iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.70897

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Wearable Seizure Detection and Alert System for Neurodegenerative Patients

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Abstract: Neurodegenerative disorders, such as epilepsy, pose a significant threat to patients quality of life. Seizures can occur unexpectedly, leading to injuries, emotional trauma, and social stigma. The study presents a wearable seizure detection and alert system designed for neurodegenerative patients. Our system utilizes a multimodal sensor approach, incorporating electrodermal activity (EDA) sensors to measure skin conductance, gyroscope and accelerometer sensors for motion detection, and pulse oximetry (SpO2) and heart rate sensors for vital sign monitoring. Machine learning algorithms are employed to analyze the sensor data and detect seizure onset. Upon detection, the system alerts caregivers and emergency services through a mobile application, ensuring timely intervention and support. The results demonstrate the effectiveness of the proposed system in detecting seizures with high accuracy, sensitivity, and specificity. The wearable system has the potential to improve the lives of neurodegenerative patients, enhancing their safety, independence, and overall well-being.
Keywords: Wearable technology, seizure detection, neurodegenerative disorders, multimodal sensors, machine learning, alert system.

I. INTRODUCTION

Neurodegenerative disorders, such as epilepsy, affect millions of people worldwide, causing unpredictable seizures that can lead to injuries, emotional trauma, and social stigma. Despite advances in medical treatment, seizures remain a significant challenge for patients, caregivers, and healthcare systems. Traditional seizure detection methods, such as electroencephalography (EEG) and video monitoring, are often invasive, expensive, and limited to clinical settings.

The development of wearable technologies has opened new avenues for seizure detection and monitoring. Wearable sensors can track physiological signals, such as heart rate, skin conductance, and motion, providing valuable insights into seizure onset and progression. The existing wearable seizure detection systems often rely on single-modal sensors, which may not capture the complex physiological changes associated with seizures.

Furthermore, current seizure detection systems often require manual input from patients or caregivers, which can be unreliable and lead to delayed medical intervention. In addition these systems may not provide real-time alerts to caregivers and emergency services, which can be critical in ensuring prompt medical attention. To address these limitations, the study aims to design and develop a wearable seizure detection and alert system that leverages multimodal sensors to detect seizures in real-time. Our system integrates electrodermal activity (EDA) sensors, gyroscope and accelerometer sensors, and pulse oximetry (SpO2) and heart rate sensors to capture a comprehensive range of physiological signals. Machine learning algorithms are employed to analyze the sensor data and detect seizure onset, triggering alerts to caregivers and emergency services through a mobile application.

The proposed system has the potential to improve the lives of neurodegenerative patients, enhancing their safety, independence, and overall well-being. By providing timely and accurate seizure detection, the system can reduce the risk of seizure-related injuries, facilitate prompt medical intervention, and alleviate the emotional burden on patients and caregivers.

II. RELATED WORKS

1) Wearable Multi-Sensor System for Seizure Detection in Parkinson's Disease Patients

This paper presents a wearable system that combines accelerometers and electroencephalogram (EEG) signals to detect seizures in patients with Parkinson's disease. The system monitors abnormal movements through accelerometer data and brain activity through EEG, differentiating seizure-related movements from Parkinsonian tremors. The integration of both sensors improves detection accuracy and helps reduce false positives. This multi-sensor approach offers real-time monitoring and timely alerts, enhancing patient safety and care.

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2) Real-Time Seizure Detection for Alzheimer's Disease Patients Using Accelerometers and Heart Rate Sensors

This research focuses on developing a seizure detection system tailored for Alzheimer's patients using accelerometers and heart rate sensors. The system tracks abnormal body movements and physiological changes related to seizure activity, such as sudden increases in heart rate and irregular movements. The approach aims to improve the safety of Alzheimer's patients by providing caregivers with immediate notifications of seizure events, thus minimizing the risk of injury and promoting quicker intervention.

3) Seizure Prediction and Detection in Epileptic and Neurodegenerative Patients Using Machine Learning

This paper investigates the use of machine learning algorithms to predict and detect seizures in patients with both epilepsy and neurodegenerative conditions. By analyzing a combination of EEG data and accelerometer readings, the proposed model learns patterns that precede a seizure, allowing for predictive alerts. The research focuses on improving the accuracy of seizure prediction, which can help in reducing the impact of seizures by alerting caregivers ahead of time for timely intervention.

4) A Non-Invasive Seizure Detection System for Elderly Neurodegenerative Patients Using Smart Wearables

This paper introduces a non-invasive wearable system designed for elderly patients with neurodegenerative diseases such as Alzheimer's and Parkinson’s. The system combines accelerometers, gyroscopes, and electrodermal activity sensors to monitor both movement patterns and autonomic responses during seizures. By providing real-time seizure alerts to caregivers via mobile applications, the system aims to improve safety and prevent injuries associated with seizures or falls, providing a cost-effective and user-friendly solution for elderly care.

5) Fusion of EEG and Accelerometer Data for Seizure Detection in Neurodegenerative Diseases

This paper explores the fusion of EEG and accelerometer data to develop an accurate seizure detection system for neurodegenerative patients. The system analyzes both brain activity and physical movement, ensuring a comprehensive approach to seizure detection. By fusing these two sources of data, the system can identify both motor and non-motor symptoms of seizures, offering higher detection accuracy and fewer false positives compared to systems relying on single data sources. The approach is particularly effective for neurodegenerative diseases where symptom overlap can complicate seizure identification. These papers illustrate various innovative approaches to seizure detection and prediction, focusing on integrating wearable technology, multi-sensor systems, and machine learning to enhance the care and safety of patients with neurodegenerative diseases.

III. METHODOLOGY

A. Sensor Data Acquisition

The proposed system continuously collects real-time physiological and kinematic data using a series of integrated sensors. Electrodermal activity (EDA) is monitored through a galvanic skin response (GSR) sensor, which captures dynamic fluctuations in skin conductance linked to sympathetic nervous system activity, an early sign of seizure onset or stress. The MAX30100 sensor is employed for dual-function monitoring of oxygen saturation (SpO2) and heart rate, offering continuous tracking of these essential biometrics. In parallel, a 6-axis MPU6050 module records detailed motion data, including linear acceleration and angular velocity, which are critical for detecting erratic bodily movements commonly observed during tonic-clonic seizures. These sensors are interfaced with an Arduino Nano microcontroller, chosen for its small footprint, low power requirements, and compatibility with various analog and digital input protocols. Data acquisition is performed through both analog input and I2C communication, with sampling intervals ranging from 500 milliseconds to 1 second to balance response time and power efficiency based on the sensor type and required sensitivity.

B. Signal Preprocessing

Sensor outputs are prone to noise, drift, and interference caused by environmental factors or involuntary user movement. To enhance the reliability of acquired data, a set of preprocessing techniques is applied. A moving average filter is implemented to smooth fluctuations in EDA and heart rate signals, eliminating short-term spikes while preserving significant trends. For motion data, particularly from the accelerometer, a high-pass filter is applied to isolate rapid, high-magnitude movements that are indicative of convulsions or jerks associated with seizures. Signal normalization is also performed across all sensor inputs, converting data into a standardized range. This enables uniform interpretation regardless of the user’s physiological baseline or sensor variability, thus improving the robustness of the detection algorithm.

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C. Feature Extraction

After preprocessing, critical features are derived from the cleaned signals to facilitate seizure event classification. For EDA, parameters such as the rate of change (slope) in skin conductance and the occurrence of signal peaks serve as reliable stress markers. Heart rate analysis includes the computation of average beats per minute (BPM), heart rate variability (HRV), and the detection of abrupt BPM increases.

In the case of SpO2, sudden decreases in oxygen saturation levels are tracked, which may correlate with breathing irregularities during seizure episodes. Motion features extracted from the accelerometer and gyroscope data include metrics such as acceleration magnitude, angular velocity, and zero-crossing rates. These features collectively help differentiate between seizure-related movements and regular daily activity, improving the specificity of the detection logic.

D. Threshold-Based Detection

At the initial detection stage, the system relies on predefined threshold values to identify abnormal physiological and motion events. Each feature extracted from the sensor data is compared against calibrated thresholds derived from experimental data and test simulations. For example, a skin conductance rise exceeding 4 µS, coupled with a heart rate above 120 BPM and significant accelerometer activity, may indicate a potential seizure occurrence. These thresholds are not fixed; they are designed to be adjustable based on user-specific baseline readings, enhancing personalization and system accuracy. Initial thresholds were established through controlled simulations involving healthy participants emulating seizure behavior, allowing the model to differentiate between normal exertion and actual seizure indicators while minimizing false alarms.

E. Machine Learning Integration

To enhance detection reliability beyond static thresholding, a lightweight machine learning model is incorporated into the system. Due to memory constraints on the Arduino Nano, a decision tree classifier is chosen for its simplicity and efficient memory usage. The classifier is trained offline using labeled datasets generated from controlled simulations, with sensor-derived features serving as the input parameters.

The classifier's structure is then embedded into the Arduino firmware using hard-coded logic derived from training in Python with libraries such as scikit-learn. The hybrid detection mechanism combining both threshold analysis and decision tree-based classification offers a balanced solution that leverages real-time responsiveness without compromising accuracy or exceeding hardware limitations.

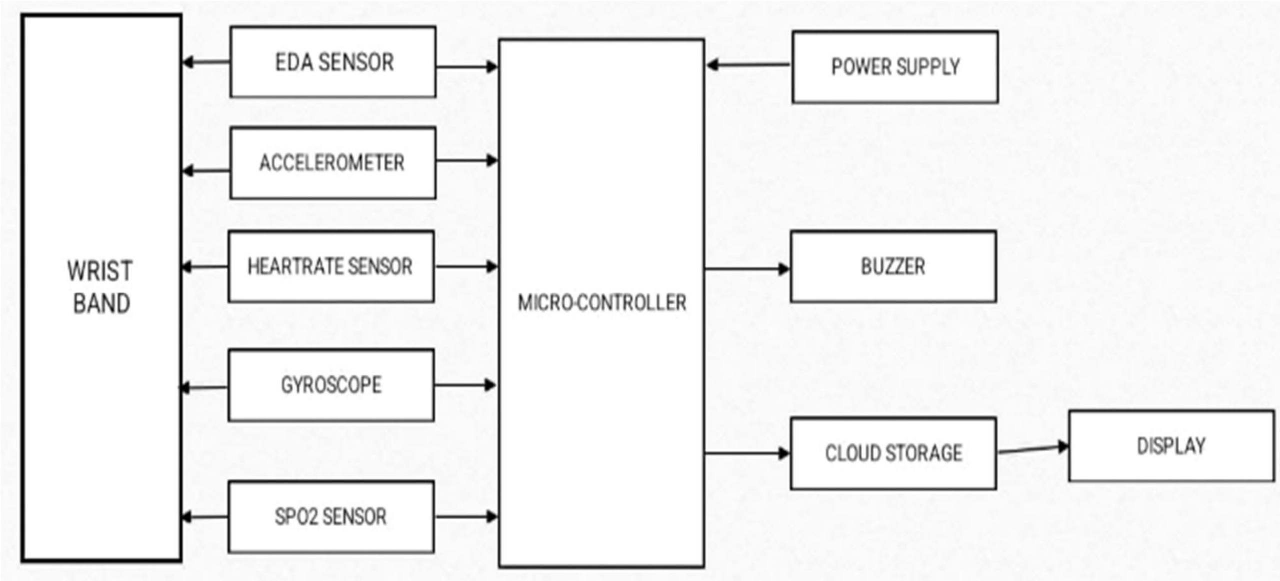
F. Alert System Design

When the system confirms the occurrence of a seizure, it activates an immediate alert via the HC-05 Bluetooth communication module. This module transmits the alert to a mobile application developed using MIT App Inventor. The app displays key information such as the patient ID, time of alert, and current readings from all sensors, providing caregivers with vital data in real-time. The approach ensures rapid response during critical medical events. Future iterations of the system are planned to include integration with IoT-capable modules like the ESP8266, which would allow cloud-based data logging and enable remote access to patient data by healthcare providers through secure platforms.

G. Simulation And Testing Setup

To evaluate the system's performance, a series of simulation tests were conducted in a controlled laboratory environment with volunteer participants. Seizure-like activities were mimicked through repetitive muscle contractions, sudden limb movements, and rapid breathing to create conditions representative of seizure onset. The output from each sensor was recorded and analyzed in real time, then cross-referenced with the system's alert triggers to verify accuracy. Multiple activity scenarios including passive states (resting, sitting), active states (walking, exercising), and simulated seizures were included in the tests. The system's performance was assessed using key metrics such as detection accuracy, false positive rate, latency in alert delivery, and power consumption. Initial tests showed reliable seizure detection, prompt alerting (within 1.5 seconds), and continuous device operation for over 10 hours on a single battery charge. These simulations provided valuable feedback to fine-tune system thresholds and improve the decision-tree model's performance

IV. BLOCK DIAGRAM



V. HARDWARE DESCRIPTION

A. Arduino

An arduino is an open-source electronics platform based on easy-to-use hardware and software, widely used for building digital devices and interactive objects. At its core, it features a microcontroller typically an ATmega series chip (like ATmega328 on the Arduino Uno) which acts as the brain of the board, processing input and controlling outputs based on user-written code. The board includes various digital and analog I/O pins that can be connected to sensors, actuators, LEDs, motors, and other components. It also features a USB interface for programming and communication, a voltage regulator, and often comes with built-in features like a power jack, reset button, and LEDs for basic status indication. Arduino boards are popular in DIY electronics, robotics, IoT projects, and educational environments due to their simplicity, flexibility, and strong community support.

B. Heart Rate Sensor (MAX30100/MAX30102 or AD8232 ECG Module)

The heart rate sensor, such as the MAX30102 or AD8232 ECG module, plays a crucial role in this project by continuously monitoring cardiovascular signals, which are directly affected by thyroid hormone levels. These sensors operate on principles such as photoplethysmography (PPG) or electrocardiography (ECG) to detect pulse and blood oxygen saturation. The MAX30102 integrates LEDs, a photodetector, optical elements, and low-noise electronics in a single package, offering accurate and low-power pulse detection. On the other hand, the AD8232 module can provide raw ECG signals, ideal for more detailed heart rhythm analysis. In the context of thyroid disorders, heart rate is an essential biomarker hyperthyroidism typically causes elevated heart rates, while hypothyroidism can lead to bradycardia. This sensor is interfaced with the ESP32 using either analog or I2C protocols, allowing real-time data acquisition and analysis. The sensor data is pre-processed on the microcontroller before being transmitted to the mobile application for display and interpretation. With high sensitivity and compact size, the heart rate sensor is suitable for wearable designs, making it ideal for continuous, non-invasive monitoring in this thyroid system.

C. Electodermal Sensor

Electrodermal sensor (GSR sensor) is useful for detecting seizures by measuring changes in skin conductance, which reflect the amount of sweat produced and are influenced by the autonomic nervous system's response to stress or physiological changes during a seizure. In seizures, particularly generalized tonic-clonic seizures, there can be an increase in sympathetic nervous system activity, which triggers sweating and reduces skin resistance both of which the sensor can detect. When integrated with other sensors like EEG or motion detectors, the electrodermal sensor becomes part of a multi-sensor system that tracks brain activity, heart rate, and skin conductance. While this combination can assist in identifying or predicting seizures, it is not entirely reliable due to the potential for false positives from factors like emotional stress and the variability of individual responses.

D. SpO2 Sensor

SpO2 (peripheral capillary oxygen saturation) refers to the proportion of oxygen-saturated hemoglobin in the blood, which indicates how well oxygen is being delivered to tissues throughout the body. It is commonly measured using a pulse oximeter, a small, non-invasive device that is typically clipped onto a fingertip, earlobe, or toe. The pulse oximeter works by emitting light at specific wavelengths and measuring how much light is absorbed by the blood, which helps calculate the oxygen saturation. A normal SpO2 value typically ranges from 95% to 100%, and anything below 90% may indicate insufficient oxygen levels in the blood, known as hypoxemia. Monitoring SpO2 levels is essential for evaluating respiratory health, especially in conditions like asthma, COPD, sleep apnea, or during surgeries and critical care situations.

E. Accelerometer

An accelerometer can play a crucial role in seizure detection by monitoring sudden movements and changes in orientation that typically occur during a seizure. Seizures, particularly generalized tonic-clonic seizures, often involve rapid and involuntary muscle contractions, leading to violent body movements or falls. Accelerometers, when worn on the body, can track these abnormal movements by measuring acceleration in multiple directions, helping to identify the onset or occurrence of a seizure. The data from the accelerometer can be analyzed to distinguish between normal activities and seizure events, allowing for real-time monitoring and alert systems. When combined with other sensors like EEG or heart rate monitors, accelerometers can enhance the accuracy of seizure detection, providing valuable support for individuals with epilepsy or other seizure disorders.

VI. CONCLUSION

This study presents a portable, cost-effective wearable system designed for real-time seizure detection, particularly in individuals with neurodegenerative disorders. It employs a suite of physiological and motion sensors including electrodermal activity (EDA), blood oxygen saturation (SpO_2), heart rate, accelerometer, and gyroscope to continuously track biomarkers commonly affected during seizure onset.Built around an Arduino-based microcontroller, the system offers low power consumption, affordability, and ease of use, making it suitable for clinical and home-care settings. During prototype testing using simulated conditions, the device effectively differentiated seizure-like episodes from normal activities, showing promising reliability. The system features Bluetooth connectivity, allowing real-time alerts to be transmitted to a caregiver's mobile device, enabling faster emergency responses and improved patient safety. Its open-source hardware and software design promotes customization, scalability, and adoption by researchers and developers.Detection is currently handled through a hybrid approach combining threshold logic with lightweight decision tree classifiers. Planned improvements include the integration of advanced machine learning and deep learning algorithms to enhance detection accuracy and reduce false positives. Personalization based on individual health data will also be explored.Future work will focus on enhancing connectivity via IoT modules for cloud-based data sharing, allowing remote health monitoring by professionals. Clinical trials with real patients will be essential for validating the system's performance across diverse seizure types. The wearable device represents a step forward in continuous health monitoring and timely intervention.

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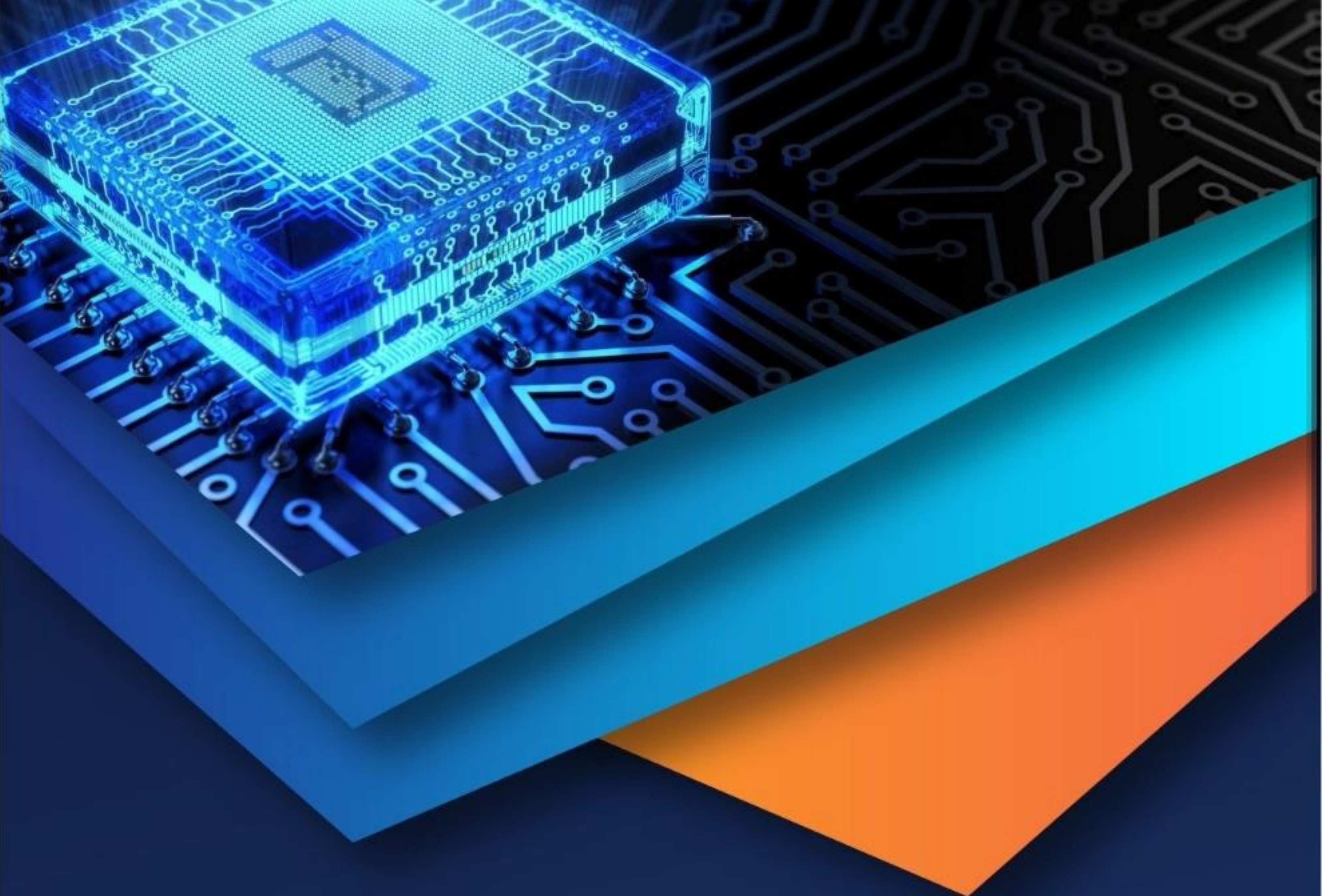

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