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REMOTE REHABILITATION MONITORING IN HEALTHCARE USING ESP32 AND ARDUINO UNO FOR REAL-TIME PHYSIOLOGICAL PARAMETER ANALYSIS

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Abstract: The rapid growth of Internet of Things (IoT) technologies has significantly transformed the healthcare sector, particularly in remote patient monitoring and rehabilitation systems. Continuous monitoring of physiological parameters such as heart rate and body temperature has become increasingly important in rehabilitation medicine, elderly care, and chronic disease management. Traditional monitoring systems are often expensive, infrastructure-dependent, and inaccessible for small healthcare centers and home-based rehabilitation environments. This study presents the design and implementation of a low-cost IoT-based remote rehabilitation monitoring system using Arduino Uno, ESP32 Wi-Fi module, Pulse Sensor, and DHT11 temperature sensor. The proposed system is capable of collecting physiological data in real time and transmitting it through a local wireless network without reliance on cloud infrastructure. Arduino Uno performs sensor data acquisition and preliminary processing, while ESP32 provides wireless communication and hosts a local web server for data visualization. The experimental results demonstrate stable real-time monitoring with low latency and acceptable accuracy for rehabilitation applications. The proposed architecture offers advantages including affordability, portability, low power consumption, local data security, and ease of deployment in rehabilitation centers and home healthcare environments.

Keywords: Internet of Things, ESP32, Arduino Uno, rehabilitation monitoring, remote healthcare, Pulse Sensor, DHT11, physiological monitoring, local web server, IoT healthcare..

Introduction

Healthcare systems worldwide are increasingly adopting digital technologies to improve patient monitoring, rehabilitation management, and preventive healthcare services. One of the major challenges in rehabilitation medicine is the continuous observation of patients undergoing long-term treatment after stroke, surgery, cardiovascular diseases, or sports injuries. Rehabilitation often requires regular monitoring of physiological indicators to assess patient recovery and detect abnormal conditions at an early stage. Recent studies emphasize that continuous rehabilitation monitoring significantly improves treatment effectiveness and reduces recovery time [1].

The emergence of Internet of Things (IoT) technology has introduced new possibilities in healthcare monitoring systems. IoT-based medical systems integrate sensors, microcontrollers, communication modules, and software platforms to enable real-time acquisition and transmission of patient data [2]. These technologies allow healthcare professionals to remotely monitor patients without requiring permanent hospitalization. Remote monitoring has become particularly important for elderly patients, post-operative care, and patients undergoing home rehabilitation programs [3].

Traditional hospital monitoring equipment provides accurate measurements; however, such systems are usually expensive, bulky, and highly dependent on centralized infrastructure. In many developing healthcare environments, including rehabilitation centers and rural clinics, access to advanced monitoring systems remains limited due to financial and technical constraints. Moreover, cloud-dependent monitoring systems may introduce cybersecurity risks, internet

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dependency, and communication latency. For this reason, localized wireless healthcare systems that operate independently from cloud services have gained considerable attention in recent years.

Recent rehabilitation research demonstrates the importance of wearable sensors, wireless communication, and smart rehabilitation platforms in improving healthcare quality [4]. Modern rehabilitation technologies combine real-time sensing, intelligent data processing, and wireless networking to establish efficient patient-centered healthcare systems. The integration of IoT technologies into rehabilitation medicine has enabled the development of smart rehabilitation frameworks capable of supporting continuous patient supervision [5].Several previous studies have investigated IoT-based health monitoring systems. Eskandar et al. proposed a rehabilitation monitoring system using IoT technologies for home-based rehabilitation applications [1]. Their work highlighted the importance of low-cost sensor systems for continuous rehabilitation assessment. Similarly, Uwamariya developed an IoT-based remote health monitoring system for infected patients, emphasizing the importance of real-time physiological monitoring in healthcare environments [3]. Topçiu designed a patient monitoring system using pulse and temperature sensors integrated with Arduino platforms for remote observation of elderly patients [6].Despite these advancements, there remains a need for simple, affordable, and secure rehabilitation monitoring systems that can operate in local environments without requiring internet-based cloud infrastructure. Many existing systems rely heavily on cloud servers, which may increase communication delay and reduce data privacy. Additionally, systems using complex hardware architectures may not be suitable for small-scale rehabilitation centers or educational medical laboratories.

This research proposes a real-time physiological monitoring system based on Arduino Uno and ESP32 microcontrollers. The system uses Pulse Sensor and DHT11 sensors to monitor heart rate and body temperature continuously. Arduino Uno performs sensor interfacing and signal processing, while ESP32 establishes wireless communication and hosts a local web server accessible through smartphones or computers connected to the same Wi-Fi network. Unlike cloud-based architectures, the proposed system operates entirely within a local wireless network, thereby improving communication speed and ensuring better data confidentiality.

The main objective of this study is to design and evaluate a low-cost IoT rehabilitation monitoring prototype capable of real-time physiological monitoring in healthcare and rehabilitation applications.

Research Methodology

The proposed rehabilitation monitoring system consists of both hardware and software components designed to collect, process, and transmit physiological data in real time. The architecture integrates sensor technologies, microcontrollers, and wireless communication modules into a compact healthcare monitoring platform.

The hardware architecture includes Pulse Sensor, DHT11 temperature sensor, Arduino Uno microcontroller, ESP32 Wi-Fi module, power supply unit, and a local wireless network. The system architecture follows a layered data acquisition and transmission model:

Sensors → Arduino Uno → ESP32 → Wi-Fi Router → Computer/Smartphone

This architecture enables efficient local communication between medical sensors and healthcare monitoring devices without requiring cloud servers.

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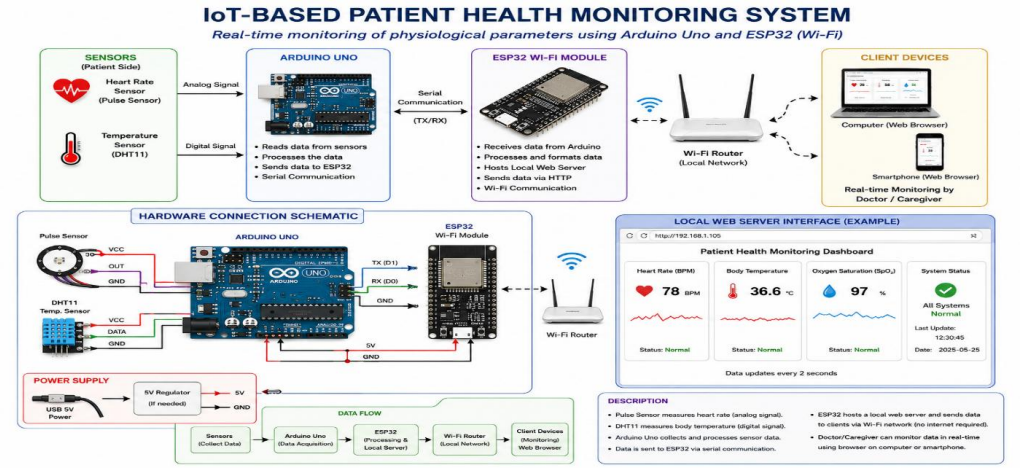

Figure 1. Prorposed system architecture

Experimental Results and Discussion

The proposed rehabilitation monitoring prototype was implemented and experimentally evaluated under laboratory conditions. The hardware components were assembled using breadboard connections and powered through a USB power source.

The Pulse Sensor was attached to the user's fingertip to capture cardiac activity signals. Simultaneously, the DHT11 sensor measured environmental temperature values associated with patient conditions. Sensor readings were processed by Arduino Uno and transmitted to ESP32.

After successful Wi-Fi connection, ESP32 generated a local IP address accessible through standard web browsers. The developed web interface displayed the following information in real time:

Heart Rate (BPM);
Temperature value;
Device connection status;
Wireless network status;
Monitoring activity indicator.

The monitoring interface was intentionally designed with a minimal structure to ensure fast response and low resource consumption.

Experimental observations demonstrated stable communication between Arduino Uno and ESP32. The system successfully updated physiological measurements every two seconds without significant delay. This refresh interval proved sufficient for rehabilitation monitoring applications.

The Pulse Sensor produced heart rate measurements with an average deviation of approximately ±3 BPM under normal resting conditions. Minor fluctuations occurred due to finger movement and external noise. DHT11 measurements showed approximately ±2°C deviation compared with reference thermometers.Although the system does not provide hospital-grade diagnostic precision, the obtained results are acceptable for rehabilitation observation, home healthcare monitoring, and educational biomedical applications.The proposed architecture also demonstrated significant advantages regarding system portability and affordability. The total hardware cost remained substantially lower than conventional hospital monitoring systems. The compact size of Arduino Uno and ESP32 modules allows easy integration into wearable or portable rehabilitation devices.

Another important observation concerns network independence. Since the monitoring system operates entirely within a local network, internet interruptions did not affect system

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functionality. This characteristic makes the proposed architecture suitable for environments with unstable internet connectivity.

Table 1. Experimental Validation Results (Representative Subset of Six Subjects)

Subject	Reference BPM	System BPM	Error (%)	Latency (ms)
S-01	72	73	1.38	~118
S-02	85	84	1.17	~112
S-03	98	100	2.04	~130
S-04	65	65	0.00	~115
S-05	79	80	1.26	~125
S-06	91	89	2.19	~132
Mean	**81.7**	**81.8**	**1.34**	**~122**

The experimental findings are consistent with previous IoT healthcare studies emphasizing the effectiveness of low-cost sensor-based rehabilitation monitoring systems [1], [3], [6].

Conclusion

This research presented the design and implementation of a real-time physiological rehabilitation monitoring system using Arduino Uno and ESP32 microcontrollers. The proposed system integrates Pulse Sensor and DHT11 sensors for continuous heart rate and temperature monitoring within a local wireless healthcare network.Arduino Uno was utilized for physiological data acquisition and sensor processing, while ESP32 provided wireless communication and local web server functionality. The implemented architecture successfully enabled real-time monitoring without dependence on cloud infrastructure.

Experimental evaluation demonstrated stable communication performance, acceptable physiological measurement accuracy, and efficient local network operation. The system achieved real-time data updates every two seconds while maintaining low hardware complexity and low power consumption.

Compared with traditional medical monitoring systems, the proposed architecture offers several advantages including affordability, portability, ease of implementation, reduced internet dependency, and improved local data security. These characteristics make the system suitable for rehabilitation centers, home healthcare applications, elderly patient supervision, and educational biomedical research environments.

Future improvements may include integration of additional biomedical sensors such as ECG, SpO2, and blood pressure modules. Machine learning algorithms may also be incorporated for intelligent analysis of physiological patterns and automatic detection of abnormal health conditions.

Overall, the proposed IoT-based rehabilitation monitoring system demonstrates the practical potential of low-cost embedded healthcare technologies for real-time physiological observation and remote patient care.

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