ICU Connect: IoT-Enabled Remote ICU Patient Monitoring System

D. Sathish[1], Mekali Anusha[1], Thummala Sindhu[1], Ghanapuram Ganesh[1], Mende Chethan[1], Y. Tharun Yadav[1]
[1]Department of Electronics and Communication Engineering, [1]Sree Dattha Institute of Engineering and Science, Sheriguda, Ibrahimpatnam, 501510, Telangana, India.

ABSTRACT
Continuous monitoring of patient health, especially in intensive care environments such as the Intensive Care Unit (ICU), is essential for timely diagnosis and effective medical intervention. Traditional healthcare systems rely on manual observation and periodic measurements, which can delay the detection of critical changes in patient conditions. These methods lack real-time tracking, remote accessibility, and automated alert mechanisms, increasing the risk of complications. Therefore, there is a growing need for a smart and connected healthcare solution that enables continuous and accurate monitoring. The proposed system introduces a wearable health monitoring network based on the Internet of Things (IoT). It utilizes wearable sensors to measure key physiological parameters such as heart rate, body temperature, and movement, which are processed using an Arduino microcontroller (open-source embedded system platform). The collected data is transmitted via the ESP8266 Wi-Fi module (Wireless Fidelity communication module) to an IoT cloud platform for storage, processing, and visualization. A smart IoT gateway is also implemented to support local processing, web server functionality, and cloud integration. The system continuously analyzes patient data and generates alerts when abnormal conditions are detected, ensuring immediate notification to authorized personnel. Additionally, Machine Learning (ML) techniques are incorporated to improve prediction accuracy and health assessment. The wearable and portable design allows patients to be monitored remotely from anywhere in the world. Overall, the system provides a reliable, real-time, and cost-effective solution that enhances patient safety and supports modern smart healthcare applications.

Keywords: Internet of Things (IoT), Intensive Care Unit (ICU), Arduino Microcontroller, ESP8266 Wi-Fi Module, Machine Learning (ML), Remote Patient Monitoring, Vital Sign Monitoring.

1. INTRODUCTION

The healthcare domain is experiencing a significant shift due to the rapid adoption of advanced digital technologies that enhance the delivery and management of medical services. Modern solutions such as electronic health systems and mobile-based healthcare applications are enabling continuous interaction between patients and healthcare providers, improving accessibility and responsiveness. These technologies support real-time communication, including alert mechanisms that notify caregivers or family members during emergencies, thereby reducing delays in medical attention. The integration of information and communication technologies into healthcare has created a connected ecosystem where patient data can be collected, shared, and analyzed efficiently, leading to better clinical outcomes and improved patient engagement.

A major challenge in the current healthcare landscape is the increasing demand for continuous monitoring due to the rising global population, ageing societies, and the growing incidence of chronic diseases such as diabetes, cardiovascular conditions, and obesity. Traditional healthcare systems are often limited by periodic monitoring and dependency on hospital visits, which may delay diagnosis and treatment. To overcome these limitations, wearable sensor networks have been introduced as an effective solution for real-time health monitoring. These systems consist of multiple sensors placed on the human body to measure vital physiological parameters such as heart rate, body temperature, blood pressure, and activity levels. The collected data is transmitted through wireless communication technologies to centralized platforms where it can be analyzed and interpreted. This enables early detection of abnormalities and supports timely medical intervention without requiring constant physical supervision. In addition, rapid urbanization and increasing pressure on healthcare infrastructure have further highlighted the need for scalable and efficient monitoring solutions. Remote healthcare systems based on cloud computing allow continuous storage, processing, and visualization of patient data, making it accessible from any location. These platforms can integrate intelligent algorithms to analyze large volumes of data, identify patterns, and assist in predictive healthcare. The combination of wearable devices, wireless networks, and cloud-based analytics provides a cost-effective and reliable approach to healthcare delivery. It reduces the burden on hospitals, minimizes operational costs, and enhances the overall quality of care. Ultimately, this technological convergence supports a proactive healthcare model that focuses on prevention, early diagnosis, and continuous patient monitoring, contributing to a more sustainable and efficient healthcare system.

2. RELATED WORK

2.1 IoT-Based Remote Patient Monitoring Systems

The integration of IoT into healthcare has enabled continuous and remote monitoring of patient conditions by connecting sensors, processing units, and cloud platforms into a unified system. Lee, et al. [2] proposed an early web-enabled monitoring framework that allows physiological data to be transmitted and accessed through internet-based interfaces, enabling doctors to analyze patient conditions without physical interaction. This approach significantly improves accessibility and reduces geographical barriers, especially for patients in remote areas. Further advancements are seen in the work of Ani, et al. [5], where IoT systems are combined with machine learning techniques to not only monitor but also predict health conditions based on real-time data. These systems support data storage, visualization, and remote consultation, forming the foundation for modern smart healthcare environments. However, challenges such as network dependency, latency, and limited emergency handling capabilities still affect their reliability in critical situations.

2.2 Wearable Sensor-Based Health Monitoring Systems

Wearable health monitoring systems have become a key component in personalized healthcare by enabling continuous tracking of vital parameters through compact and portable devices. Fezari, et al. [1] developed a microcontroller-based system for real-time heart rate monitoring, demonstrating the feasibility of low-cost embedded solutions in healthcare. Similarly, Mamidi, et al. [3] introduced a system capable of detecting abnormal pulse patterns and triggering alerts for potential cardiac events. These systems allow patients to move freely while being continuously monitored, making them highly suitable for elderly individuals and patients with chronic diseases. The collected physiological data can be used for early diagnosis and preventive care. Despite their benefits, issues such as limited battery life, sensor calibration, and user adaptability pose challenges for long-term deployment and widespread adoption.

2.3 Wireless Communication and Emergency Alert Systems

Wireless technologies play a crucial role in enabling seamless communication between patients and healthcare providers. Aref, et al. [6] designed a wireless nurse call system that allows patients to send alerts directly to medical staff, improving response time and patient safety in healthcare facilities. In another approach, D'Souza, et al. [7] developed a remote ECG monitoring system that uses wireless communication to transmit cardiac data for real-time analysis. These systems ensure that critical health information is delivered promptly, enabling quick medical intervention during emergencies. The inclusion of alert mechanisms such as SMS notifications or automated warnings further enhances system effectiveness. However, reliability issues such as signal interference, communication delays, and dependency on network infrastructure remain significant concerns.

2.4 IoT Integration with Smart Healthcare Technologies

The combination of IoT with advanced computing technologies has led to the development of intelligent healthcare systems capable of continuous monitoring and data-driven decision-making. Baker, et al. [4] provided a detailed overview of IoT-based healthcare architectures, emphasizing the role of interconnected devices, cloud platforms, and data analytics in modern medical systems. These systems enable real-time data collection, processing, and visualization, allowing healthcare providers to make informed decisions quickly. The integration of cloud computing further enhances scalability and accessibility, enabling large-scale deployment of monitoring systems. However, the increased use of interconnected devices introduces challenges related to data privacy, system interoperability, and standardization, which must be addressed for effective implementation.

2.5 Limitations and Research Challenges in Existing Systems

Although significant progress has been made in the development of smart healthcare monitoring systems, several limitations still persist across existing approaches. Many systems rely heavily on continuous internet connectivity, making them unsuitable for areas with limited network access. Data security and privacy remain critical concerns, particularly when sensitive patient information is stored and transmitted through cloud platforms. Additionally, the integration of multiple sensors and communication modules increases power consumption, affecting the efficiency of wearable devices. Most systems also lack advanced real-time decision-making capabilities and fail to provide a fully autonomous solution. These challenges highlight the need for more efficient, secure, and scalable healthcare monitoring systems that can operate reliably under diverse conditions while minimizing resource consumption.

3. PROPOSED SYSTEM

The system architecture is designed as an integrated IoT (Internet of Things)-based health monitoring framework that combines multi-sensor data acquisition, embedded processing, real-time visualization, alert generation, and cloud communication into a continuous operational pipeline. During initialization, the microcontroller unit (MCU) configures all peripheral components, including the LCD (Liquid Crystal Display) for user interaction, buzzer for alert signaling, vibration sensor for motion detection, and communication interfaces, while also establishing serial communication protocols for stable data transfer. The WiFi (Wireless Fidelity) module is initialized using AT (Attention) command sequences to authenticate with the network and create a TCP (Transmission Control Protocol) connection with the remote server, enabling reliable data exchange. Once connectivity is established, the system enters a continuous loop where it simultaneously acquires environmental and physiological parameters, including temperature and humidity from the DHT11 sensor, and heart rate along with SpO_2 (Peripheral Capillary Oxygen Saturation) values from the MAX30105 pulse sensor, which operates based on PPG (Photoplethysmography) signal acquisition.

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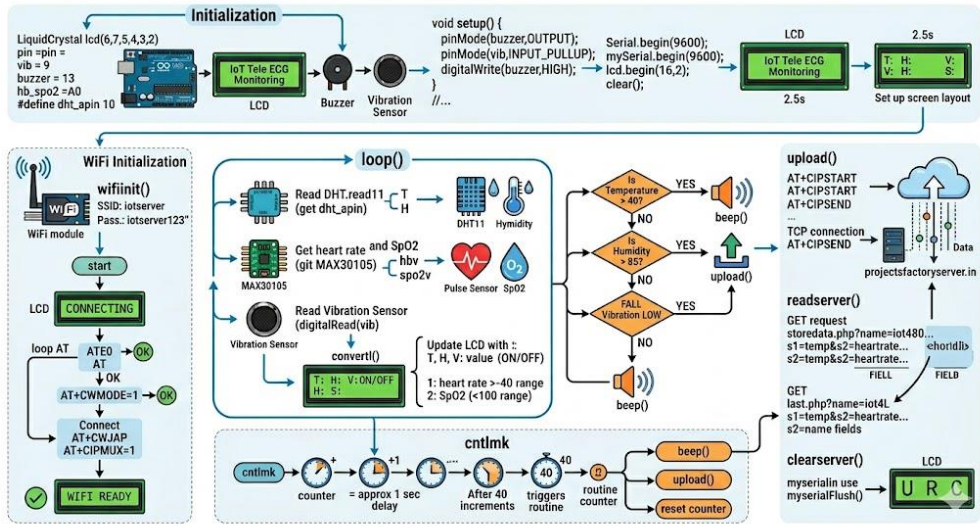

Fig. 1: Proposed system architecture

In parallel, the vibration sensor monitors sudden movements or fall conditions, ensuring event-based detection. The raw sensor data is processed and converted into calibrated values, which are then displayed on the LCD for real-time monitoring. A rule-based decision mechanism evaluates these parameters against predefined threshold values to detect abnormal conditions such as high temperature, excessive humidity, irregular heart rate, low SpO_2 levels, or abnormal vibration patterns, and upon detection, the system activates the buzzer to generate immediate alerts. Additionally, a timing control mechanism regulates periodic data transmission by maintaining counters and executing upload routines after fixed intervals, ensuring efficient and consistent communication. The processed data is formatted into structured fields and transmitted to a cloud server through TCP-based communication, allowing remote monitoring, storage, and retrieval using GET and SEND operations. Buffer clearing and counter reset mechanisms are also incorporated to maintain system stability and prevent data redundancy during long-term operation. As illustrated in Fig. 1, this architecture ensures seamless integration of sensing, processing, communication, and alerting modules, enabling a robust, real-time, and scalable remote health monitoring system.

4. RESULT AND DISCUSSION

The Results and Discussion section presents the performance evaluation and experimental outcomes of the proposed ESP32-based biometric monitoring and tracking system. Various hardware modules, including the fingerprint sensor, GPS module, LCD display, and communication components, were successfully integrated and tested under real-time operating conditions. The obtained results demonstrate the system's ability to accurately perform user authentication, location tracking, and status monitoring with minimal delay. Experimental observations confirm the reliability and effectiveness of the developed prototype in providing secure and continuous monitoring. Furthermore, the discussion highlights the system's operational efficiency, practical applicability, and overall performance in real-world scenarios.

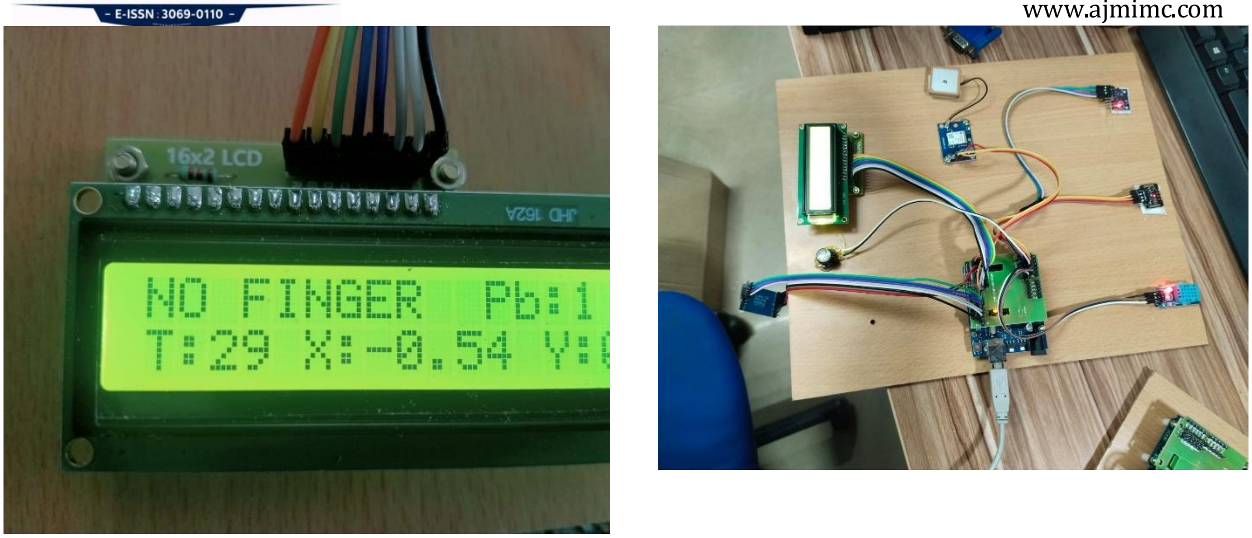

Fig. 2. Experimental setup and LCD output of the ESP32-Based biometric monitoring and tracking system

Fig. 2 presents the developed ESP32-based biometric monitoring and tracking system along with its real-time LCD output. The hardware setup integrates an ESP32 microcontroller, GPS module, fingerprint sensing interface, environmental sensing modules, buzzer, and a 16×2 LCD display to perform authentication, sensing, and location-tracking functions. The ESP32 serves as the central controller, facilitating data acquisition, processing, and communication among all connected peripherals. The LCD screen displays real-time authentication status, sensor readings, and system information, as illustrated by the "NO FINGER" message when no fingerprint is detected. The integrated prototype demonstrates the effective implementation of an IoT-enabled embedded platform capable of user authentication, environmental monitoring, alert generation, and location-based tracking in real-time applications.

5. CONCLUSION

An IoT-based telehealth system has been developed using an ESP32 controller by integrating multiple input sensors such as temperature, humidity, motion/position, heart rate, and oxygen level monitoring modules. The system also includes output components like an LCD display and buzzer for real-time feedback and alerts. All collected physiological data is processed and transmitted wirelessly to an IoT platform for remote monitoring and storage. The system continuously analyzes the received data and generates alerts when abnormal conditions are detected. It enables effective tracking of patient health parameters such as pulse rate, body temperature, and movement status. This approach improves remote healthcare monitoring and reduces the need for constant manual supervision. Future enhancements may include the integration of additional sensors such as a glucometer and body fat measurement devices to further extend system capabilities.

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