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Epileptic Seizure Detection Using Wearable Sensors and the Internet of Things: A Simulation-Based Proof of Concept

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ABSTRACT

Purpose: This study reports the design, implementation, and simulation-based evaluation of the proposed system as a proof of concept for real-time epileptic seizure detection and emergency alerting.

Materials and Methods: The system integrates a MAX30105 sensor for heart rate and blood oxygen saturation, an MPU6050 accelerometer/gyroscope for motion detection, a GPS module for location tracking, an OLED display, and an ESP32 microcontroller hosting a threshold-based multi-sensor detection algorithm. Upon detecting concurrent abnormal physiological and motion patterns, the system activates the GPS module and transmits emergency alerts through the Telegram Bot API. Five healthy volunteers participated, and evaluation followed a controlled simulated-seizure protocol reproducing abnormal heart rate, oxygen desaturation, and convulsive movements.

Results: Under normal conditions, all readings remained within expected ranges with no false alarms. During simulated seizure trials, the system accurately detected abnormal motion and physiological patterns in all participants, activated GPS tracking, and delivered emergency alerts in real time, confirming functional reliability and responsiveness.

Conclusions: The findings validate the feasibility of the proposed wearable system as a proof of concept for seizure detection and emergency alerting. Clinical validation, adaptive machine-learning detection, and improved robustness are recommended for future work. *(J Multidiscip Eng 2026;1:118-124)*

Keywords: Epileptic seizure detection, wearable healthcare devices, Internet of Things, physiological parameters, multi-sensor monitoring.

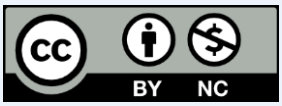
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1. INTRODUCTION

Epilepsy is one of the most common chronic neurological disorders worldwide, characterised by recurrent, unprovoked seizures arising from abnormal electrical activity in the cerebral cortex.[1] Although many patients respond well to medication, seizure control remains incomplete in a substantial proportion of cases, and unpredictable or nocturnal events continue to expose patients to injuries, psychosocial burden, stigma, and an elevated risk of premature death, including sudden unexpected death in epilepsy (SUDEP).[2-6] Timely detection and intervention are therefore critical, yet conventional monitoring approaches such as video-electroencephalography (EEG) are resource-intensive and restricted to hospital settings, leaving patients largely unmonitored in daily life.[7]

In response, wearable sensors combined with Internet of Things (IoT) technologies have emerged

as a practical route toward continuous, non-invasive, remote monitoring. Modern wearable devices can acquire heart rate, blood oxygen saturation, motion patterns, and electrodermal activity in real time, while IoT connectivity enables data transmission to caregivers and clinicians for immediate action.[2,8] Machine learning has further advanced this field, with hybrid support vector machine models reaching classification accuracies of up to 99.4% on EEG signals[9] and wrist-worn multisensor studies demonstrating area-under-curve values as high as 0.995 across nine seizure types.[10] Hardware-oriented prototypes have likewise shown promise: an Arduino-based wearable belt using heart rate, electromyography, blood oxygen, and accelerometer signals triggered reliable alarms under simulated conditions;[11] an IoT monitoring platform reported detection accuracies between 83% and 98.9% using ECG, EMG, accelerometer, and temperature sensors,[8] and a wristband with an artificial neural network achieved 100% sensitivity for nocturnal tonic seizures with an average detection latency of 14.1 seconds.[11,12] More recently, edge-based IoMT devices running random forest classifiers on an ESP32 reported 95% accuracy with under 4% false positives,[12] while fuzzy-logic IoT systems achieved 94% accuracy with automatic GPS-enabled notifications.[13] Federated-learning wristbands have additionally addressed privacy concerns in convulsive seizure detection.[14]

Despite this progress, many proposed systems remain computationally demanding, power-hungry, or dependent on cloud infrastructure, limiting their suitability for continuous, low-cost, wearable operation. The present study addresses this gap by designing and evaluating a compact, low-complexity wearable system that integrates physiological sensing, motion analysis, GPS location tracking, and instant Telegram-based alerting on a single ESP32 platform. Rather than pursuing algorithmic complexity, the system adopts a threshold-based multi-sensor strategy that is intentionally simple enough for real-time execution on resource-constrained hardware. This article reports the design, implementation, and simulation-based evaluation of the proposed system as a proof of concept for real-time epileptic seizure detection and emergency alerting.

2. MATERIALS AND METHODS

2.1. System Overview

The proposed epileptic seizure detection system was built around an ESP32 microcontroller (Espressif Systems) serving as the central processing unit, interfaced with a MAX30105 optical sensor for heart rate and blood oxygen saturation (SpO_2), an MPU6050 six-axis accelerometer/gyroscope module for motion and orientation detection, a NEO-6MV2 GPS module for patient location tracking, and a 128×64-pixel OLED display for local visual feedback. The overall operational workflow of the system is depicted in Figure 1. All components were assembled on a breadboard prototype and subsequently integrated into a wearable wristband enclosure. The total hardware cost was approximately 205 Libyan dinars (≈ 32.8 USD), as detailed in Table 1.

Table 1: Hardware components of the proposed system and their estimated cost.

Component	Quantity	Role in the system	Cost (LYD)
ESP32 microcontroller	1	Data acquisition, processing, decision-making, Wi-Fi connectivity	45
MAX30105 sensor	1	Heart rate and SpO_2 measurement	15
MPU6050 module	1	Accelerometer/gyroscope motion detection	12
NEO-6MV2 GPS module	1	Real-time location tracking	75
OLED display (128×64)	1	Local display of vital signs and alerts	55
Jumper wires	1	Interconnection of components	3
Total	—	—	205



Fig. 1: Workflow of the proposed epileptic seizure detection and alert system.

2.2. Sensor and Communication Configuration

The MAX30105 and MPU6050 sensors were both interfaced through the shared I²C bus of the ESP32, using GPIO 21 (SDA) and GPIO 22 (SCL), and were powered from the 3.3 V rail with a common ground.[15,16] The NEO-6MV2 GPS module communicated with the ESP32 via UART, with its TX pin connected to GPIO 16 and its RX pin to GPIO 17, and was supplied at 5 V.[17] The OLED display was attached to the same I²C bus and rendered heart rate, SpO_2, system status, and alert information in real time. Firmware was developed in C++ using the Arduino IDE, while a web-based user interface was created with HTML and JavaScript, and a Python backend handled data management and communication with the ESP32.

2.3. Detection Algorithm and Alert Mechanism

The detection strategy relies on a threshold-based multi-sensor algorithm executed directly on the ESP32. The MAX30105 continuously acquires photoplethysmographic signals from which heart rate and SpO_2 are derived, while the MPU6050 streams three-axis acceleration and angular velocity data. The ESP32 filters the incoming signals and compares the extracted parameters with predefined thresholds. A seizure event is declared only when abnormal physiological values (elevated heart rate and/or reduced SpO_2) and abnormal motion patterns (sudden acceleration indicative of a fall, or sustained high-frequency repetitive

movement indicative of convulsions) occur simultaneously and persist for a defined duration. Upon detection, the system activates the GPS module, retrieves the patient's geographical coordinates, and dispatches an HTTP request through the ESP32's built-in Wi-Fi to the Telegram Bot API, which delivers an emergency alert containing the event status, timestamp, and live location to the caregiver's Telegram account. The system then automatically resumes continuous monitoring. The complete workflow is summarized in Figure 1.

2.4. Study Sample and Simulated Seizure Protocol

Because genuine seizures are infrequent, unpredictable, and cannot ethically be induced, the system was evaluated using five healthy volunteers (three females, two males; aged 15–49 years) with no history of epilepsy or neurological disease. A controlled simulated-seizure protocol was designed to emulate seizure-associated patterns: heart rate values within a normal range of 65-95 beats per minute (bpm) with occasional elevated values, SpO_2 within 95-99% under normal conditions with lower values representing oxygen desaturation, and motion patterns generated with the MPU6050, including sudden acceleration for fall-like events and continuous high-frequency vibration with repetitive shaking for convulsive activity. A simulated seizure was registered when abnormal motion persisted beyond a preset time threshold and coincided with abnormal physiological values.

2.5. Experimental Procedure

Each participant wore the device on the wrist. After power-on, the ESP32 initialised all sensors and communication modules, and baseline physiological and motion data were recorded while the participant rested. Participants then performed the predefined simulated-seizure movements. Throughout each session, the system continuously acquired, processed, and evaluated sensor data in real time; upon simultaneous threshold violations, it classified the event as a seizure, captured the GPS location, and transmitted a Telegram emergency alert, after which monitoring resumed automatically. The study followed ethical research principles: all participants were informed of the study purpose, procedures, and data types, no real seizures were induced, and confidentiality was maintained throughout.

3. RESULTS

Under normal monitoring conditions, heart rate ranged from 86 to 93 bpm and SpO_2 from 95% to 98% across the five participants, and no falls or seizure events were registered, indicating stable operation without false alarms (Table 2).

During simulated seizure trials, the MPU6050 consistently captured the abnormal and repetitive motion patterns, and the concurrent physiological deviations triggered seizure classification in all five test cases (Table 3). In every case, the GPS module was successfully activated, accurate latitude/longitude coordinates were retrieved, and an emergency alert containing heart rate, SpO_2, and location information was delivered to the caregiver's Telegram account in real time. Following each alert, the system returned to continuous monitoring without manual reset.

Table 2: Sensor readings recorded from participants under normal resting conditions (no simulated seizure).

Subject	Age years	Gender	Heart rate bpm	SpO_2 %	Fall detection	Seizure detection
1	49	Female	93	96	None	None
2	18	Male	86	97	None	None
3	15	Male	92	98	None	None
4	23	Female	90	98	None	None
5	21	Female	92	95	None	None

4. DISCUSSION

The findings demonstrate that a low-complexity, threshold-based multi-sensor strategy can reliably distinguish normal physiological states from seizure-like events in a wearable IoT platform. During routine monitoring, all parameters remained

within physiological ranges and no false alarms occurred an essential property for user acceptance and long-term wearability, since excessive false positives are a well-known cause of alarm fatigue and device abandonment in seizure monitoring.[8,10] Under simulated seizure conditions, the system consistently detected the concurrent motion and physiological abnormalities, activated GPS positioning, and delivered instantaneous Telegram alerts, confirming end-to-end functional reliability.

Table 3: System response during simulated epileptic seizure conditions.

Subject	Age (years)	Gender	Heart rate (bpm)	SpO_2 (%)	Fall detected	Seizure detected	GPS activated	Alert sent
1	49	Female	92	96	Yes	Yes	Yes	Yes
2	18	Male	75	97	Yes	Yes	Yes	Yes
3	15	Male	86	97	Yes	Yes	Yes	Yes
4	23	Female	93	95	Yes	Yes	Yes	Yes
5	21	Female	74	98	Yes	Yes	Yes	Yes

The multi-sensor design proved to be a central strength. Relying on simultaneous violations of motion and physiological thresholds rather than any single signal mirrors the logic adopted by Alzghoul et al., whose wearable belt required two or more sensor parameters to exceed preset limits before alarming,[11] and by Hassan et al., who fused heart rate, temperature, muscle spasm, and fall signals through fuzzy logic.[8] Compared with machine-learning approaches, which demand substantial labelled datasets and computational resources for example, the random forest edge model of Raman and Velmurugan reaching 95% accuracy,[12] the artificial neural network of Larsen et al. achieving 100% sensitivity for nocturnal tonic seizures,[18] or the convolutional network benchmark of Basavaiah et al. at 95.3%[19] the present threshold-based design offers simplicity, minimal power consumption, and real-time operation directly on the ESP32, at a total hardware cost of roughly 33 USD. These properties make it particularly attractive for low-resource settings and continuous home monitoring.

Several limitations must nevertheless be acknowledged. The evaluation relied on simulated seizures performed by healthy volunteers, so detection performance on genuine, clinically heterogeneous seizures remains unverified a limitation shared with comparable early-stage prototypes.[11,12] Inter-individual variability in physiology and movement, as well as everyday activities such as exercise, may mimic seizure patterns and could increase false alarms in real-world deployment. The GPS module also showed reduced accuracy indoors, where signal attenuation can compromise location precision, and reliable Telegram alerting presupposes stable internet connectivity, which is not guaranteed in all environments. Finally, the threshold-based algorithm is inherently static; adaptive, personalised machine-learning detection is likely to improve robustness as larger datasets become available.[2,9,20]

5. CONCLUSION

This study presented the design and simulation-based evaluation of a wearable IoT system for epileptic seizure detection and emergency alerting. By combining heart rate, blood oxygen saturation, and motion sensing with GPS location tracking and instant Telegram notifications on a single low-cost ESP32 platform, the system reliably differentiated normal from seizure-like conditions, generated no false alarms during routine monitoring, and successfully delivered location-tagged emergency alerts in every simulated trial. Although clinical validation with genuine patients is still required, the results establish a solid, affordable proof of concept for continuous seizure monitoring. Future work will integrate additional sensors such as temperature, ECG, and EEG; improve enclosure design for comfort and durability; adopt artificial intelligence

techniques for adaptive and personalised detection; and develop fallback alert channels such as SMS to guarantee reliable notification when internet access is limited.

AUTHOR CONTRIBUTIONS

All authors contributed equally for: Conceptualization, methodology, writing – original draft, investigation, data curation, validation, manuscript preparation, critical review, writing – review & editing, and final approval of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest concerning the research, authorship, and publication of this article.

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