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Real-Time Health State Assessment Using ESP-32 Enabled IoT Architecture with Integrated Sensor Fusion and Alert Mechanisms

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ABSTRACT
This research introduced an Internet of Things (IoT)-based health assistance system designed to enable continuous and real-time monitoring of essential physiological parameters. The system integrated multiple sensors, including Digital Temperature and Humidity Sensor (DHT11) for measuring temperature and humidity, a Pulse Oximeter (SpO2 – Peripheral Capillary Oxygen Saturation) sensor for monitoring blood oxygen levels, and Micro-Electro-Mechanical Systems (MEMS) sensors for motion detection, ensuring comprehensive health monitoring. All sensor data was processed and managed by the Espressif Systems Microcontroller (ESP-32), which acted as the central control unit for data acquisition, processing, and transmission. A touch-enabled Graphical Liquid Crystal Display (GLCD) interface was incorporated to present real-time health readings in an intuitive and user-friendly manner. Additionally, a buzzer-based alert mechanism was implemented to notify users in case of abnormal readings, enabling timely medical intervention. The system utilized IoT connectivity to transmit collected data to cloud platforms, facilitating remote monitoring and analysis by healthcare professionals. A regulated power supply ensured stable and reliable system operation, while efficient software integration supported seamless data handling and visualization. By combining real-time sensing, cloud-based monitoring, and intelligent alert mechanisms, the system provided a scalable, efficient, and accessible healthcare solution that enhances patient safety and enables proactive health management.

Key words: Internet of Things (IoT), Health Monitoring System, Buzzer Alert System, Embedded Systems, Data Acquisition, Healthcare Automation

1. INTRODUCTION

In the contemporary era of rapid digital transformation, the healthcare sector has increasingly adopted intelligent monitoring solutions to address the growing demand for continuous, accurate, and remote patient care. The rising incidence of chronic diseases, aging populations, and the need for early diagnosis have driven the development of advanced systems that can operate autonomously while delivering real-time health insights. In response to these challenges, an IoT-based Health Assist system was designed to provide a comprehensive, reliable, and scalable platform for monitoring essential physiological parameters. This system integrated Internet of Things (IoT) technology with embedded systems and smart sensing components to enable continuous data acquisition, processing, and remote accessibility, thereby shifting healthcare from a reactive model to a proactive and preventive approach.

The architecture of the system incorporated multiple sensors to ensure multidimensional monitoring of patient health. A Digital Temperature and Humidity Sensor (DHT11) was utilized to measure body temperature and surrounding environmental conditions, while a Pulse Oximeter (SpO2 – Peripheral Capillary Oxygen Saturation) sensor continuously tracked blood oxygen levels, which are critical indicators of respiratory and cardiovascular health. Additionally, a Micro-Electro-Mechanical System (MEMS) sensor was integrated to detect motion and physical activity, which is particularly useful for monitoring elderly or immobilized patients and identifying abnormal movement patterns such as falls. These sensors generated continuous streams of data that were processed by the ESP-

32 microcontroller, chosen for its high computational efficiency, low power consumption, and integrated wireless communication capabilities including Wi-Fi and Bluetooth, enabling seamless data transmission.

To enhance user interaction and accessibility, the system featured a touchscreen-enabled Graphical Liquid Crystal Display (GLCD) that provided a clear and intuitive interface for displaying real-time health parameters. This interface allowed users and caregivers to easily monitor patient status and interact with the system without requiring advanced technical knowledge. The IoT-enabled communication module facilitated the transmission of collected data to cloud-based platforms, allowing healthcare professionals and family members to remotely monitor patient conditions, analyze trends, and make informed decisions. This feature was particularly beneficial in remote or underserved regions, as well as in scenarios requiring minimal physical contact, such as during infectious disease outbreaks.

An important safety component of the system was the integration of a buzzer-based alert mechanism, which was programmed to trigger immediate notifications when any monitored parameter exceeded predefined threshold values. This ensured rapid awareness of critical conditions such as elevated temperature, reduced oxygen saturation, or abnormal movement, enabling timely medical intervention. Furthermore, a regulated power supply unit was incorporated to ensure stable and uninterrupted operation of the system, preventing failures that could compromise patient safety. The software architecture was carefully designed to handle real-time data processing, sensor integration, display management, and cloud communication with minimal latency and high reliability. It also supported scalability, allowing future integration of additional sensors, advanced analytics, or Artificial Intelligence (AI)-based predictive modules. The system demonstrated a robust and efficient approach to modern healthcare monitoring by combining real-time sensing, intelligent data processing, and remote accessibility. It not only improved patient safety and early detection of health abnormalities but also enhanced the overall quality of healthcare delivery. The system highlighted the potential of integrating IoT and embedded technologies to create cost-effective, user-friendly, and scalable healthcare solutions capable of addressing real-world medical challenges.

2. LITERATURE SURVEY

D. Antony Pradeesh, et al. [1] developed an IoT-enabled smart health monitoring system that integrated DL models such as LSTM and GRU to perform real-time anomaly detection and predictive health risk analysis. Their system focused on continuously collecting physiological data from sensors and processing it using sequential DL models capable of capturing temporal dependencies in health signals. The incorporation of LoRa technology enabled efficient long-range and low-power communication, making the system suitable for remote and rural healthcare applications. Their approach demonstrated improved capability in identifying abnormal health patterns at an early stage, thereby supporting proactive medical intervention and reducing the risk of severe health conditions. K. Qi, et al. [2] proposed a secure IoT-based healthcare monitoring framework that utilized multilayer ML algorithms for accurate diagnosis and health condition classification. Their system incorporated ANN models to analyze patient data and achieved high diagnostic accuracy. A key contribution of their work was the integration of lightweight encryption mechanisms to ensure data privacy and secure transmission across IoT networks. The framework addressed critical challenges related to data security, making it suitable for real-world healthcare applications where confidentiality and integrity of patient information are essential. M. Hassan, et al. [3] designed an IoT-based smart health monitoring system aimed at continuously tracking vital signs such as heart rate and body temperature. Their system emphasized real-time data acquisition and visualization, enabling healthcare providers to monitor patient conditions remotely. The design included a user-friendly interface to improve accessibility for both patients and medical staff. Their approach enhanced healthcare service efficiency by reducing manual monitoring efforts and enabling timely decision-making based on continuously updated health data. N. M. Ghazaly, et al. [4] implemented an IoT-based health monitoring system that combined wearable sensor technology with ML techniques for anomaly detection. Their system was capable of collecting real-time physiological data and analyzing it to identify irregular patterns indicative of potential health issues. The study focused on ensuring secure data storage and efficient processing, enabling reliable long-term monitoring. Their approach supported proactive healthcare by enabling early detection of abnormalities and assisting healthcare professionals in making informed decisions.

M. Z. Rahman, et al. [5] developed an intelligent IoT-based healthcare system using fuzzy logic to monitor cardiac arrhythmia conditions. Their system analyzed patient health data to identify irregular heart patterns and provided timely alerts for critical conditions. The integration of fuzzy logic allowed the system to handle uncertainty and imprecision in medical data effectively, improving diagnostic accuracy. Their approach contributed to reducing mortality risks by enabling early detection and continuous monitoring of cardiac-related health issues. A. A. Mamun, et al. [6] proposed a scalable IoT-based health monitoring system that integrated multiple sensors for comprehensive tracking of patient health parameters. Their system focused on flexibility and adaptability, allowing it to be deployed across various healthcare environments, including hospitals and home care settings. The design emphasized efficient data processing, real-time monitoring, and ease of use, ensuring accessibility for a wide range of users. Their approach demonstrated the importance of scalable architectures in handling large volumes of health data while maintaining system performance and reliability. M. M. Jaber, et al. [7] developed a remote health monitoring system that integrated IoT-based wearable devices with convolutional neural networks and metaheuristic optimization techniques. Their system focused on accurately analyzing patient health data collected from wearable sensors and predicting health conditions in real time. By combining deep learning with optimization algorithms, their approach improved prediction accuracy and enhanced the reliability of remote patient monitoring, making it suitable for managing large-scale healthcare data. V. Kamalkumar, et al. [8] designed an IoT-based health monitoring system that incorporated GSM communication modules and display units for real-time visualization of patient data. Their system emphasized emergency response by integrating an alert mechanism that transmitted notifications through SMS when abnormal health conditions were detected. This approach ensured timely assistance during critical situations and highlighted the importance of communication technologies in healthcare monitoring systems. H. S., et al. [9] proposed an IoT-based monitoring system that utilized non-invasive sensors to continuously track patient health parameters. Their system enabled real-time data transmission to cloud platforms, allowing healthcare professionals to monitor patients remotely without physical presence. The study focused on improving accessibility and reducing the burden on healthcare infrastructure by enabling continuous and automated patient observation.

A. Kishor, et al. [10] developed a Healthcare 4.0 monitoring system by integrating Artificial Intelligence (AI) with IoT technologies to enable intelligent health analysis. Their system utilized predictive analytics to identify potential health risks at an early stage and provided data-driven insights for healthcare decision-making. The integration of AI enhanced the system's capability to analyze complex health data and improved the overall efficiency of patient monitoring. Z. Chen, et al. [11] designed an IoT and mobile application-based healthcare monitoring system aimed at early detection and prevention of diseases. Their approach focused on real-time data collection and analysis through connected devices, enabling timely intervention and reducing the spread of infectious diseases. The system also improved accessibility by allowing users and healthcare providers to monitor health conditions through mobile platforms. S. Jeong, et al. [12] proposed a secure healthcare monitoring framework by integrating blockchain technology with IoT systems. Their approach ensured data integrity, privacy, and secure storage of patient information by utilizing decentralized ledger mechanisms. This integration enhanced trust in digital healthcare systems and addressed critical challenges related to data security and unauthorized access in IoT-based health monitoring environments. P. Kaur, et al. [13] developed an IoT-based healthcare monitoring system that incorporated Random Forest algorithms for accurate classification and analysis of patient health data. Their system focused on processing data collected from sensors to identify patterns and classify health conditions effectively. The use of ensemble learning techniques improved prediction accuracy and supported better clinical decision-making by providing reliable insights into patient health status. A. D. Acharya, et al. [14] proposed a portable IoT-based healthcare monitoring kit designed to measure essential physiological parameters such as body temperature and heart rate. Their system emphasized affordability, simplicity, and ease of use, making it suitable for deployment in remote and resource-constrained environments. The design enabled continuous monitoring and provided basic healthcare support where access to advanced medical infrastructure was limited. M. Krichen, et al. [15] conducted a comprehensive study on verification and validation techniques for IoT systems, focusing on ensuring reliability and security in healthcare applications. Their work highlighted the importance of systematically testing IoT-based systems to prevent failures and ensure accurate data transmission. The study provided guidelines for designing robust and dependable healthcare monitoring solutions by addressing challenges related to system correctness, performance, and data integrity.

3. PROPOSED SYSTEMS

The proposed system architecture represents a multifaceted IoT solution designed to bridge the gap between real-time health monitoring and environmental sensing through high-performance embedded systems. Central to this framework is the ESP-32 microcontroller, which provides the necessary computational power and wireless connectivity required for a modern healthcare application. This architecture, as depicted in the detailed schematic of **Fig 4.1**, operates on a modular principle where sensors and output devices are treated as independent nodes managed by a central logic unit. By integrating an SpO2 sensor for blood oxygen tracking, a DHT11 for atmospheric conditions, and a MEMS sensor for motion detection, the system creates a comprehensive profile of the user's status. The software layer within the microcontroller is optimized to handle concurrent data processing, ensuring that latency is minimized during critical events such as heart rate spikes or sudden falls. This design also emphasizes power efficiency, utilizing regulated power distribution to maintain the longevity of sensitive electronic components during continuous operation. Furthermore, the inclusion of both local feedback via LCD and remote logging via IoT cloud platforms ensures a redundant safety net for the user. This dual-pathway communication is essential for medical scenarios where immediate local alerts must be backed up by historical data logs for clinical review. The synergy between hardware and embedded software allows for a scalable architecture that can be adapted for various wearable or stationary monitoring needs. Beyond simple monitoring, the system acts as a reliable data aggregator that filters noise and prioritizes critical medical information for transmission.

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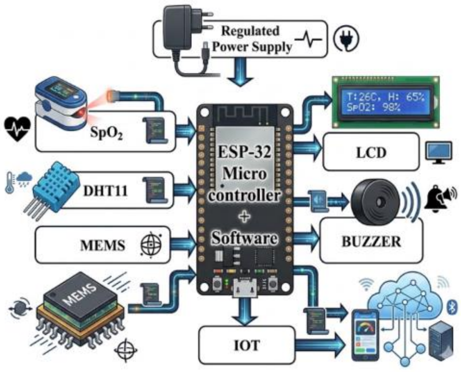

Fig. 1: Proposed System Architecture

This comprehensive approach ensures that all physiological variables are accurately recorded while maintaining a high degree of system uptime and responsiveness. By leveraging the dual-core architecture of the ESP-32, the system handles sensor polling on one core while managing Wi-Fi stack operations on the other, preventing data loss. Ultimately, the framework serves as a robust gateway that transforms raw analog and digital inputs into meaningful health metrics and actionable environmental alerts.

4. CONCLUSION

In summary, the proposed AI-driven smart health monitoring and automated medicine dispensing system provided a comprehensive solution for managing continuous healthcare, particularly for elderly individuals and patients with chronic conditions. The system integrated sensor-based monitoring of vital parameters with automated drug delivery and IoT-enabled data transmission, ensuring accurate medication schedules, early identification of health issues, and instant notifications to caregivers and medical professionals. The use of the ESP-32 microcontroller, combined with cloud-based communication and user-friendly interfaces such as LCD displays and alert mechanisms, improved system efficiency and ease of use. By minimizing the need for frequent hospital visits and enabling remote supervision, the system supported better self-management of health, enhanced patient safety, and contributed to improved accessibility and overall quality of healthcare services.

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