# A Comprehensive Review of Epileptic Seizure Prediction using Medical Internet of Things

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## ABSTRACT

A neurological disorder in the nervous system is a structural, biochemical or electrical abnormality in the brain or spinal cord. Epilepsy is the most common disorder among various neurological disorders, and recurrent epileptic seizures characterize it. A seizure is a period of symptoms due to excessive neuronal activity in an abnormal manner. Seizures are either due to provoked conditions like blood sugar, brain infections, and fever or unprovoked conditions like stress or sleeplessness. The reliable prediction of epileptic seizures involves pre-processing of signals from EEG sensors by enhancing the signal to noise ratio. By recording the brain's electrical activity using electrodes attached to the brain, epilepsy has been diagnosed. Nowadays, IoT based epilepsy detection is the most common real-time diagnostic procedure for detecting abnormalities in the brain using EEG sensor data. The involvement of sensors and IoT in medical healthcare research implementations can improve the diagnosis and detection of brain abnormalities which results in the enhancement of smart healthcare research. The high-end device utilization affects high energy consumption, leading to prolonged diagnostic decisions. The signal quality analysis process lags due to less concentrated research in classification and detection. The delay and error rate has to be reduced by concentrating more on energy management. An energy-efficient epileptic seizure prediction framework using EEG sensor data has been proposed to resolve and reduce such issues. The energy utilization of the epileptic seizure prediction using the Medical Internet of Things (MIoT) will be optimized. The trade-offs between accuracy, reliability, and delay of the effective energy-optimized epileptic seizure prediction using the MIoT framework will be enhanced.

Keywords: IoT, Epileptic seizures, Medical IoT, EEG sensor, neurological disorder.

**The general explanation of epileptic seizures**

Clinical symptoms of epileptic seizures are triggered by improper synchronization and fast neuronal activity in the brain. Around 50 million individuals worldwide suffer from a neurological condition characterized by epileptic seizures caused by the brain cells' active electrical activity. These epileptic seizures may have neurological, physiological, social, and cognitive effects resulting from the loss of consciousness. In the absence of adequate monitoring and diagnosis, they can even lead to death [1]. Emotional anguish is also common in persons with epileptic seizures because they are embarrassed by their condition or lack the proper social standing. Early detection of seizures may help people with epilepsy and improve their quality of life [2]. Diagnoses are the most important component of a person's daily existence. A timely and accurate diagnosis can save a person's life. As a result, the medical research community is devoted for improving diagnostic and treatment applications. Epilepsy is a disorder that is notoriously difficult to diagnose accurately [3]. The most typical signs of epileptic seizures are jerking movements, loss of consciousness, a short period of blank gazing, and bewilderment. In spite of modern technology such as robotics, wireless transmission of data from embedded sensor nodes to extract data from the human brain, the Internet of Things (IoT), and so on, epileptic seizures are difficult to detect visually because of the disparity in their symptoms [4]. Around 50 Million people worldwide suffer from epilepsy, a condition that is often misunderstood because of cultural and anthropological biases [5]. Epilepsy that affects the whole brain and disrupts the normal functioning of all of the brain's neurons is known as general epilepsy. Neurons in the hemisphere where epilepsy occurs produce focal epilepsy in partial epilepsy [6]. To determine whether someone has epilepsy, doctors will often do a thorough physical examination and other diagnostic tests, including blood test, Electroencephalograms (EEGs), and various imaging techniques including positron emission tomography, magnetic resonance imaging, and computed tomography (PET) scans. Since it can identify electrical anomalies with temporal clarity, the EEG is the most extensively used instrument for epileptic seizure diagnosis [7]. Patients with epilepsy discovered at an early stage and treated with medication and surgery are expected to enjoy seizure-free lives. Computed Tomography (CT), EEG, MRI, and PET are some of the most often

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used non-invasive procedures to diagnose epilepsy [8]. Most epilepsy patients are effectively treated with surgery and antiepileptic medications (AEDs), but approximately one third do not respond [9]. The electrical activity of neurons is recorded and presented as EEG data in a therapeutic setting. These biological signals are very challenging to analyze manually. Long-term EEG recordings need a neurologist's constant availability, which is impossible with manual EEG signal assessment [10]. Anti-seizure medications may be used to manage seizures. Thirty percent of epilepsy patients do not respond to anti-seizure medications as intended. Side effects of anti-seizure medications are also present. Epilepsy patients benefit from seizure prediction because it helps them prevent harm caused by seizures and enhances their quality of life [11]. They may be difficult to identify because of their similarities to ES and the nonspecific abnormalities seen in these individuals' neurophysiological and radiological workup. Other factors contributing to the delay in diagnosis include doctors' lack of familiarity with FS, the negative connotation connected with their diagnosis, and insufficient diagnostic facilities [12]. Many studies have shown that the frequency components in EEG signals may fluctuate over time, and hence time-frequency analysis approaches have been designed to circumvent this constraint [13]. It is common for a neurologist to diagnose epilepsy based on EEG records, but the method is lengthy and costly. The manual seizure diagnostic procedure might take a day to distinguish the EEG patterns of pre-ictal, ictal, and inter-ictal seizures [14]. Using wireless headsets to record EEG data for ambulatory use cases is still challenging despite recent improvements in sensor design, low-energy wireless transmission, and affordable processing gear. may conceal the precise nature of clinical indicators since it is susceptible to motion-related distortions [15].

**Previous work related to the prediction of epileptic seizures (Related Work)**

Shiqi Zhao et al. (2021) [16] proposed that seizure prediction may improve quality of life and reduce anxiety for drug-resistant epilepsy patients. When it comes to diagnosing and predicting seizures, various Deep Learning Algorithms (DLA) have been suggested. These approaches are not only resource and parameter-intensive, but also quite power-consuming. As a result, these approaches are not suitable for wearable, low-power medical devices. The gadgets should constantly inform patients with epilepsy. This research focuses on developing methods for predicting epileptic seizures that are both energy efficient and hardware-friendly. Khansa Rasheed et al. (2020) [17] discussed that the researchers were attempting to use Artificial Intelligence (AI) and Machine Learning (ML) approaches to improve clinical practice. This was particularly true with epilepsy, marked by frequent and unpredictability convulsions. It was possible to alleviate the negative effects of epileptic seizures if they could be foreseen. However, after decades of study, seizure forecasting was still a mystery, and this was likely to persist due to the absence of data available to address the issue. AI based systems have recently made significant progress in predicting epileptic episodes.

Barkin Buyukcakir et al. (2020) [18] suggested for those with epilepsy; a seizure prediction system was vital for managing their condition. The Hilbert Vibration Decomposition (HVD) approach would be used to construct and demonstrate utilizing surface EEG recordings from 10 patients from the CHB-MIT database, a non-patient-specific seizure prediction algorithm. With the HVD in sliding windows, 18 EEG channels were broken into seven subcomponents. After that, features for an MLP classifier are calculated using the subcomponents from all of the input channels. All patients were categorized simultaneously, and the classifier was not given any knowledge about the patients' identities. The classification was followed by developing an alert system that determines the frequency with which pre-ictal predictions were made.

Yankun Xu et al. (2020) [19] described that conventionally, seizure prediction relies on EEG records and classification methods like regression and Support Vector Machines (SVM). Although these approaches may be used to make accurate predictions, they were constrained because they rely on hand-crafted features and regression and SVM algorithms, which have limited classification abilities. Convolutional Neural Networks (CNNs) are proposed in this research as an end-to-end solution for deep learning. Kernels of one and two dimensions are used in the early and the later stages of convolution and the max-pooling layer.

Zuyi Yu et al. (2018) [20] stated that effective seizure prediction system may improve the quality of life and offer new treatment options for epileptic patients. As a result of this research, a novel strategy for seizure prediction is offered that combines LMD and CNN. Decomposing raw EEG data into a series of product functions is done first using the LMD (PFs). The deep CNN is then used to automatically train three PFs (PF2–PF4) on the EEG characteristics. The principal component analysis reduces redundant characteristics from the data recovered by the CNN to acquire the most significant information.

Itaf Ben Slimen et al. (2020) [21] developed a technology that can identify these signs, forecast seizures and improve the quality of life for epilepsy patients. In order to explain the frequencies, forms, and amplitudes of seizures—all of which are impacted by the commencement of a seizure—various epileptiform discharges, such as varied spike patterns, are widely employed. A Spike rate is employed in this research to indicate impending seizures in the EEG data. A mean filter follows Inter-ictal, pre-ictal, and ictal EEG spike detection to reduce the number of spikes. During inter-ictal phases, the maximal spike rate is employed to predict seizures. An alert is sounded when the number of pre-ictal spikes surpasses the threshold.

Anibal Romney et al. (2020) [22] focused on the most unpleasant and distressing features of the condition: the psychological load of uncertainty around the incidence of spontaneous seizures. The need for a non-invasive prediction system that stops epileptic seizures persists despite the advances achieved in this sector. Patients and recordings of EEG produce constantly changing signals. A frontal-temporal electrode channel based on EEMD and relief techniques was proposed to address these issues. This was done using the EEMD, which breaks down the ictal data frame into its choosing the most important oscillatory components utilizing relief after selecting intrinsic mode functions.

Yanli Zhang et al. (2020) [23] prepared a study of the EEG's characteristics based on roughness-length approach used to analyze EEG signals' structural complexity and amplitude roughness in various stages to detect antecedents of epileptic episodes. For this purpose, it has been created a patient-specific seizure prediction system that utilizes the considerable changes in both the dimensions and intercepts seen in the pre-ictal phase about those observed in the inter-ictal phase. The probabilistic outputs of the trained gradient boosting classifier are further processed to distinguish between pre-ictal and inter-ictal EEG and to provide seizure warnings using threshold comparison and rule-based judgment.

Toshitaka Yamakawa et al. (2020) [24] stated that epileptic patients may benefit from warnings before seizures begin. Analyzing the viability of a wearable device that used machine learning to predict epileptic seizures was done. The R-R intervals of an Electrocardiogram (ECG) were continuously measured using an original telemeter. Heart rate variability is measured using R-R intervals, and the smartphone app uses multivariate statistical process control to monitor the indices in real-time. Using seven epilepsy patients, the suggested approach was tested. When compared to a standard ECG, the R-R interval measurement performed well enough for heart rate variability analysis.

Abdalla Gabara et al. (2020) [25] discussed that previous studies have looked at EEG signals for Using machine learning and deep learning models, identify and forecast seizures, such as SVM and CNN. By building realistic hardware-implementable ML classifier models, seizure onsets may be predicted with high accuracy and sensitivity. Each patient's EEG data is processed individually to extract the features, which are then fed into an SVM classifier trained on the resulting feature sets.

Jie Yang et al. (2020) [26] proposed that the unpredictability of seizures was a key issue for most epileptic patients. Therefore, accurate seizure prediction may considerably impact their quality of life. Today, the advancement of algorithms, notably in ML, allows desktop computers to anticipate seizure activity accurately. Research efforts have been focused on constructing Integrated Circuits (ICs) for seizure detection; nevertheless, no specific seizure prediction integrated circuits have been constructed. To assist transform scientific theory into a more practical, intelligent, integrated, and low-power system for epileptic patients, it is possible to study system design, analog and digital integrated circuits, and machine learning algorithms cross-disciplinaryly.

Fengshi Tian et al. (2021) [27] prepared CNNs that have been used to predict seizures with great specificity and sensitivity. The downside of CNNs was that they need a lot of processing resources and are quite power-hungry. Because of these drawbacks, it was difficult to deploy CNN-based algorithms on wearable devices. The goal of this study was to develop an energy-efficient neuromorphic computing method for seizure prediction. Spiking Neural Networks (SNNs). EEG spike sequences were generated using a customized gaussian random discrete encoder. Predictions were made in a CNN (Spiking-CNN) that incorporates the benefits of both CNN and SNN.

Anup Das et al. (2020) [28] focused on pre-ictal the patient's variability and global spatiotemporal dynamics. Large brain parts are left undetected by ECoG electrodes, which exclusively record from the cortex. A precision matrix that is sparse-plus-latent-regularized (SLRPM) technique, which calculates connectivity using partial correlations of the conditional statistics of the observable areas given the latent regions, was utilized to determine brain connection. The pre-ictal durations of all of the patient's seizures were used to quantify the degree of heterogeneity in their brain connections as measured by Eigenvector Centrality (EC).

Various literature survey is carried out in this article. Their advantages and disadvantages are summarized and listed in table 1.

**Table 1: Advantages and disadvantages of the above research works**

| Authors | TITLE | ADVANTAGES | DISADVANTAGES |
|---|---|---|---|
| Shiqi Zhao et al [16] | Energy-Efficient Neural Network for Epileptic Seizure Prediction | For scalp EEG and intracranial EEG, low-power wearable and implanted devices, for example, need energy consumption that is between 10 mJ and 0.5 mJ per inference, respectively. | More usage of wearable devices leads to less model compression |
| Khansa Rasheed et al [17] | Machine Learning for Predicting Epileptic Seizures using EEG Signals: A Review | New breakthroughs in Effective and precise epileptic seizure prediction may undergo a paradigm shift thanks to machine learning-based systems. EEG signals can be used to predict seizures at an early stage, and the most current machine learning algorithms were discussed. | Annotation performance should be taken into account in the creation of future models for Epileptic Seizures prediction utilising Machine Learning techniques |
| Barkın Büyükçakır et al [18] | Hilbert Vibration Decomposition-based epileptic seizure prediction with neural network | Within 120 minutes of the alert being produced, an estimated false alarm rate of 0.081/h was reached, with a 4 minute seizure prediction horizon for all individuals.<br><br>When it comes to predicting epileptic seizures, this study shows a clear advantage to using an epileptic seizure warning system that is both robust and dependable. | Various classifiers would need to be evaluated in the future in order to draw more accurate conclusions. To further support the Hilbert Vibration Decomposition's applicability for epileptic seizure prediction using EEG data, it was necessary to examine other signal decomposition methods and conduct efficiency comparisons. |
| Yankun Xu et al [19] | An End-to-End Deep Learning Approach for Epileptic Seizure Prediction | On Kaggle intracranial and CHB-MIT scalp EEG datasets, the suggested CNN model is assessed. The suggested approach outperforms current best practises in prediction, as shown by comparisons with leading-edge research. | The anticipated hardware-oriented implementation's estimated area grows, the power consumption usage increases with more execution time. |
| Zuyi Yu et al [20] | Epileptic seizure prediction based on local mean decomposition and deep convolutional neural network | The experimental findings demonstrate that the suggested seizure prediction technique has a high sensitivity of 87.7% and a low false positive rate of 0.25/h using the Freiburg dataset. This method's FPR is too high, and the prediction alert would sound incorrectly once every 4 hours or so. | More continuous EEG data and network adjustments to lower the FPR is not achieved and lesser efficiency is obtained |
| Itaf Ben Slimen et al [21] | Epileptic seizure prediction based on | In this study, the electroencephalogram (EEG) signal's spike rate is used as a | An epilepsy prediction device should use a simple |

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| | EEG spikes detection of ictal-pre-ictal states | predictor of seizures. The proposed method, which relied on the CHB-MIT database, was able to accurately predict seizure onset in 92% of cases. | and clear method to verify the accuracy of a seizure prediction algorithm before it can be utilized. |
| Aníbal Romney et al [22] | Comparison of Frontal-Temporal Channels in Epilepsy Seizure Prediction Based on EEMD-ReliefF and DNN | Seizure prediction and early identification of patient-specific EEG signals can be performed by a deep neural network (DNN) model that learns Non-fontal-temporal seizure behaviors. The model as a whole produces an average sensitivity and specificity of 86.7% and 89.5%. | Further investigations are needed to prove that the detection and prediction results can be used in the treatment of epilepsy patients. |
| Yanli Zhang et al [23] | Roughness-Length-Based Characteristic Analysis of Intracranial EEG and Epileptic Seizure Prediction | Metrics for the fractal dimension and intercept can effectively forecast the incidence of seizures. The authors' findings also serve as a guidance when it comes to selecting the smallest window size for use in computing fractal dimensions and amplitude roughness | One drawback is the lack of investigation into the impact of artefacts and paroxysmal action on the assessment of fractal dimension and amplitude roughness. |
| Toshitaka Yamakawa et al [24] | Wearable Epileptic Seizure Prediction System with Machine-Learning-Based Anomaly Detection of Heart Rate Variability | The wearable system's ability to forecast a seizure in actual environments and operate continuously would enable for applications in the real world. | As long as the multivariate statistical process control model is active, patient data can be used to refine it. For example, this may help to increase the model's sensitivity and adaptability when it comes to a patient's natural condition.<br>But the proposed method is not implemented in the real-world settings of epilepsy patients. |
| Abdalla Gabara et al [25]<br>25 | Patient-Specific Epileptic Seizures Prediction based on Support Vector Machine | Predictive SVM models were lowered in difficulty by deleting key channels from the feature extraction stage and restricting the feature extraction stage to a minimal range of features for each patient while keeping a high effectiveness level for each patient in this research. | It is, however, more difficult to create generic classifiers for more than one patient because of the unique nature of epilepsy. |
| Jie Yang et al [26] | From Seizure Detection to Smart and Fully Embedded Seizure Prediction Engine: A Review | Solution architecture, The study of analog and digital integrated circuits, as well as machine learning methods, according to the authors, to help translate scientific theory into a more realistic, integrated, and power-efficient system for epileptic patients. | As long as the remaining hurdles are overcome, the major improvements are expected in the quality of life for epileptic patients. |
| Fengshi Tian et al [27] | A New Neuromorphic Computing Approach for Epileptic Seizure Prediction | The temporal Gaussian random sparse encoding method has been presented for encoding the raw EEG into spike sequences, together with all the necessary modules for energy-efficient forecasting of epileptic seizures. | As a result of the uneven training sample, the trained model may perform poorly because of the imbalance in the raw EEG data. |
| ANUP DAS et al [28] | Heterogeneity of Pre- | ECoG recordings of the human brain's | Due to the fact that only a |

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| | ictal Dynamics in Human Epileptic Seizures | preictal broadband connection was examined using a network-based technique to tackle the development of seizure. | portion of the cortex was recorded The sparse-plus-latent-regularized precision matrix (SLRPM) technique was used to estimate brain connections using ECoG electrodes. It establishes connections through partial correlations of the conditional statistics of the visible areas given the latent regions that are not yet discovered. |

The epilepsy system detects the sleep patterns of people with epilepsy during the night. Using specialized sensor technology, it is possible to tell the difference between a typical person's motions in sleep and an epileptic seizure. An EEG measures electrical impulses in the nervous system throughout a testing session. The electrical activity in a person's brain alters during an epileptic seizure. The epileptiform brain activity is used to designate this kind of alteration in brain activity. However, in this research, the authors explained the epileptic seizures prediction using EEG sensors with the help of medical IoT.

## Conclusion

Epileptic seizures and other neurological problems affect a large number of individuals nowadays. People with epilepsy should receive early diagnosis of seizures to improve their quality of life and self-confidence. Numerous studies have been conducted on the various methods of diagnosing epileptic seizures. Automatic EEG epileptic seizure detection and categorization methods were examined and evaluated in this work. Inter-ictal intervals of EEG signals may also be used to identify the early stages of seizures to administer medicine to the patient to avoid seizures. The appropriate structure should be selected depending on the information and issue features, such as the necessity for authentic diagnosis or minimally acceptable reliability or even the usage of well before systems. This topic of study needs additional research that integrates several screening approaches to identify epileptic seizures more accurately and quickly. This study reviewed the existing literature and discussed the importance of early epileptic seizure prediction and the methods used. According to this study, prior surveys tended to concentrate on developing prediction algorithms rather than expanding beyond EEG analysis.

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