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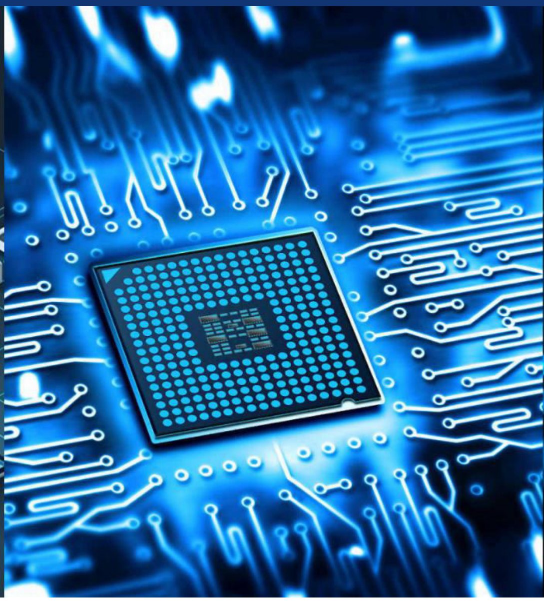

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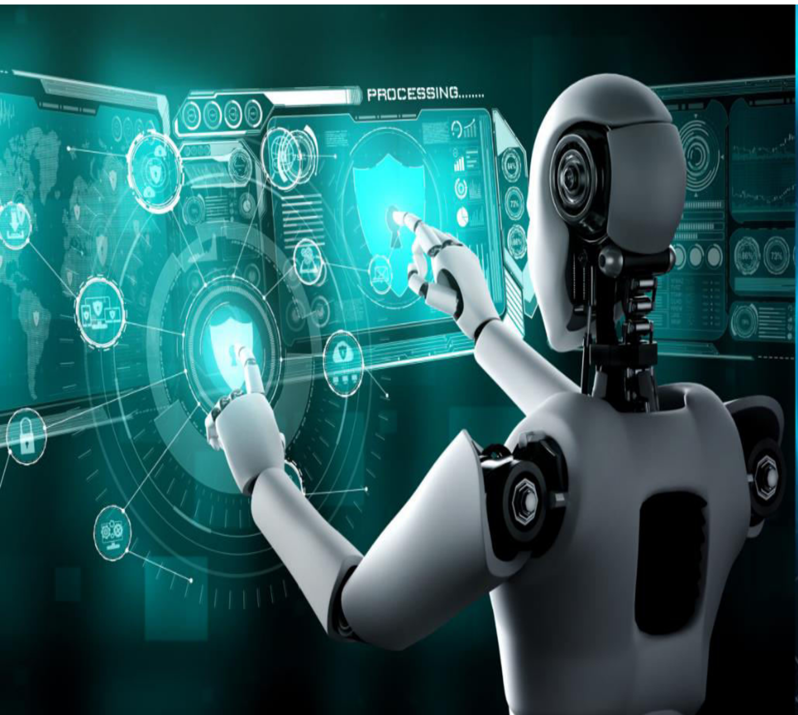

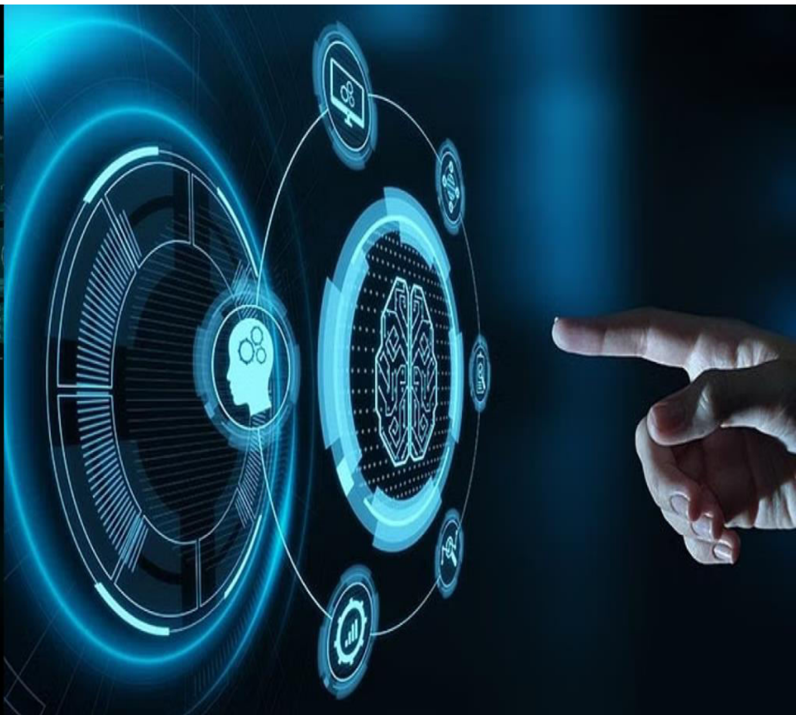

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Multi-Organ Failure Detection System Using Biomedical Signals and Machine Learning

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ABSTRACT: Multi-Organ Failure (MOF) is a severe and life-threatening medical condition characterized by the simultaneous or sequential failure of multiple organ systems, requiring immediate and continuous monitoring for effective diagnosis and treatment; therefore, early detection plays a crucial role in reducing mortality rates and improving patient outcomes. To address this challenge, the proposed system presents a portable, cost-effective, and intelligent healthcare monitoring solution that integrates biomedical signal acquisition, machine learning, and Internet of Things (IoT) technologies into a unified framework. The system continuously collects physiological signals such as Electrocardiogram (ECG) for monitoring cardiac activity, Electromyography (EMG) for assessing muscle function, Electroencephalography (EEG) for analyzing brain activity, Electrooculography (EOG) for tracking eye movements and neurological responses, and Photoplethysmography (PPG) for measuring blood volume changes and oxygen saturation levels, thereby providing a comprehensive view of multiple organ functions. These signals are captured using appropriate sensors and processed by the ESP32 microcontroller, which is selected for its low power consumption, high processing capability, and built-in wireless communication features such as Wi-Fi and Bluetooth. The ESP32 performs essential tasks including signal conditioning, noise filtering, amplification, analog-to-digital conversion, feature extraction, and real-time data analysis to convert raw sensor inputs into meaningful physiological parameters. Furthermore, advanced machine learning algorithms are implemented to analyze patterns within the extracted features and classify the patient's condition as normal or abnormal, enabling intelligent decision-making and reducing the dependency on constant human supervision. The integration of IoT technology allows seamless transmission of processed data to a cloud-based platform, where it is stored, analyzed, and visualized through an interactive dashboard accessible to healthcare professionals from remote locations. This remote monitoring capability is further enhanced with automated alert mechanisms that generate notifications or alarms when abnormal conditions are detected, ensuring timely medical intervention. In addition, the system is designed to be scalable, user-friendly, and suitable for both hospital and home-care environments, making it highly beneficial in rural and resource-limited settings where access to advanced medical facilities is limited. Overall, the proposed solution significantly improves early diagnosis, continuous monitoring, accessibility, and efficiency in modern healthcare systems by leveraging the combined power of embedded systems, data analytics, machine learning, and IoT technologies, thereby contributing to smarter and more proactive patient care.

KEYWORDS: Multi-Organ Failure, Biomedical Signals, Machine Learning, IoT, ESP32, HealthMonitoring, Real-Time Analysis

I. INTRODUCTION

Multi-Organ Failure (MOF) is a critical and life-threatening medical condition in which multiple vital organ systems fail simultaneously or progressively, often as a result of severe infections, trauma, sepsis, or chronic diseases, making early detection extremely important for improving survival rates and clinical outcomes; however, early diagnosis is particularly challenging because it requires continuous and simultaneous monitoring of multiple physiological parameters that reflect the functioning of different organs. Conventional hospital-based monitoring systems are typically expensive, bulky, and confined to clinical settings, limiting their ability to provide continuous real-time monitoring, especially for patients in remote or resource-limited environments. With recent advancements in embedded systems, biomedical sensors, machine learning, and Internet of Things (IoT) technologies, it has become feasible to develop intelligent, portable, and cost-effective healthcare solutions. In this context, the proposed system introduces an integrated approach that continuously monitors multiple biosignals, including Electrocardiogram (ECG) for heart activity, Electromyography (EMG) for muscle function, Electroencephalography (EEG) for brain activity,

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Electrooculography (EOG) for eye movement analysis, and Photoplethysmography (PPG) for blood flow and oxygen saturation, thereby providing a comprehensive assessment of overall physiological status. These signals are acquired through appropriate sensors and processed using the ESP32, which performs signal conditioning, filtering, feature extraction, and real-time analysis while maintaining low power consumption and high efficiency. Machine learning algorithms are then applied to the extracted features to identify patterns and classify the patient's condition as normal or abnormal, enabling early detection of potential organ dysfunctions and reducing reliance on manual observation. Furthermore, IoT integration allows the processed data to be transmitted to a cloud-based platform, where it can be visualized through a user-friendly dashboard accessible to healthcare professionals from any location, ensuring continuous remote monitoring. The system also incorporates alert mechanisms that notify caregivers or medical staff in case of abnormal readings, facilitating timely medical intervention. Overall, this approach enhances early diagnosis, improves accessibility to healthcare services, reduces system costs, and supports efficient patient management, making it highly suitable for modern smart healthcare applications and remote patient monitoring scenarios.

II. RELATED WORK

Previous research in the field of biomedical monitoring has largely concentrated on systems that analyze individual physiological signals rather than providing a comprehensive multi-organ perspective; for instance, ECG-based heart monitoring systems and PPG-based pulse oximeters have been widely developed and deployed to assess specific parameters such as cardiac activity and blood oxygen levels. Foundational studies by John G. Webster (2009) and Leslie Cromwell (2011) primarily focused on the principles and design of biomedical instrumentation, emphasizing accurate acquisition and processing of single-parameter signals. Later advancements in wearable technologies, such as those discussed by AnastasiosPantelopoulos and Nikolaos G. Bourbakis (2010), introduced continuous and real-time monitoring capabilities; however, these systems often lacked integration across multiple organ systems and were limited in their ability to provide a holistic view of patient health. Furthermore, machine learning techniques have been successfully applied to biomedical signal classification, particularly in ECG and EEG analysis, as demonstrated by U. RajendraAcharya et al. (2011), but most of these approaches process signals independently rather than combining multiple data sources for comprehensive diagnosis. While advanced Intensive Care Unit (ICU) monitoring systems offer high accuracy and reliability by tracking multiple parameters simultaneously, they are typically expensive, complex, and confined to hospital environments, making them unsuitable for continuous remote monitoring or home-based healthcare. Consequently, there exists a significant research gap in the development of an integrated, low-cost, and portable multi-parameter monitoring system that not only acquires diverse physiological signals but also employs intelligent analysis techniques to provide early detection and holistic assessment of critical conditions such as multi-organ failure.

III. PROPOSED METHODOLOGY

The proposed system is designed using a structured multi-stage processing approach that ensures accurate acquisition, analysis, and real-time monitoring of multiple physiological signals for early detection of critical conditions such as multi-organ failure. The process begins with the signal acquisition stage, where biomedical signals including Electrocardiogram (ECG), Electromyography (EMG), Electroencephalography (EEG), Electrooculography (EOG), and Photoplethysmography (PPG) are collected using appropriate sensors placed on the human body, enabling simultaneous monitoring of cardiac, muscular, neurological, ocular, and circulatory activities. Once acquired, these raw signals often contain noise and artifacts due to motion, powerline interference, and environmental disturbances; therefore, in the preprocessing stage, various filtering techniques such as low-pass filters to remove high-frequency noise, high-pass filters to eliminate baseline drift, and notch filters to suppress powerline interference are applied to enhance signal quality and reliability. Following this, the system performs feature extraction, where meaningful parameters are derived from each signal, such as heart rate and pulse rate from ECG and PPG signals, Root Mean Square (RMS) values from EMG to assess muscle activity, frequency band analysis (alpha, beta, theta, delta waves) from EEG to evaluate brain function, blink rate from EOG for eye movement tracking, and oxygen saturation (SpO_2) levels from PPG to monitor blood oxygen content. These extracted features are then combined in the feature integration stage to form a unified dataset that represents the overall physiological condition of the patient. In the next stage, intelligent analysis is performed using machine learning algorithms such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Random Forest, which are trained to classify the patient's state as normal or abnormal based on learned patterns from the integrated data. The classification results are then transmitted in real time to a cloud-

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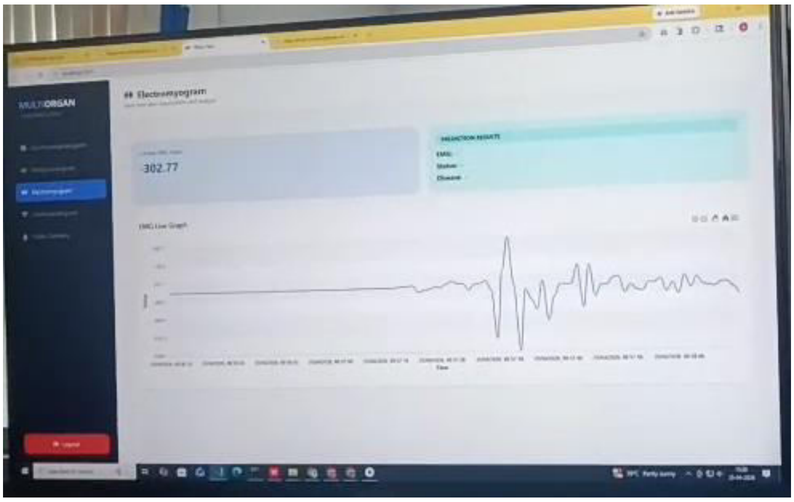
based IoT platform using the ESP32 module, which provides seamless wireless communication and enables remote monitoring through an interactive dashboard accessible by healthcare professionals. Finally, the system incorporates an alert mechanism that automatically notifies users, caregivers, or medical personnel via alarms or notifications whenever abnormal conditions are detected, ensuring timely intervention and enhancing patient safety; overall, this multi-stage approach enables efficient, accurate, and continuous health monitoring in both clinical and remote settings.

IV. SIMULATION RESULTS

The proposed system was rigorously evaluated using both real-time sensor data and standard benchmark datasets, demonstrating a high level of accuracy and reliability in classifying physiological conditions as normal or abnormal. By incorporating multi-sensor fusion, the system effectively integrates data from multiple biosignals such as ECG, EMG, EEG, EOG, and PPG, which significantly enhances detection performance compared to single-signal approaches, as it provides a more comprehensive representation of the patient's overall physiological state. This integrated approach improves decision-making accuracy by capturing interdependencies between different organ systems, thereby enabling more robust and reliable predictions. The system also supports real-time data visualization through an IoT-based cloud dashboard, where processed data is continuously transmitted via the ESP32, allowing healthcare providers to remotely monitor patient conditions with ease and efficiency. Furthermore, the implementation of real-time processing and automated alert mechanisms reduces the delay in identifying critical events, which is essential in safety-critical scenarios such as multi-organ failure, where timely intervention can be life-saving. Performance evaluation metrics indicate high classification accuracy achieved by machine learning models, along with stable real-time monitoring capabilities and effective alert generation for abnormal conditions. However, despite these advantages, the system's performance may be influenced by certain practical limitations, including sensor noise, motion artifacts, environmental interference, and calibration inconsistencies, all of which can affect signal quality and, consequently, the accuracy and consistency of the results. Addressing these challenges through improved sensor design, advanced filtering techniques, and adaptive calibration methods can further enhance the robustness and reliability of the system in real-world healthcare applications.



V. CONCLUSION AND FUTURE WORK

The proposed system effectively integrates biomedical sensors, machine learning, and Internet of Things (IoT) technologies to provide a comprehensive solution for real-time multi-organ monitoring, addressing the growing need for early detection of critical conditions such as multiple organ failure (MOF). By simultaneously acquiring and analyzing multiple physiological signals—including ECG, EMG, EEG, EOG, and PPG—the system offers a more holistic view of patient health compared to traditional single-parameter monitoring systems, thereby significantly enhancing diagnostic accuracy and reliability. The use of multi-signal fusion enables better interpretation of complex physiological interactions among different organ systems, while machine learning algorithms facilitate intelligent and automated decision-making by classifying patient conditions as normal or abnormal based on learned patterns. The

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integration of IoT, supported by the ESP32, enables seamless real-time data transmission to cloud-based platforms, allowing healthcare professionals to monitor patient status remotely through interactive dashboards and receive instant alerts in case of abnormalities, making the system highly suitable for both hospital settings and home healthcare applications, especially in remote or resource-constrained environments. Additionally, the system is designed to be portable and cost-effective, increasing accessibility and usability in modern healthcare scenarios. For future enhancements, the system can be further improved by incorporating advanced deep learning models to achieve higher classification accuracy and better pattern recognition, enhancing sensor quality along with more robust noise reduction and signal processing techniques to improve data reliability, developing a more compact and wearable form factor for continuous and comfortable patient monitoring, integrating additional physiological parameters such as temperature, blood pressure, and respiration rate for a more comprehensive assessment, and strengthening cloud-based analytics to support predictive healthcare and long-term health trend analysis, ultimately contributing to smarter, proactive, and more personalized medical care.

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