Epilepsy Detection Using EEG Signal and Machine Learning Classifiers: A Survey

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Abstract: Epilepsy is a critical neurological disorder caused by abnormal function of the neurons resulting in unusual behaviour of the patients sometimes at its worst phase results in recurrent seizers and unconsciousness of the patients. Neurons are connected in the complex way and carry the information across different neurons controlling all the organs of the human body. Using electrical and chemical signals, they help to coordinate all the necessary functions of life. The effective tool used to monitor these brain signal in medical diagnosis to detect any sizers is Electroencephalogram (EEG). These signals are complex, noisy, non-linear, non-stationary and produce a high volume of data. Hence, the detection of seizures and discovery of the brain-related knowledge is a challenging task. Machine learning classifiers are able to classify EEG data and detect seizures along with revealing relevant sensible patterns without compromising performance. As such, various researchers have developed number of approaches to seizure detection using machine learning classifiers and statistical features. The main challenges are selecting appropriate classifiers and features. The aim of this paper is to present an overview of different types of machine learning classifiers used in detection of epilepsy using EEG signals.

Keywords: Epilepsy, seizure, Electroencephalogram, machine learning, classifiers

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1. Introduction

The brain is one of the largest and most complicated organs in the human body comprising of billions of neurons. These neurons are highly specialized cells and can be prone to chemical and electrical stimulation easily. The data that passes through the Central Nervous System (CNS) is controlled and processed by various neurons only. One of the chronic neuronal disorders whose occurrence is primarily in brain and affecting approximately 1% of the human population is epilepsy [1]. Epilepsy is a neurological disorder caused by the sudden abnormal discharge of brain neurons. The typical characteristics of epilepsy are recurrent, unconscious body movements, and so on. Uncontrollable seizures are more likely to induce Depression, Cardiovascular disease, and other diseases making patients and their families miserable. The World Health Organization (WHO) report manifests that approximately 50 million people have epilepsy worldwide. Knowing the precursors of epilepsy can allow patients to avoid the pain of epileptic seizures through drug control, so there is an urgent need for simple, fast and effective epilepsy detection methods.

As a consequence of gigantic synchronization of chemical and electrical activity of the neurons, an epileptic seizer is caused. During the seizers, a specific number of neurons discharge in a synchronous manner which results in a very large frequency and amplitude. This sort of synchronized discharges happens because of metabolic disorders, infections, tumours and genetic history. This sort of seizer disorder is one of widely occurred neurological disorder. The clinical symptoms of this epilepsy disorder involve outbursts which are much aggressive in nature like muscle spasms, loss of awareness, rapid eye and muscle movement followed by extreme fatigueness [2].

Electroencephalogram (EEG) is an effective, affordable, communicable techniques used in clinical studies to examine the chemical and electrical activity of the brain. EEG is one of the handy approaches to identify an abnormal function of the brain. Epilepsy is one of the chronic and non-communicable neurological disorder that can be examined using the EEG. This neurological disorder is characterised by the recurrent seizers, an electrical disruption in the brain. These seizures may cause a disturbance in movement, control of bowel or bladder function, levels of consciousness and many other disturbances in cognitive functions.

A seizure is an outburst of the uncontrolled chemical and electrical activity of the neurons in the brain that causes the abnormalities in the muscles, behaviours, sensations and prolonged convulsion. The seizers occurring recurrently and all of sudden are dangerous and lead to the critical states. In clinical examinations if two or more than two motiveless seizers occur, then it might cause epilepsy. If the seizure is owing to epilepsy, then the detection of epilepsy at its initial stage is very useful for early stage of treatment with anti-epileptics for improving the quality of life and care of epileptic persons. The epileptic seizures generally start and end with out any external intrusion. If the seizers occur unpredictably it causes many physical risks due to un expected accidents mainly falling down and resulting in head injuries. The most affordable and effective clinical diagnostic method for epilepsy detection is based on the analysis of EEG signals. EEG analyses not only distinguish epileptic data from normal data, and also differentiate epileptic seizure or ictal from pre-ictal or inter-ictal data. The neurophysiologists visually examine the EEG signals and detect epilepsy.

EEG is most commonly used method to examine the epilepsy from the clinical diagnosis. However, it is highly time consuming and laborious process due to neuropathologists has to go through the long data and from patients to patients the seizers vary and their symptoms. To save the time of the neuropathologists and avoid the confusion of which sort of seizer is there is a need for developing the reliable automatic epilepsy detection system, which can significantly improve the quality of the epilepsy treatments. Cerebral Function Monitor introduce earlier helps to monitor the long time EEG, which can be used to record the number of seizers. Subsequently, selectively recorded the EEG signals of epileptic in the interictal and ictal as samples and used its amplitude, period, and other characteristics to distinguish whether the samples were in the state of epileptic seizures. realized the epileptic seizure detection by extracting the non-linear indicators of the EEG signal around seizure onset.

The automatic epilepsy detection uses the systems to automatically collect the EEG data with epilepsy and try to extract the characteristics that cause epilepsy, but these characteristics will not alone help to realize the prediction of epileptic seizures, and it is only a limited help to clinical staff and epilepsy patients. But with advancement of research in the field of machine learning encourages the development of automatic detection of epilepsy, thus attracting more researchers to develop the automatic detection of epilepsy to help the medical staff directly or indirectly. The Researcher named Chen proposed an epilepsy detection framework based on machine learning to realize epileptic seizure detection. By following his research Craley developed an end-to-end deep learning model for automatic seizure detection in multichannel EEG recording. Their outstanding research has made machine learning a step toward success in the field of automatic epilepsy detection. Now, the most of the patients with epilepsy can be treated with drugs Later the researcher Liu and Ito et al. used EEG observing epileptic discharges to verify anti-epileptic drugs' reliability. The patients with drug-resistant epilepsy the surgical treatment, such as Temporal Lobectomy is used to control seizures. And for the patients with refractory epilepsy vagus nerve stimulation has to be used for the significant therapeutic effect. Under this kind of variations, machine learning algorithms comes as an aid for the neuropathologists to realize the epileptic detection and to provide the treatment for epileptic.

The machine learning algorithm mainly compares the abnormal time-frequency domain characteristics of the EEG signal of patients with epileptic seizures to detect epileptic seizures. In recent years, seizure detection has also promoted the development of seizure prediction and location.

2. EEG Data acquisition and pre-processing

Machine learning systems require two major resources to work, data and models. When acquiring the data, be sure to have enough features which covers most of the aspects help to prediction and helps to learn correctly. There are many devices for collecting the EEG signals, such as Brain- Computer interface (BCI), portable EEG acquisition equipment and neuroscan.

The EEG signals are acquired by placing EEG electrodes on the scalp of patients with epilepsy. EEG electrodes can be placed on the whole brain according to the international 10–20 EEG system for EEG electrode placement. Before collecting the real time epilepsy EEG signals, it is a regulation method to use the publicly available epilepsy EEG signal data set example epilepsy EEG dataset of Children Hospital Boston, Massachusetts Institute of Technology to establish and check the EEG detection model. In order to improve the machine learning model some researchers used clinical epilepsy EEG data by clinicians to verify the reliability of the epilepsy detection model along with publicly available datasets. Furthermore, some researchers evaluated the model's reliability through different cross-database used. Five different epilepsy EEG datasets for the first time to verify the capability of seizure detection models. The collected epilepsy data needs to undergo pre-processing, including artifacts removing and noise filtering, to obtain a clean epilepsy EEG signal for the next step, feature extraction.

3. Feature Extraction

Feature extraction is the most challenging and most essential step in automatic machine learning prediction systems. Feature extraction is a process of reduction in dimensionality of data by which initial set of data is reduced to some characteristics group for processing. A characteristic of these large datasets is a large number of variables that require a lot of computing resources to process.
Feature extraction is an essential step in epileptic seizure detection, which is used to establish an epilepsy detection model via standard epilepsy data, and epilepsy detection from actual collected EEG signal data. The effective way of feature extraction is directly related to the accuracy of the epilepsy detection. So, it is inevitable to improve the feature extraction to arrive at good accuracy in prediction of epilepsy. And the research shows that different dimensionality of feature extraction can improve the accuracy of the results. The researcher named Al-Hadeethi in the year 2020 proposed for the first time to use the covariance matrix for reducing EEG signals dimensionality and extract its statistical features, and use nonparametric tests to obtain the set that has the most distinguishing features, which can be used as the input of Adaptive Boosting Least Square-Support Vector Machines (AB-LS-SVM) model to achieve satisfactory results. The researchers Vicnesh and Hagiwara in the year 2019 extracted the non-linear features from the EEG data, and used decision tree algorithm to classify the different epilepsy classes.

EEG signals are non-linear and non-stationary time signals. Wavelet transform is most commonly used method to re express the EEG signals for the dimensionality reduction. And later linear discriminant analysis and k -nearest neighbor classifiers are used to extract the standard deviation and variance. On CHB-MIT, the method yielded a classification accuracy of 99.45% using the KNN classifier. The researcher Wang in the year 2017 presented a three-class classification system based on discrete wavelet transform and the non-linear sparse extreme learning machine. Three-level lifting DWT using Daubechies order four wavelets was introduced to decompose the Bonn University EEG dataset, and the maximum and standard deviation values of each sub band were computed. Along with wavelet transform, empirical mode decomposition and wavelet packet decomposition can be used for the transformation of epilepsy of EEG signals. A new approach was presented Ahmet and Aydin in the year 2018 to analyse intrinsic mode functions decomposed by EMD. Statistical features of the best AR model coefficients were calculated and fed into RF classifier for classification. Another critical step after feature extraction is classification, which will give the final epilepsy detection results from the extracted features.

4. Classification

In recent years, with advancement of machine learning algorithms and availability of the datasets attracting the many researchers to work on the classification of epilepsy diagnosis to help the neuropathologists and epilepsy patients. And many machine learning algorithms are already used for the epilepsy detection and classification mainly including support vector machines (SVM), convolutional neural networks (CNN), Extreme learning machines (ELM), Artificial neural networks (ANN) and K- nearest neighbour (KNN) are summarized in the Table.1.

Author	Model	Accuracy
Janjarasjitt and Suparerk	SVM	96.87
Chen	LS-SVM	99.5
Al-Hadeethi	AB-LS-SVM	99
Qi et al	ELM	96.5
Li et al.	M-ELM	100
Song et al	FF-ELM-SD	97.3
Wang et al	SELM	97.6
Acharya	CNN	88.67
Wei et al.	CNN	90.57
Nogay and Adeli	DRNN	100
Choubey and Pandey	ANN+KNN	KNN-98, ANN-94
Yuan	BLDA	95.74
Zeng	GRP-DNET	100
Juarez-Guerra	MRW-FFWNN	95

Table 1:Summary of machine learning algorithms used for epilepsy detection

Support vector machines is a commonly used classifier, the classification results can be changed using different kernel functions and different cross-validation multiples. The researcher, Janjarasjitt in the year 2017 applied SVM to classify single-channel scalp EEG data features times. Moreover, the test got an average classification accuracy rate of 96.87% using 10-fold cross-validation [5]. Besides, many researchers combine different algorithms with SVM to obtain better classification accuracy and detection efficiency. The researcher Makaram in the year 2020 extracted the time domain characteristics and signal complexity. Further, they used the Support Vector Machine- Error-Correcting Output Codes (SVM-ECOC) to train the classification algorithm, and the improvement in classification accuracy had been obtained. Ramakrishnan and Murugavel in the year 2019 proposed a new seizure detection model using layered directed acyclic graph SVM (LDAG-SVM), which improved classification accuracy and reduced detection time compared to existing methods [8]. After performing DWT, Chen et al. (2019) extracted the non-linear features of each sub-band and inputted them into six different classifiers for training. Finally, they increased the classification accuracy of Least Square-Support Vector Machines (LS-SVM) to 99.5%, which was better than five other classifiers. Based on LS-SVM, Al- Hadeethi et al. (2020) further applied the AB-LS-SVM model for epilepsy detection.

In 2006 Huang improved the learning efficiency by improving the Backward propagation , and by simplifying the learning parameters he proposed the Extreme learning machines (ELM) Then Qi during 2011 extracted nonlinear features and applied ELM for an epilepsy diagnosis. The classification accuracy was improved to 96.5%, which was better than BP and SVM in both classification accuracy and training time [7]. To produce the better ELM application, Li during used a ternary classification system based on the Multiplicative Extreme Learning Machine (M-ELM), with a maximum classification accuracy of 100%. Song during 2016 proposed a novel fusion feature and integrated the fusion feature and ELM. Experimental results demonstrated 97.35% classification accuracy. Wang during 2017 applied SELM for epilepsy detection. Liu during 2017 proposed Kernel ELM and introduced Cholesky decomposition to reduce the computation of out weights. The experimental results showed that the method can achieve an average classification accuracy of 96.5%. On this basis, Zhan during 2019 proposed Expectation Kernel ELM (EKELM) to further improve ELM classification abilities [11].

In 2018, Acharya applied CNN to the study of EEG signals for the first time and realized a 13-layer deep convolutional neural network for epilepsy detection without separate feature extraction and feature selection [3]. The proposed technique achieved an accuracy of 88.67%. Iesmantas and Alzbutas during the year 2020 extracted different features from clinical epilepsy EEG signals and applied CNN for training data. Wei during the year 2019 used the increasing and decreasing sequences (MIDS) merger to highlight the characteristic of waveforms and a data augmentation method for increasing the sample diversity and EEG information. Furthermore, they applied CNN classifier for epilepsy detection to get 90.57% accuracy. Nogay and Adeli during the year 2020 proposed a machine learning method for seizure detection using the pre-trained deep two-dimensional CNN and transfer learning concept that achieved 100% accuracy for binary classification and ternary classification for epileptic seizure detection [12].

With the continuous development of machine learning, new algorithms are constantly being introduced into seizure detection. Akyol in the year 2020 proposed a new deep neural network for seizure detection that successfully obtained an average accuracy of 97.17%. Choubey and Pandey in the year used Artificial Neural Network (ANN) and KNN to achieve seizure detection. Yuan in the year 2018 applied a Bayesian linear discriminant analysis (BLDA) classifier to classify the CHB-MIT scalp EEG dataset and achieved an average classification accuracy of 95.74%. Zeng in the year 2021 combined gray recurrence plot (GRP) and densely connected convolutional network (DenseNet) for epilepsy detection and even achieved 100% excellent classification accuracy in each classification experiment. Mouleeshuwara pprabu and Kasthuri (2020) proposed a Non-linear Vector Decomposed Neural Network (NVDN) detect epileptic seizures and obtained 95.60% effective epilepsy detection results. Sharma et al. (2020) described a computationally fast seizure classification algorithm using non-linear higher-order statistics and deep neural network algorithms. This technique could capture weak information related to epilepsy EEG signals and achieved 100% seizure classification accuracy. Juarez-Guerra in the year 2020 proposed a new epilepsy seizure detection method for classifying epilepsy seizures, namely Multidimensional Radial Wavelons Feed- Forward Wavelet Neural Network (MRW-FFWNN). The experiment showed that the accuracy of the three classifications was 93.33%. From the above research results, it is not difficult to find that the research on epilepsy detection has been fruitful, and even some epilepsy detection algorithms have reached 100% accuracy. However, scientists' research on epilepsy does not stop there. The goal they really want to achieve is to prevent it before it happens, in other words, to predict epilepsy.

5. Conclusion

In the era of twenty first century, the rapid development in the field of Machine learning and artificial intelligence, automated epilepsy detection techniques using EEG signals has attracted more researchers. This survey paper mainly talks about the basic idea of epilepsy detection using EEG signals. The process of epilepsy detection has many sub processes like EEG data acquisition, feature extraction and selecting machine learning models. The review of different machine learning classifiers used for automated epilepsy detection are given in this paper along with the accuracy of the models. Due to the random nature of epileptic seizures, fast and convenient seizure detection is essential for the immediate treatment of epilepsy patients. There is still much room for the development of epilepsy detection techniques. Here are a few points about the future development trend of epilepsy detection techniques based on EEG signals. One among that is seizure prediction and localization are still one of the future development directions of epilepsy detection. Seizure prediction can effectively improve the quality of epilepsy patients, and non-invasive epilepsy focus localization can better assist clinicians in epilepsy diagnosis time and save costs. Epilepsy detection is related to the patient's age, region, and other things, but the publicly available epilepsy EEG datasets are limited. Therefore, many epilepsy clinical EEG data from different countries and different countries and different age groups need to be improved.

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