Epilepsy prediction and classification using expert systems: A Review

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Abstract : Our brain is the most important organ of our body; it controls all the parameters of life through its neuro physiological co-ordination. The functioning of a normal brain can be measured by using EEG signals. Electroencephalography (EEG) is an efficient tool for monitoring the activities of brain which is further important for identifying epileptic seizure. This work presents a rigorous review about brain, epilepsy, EEG, various features which can be extracted from EEG like PCA, wavelet transform, and other statistical features. The study also discuss about various machine learning algorithms like random forest, SVM, k-NN and Naive Bayes algorithm which couldused for classification purpose of epileptic seizures.

IndexTerms - Epilepsy, electroencephalography (EEG), feature extraction, classification algorithms, machine learning.

I. Introduction

Epilepsy is a kind of neurological disorder which is uniformly distributed around the world. There are no boundaries of races, social-class or demography. It may occur in and kind of sexes, at all ages, especially in childhood, and increasingly in old age populations. It is a common disorder of the brain. A report says that one of every ten people may have at least one epileptic seizure during his normal lifespan, and every third of these may develop epilepsy in near future [1]. According to a 2012 report published by the World health organization (WHO 2012), approx 50 million people worldwide are suffering from epilepsy. Nearly 80% of the people in developing regions are found with epilepsy. Many of which of affected people indeveloping countries do not get the treatment on time and as per requirement. Epilepsy is characterized by a sudden and recurrent malfunction in brain,which creates an excessive and hyper synchronous activity of neurons [1].

Electroencephalography (EEG) is commonly known as the recording of electrical activity of brain. It is a simple, non invasive and cheap technique which provides a measure of mapping the neuronal functioning of brain.During on ongoing seizure, theelectroencephalogram (EEG) signal changes dramatically, the value of amplitude increases by some order of magnitude and a time-varying characteristic pattern appears [2].

The detection process of epileptic seizures by just visually scanning a specific patient's EEG data collected is a time-consuming and tedious process. It also requires an expert to understand and analyze the entire length of the EEG recordings, in order to detect any epileptic activity. An automatic, reliable and accurate classification and detection epileptic diagnosis system would ensure a fast and an objective treatment, it will definitely improve the diagnosis of epilepsy and might also help in long-term treatment and monitoring of epileptic patients [3].Different researchers have extracted varied features from EEG for further processing and epilepsy detection. For classification purpose many types of algorithms are being in used like:SVM, k-NN, Random forest etc.

The current era requires an innovative idea of wearable devices, which can provide a system and methods for the portable, compact, cost effective, easy to use seizure detection and controlling services for epileptic patients by monitoring their EEG signals. Such devices must send alerts based on classification of EEG, to the patient, their guardians or friends and nearest medical services available about their conditions. Such a mechanism will be able to provide fast results and actions taken on time will be very helpful to the epileptic patient and can even save their lives. Such a device can also have an inbuilt mechanism of infusion of anti-epileptic drug which can inject the drug at the time of emergency.

Modern times require an epileptic seizure classifying, monitoring and controlling device, which can record the brain waves (EEG) signals continuously from the patient, process the EEG waves and can come up to with some real time preventive methods.

II. Literature Review

About EEG:

Electroencephalogramreflects the neuronal functioning of brain. According to known facts the first recording electrical activity of brain was performed in 1875 by a scientist Richard Canton using a galvanometer connected to the scalp of a human subject through two electrodes. At that time, the term “electroencephalogram” (EEG) was used to denote the writing of electrical activity of brain recorded from the head. However, the first report of the EEG is found in 1929 by a German psychiatristHans Berger, who is known amongst electroencephalographers as the discoverer of the human EEG.

Our Central Nervous System (CNS) consists of the brain and its natural extension, the spinal cord. The brain is largely made up of nerve cells (or neurons). Neurons transmit information by electro-chemical signaling, they are known as electrically excitable cells. A typical neuron consistsof a cell body (signal processor) with branching dendrites (signal receivers) and an axon (signal transmitter) often sheathed in myelin, shown in figure 1.

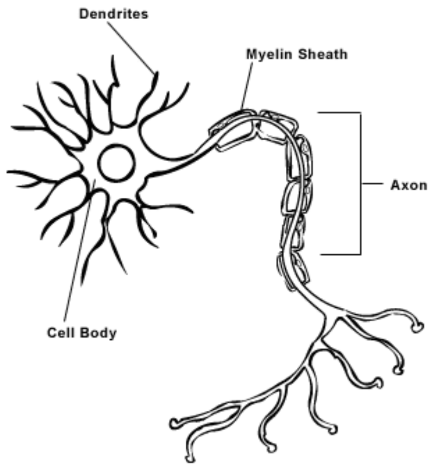

Figure 1. Structure of a neuron

EEG recognizes five major brain rhythms: delta, theta, alpha, beta and gamma, each characterized by a specific frequency range.

Table 1: Frequency range of EEG rhythms

Rhythm	Frequency Range [Hz]
delta	0.5-4
theta	4-8
alpha	8-13
beta	13-30
gamma	>30

A multichannel EEG recording is performed using scalp electrodes, commonly Ag/AgCl disks which have less than 3 mm diameter, they have long flexible leads that can be plugged to an amplifier. The electrode impedance is generally kept below 5kΩ, in order to avoid distortion. Electrodes are applied on the scalp of the subject according to the International 10-20 system of electrode placement as shown in figure 2.

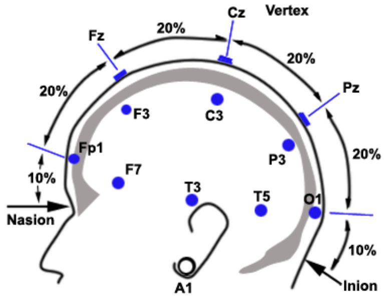

Figure 2. 10-20 system

Raw EEG may become corrupt by many physiological and non-physiological artifacts. The recorded EEG signals have to be filtered prior being analyzed. A high pass filter, with cutoff frequency below 0.5 Hz, is generally used in order to remove low frequency baseline drift. While alow pass filter is used to reject high frequency noise and for preventing aliasing [5].

Initially EEG was seen as an apparently random or aperiodic signal. Such signals were studied using Fourier transform which is a mathematical tool used to decompose a signal to set of sinusoidal components whose amplitudes and phases are shown in the frequency domain. In frequency domain the system which describes how the power of the signal is distributed over frequency is given by power spectral density [6].

The EEG signal is a fractal-like signal whose mechanism reflects the complexity of brain activity. The fractal dimension, is a powerful EEG index used for characterization of psychiatric brain diseases likeschizophrenia, neurological disorders like Alzheimer's disease and for epileptic seizure detection and prediction [8]. Commonly used methods of fractal dimensions to identify the most accurate and reliable algorithm for estimation of EEG are: the box-counting method, Katz's algorithm and Higuchi's algorithm [7].

About Machine learning algorithms:

- J. Gotman (1982) proposed first automated diagnosis system for epilepsy
- A. M. Murro, D. W. King, J. R. Smith, B. B. Gallagher, H. F. Flanigin and K. Meador (1991) presented computerized epilepsy diagnosis system
- J. Gotman (1997) proposed nearest-neighbor classifier
- M. Akin, M. A. Arserim, M. K. Kiymik, and I. Turkoglu (2001) reported Layer Feed Forward neural network for the diagnosis of epilepsy
- Akin M. et al. (2001) proposed Multi Layer Feed Forward Neural Network for the diagnosis of epilepsy.
- L. Szilagnyi et al. (2002) proposed standard back propagation feed forward three layer network with a single hidden layer.
- ElifDeryaUbeyli et al. (2004) proposed Multi layer perceptron Neural Network (MLP) with backpropagation, Delta-Bar-Delta,Quick propagation and Levenberg-Marquardt algorithm for detecting the electrocardiographic changes in patients with partial epilepsy.
- Srinivasan V. et al. (2004) proposed four different types of neural networks, namely, Multi Layer Perceptron (MLP), Elman Network (EN), Probabilistic Neural Network (PNN) and Learning Vector Quantization for the detection of epilepsy.
- Harikumar R. et al. (2004) described Genetic Algorithm based epilepsy risk level classifier from EEG signal parameter.
- AbdulhamitSubasi et al. (2005) proposed artificial neural network(ANN) and logistic regression (LR) methods for the classification ofEEG signal and diagnosis of epilepsy
- Vairavan Srinivasan, Chikkannaneswaran, and Natarajan Sriraam (2007) proposed a system where, Elman network and probabilistic neural network were used for epileptic seizure detection.
- Pravin Kumar S., Sriram N. and Benakop P. G. (2008) proposed an automated epileptic EEG detection model based on recurrent Elman network and radial basis network

- Patnaik L. M. et al. (2008) proposed a five level wavelet (Db4) based feed-forward back propagation artificial neural network.
- Clodoaldo A. M. Lima et al. (2009) proposed Relevance Vector Machine (RVM) based EEG signal classification for the epilepsy diagnosis.
- UmutOrhan et al. (2011) introduced the multilayer perceptronneural network based classification model as a diagnosis decisionsupport mechanism in the epilepsy treatment.
- Tapan Gandhi et al. (2011) proposed Probabilistic Neural Network(PNN) and Support Vector Machine (SVM) classifier for thediagnosis of epilepsy.
- Marcus Musselman et al. (2012) proposed support vector machine for epilepsy classification.
- Guangyi Chen (2014) proposed nearest neighbor (NN) classifier for the classification of dual-tree complex wavelet (DTCWT) features extracted from the EEG signals.
  - EllyMatulImah (2017) proposed a comparative study of various machine learning algorithms.
  - MdMursalin (2019) uses some statistical sampling techniques for feature selection and then apply various machine learning algorithms for evaluating these statistical sampling techniques.

III. EEG Pre processing & Feature Extraction

To improve the quality of the raw EEG and to reduce the effect of artifacts, preprocessing of the data is required. First, a high-pass filter of 0.5Hz is used to remove the slow drifts. After this, to remove the noise in powerline a band-stop filter is applied. To remove low quality data epochs, an artifact rejection step is applied. Finally, if there is some high-frequency (> 50 Hz) content, a low-pass 6th order Butterworth filter (with 50Hz cut-off frequency) is used to remove these from time series.

The commonly feature extraction methods used are given as under:

Principal Component Analysis (PCA)

Principal Component Analysis is one of the feature extraction method used for dimensionality-reduction. When we reduce the dimensionality the problem is that we need to compromise with the accuracy. The ides in PCA is simple: it reduce the number of variables in a data set but also preserves the maximum information as well. PCA includes steps like:

a. Standardization: this step standardizes the range of every, such that each variable contributes equal to the data analysis.

b. Covariance matrix: This step makes us understand how the different variables of input data set are vary from the mean with respect to one another.

c. Computing the eigenvectors and eigen values of the covariance matrix to identify the principal components

Wavelet Transform

Wavelet feature extraction is a good performance indicator in identifying epileptic nature of seizure in EEG. It works in time domain, as contrast to PCA which works in spatial domain. WT is an extension to Fourier Transform in it instead of working on a single scale it works on multi-scale basis and the problem of non-stationary signals is addressed using WT. This technique is quite efficient for analysis of signal in contrast to other available transform methods such as Short Time Fourier Transform and Fourier transform. Its main advantage is that window size used here is varying, for low frequencies his window size is broad while for high frequencies it is narrow. This distribution leads to an optimal time frequency resolution for all frequency ranges.

Statistical Features

Time domain features such as: skewness, minimum, maximum, mode, mean, standard deviation, median, standard deviation, Shannon entropy , interquartile range, first quartile, third quartile, fluctuation index, Hurst exponent, sample entropy and kurtosis are also used as important features of time series.

IV. CLASSIFICATION ALGORITHMS

After feature extractions these features are uses for classification purpose. This section will discuss the prominent machine learning algorithms used for classifying epileptic seizure.

Random Forest classifier. This is a supervised classification machine learning algorithm. It creates forest which is a collection of decision trees. This is the reason this method is more robust. The Random Forest classifier works with two methods: randomized node optimization and bagging [9]. In random forest trees, every node is divided by the best subset from the predictors. This algorithm has variety of benefits:

- Excellent accuracy compared to other algorithm.
- Works well with large databases
- It estimates which variables are better for classification
- It has effective method for error balancing

Support Vector Machine (SVM): It is a machine learning algorithm used for both classification and regression analysis. It uses decision planes to construct decision boundaries [10]. SVM plots each data point as a point in n-dimensional space, where n is the number of features. Each feature value represents value of a particular coordinate. In the next step, classification is performed by finding the hyper-plane that differentiate the two classes[11]. In this machine learning algorithm, the input data is transformed to higher dimensional feature space, then an optimal hyperplane is constructed for separating varied classes. The data vectors which are nearest to the constructed line are called support vectors [12].

Logistic Model Trees (LMT): LMT is a classification model based on logistic regression functions. LMT combines two methods: logistic regression (LR) and decision tree. Logistic model tree is build by growing a standard classification tree, building a logistic regression models for each node, using a pruning criterion pruning some of the subtrees, and finally combining the logistic models into a single model in some fashion[14].

Naive Bayes (NB): Naïve Bayesian classifier is a simple and effective classifier. Using Bayes theorem, we find the probability of event **A** happening, given that event **B** has already occurred. Here, in this scenario **B** is the evidence and **A** is the hypothesis. Here, we make an assumption that the predictors/features are independent of each other. This means that presence of one particular feature has no impact on the other. Thus it is called naive. Naïve Bayes classifier assigns a new observation to the class which is most suitable and finally assumes that the features are conditionally independent [13].

k-Nearest Neighbor (k-NN): This algorithm make use of a similarity index to classify new cases from all the available cases. This algorithm is made up of two steps: the first is learning step; this step finds k number of training samples nearest to the given sample. The second is classification step, in it the commonly occurring classification for these k samples is done. This algorithm use regression method for finding the average value of its k-nearest neighbors.

V. CONCLUSION

This work discuss in detail about neuronal activities of brain, about EEG, how and what features could be extracted from EEG signal and finally about the varied machine learning algorithms suitable for classification of EEG signal. This review work is helpful in understanding how expert systems can be helpful in our modern health care industry. Seizure classification and prediction techniques will provide new and individually targeted opportunities for the diagnosis and intervention in the field of epilepsy. Using such a mechanism will help to detect priory the onset of seizures. Furthermore, these systems will be very beneficial for accident prevention of the patient in extreme conditions and seizure tracking and could further be useful in closed-loops to facilitate the prevention of seizure .

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