

EEG Signal Analysis based Detection and Prediction of Epileptic Seizure: A Review

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Abstract—This paper presents a review on the analysis of Electroencephalogram (EEG) for detection and prediction of seizures in patients who are suffering from epilepsy. Epilepsy analysis requires the patient to be on bed for acquisition of the EEG and these signals are studied by practitioners to identify its preictal, ictal and interictal stages which help in the diagnosis of epileptic seizures. With an automation of the detection of these stages and the spikes that are an indication of seizure occurrences, it would be helpful in the early and timely prediction of seizure and also with the continuous monitoring of patients in the ICU. Based on previous studies that have been conducted to develop an automated seizure prediction mechanism from EEG signals it is evident that early prediction of epileptic spikes is crucial. Literature reveals that the signals from an EEG are first preprocessed, to remove noise and other artifacts and then the signals are subject to the feature extraction and classification. The spikes in the signal are identified based on the frequency and amplitude of the signals. Most of the works in this area is centered on the use of Power Spectrum Analysis and Machine learning approaches for analysis and processing of the signals.

Index Terms— Electroencephalogram (EEG), Epilepsy, Seizure, Spike, Machine Learning, Power Spectrum Analysis.

I. INTRODUCTION

Epilepsies are a heterogeneous group of neurological disorders and syndromes characterized by recurrent, involuntary, paroxysmal seizure activity, typically associated with a clinico-electrical correlation on the electroencephalogram (EEG). The diagnosis of epilepsy can be made, following events of two or more unprovoked seizures. In the absence of a reliable trained practitioner, diagnosis in the early stages of the onset of this disease is almost impossible, which may delay initiation of treatment. The interpretation of EEG signals is currently performed by trained clinicians which is time consuming. The advancement in the automation of the seizure detection and prediction [1] led to a breakthrough in minimization of the time taken.

Traditionally, suspected seizures are evaluated using a routine EEG, which is a test that detects electrical activity in the brain using electrodes attached to the scalp. Since this is a short duration test, it is uncertain that actual events are recorded. Fig 1. (a) depicts the process used to acquire the EEG signal data from patients using scalp Electrodes. The signals are obtained using multiple electrodes. Epilepsy is a chronic neurological disorder characterized by recurrent seizures, which are sudden and unprovoked electrical disturbances in the brain. As shown in Fig 1. (b) the recorder signals contain interictal, preictal and ictal stages of epilepsy, including spikes, sharp waves, or spike-and-wave complexes.

Identifying and classifying these different stages of epileptic activity, is crucial for effective diagnosis, treatment planning, and seizure prediction as they contain the brain activity, between seizures, before a seizure and during a seizure respectively.

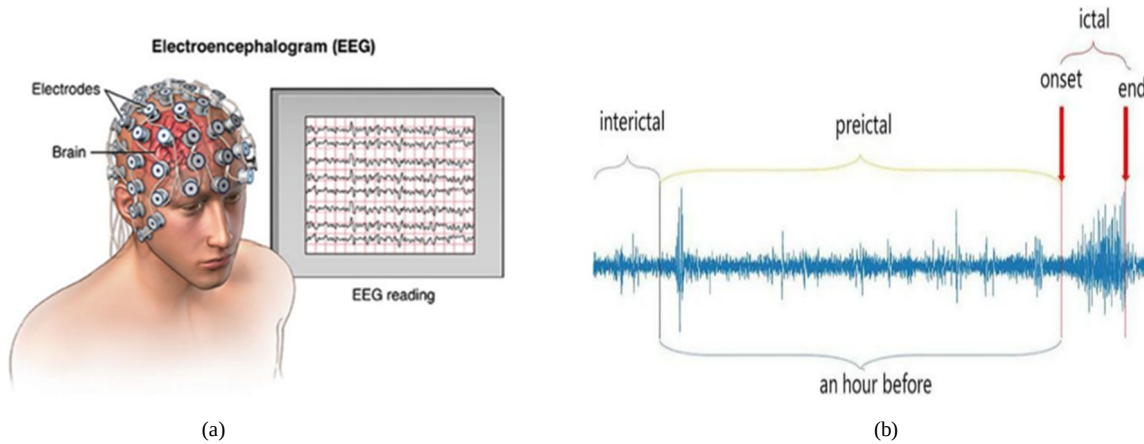


Fig 1. (a) EEG acquisition process. (pc: Siuly et. al., [44]), (b) EEG signal showing the Interictal, preictal and ictal stages. (pc: Wei et. al., [45]),

The monitoring of the patient is done as an Inpatient procedure through continuous recording and observation of the EEG signal activity [2]. Billions of neurons are interconnected throughout the body making the human system complex in nature. This accounts to the nature of the EEG signals to be perplexed, non-linear, nonstationary, and non-deterministic. The signal is composed of Sine and Cosine components which are decomposed using Fourier transforms [3] into their different frequency bands [4] as detailed below:

- Delta (<4Hz): Deep sleep stage of a normal adult.
- Theta (4-8Hz): Normal infants and children as well as during drowsiness and sleep in an adult.
- Alpha (8-14Hz): Normal adult during relaxed and mentally inactive awakens.
- Beta (14-30Hz): It is enhanced by expectancy state and tension.
- Gamma (>30Hz): Usually it is not of clinical and physiological interest therefore often filtered out in EEG recording.

High - amplitude, high - frequency synchronized waveforms characterizes the scalp EEG of epileptic patients during seizure. Methods like Chaotic nonlinear dynamics (Lyapunov exponents) wavelet [5, 6] and complexity analysis (entropy) [7–11] have been proposed to analyze seizure discharges by many researchers. To analyze the fundamental and harmonic frequencies the time – frequency based techniques like short-time Fourier transforms [12–14] and transforms [15] are commonly used. An integrated approach using the above specified methods have also been proposed by researchers [16, 17] for seizure detection by analyzing specific EEG sub bands. For classification of normal and seizure events neural networks and adaptive neuro fuzzy systems supporting the self-training capability, [11][13][16–20] have also been utilized.

II. BACKGROUND STUDY

Background study based on Classification, Detection and Prediction of seizures from EEG signal reveals that plenty of literature is available in this area. The basic idea behind classifying the EEG signal into its various stages include frequency decomposition of the signal which are then analyzed to identify the signal patterns. Many researchers have contributed to this study, of which a brief on the recent works has been presented below. Kumar et.al.[21] in their work have developed an expert system for diagnosis of seizures by classifying the signals using Wavelets and machine Learning approaches. Working on the EEG signals recorded during different cognitive conditions, Hafeez Ullah Amin et. al., [22] have discussed the applicability of pattern recognition in discrimination of the signals.

Jing-Shan Huang et. al, [23] classified EEG signals using sparse representation and fast compression residual convolutional neural networks, by sub-signaling of the EEG waveforms combined with the common spatial patterns to obtain the features of the EEG signal. In the work presented by Apu Nandy et. al, [24] a combination of time, spectral and wavelet domain features were extracted along with the connectivity and entropy based features for detection of seizures. They developed a fully automatic system using the multi-objective evolutionary algorithm and an SVM classifier with a Bayesian optimization function. The logarithm of the Power Spectral Density of the EEG data for each channel was used to extract features in the form of absolute

band powers by Smita Tiwari et al. [25] in their work. They classified and analyzed the EEG signals corresponding to the eight cognitive imagery tasks.

Wen et. al., [26] in their study proposed a deep network model for autonomous learning and classification of EEG signals, that supported self-adaptive classification of EEG signals with different sampling frequencies and lengths. Focusing on extracting the superlative distinguishing features of seizure EEG recordings Aayesha Zia et.al. [27] employed both fuzzy-based and traditional machine learning algorithms for epileptic seizure detection and classification of the EEG signal segments into ictal and interictal stages.

For effective analysis of the signal required for the continuous auto-monitoring of seizures in epileptic patients., the detection of the spikes is an important step. Itaf Ben Slimen et. al, [28] proposed a method based on the spike rate in the EEG signal. Here the number of spikes in all channels over three EEG periods were calculated using the local maximum, given the time interval and amplitude of spike. Singh et. al., [29] have used an Empirical Mode Decomposition and Intrinsic Mode Features obtained thus for extraction of the signal spikes.

Ebrahim and Senan [30] in their paper presented a generalized linear model using SVM and Multi - Layer Perceptrons for classification of seizures from continuous EEG data.

Ding et. al., [31] proposed a target detection using YOLOV3 and CNN model to detect spike waves in EEG. Researches on early prediction of seizures has been carried out decades before by researchers like Salant et al. [32], Drogenlen et. al., [33] and advancements in this area has gained a lot of prominence in the recent times. Gómez, et al., [34] have in their work transformed the time domain signals to frequency domain features by calculating the power spectrum density for a window of 10 seconds. They used a fully convolutional neural network system based on Multilayer Perceptron to detect seizures automatically.

Some of the most recent advancements in the analysis of EEG signal for seizure prediction shows that both time and frequency domain approaches are used for feature extraction. In this regard the study by Zhou et. al., [35] for detecting epileptic seizure activity from EEG signal use Convolutional Neural Network (CNN). By analyzing Freiburg and CHB-MIT databases, they have reported that frequency domain signals outperformed time domain signals in classification accuracy. They have shown a successfully distinguishing between ictal, preictal and interictal states using frequency domain signals. Yogarajan et. al., [36] presents an advanced automatic seizure detection system that utilizes a Deep Neural Network (DNN) and Binary Dragonfly Algorithm (B DFA) model. This system analyses EEG signals to extract key features for identifying seizure activity. It has been stated that the use of B DFA optimizes feature selection, enabling faster training and improved performance. They have claimed to have achieved 100% accuracy, which outperform the existing other methods.

Wong et. al., [37] in their work highlights the significant variability among publicly available EEG datasets used for seizure detection and prediction, analyzing its unique characteristics. By identifying 17 key dataset characteristics, their study offers valuable guidelines for researchers in selecting appropriate dataset for their tasks. In the study by Aslam et. al., [38] the critical challenge involved in predicting seizures in epileptic patient by a 3 step approach using scalp EEG signals has been addressed. Advanced preprocessing is done using a regression-based method for improved signal-to-noise ratio (SNR), handcrafted statistical features, and automated feature extraction via Convolutional Neural Network (CNN). The classification is done using long short-term memory (LSTM) networks, achieving an accuracy of 94% when validated by CHB-MIT dataset.

The paper by Zazzaro et. al., [39] presents an innovative approach to automating seizure detection using EEG signals, addressing lengthy manual analysis performed by Epileptologists. Author developed a versatile tool for feature extraction from time series data, integrating signal processing techniques with a sliding window. Using Support Vector Machine (SVM), they have claimed an accuracy of 99% achieved on publicly available EEG dataset. Alharthi et. l., [40] introduces a framework by combining local EEG signals from epilepsy center into CHB-MIT dataset, it addresses the issue of imbalanced datasets. They have proposed a novel algorithm to read XLTek EEG data and select dominant channels. The combined data was tested using deep learning models such as 1D-CNN, Bi-LSTM, achieving accuracy up to 96%. This system helps to detect epileptic seizures and offers potential future application in wearable devices.

Shoka et. al., [41] provides a study on the challenges involved in the manual analysis of the disorder in EEG data highlighting the need for automation. Various preprocessing techniques, feature extraction methods and classification approaches are discussed by the authors which prove to be helpful for budding researchers. They have also provided an insight into the potentials of integrating IoT with Machine Learning for remote patient monitoring. In yet another work Kantipudi et. al., [42] proposes an automated epileptic seizure detection using advanced signal processing techniques which uses Finite Linear Haar wavelet-based Filtering (FLFH) for signal filtering, Fractal Dimension (FD) for feature extraction, Grasshopper Bio-Inspired Swarm Optimization (GBSO) for feature selection and Temporal Activation Expansive Neural Network (TAENN) for classification. The combined approach is claimed to have improved the detection accuracy and reduce complexity. Kanamaneni et.

al., [43] work reviews deep learning techniques for EEG signal analysis in epilepsy detection, highlighting their potential to improve diagnosis of disorder. Various frameworks like CNN, RNN, hybrid models, attention mechanisms, transfer learning, GAN and ensemble methods have been discussed in their paper. There are numerous more research papers available in this area, all of which emphasize on the fact that there is scope for refinement and further developments that can be achieved in the automation of EEG signal analysis for seizure prediction. Some of the observations made from this study are provided in this paper.

III. FINDINGS AND OBSERVATIONS

- The exploitation of EEG Signals for epileptic seizure prediction and detection has been an area of interest for decades and is gaining prominence in the recent years.
- The analysis of the signals using Machine Learning based approaches like SVM, MLP, CNN and DNN are being widely used for this purpose.
- Using a combination of different techniques for identifying the spikes can help in increasing the accuracy of seizure prediction.
- Classification of EEG signal into pre-ictal, ictal and inter-ictal stages forms the basis for localizing the region prone to contain the information regarding the probability of seizure occurrence.
- From the available literature it is evident that the analysis of EEG signal data using advanced techniques that help in increasing the classification and prediction accuracy are crucial for epileptic region localization and for timely prediction and detection of seizures.
- It has been reported by many researchers that the analysis and classification is best achieved in the frequency domain.
- Automation of EEG signal analysis is crucial. This would be very helpful for real time monitoring of epileptic patients and provide assistance to the duty nurses in the ICU.
- Prediction of occurrence of seizures well in advance can help in the timely treatment of the patient.

IV. CONCLUSION

A comprehensive review of the available researches in the field of EEG signal analysis for prediction and detection of epileptic seizures has been presented in this paper. Based on the observations from the reviewed literature it can be comprehended that automation of the seizure prediction by detecting the spikes in an EEG signal data has gained ample significance among researchers.

A system for continuous monitoring of epileptic patients from real time analysis of Scalp EEG signal data is found to help with the prior detection of the occurrence of seizures thus helping with the planning and treatment of patients. Literature shows that both time and frequency domain techniques along with the classifiers like SVM, CNN, DNN or a combination of various methods have been used for signal decomposing, feature extraction, spike detection and classification. It can hence be concluded that use of more advanced techniques to improve the accuracy of the prediction, development of an EEG auto-monitoring compatible and customized system depending on the doctors' needs would prove to be a great contribution to this area of research.

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