyond clinical environments. In many cases, implementations concentrated on a single parameter, such as ECG for cardiac monitoring or EEG for neurological analysis. While these approaches proved effective within their specific domains, they often lacked the ability to provide a comprehensive view of patient health.

More recent work has attempted to combine multiple sensing modalities. By integrating physiological signals with motion data, these systems improve context awareness, par- ticularly in applications such as fall detection and rehabilita- tion monitoring. However, increasing the number of sensors introduces additional complexity. In several implementations, a single microcontroller is used to handle acquisition, pro- cessing, and communication simultaneously. Under continuous operation, this can lead to processing delays and reduced transmission reliability.

Energy efficiency has also been a major consideration in WBAN design. Techniques such as duty cycling and adaptive data transmission have been proposed to extend system life- time. Although these methods can reduce power consumption, they may also increase system complexity or require special- ized hardware, limiting their use in cost-sensitive applications. The adoption of WiFi-enabled microcontrollers, including ESP8266 and ESP32, has simplified cloud connectivity. De- spite this progress, many systems do not clearly separate sens- ing and communication tasks. As a result, performance may degrade when multiple data streams are handled concurrently. A comparison of representative approaches is presented in Table **??**. The table highlights common design choices and their limitations, particularly with respect to scalability and
processing efficiency.

From this overview, it can be observed that although multi- sensor monitoring has been explored, efficient task separa- tion remains insufficiently addressed in many designs. The approach presented in this work focuses on distributing sens- ing and communication responsibilities across separate units, thereby reducing processing conflicts and improving system reliability during continuous operation.

## III. Proposed Method

### A. *System Overview*

The proposed system follows a layered structure in which sensing, processing, communication, and cloud interaction

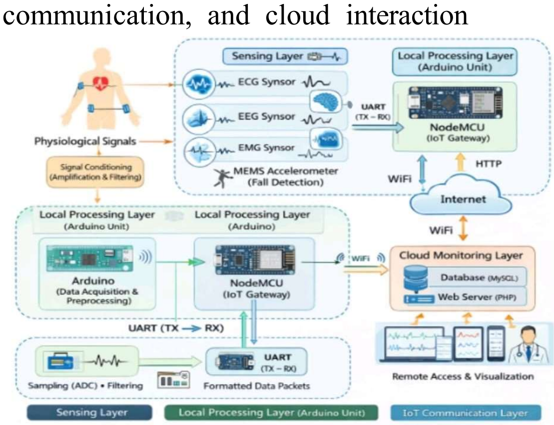


Fig. 1. Architecture of the proposed WBAN system showing sensing, processing, communication, and cloud layers

are handled in separate stages. Rather than relying on a single processing unit, the design distributes tasks across two controllers to avoid performance limitations during continuous operation.

Biomedical sensors are connected to an Arduino microcon- troller, which is responsible for acquiring and preparing phys- iological data. A NodeMCU module operates independently as a communication gateway, transmitting the processed data to a cloud server through a wireless network. This separation ensures that communication delays do not interfere with signal acquisition.

### B. Sensing Layer

The sensing layer consists of multiple wearable sensors placed on the human body to capture different physiological parameters. Each sensor provides a specific type of informa- tion:

- ECG sensor for monitoring cardiac activity
- EEG sensor for observing neural signals
- EMG sensor for detecting muscle activity
- Accelerometer for identifying motion and fall events The signals obtained from these sensors are typically low

in amplitude and may include noise due to motion or envi-
ronmental interference. Therefore, basic signal conditioning is required before further processing.

### C. Local Processing Layer

Signal acquisition and preprocessing are performed by the Arduino unit. The controller samples analog inputs using its internal analog-to-digital converter and applies simple filtering techniques to stabilize the signals.
The acquired signal can be expressed as:

$$S_i(t) = A_i(t) + N_i(t)$$

(1) where $A_i(t)$ represents the actual physiological signal and
$N_i(t)$ corresponds to noise. Although only basic filtering
is applied, it is sufficient to improve signal clarity before transmission.

After preprocessing, the data is organized into structured packets. This step ensures that the communication module can interpret and transmit the data efficiently.

### D. Communication Layer

The NodeMCU (ESP8266) is responsible for all network- related operations. It receives data from the Arduino through UART communication and establishes a WiFi connection for data transmission.

Instead of performing complex processing, the module focuses on reliable delivery of data to the cloud server. This approach reduces the overall processing burden and prevents delays that may arise when multiple tasks are handled simul- taneously.
The total system delay can be modeled as:

$$T_{total} = T_{acq} + T_{proc} + T_{tx} + T_{cloud} \quad (2)$$

where each term represents acquisition time, preprocessing delay, transmission delay, and cloud response time, respec- tively.

### E. Data Flow Description

The complete operation of the system follows a sequential flow:

1) Sensors capture physiological signals from the human body
2) The Arduino samples and preprocesses the data
3) Processed data is transmitted via UART
4) The NodeMCU uploads the data through WiFi
5) The cloud server stores and visualizes the information Since sensing and communication tasks are handled sepa-

rately, interruptions in network connectivity do not affect the
acquisition process. This improves the stability of the system during continuous monitoring.

## IV. Hardware Design and Communication Model

The implementation of the proposed system is based on a compact hardware setup that integrates sensing modules, processing units, and a wireless communication interface. The design emphasizes simplicity and modularity so that individual components can be modified or replaced without affecting the overall structure.

### A. Hardware Components

The system combines multiple biomedical sensors with two microcontroller platforms. ECG, EEG, and EMG sensors are interfaced with the Arduino, which serves as the primary data acquisition unit. An accelerometer is also included to monitor motion and detect fall events.

The Arduino reads analog signals from the sensors using its internal ADC. Since the signals are often affected by noise, basic filtering is applied before further processing. Once stabilized, the data is organized into a structured format suitable for transmission.

Fig. 2. Hardware setup of the proposed WBAN system including sensors, Arduino unit, NodeMCU module, and power supply

A NodeMCU module based on the ESP8266 chipset is used for communication. It operates independently from the Arduino and handles all wireless data transfer operations.

To ensure stable operation, a regulated power supply is used. The Arduino requires 5 V, while the NodeMCU operates at
3.3 V. Appropriate voltage regulation is therefore necessary to maintain consistent performance during continuous use.

### B. Communication Model

Data transfer between the Arduino and NodeMCU is achieved using UART serial communication. The transmission rate is set to 9600 bps, which provides a balance between speed and reliability for the given application.

Once data is received, the NodeMCU establishes a connec- tion to a WiFi network and transmits the information to a cloud server using HTTP-based requests. The communication process is designed to be lightweight so that it does not introduce unnecessary delays.

By separating sensing and communication tasks, the system avoids the performance issues commonly observed in single- controller designs. Even if network delays occur, the data acquisition process continues without interruption.

### C. Power and Performance Considerations

Power consumption is an important factor, particularly for systems intended for continuous monitoring. During testing, the system operated within a range of approximately 0.42 W to 0.6 W, depending on network activity.

The packet delivery ratio was observed to be around 98.6 Another advantage of the modular design is its flexibility.

Additional sensors or processing units can be integrated with-
out requiring major changes to the existing setup. This makes the system adaptable to different healthcare scenarios.

## V. Experimental Setup

To evaluate the proposed system, a series of controlled experiments were carried out to observe its behavior during continuous monitoring. The objective was to examine how reliably the system acquires physiological data and transmits it to the cloud under normal operating conditions.

### A. Prototype Configuration

The experimental setup consisted of biomedical sensors connected to an Arduino microcontroller, along with a NodeMCU module for wireless communication. A regulated power supply was used to provide stable voltage to both units. All components were assembled on a compact prototype platform. Particular attention was given to wiring connections and sensor placement to avoid signal inconsistencies during
operation.

### B. Testing Environment

Experiments were conducted in an indoor environment with stable WiFi connectivity operating at 2.4 GHz. The NodeMCU was placed at a distance of approximately 5 to 8 meters from the router.

The environment was selected to minimize external inter- ference so that system performance could be observed under consistent conditions. While real-world environments may introduce additional variability, this setup provides a reliable baseline for evaluation.

### C. Data Acquisition

A healthy subject was considered for testing, and data was collected over multiple sessions lasting between 10 and 15 minutes. Sensors were positioned following standard place- ment guidelines to ensure meaningful signal capture.

The sampling rates for the sensors were configured as:

- ECG: approximately 250 Hz
- EEG: approximately 250 Hz

- EMG: approximately 500 Hz
- Accelerometer: approximately 100 Hz

These values were chosen to maintain a balance between signal accuracy and processing capability.

### D. Data Transmission Procedure

During operation, the system followed a continuous se- quence of steps:

1) Sensors captured physiological signals in real time
2) The Arduino processed and formatted the data
3) Data packets were transmitted to the NodeMCU via UART
4) The NodeMCU uploaded the data to the cloud server
5) The cloud platform stored and displayed the received values

Each cycle occurred at regular intervals, enabling near real- time updates on the monitoring interface.

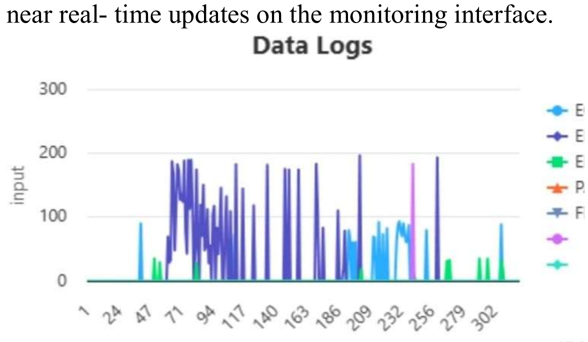


Fig. 3. Cloud-based visualization of ECG, EEG, EMG, and accelerometer signals

### E. Performance Metrics

System performance was evaluated using the following parameters:

- **Latency:** Time taken for data to travel from sensor to cloud
- **Packet Delivery Ratio (PDR):** Ratio of successfully received packets to transmitted packets
- **Power Consumption:** Average energy usage during ac- tive operation

Approximately 300 to 400 samples were collected in each session, providing sufficient data for consistent analysis.

### F. Observations

Throughout the testing process, the system operated without unexpected interruptions such as resets or communication failures. Sensor readings were captured continuously and transmitted without noticeable delay.

An important observation was that the sensing process remained stable even when minor communication delays oc- curred. This behavior reflects the advantage of separating ac- quisition and transmission tasks, allowing each unit to function independently.

## VI. Results and Discussion

The performance of the proposed WBAN system was eval- uated through continuous monitoring of physiological signals and their visualization on a cloud platform. During testing, data from all sensors was transmitted and displayed without noticeable interruption, indicating stable end-to-end operation. The ECG signal exhibited regular waveform patterns consis- tent with expected cardiac activity, suggesting reliable acqui- sition and preprocessing. EEG signals showed more irregular variations, which is typical due to the dynamic nature of neural activity. EMG readings reflected moderate fluctuations corresponding to muscle movement, while accelerometer data produced distinct peaks during sudden motion, enabling iden- tification of fall-related events.

From a system perspective, the average end-to-end latency was observed to be approximately 1.8 s. This delay remained relatively consistent across multiple test sessions. The packet delivery ratio was close to 98.6

### A. Discussion

The observed results highlight the practical advantage of separating sensing and communication tasks. In conventional single-controller designs, handling multiple sensor inputs alongside network transmission can introduce delays or data loss. In contrast, the dual-controller approach allows the Arduino to focus on signal acquisition while the NodeMCU manages data transmission independently.

Another point worth noting is the system's behavior during minor network delays. Even when transmission was temporar- ily affected, data acquisition continued without interruption. This indicates that the system is capable of maintaining stable sensing performance independently of communication conditions.

While the results obtained under controlled indoor condi- tions are encouraging, performance may vary in real-world environments. Factors such as network instability, user move- ment, and environmental noise could influence both signal quality and transmission reliability. Further evaluation under such conditions would provide a more comprehensive under- standing of system behavior.

Overall, the results demonstrate that the proposed architec- ture supports continuous multi-sensor monitoring with consis- tent performance, making it suitable for non-critical remote healthcare applications.

## VII. Conclusion

A Wireless Body Area Network-based healthcare moni- toring system has been presented, focusing on continuous acquisition and transmission of multiple physiological signals. The design integrates ECG, EEG, EMG, and accelerometer- based sensing within a dual-controller architecture.

By separating data acquisition and communication tasks, the system avoids processing conflicts commonly observed in single-controller implementations. This approach helps main- tain stable operation during continuous monitoring, even when multiple data streams are involved.

Experimental evaluation indicates that the system is capable of transmitting data with consistent latency and high reliability while operating within a modest power range. These charac- teristics make the design suitable for remote monitoring appli- cations where simplicity and energy efficiency are important considerations.

The modular structure of the system allows future exten- sions without major architectural changes. Additional sen- sors or advanced data analysis methods can be incorporated depending on application requirements. Further work may include testing under varied environmental conditions and exploring automated analysis techniques for enhanced decision support.

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