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Research Article

Development and Evaluation of a Wearable Real-Time Epileptic Seizure Alert System

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Abstract Epileptic seizures significantly impact individuals' safety, independence, and quality of life. Conventional clinical monitoring systems are effective in clinical settings but lack portability for daily use. The present research work addresses these limitations by developing a wearable device for real-time epileptic seizure detection, enhancing patient safety and bridging the gap between clinical monitoring and everyday management. The low-cost, daily-use prototype improves detection accuracy and minimizes false alarms by strategically placing the device on the back for enhanced stability and sensor performance. The system uses an Arduino Mega microcontroller for control, a gyroscope for motion detection, GPS for location tracking, and GSM for emergency alerts. Each component was individually tested before integration. The device was evaluated for detecting tonic-clonic seizures, verifying audio and SMS alerts, and monitoring performance via a custom mobile application. Over the course of three weeks of field testing, it was shown that the buzzer alert was activated within approximately 5–6 seconds, while SMS notifications were delivered within 7–9 seconds after seizure detection, allowing for a quicker emergency response. The system demonstrated reliable detection of motor seizures with minimal false positives under controlled testing conditions. Future enhancements include miniaturizing the device with a PCB, improving battery life, and integrating EEG monitoring for comprehensive seizure detection.

Keywords: Biomedical Engineering, Epilepsy, IoT, real-time alert, Sensor System, Wearable Device.

1. INTRODUCTION

Epilepsy is a chronic neurological disorder affecting over 50 million individuals globally [1]. It is characterized by recurrent, unprovoked seizures that result from abnormal electrical discharges in the brain. Seizure manifestations vary widely, from brief lapses in awareness to severe convulsions that may cause injury or lead to sudden unexpected death in epilepsy (SUDEP) [2]. Continuous monitoring is critical, as the unpredictable nature of seizures poses substantial risks to patient safety and autonomy [3].

While clinical tools such as video-electroencephalography (video-EEG) remain the gold standard for diagnosis, they are impractical for everyday monitoring due to their cost, complexity, and lack of portability [4]. Consequently, there is growing interest in wearable systems capable of detecting seizures in real time and alerting caregivers [5]. Many recent studies have proposed wearable technologies using accelerometers, gyroscopes, Electrocardiogram (ECG), Electromyography (EMG), and biosensors to monitor physiological signals and detect abnormal activity patterns associated with seizures. Additionally, recent advancements in wearable seizure-detection systems demonstrate growing interest in real-time, patient-centered monitoring solutions. A notable example is the study titled "A novel wearable device for automated real-time detection of epileptic seizures," which developed a multi-sensor wearable platform capable of analyzing physiological and motion-based signals to detect seizure activity with improved reliability [6]. The system incorporated accelerometers and biosensors with an embedded processing unit to achieve efficient on-body detection and wireless alert transmission. Its findings highlight the increasing feasibility of compact, low-cost wearable devices for continuous seizure monitoring and reinforce the need for practical designs optimized for daily use. The present study builds upon these insights by focusing on hardware simplification, sensor placement optimization, and enhanced alert responsiveness.

This research work presents the design and implementation of a wearable, back-mounted epileptic seizure alert system optimized for detecting tonic-clonic seizures. Unlike traditional wrist-based designs, the proposed approach reduces false positives through optimized sensor placement. It integrates motion detection via the MPU6050 sensor, GPS-based location tracking, Global System for Mobile Communications (GSM) for emergency alerts, and Message Queuing Telemetry Transport MQTT-enabled mobile application support. The system prioritizes low-cost hardware, ease of use, and real-time responsiveness.

Through a structured, component-level development approach and a custom-built Android application, the device enables continuous monitoring and instant alerts. The system was tested through multiple real-world simulations and evaluated for

performance metrics including response time, power efficiency, and robustness. This work contributes to the growing field of assistive seizure monitoring by offering an accessible, practical alternative suitable for everyday use and further enhancement. The main objectives of the study are as follows:

- Accurately detect tonic-clonic seizures using motion sensors and threshold-based algorithms.
- Provide immediate alerts to caregivers via SMS and real-time GPS location tracking.
- Minimize false alarms through sensor optimization and refined detection logic.
- Ensure user comfort and wearability through ergonomic design.
- Offer a secure mobile interface for real-time monitoring and system control.

2. LITERATURE REVIEW

The field of wearable seizure detection has witnessed significant advancements in recent years. Numerous systems have been developed using a variety of sensing technologies and algorithmic approaches. This section reviews selected studies and highlights their contributions, limitations, and relevance to the developed system.

2.1. Wrist-Based and Motion Sensor Systems

As shown in [4], proposed a wrist-worn accelerometer-based system for detecting short-duration convulsive seizures. The system achieved a sensitivity of 95.83% but suffered from a false alarm rate (FAR) of 0.72 per 24 hours, which increased when more seizure types were included. These results underscore the challenge of motion artifacts in wrist-mounted devices. Similarly, in [7], the study utilized a wrist-worn device integrating gyroscopes, heart rate sensors, GPS, and Wi-Fi modules. While effective, the design still suffered from motion-induced noise and limited sensor stability.

2.2. Multi-Sensor and Physiological Signal Systems

Several studies incorporated additional physiological sensors to improve detection accuracy. The study [5], introduced an Internet of Things (IoT)-based device using ECG and heartbeat sensors to detect seizure risk, while study [8], proposed a fuzzy logic system integrating ECG, EMG, accelerometers, and temperature sensors. These systems achieved high detection accuracies but increased hardware and software complexity. In [6], the authors developed a low-cost system combining accelerometer, vibration sensor, and pulse oximeter for real-time detection. Though cost-effective and accurate, the system's reliability under varying real-world conditions was not extensively validated. In [9], the study developed a wristband capable of detecting epileptic seizures using a multi-modal sensor configuration: accelerometer, gyroscope, EMG, and electrodermal activity (EDA). Tested on 36 pediatric patients, the system achieved up to 93.16% accuracy and 88.16% sensitivity when combining all sensor types. The study highlighted the effectiveness of EMG signals in distinguishing seizures from normal activity. While highly accurate, the system's reliance on multiple physiological signals and complex processing limits its feasibility for low-cost, real-time deployment in everyday settings.

2.3. Machine Learning and Ai-Based Systems

As shown in [10], the authors used federated machine learning (FML) and a multi-sensor array to train seizure detection models directly on-device. While promising, it remains in early development and lacks clinical testing. Similarly, the study [11] used feature extraction from wearable and clinical-grade sensors, requiring complex mobile processing and large datasets. Similar real-time detection frameworks based on embedded systems have been demonstrated in other domains, such as the detection of underwater species using YOLO-based computer vision models [12].

2.4. Integration and User-Centered Approaches

In [13], the study introduced EpiPatch, a system that integrated biosensors with mobile app connectivity, achieving moderate detection accuracy and good usability. The research work [14] developed a fall-detection system for elderly individuals using accelerometers and gyroscopes connected to smart homes, highlighting the relevance of wearables for safety in vulnerable populations.

2.5. Summary of Gaps in Existing Systems

While the reviewed systems demonstrate notable progress, they reveal recurring challenges:

- High FARs in motion-based designs.
- Complexity and cost associated with integrating multiple physiological sensors.
- Dependency on machine learning models requiring extensive training data.
- Lack of robust real-world testing in daily-life conditions.

2.6. Contribution of This Study

The system presented in this work addresses these gaps by:

- Mounting the device on the user's back to improve motion detection stability.
- Using a focused sensor set (MPU6050, GPS, GSM) to reduce cost and complexity.
- Providing real-time alerts through both SMS and a secure mobile app.

- Offering a practical solution suitable for low-resource settings, validated through real-world simulations.

This study contributes to the field by demonstrating a balance between system simplicity, reliability, and affordability—an essential step toward widespread adoption of seizure detection wearables in everyday contexts. To contextualize the performance of the proposed system, it is essential to compare it with existing wearable seizure detection solutions reported in recent literature. This comparison focuses on key metrics including sensor configuration, detection method, response time, communication capabilities, and system complexity. Table 1 summarizes the core features and limitations of recent wearable seizure detection systems in comparison with the proposed design.

Table 1. Comparative Analysis of Existing Wearable Seizure Detection Systems

Study/System	Sensors Used	Alert Method	Response Time	Notes and Limitations
[4]	Accelerometer (wrist-worn)	SMS	~6–10 sec	High FAR; limited to convulsive seizures
[5]	ECG, Heartbeat sensors	IoT dashboard	Not specified	Clinical-grade sensors; lacks mobility
[8]	ECG, EMG, Temp, Accelerometer	SMS + IoT	Not specified	High accuracy; increased complexity and cost
[6]	Accelerometer, Pulse Oximeter, Vibration	Smartphone App	~7–9 sec	Low cost; limited robustness testing
[13]	Biosensors + Arduino Nano 33 BLE	Mobile App	7 sec	Moderate accuracy; early prototype
[7]	Accelerometer, Gyroscope, Heart rate, GPS	Blynk IoT App + Buzzer	Not specified	High feature integration; wrist placement
[10]	IMU, Temp, Light, Microphone, ML models	On-device ML	Not specified	Early development; no real-world validation
This Study	MPU6050, GPS, GSM, ESP8266	SMS + MQTT Mobile App	~5–9 sec	Back-mounted; low cost; real-world testing included

The comparison highlights that while several systems achieve high accuracy, many require complex sensor arrays or rely on computationally intensive models. Others are limited by motion artifacts due to wrist-based placement. In contrast, the proposed system offers a balance between simplicity and effectiveness. By using a back-mounted MPU6050 sensor with carefully tuned thresholds, the system minimizes false positives. Its dual alert mechanism—via SMS and mobile application—ensures redundancy, and its modular design based on readily available components keeps cost and development time low. Furthermore, the system was validated under real-world conditions using repeated seizure simulations, demonstrating practical responsiveness within 5 to 9 seconds. This confirms its suitability for everyday use and supports its potential for deployment in resource-constrained environments where affordability, reliability, and usability are critical. Inspired by the work of Alnıacık et al. [15], future iterations of our system may also explore AI-driven detection models embedded in compact hardware to enhance anomaly detection capabilities.

3. METHODOLOGY AND EXPERIMENTAL SETUP

This section outlines the comprehensive step-by-step methodology for the design, development, and validation of the proposed real-time epileptic seizure alert system. The process includes ten structured phases to ensure a robust and functional prototype.

The project began with an in-depth literature review of existing seizure detection systems to identify performance gaps and limitations. It was found that wrist-mounted devices are prone to motion-induced false positives. Therefore, the system (Figure 1) was designed as a back-mounted wearable focused on detecting tonic-clonic seizures using motion sensors. Key objectives included low cost, portability, real-time alerting, and system reliability.

The overall system architecture, including data acquisition, processing, and alert generation, is illustrated in Figure 2. The system consists of three main stages: (1) collecting real-time motion data from sensors, (2) processing the data using threshold-based algorithms, and (3) generating alerts via buzzer and SMS when a seizure is detected. Real-time localization and tracking on embedded platforms has also been explored by Sevgi and Koçer [16], who developed a multicamera indoor localization system using ArUco markers, demonstrating high accuracy in real-world navigation scenarios.

3.1. Component Acquisition and Preliminary Setup

Selected hardware components included Arduino Mega2560 (main controller), MPU6050 (motion sensing), NEO-6M GPS (location tracking), SIM900 GSM (SMS alerts), ESP8266 (Wi-Fi), LM2596 voltage regulator, and lithium-ion batteries. Datasheets and technical documentation were reviewed to prepare for integration. Preliminary system diagrams and flowcharts were created to visualize module interactions.

Figure 1. Real developed prototype.

3.2. Breadboard Prototyping

Each component was independently tested on a breadboard. The MPU6050 was connected to the Arduino Mega via I2C, and real-time motion data was confirmed. GPS and GSM modules were tested via serial communication. AT commands were used to validate GSM functionality. The ESP8266 was powered separately and connected via UART for MQTT communication.

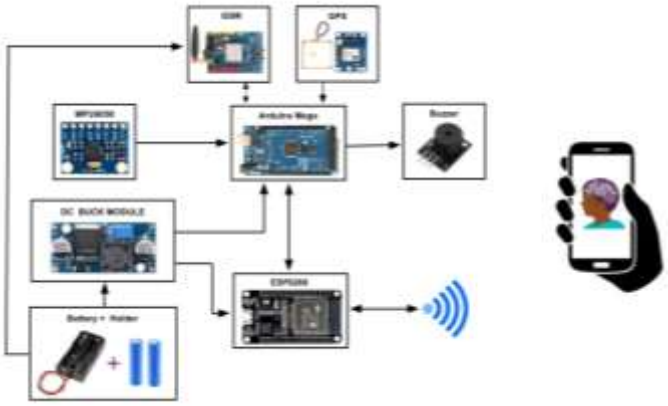

Figure 2. The system architecture.

3.3. Power System Design

Two 3.7V 2600mAh Li-ion batteries were connected in series to supply 7.4V. An LM2596 buck converter was calibrated to output a steady 5V for most modules, while the ESP8266 received 3.3V. A switch was added for user control.

3.4. System Integration

Following successful unit-level validation, modules were integrated incrementally. The Arduino Mega served as the system's control unit. Integration proceeded in phases: MPU6050 + GPS, then GSM, followed by ESP8266. Custom routines were written to manage sensor thresholds and handle alert logic. Trigger events activated a buzzer, sent SMS messages, and published MQTT messages.

3.5. Firmware and Detection Algorithm

Thresholds were set based on experimental motion testing: pitch or roll angles > ±45°, and acceleration > 2g sustained for at least 5 seconds. This delay was critical to filter out false positives. The logic was coded in Arduino IDE, with EEPROM used to store dynamic settings configurable through the app.

3.6. Mobile Application Development

Using Kodular, a visual drag-and-drop platform, the mobile app was created. MQTT support enabled real-time updates from the wearable device. The interface displayed patient data, device status, and GPS location via Google Maps. Features included login security, threshold adjustment, and alert toggling.

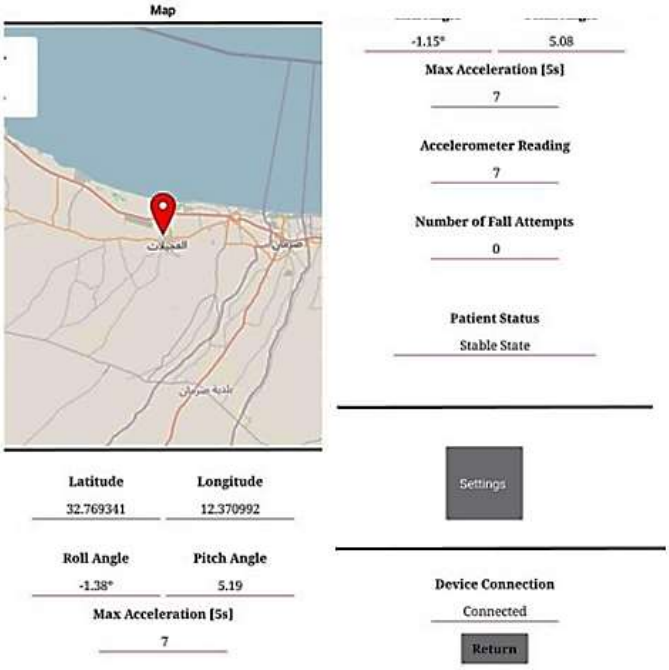

Figure 3. Application settings interface.

3.7. Device Enclosure and Mounting

The prototype was enclosed in a rigid plastic case (20.5 × 13.5 cm) and mounted on a custom back-strap harness to ensure stable sensor positioning. Figure 4 illustrates the wearable device placement on the user's back.

Figure 4. Device (prototype) placement.

3.8. Seizure Detection Algorithm and Threshold Selection

The seizure detection algorithm was implemented as a rule-based decision logic using motion features derived from the MPU6050 sensor. In particular, roll and pitch angles were continuously monitored alongside the acceleration magnitude to identify abnormal body movements associated with tonic–clonic seizures.

Threshold values were initially selected based on empirical observation and prior literature and were iteratively refined through repeated controlled simulations. A seizure event was flagged when the angular displacement exceeded predefined limits (±45°) in combination with sustained acceleration levels greater than 2g within a fixed temporal window.

To reduce false triggering caused by brief or isolated movements, a temporal verification buffer of 5 seconds was introduced. Only when the threshold conditions were continuously maintained throughout this verification period was a seizure event confirmed.

As illustrated in Figure 5, once the seizure condition is verified, the system activates a multi-channel alert routine, including a local buzzer, GSM-based SMS notification with GPS coordinates, and real-time mobile application updates via MQTT.

This threshold-based approach was selected to ensure low computational complexity, real-time responsiveness, and suitability for embedded implementation on resource-constrained hardware.

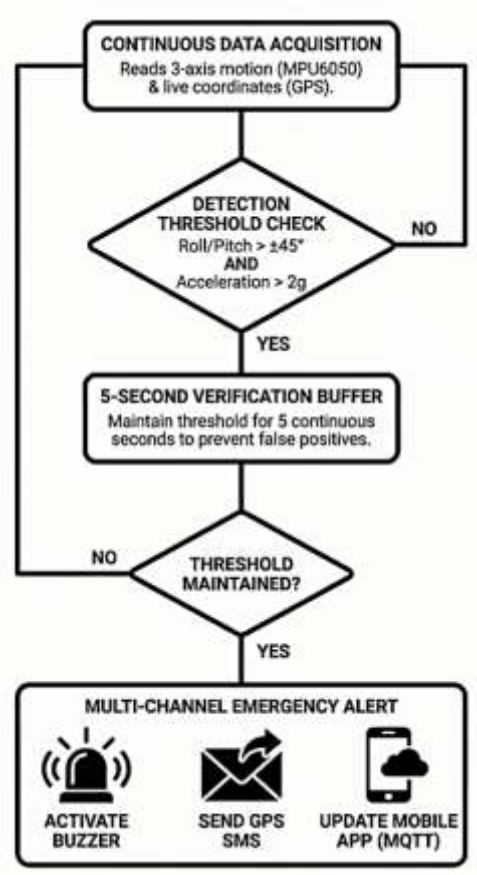

Figure 5. Flowchart of the proposed seizure detection algorithm and threshold verification process

3.9. Final Testing and Real-World Simulation

Three volunteer team members simulated tonic-clonic seizures by performing shaking and collapsing motions while wearing the device. Each test recorded the activation time for buzzer, SMS, and MQTT alerts. False positive tests involved typical daily movements like sitting, bending, and walking. In most cases, alerts were triggered within 10 seconds. Extended testing confirmed 12-hour battery life.

The above structured, iterative approach ensured both hardware and software robustness. From sourcing components to integrating and validating the full system, the methodology provides a reproducible path for developing practical health-monitoring wearables. Data were analysed descriptively by calculating the average response times for buzzer and SMS activation under different simulated conditions (pitch, roll, and acceleration events). The buzzer response ranged from 4.9 to 6.0 seconds, while SMS notifications averaged between 7.2 and 9.2 seconds. These results are visually illustrated in Figures 6 and 7, which display the time taken for the buzzer and SMS alerts to activate following simulated seizure events. The functional evaluation consisted of 30 repeated simulated seizure trials conducted under controlled conditions to assess alert latency and system stability.

All experiments were performed by the authors themselves without involving patients or collecting sensitive medical data. Hence, ethical approval was not required under institutional guidelines. The present testing was performed solely for system functionality and technical validation. The simulation procedure was designed to assess device responsiveness under controlled motion scenarios, not to replicate clinical seizure activity. Therefore, the results are intended to demonstrate proof of concept rather than clinical diagnostic validity. The wearable prototype is shown during controlled motion-based simulation to assess system responsiveness under real-use conditions (Figure 8). The test demonstrates how the device remains securely mounted on the upper back while detecting sudden collapse or convulsive motion.

3.10. Ethical Considerations

This study did not involve human subjects, patient data, or clinical testing. The testing procedure consisted exclusively of controlled, non-clinical motion simulations performed by the authors to verify device functionality. According to institutional research guidelines, such engineering validation does not require ethical review. Future work will include collaboration with

healthcare professionals to conduct clinical validation with appropriate ethical oversight and informed consent. No patient data or clinical subjects were involved, and no ethical approval was required for this engineering validation stage.

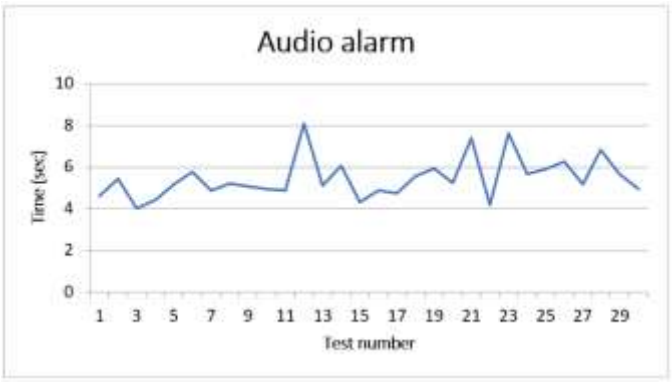

Figure 6. Audio alert time graph.

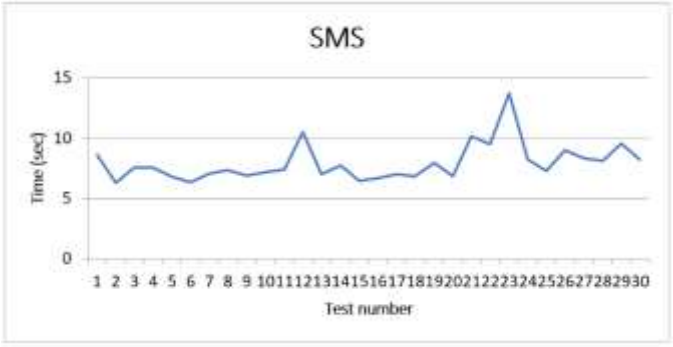

Figure 7. SMS alert time graph.

Figure 8. Device Placement during Simulated Seizure Testing.

4. RESULTS AND DISCUSSION

This section presents and discusses the results obtained from the technical validation of the developed seizure alert system. The focus is on evaluating the system's detection accuracy, responsiveness, and reliability under controlled motion-based simulation conditions. The evaluation demonstrated the proof of concept and functional feasibility of the developed design.

4.1. System Performance Evaluation

The evaluation confirmed that the developed system consistently detected simulated tonic-clonic seizure movements and generated timely alerts. The average buzzer activation time ranged between 4.9 and 6.0 seconds, while SMS notifications were successfully delivered within 7.2 to 9.2 seconds across 30 test runs. These findings verify that the system can promptly issue alerts suitable for real-time emergency response.

Sensor placement on the upper back significantly reduced false positives by maintaining a stable orientation, outperforming conventional wrist-based configurations. Integration of GSM and GPS modules ensured accurate alert transmission and location tracking. As illustrated in Figures 6 and 7, both buzzer and SMS alerts were activated within acceptable latency ranges, confirming consistent and reliable operation. During the evaluation period, no false alarms were observed during routine activities such as walking, sitting, or bending.

The developed mobile application further improved usability by allowing caregivers to visualize sensor data and patient location in real time. The secure login feature added an essential layer of data protection and privacy.

Although the testing involved simulated motion scenarios rather than actual epileptic events, the experiments successfully validated the functionality, responsiveness, and feasibility of the prototype for future clinical evaluation. Compared with existing systems summarized in Table 1, the proposed design achieves a balance between affordability, simplicity, and reliable operation—making it a viable option for low-resource environments and preliminary deployment.

In the absence of clinically validated seizure datasets, the system performance was evaluated using engineering-oriented metrics appropriate for prototype-level validation. These metrics focus on detection latency, alert delivery reliability, and system stability during non-seizure activities. As summarized in Table 2, the buzzer activation and SMS delivery times remained within acceptable ranges, while no false alerts were observed during routine daily activities.

Detection latency was defined as the time interval between the onset of simulated seizure motion and alert activation. The observed buzzer response time ranged between 4.9 and 6.0 seconds, while GSM-based SMS notifications were delivered within 7.2 to 9.2 seconds.

To assess resistance to false triggering, the system was tested during routine daily activities such as walking, sitting, bending, and normal posture transitions. No unintended alerts were recorded during these activities, indicating stable system behavior under non-seizure conditions.

Table 2. Engineering-Oriented Performance Evaluation of the Proposed Seizure Alert System

Metric	Observed Range	Description
Buzzer activation time	4.9 – 6.0 s	Time from seizure trigger to local alert
SMS delivery time	7.2 – 9.2 s	Time to caregiver notification
False trigger events	None observed	Tested during daily activities
Test scenarios	30 trials	Simulated tonic-clonic motions

The reported response times represent observed performance ranges obtained during repeated controlled trials. Due to the prototype-level nature of the evaluation and the limited number of simulations, advanced statistical measures such as standard deviation or confidence intervals were not calculated.

4.2. Limitations and Future Enhancements

The current prototype is primarily designed to detect motor (tonic-clonic) seizure types and does not yet address non-motor (absence or focal) seizures. Additionally, the current size and weight of the prototype may limit its long-term wearability, ease of transport, and user mobility during daily activities. Future iterations will focus on hardware miniaturization to improve user comfort and freedom of movement.

Future enhancements will focus on integrating EEG sensors to broaden seizure detection capabilities, adding voice call functionality for two-way emergency communication, and implementing PCB miniaturization to improve portability. Incorporating additional physiological sensors (e.g., heart rate, oxygen saturation) and cloud-based monitoring dashboards will further enhance system comprehensiveness and clinical applicability.

The experimental evaluation was conducted using controlled, motion-based simulations performed by the authors to verify system functionality and responsiveness. These tests were designed to demonstrate technical feasibility and proof of concept, rather than to replicate clinical seizure conditions or provide diagnostic validation.

Conventional clinical performance metrics such as sensitivity, specificity, and FAR are typically derived from long-term recordings involving diagnosed epilepsy patients under clinical supervision. Since the present study was limited to controlled, motion-based simulations conducted for technical validation, these metrics were not calculated. Instead, system performance was evaluated using response time, alert reliability, and false activation observations to demonstrate functional feasibility.

5. CONCLUSION AND FUTURE WORK

The study presented the design, implementation, and functional validation of a wearable, back-mounted seizure alert system capable of detecting tonic-clonic seizures in real time. The system integrates motion sensing, GPS location tracking, GSM-based SMS alerts, and a mobile application for continuous monitoring. It was evaluated through structured testing with simulated seizure scenarios, achieving reliable alert delivery, with buzzer activation and SMS notification occurring within seconds of seizure detection, and demonstrating feasibility for practical use.

By leveraging a simplified hardware configuration and focusing on sensor stability through back placement, the proposed solution addresses key limitations found in many existing systems, such as high FARs and complex integration. The modular design, low cost, and real-time response make it suitable for deployment in low-resource environments and daily life.

This research was conducted without external funding and was fully supported by the authors, highlighting the cost-effective and self-supported nature of the proposed system.

Future enhancements to the system will focus on the following directions:

- Integrating EEG sensors to expand detection capabilities to non-convulsive seizure types.
- Adding voice call functionality for two-way emergency communication.
- Designing a compact PCB-based version to enhance portability, wearability, and user mobility.
- Including additional physiological sensors (e.g., heart rate, oxygen saturation) to support multi-parameter health monitoring.
- Exploring cloud-based monitoring dashboards for broader caregiver access and clinical integration.
- A subsequent phase will involve collaboration with clinical partners to validate the system under medical supervision with appropriate ethical approval and patient consent.

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Authors' Contributions

In this study, authors contributed equally to the study.

Competing Interests

The authors declare that they have no conflict of interest.

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