Journal of Environmental Science, Computer Science and Engineering & Technology

An International Peer Review E-3 Journal of Sciences and Technology

Available online at www.jecet.org

Section B: Computer Science

Research Article

EEG Signal for Epilepsy Detection: A Review

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Received: 19 March 2016; **Revised:** 28 March 2016; **Accepted:** 31 March 2016

Abstract: EEG (electroencephalogram) is used for capturing the impulses following through the brain. The signals are recorded to check any abnormalities in working of the brain. The impulses so recorded can be contaminated with noise which needs to be filtered to get the actual brain signal. Normal brain signals differ much from abnormal brain signals. The cleansed signal so obtain can check for various brain disorders, epilepsy being one of them. The paper is an overview of how EEG works and the filtering process and reviews few algorithms that are being used to detect epilepsy.

Keywords: EEG, Adaptive filter, ICA, Epilepsy, Entropy, Nearest Neighbor, Pattern Recognition.

INTRODUCTION

EEG of brain, i.e. electroencephalogram of the brain is a process that can detect abnormalities related to the electrical impulses in the brain. Impulses flow through the brain cells to process information and pass information. In an EEG, 10 to 20 Small and flat discs like structures made of metal, called electrodes are attached to the scalp with wiresat places as decided by the International Federation of Societies for electroencephalography. These electrodes analyze the electrical impulses in the brain and send signals to a computer, where the results are recorded. The cortical nerve cell inhibitory and excitatory postsynaptic potentials generate the EEG signals [1].

Queen Square system of electrode placement has been proposed as a standard in recording the pattern of evoked potentials in clinical testing [2]. Bipolar or unipolar electrodes can be used in the EEG measurement. In the first method the potential difference between a pair of electrodes is measured. In the latter method the potential of each electrode is compared either to a neutral electrode or to the average of all electrodes. The diagram, **Figure 1**, shows how electrodes are placed for simple EEG signal gathering [3].

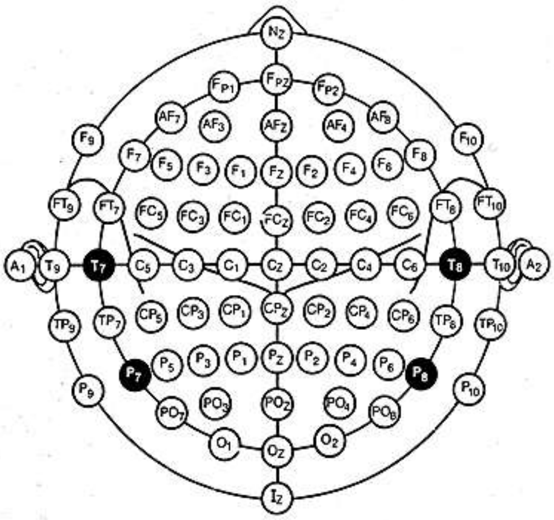


Figure 1: Placing of Electrodes for simple EEG signal gathering.

EEG helps to diagnose Epilepsy or other seizure disorder, brain tumor, head injury, brain dysfunction that may have a variety of causes (encephalopathy), inflammation of the brain (encephalitis), stroke, sleep disorders, dementia. It is used to confirm brain death. A continuous EEG is used to help find the right level of anesthesia for someone in a medically induced coma. However, EEG of the brain cannot measure intelligence or detect mental illness. EEG waveforms are classified based on frequency, amplitude, and shape, besides position on the scalp at which they were recorded. EEG signals have alpha, beta, theta and delta waves (**Figure 2**). From the EEG signal it is possible to differentiate alpha (α), beta (β), delta (δ), and theta (Θ) waves as well as spikes associated with epilepsy, and signal associated with brain death [4].

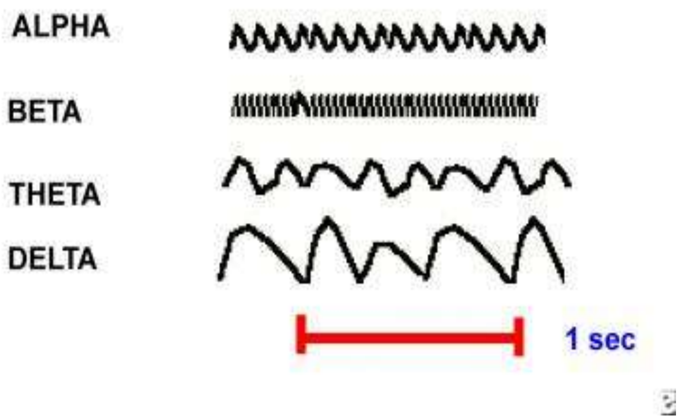


Figure 2: EEG signals.

The following Table shows the various EEG waves and their frequencies and significance:

Waveforms	Frequency	Position of Scalp	State of the Subject
Delta	0.5 to 4 Hz		Infants Deeply Sleeping Adults
Theta	4 to 8 Hz		Infants Children Drowsy Adults
*Alpha	8 to 13 Hz	Occipital	Normal Relaxed Adults
Beta	13 to 30 Hz	Frontal Parietal	All Anxious Subjects
Gamma	26 to 100 Hz		

Along with the above waves, EEG may carry frequencies or waves which are extraneous in nature. Such signals are called artifacts. EEG artifacts are recorded signals that are non cerebral in origin. There are two types of EEG artifacts: physiological artifacts and non physiological artifacts.

Non physiological artifacts can be categorized as

- Powerline noise
- Baseline noise

Powerline noise occur due to interference of the external power sources and also from internal electrical malfunctioning of the recording system. Baseline noise occur from poor contact of the electrodes with the patient or from perspiration of the patient under the electrode. Physiological artifacts arise due to pulsation of the scalp arteries, various body movements, including movements of head, eyes, tongue. Altered volume conduction due to conductance of tissues and fluids between the cerebral cortex and the recording electrodes. One of the mmost common artifact is considered to be ocular artifact, i.e, artifacts related to eye movements.In EEG, signal to noise ratio is very small [5]. Namratha D'cruz in her article has explain the effect of artifacts in EEG signal using following diagram [6]. This is shown in **Figure 3**.

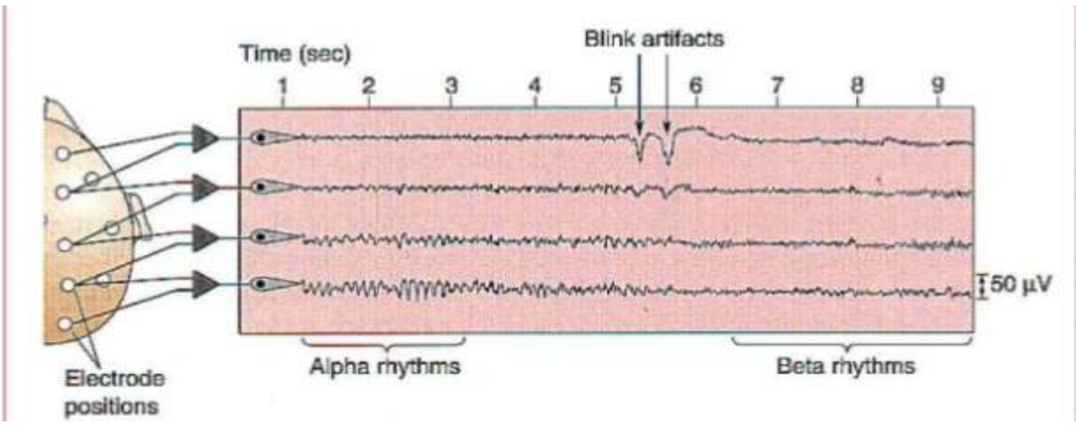


Figure 3: ffect of artifacts in EEG signal.

ARTIFACT REMOVAL METHODS

The EEG signal captured from the EEG machine is available in the EDF format (European Data Format). It is converted into .wav format for any further processing. The signals are then filtered.

Adaptive Filters: To filter EEG signals, conventional filtering like band-pass, the low-pass or high-pass filters cannot be applied to eliminate or attenuate the artifacts without losing significant frequency components of EEG signal because EEG has biological noise whose spectra overlaps with EEG signals [5]. Due to this reason, the adaptive interference cancellation scheme is a very efficient method to solve the problem when signals and interferences have overlapping spectra. Adaptive filters are based on the optimization theory and they have the capability of modifying their properties according to selected features of the signals being analyzed. The objective of an adaptive filter is to change the coefficients of the linear filter, and hence its frequency response, to generate a signal similar to the noise present in the signal to be filtered. Then the signal so generated is subtracted from the EEG to get the EEG signal to be analyzed for any brain activities.
The **Figure 4** explains the adaptive filter theory [7].

x (n): the input signal

d (n): the reference signal or the desired output signal (some noise component are present in it).

y (n): the output signal

e (n): the error signal which is computer as

e (n) = d (n) – y (n)

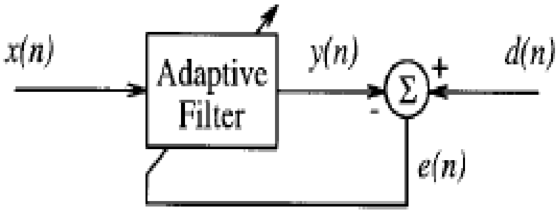


Figure 4: Adaptive filter theory.

Least mean square algorithm is used to calculate the function for the noise function generation. It can be said that a better alternative to LMS function is NLMS function of noise generating signals [8], but Kalman filter for EEG prediction gives more precise results. Poonam Dhankhar, Suresh Khaleri has used the following diagram to explain working of adaptive filter in their work [7].

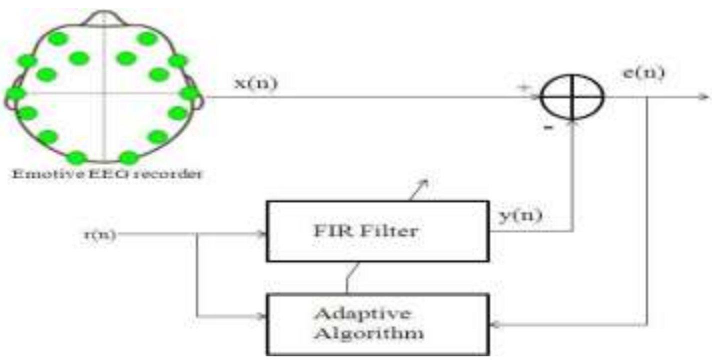


Figure 5: Working of adaptive filter.

Along with the above mentioned adaptive algorithms, finite impulse response and infinite impulse response filters can be used in adaptive filtering, most common being FIR filter which is used for normalizing the signal.

ICA: EEG signals suffers from what we call cocktail-party problem [9]. A promising method which has established itself as an important part of EEG analysis is the application of independent component analysis (ICA) for data decomposition and separation of neuronal activity from artifacts. The idea central to this method is that the EEG signal is a mixture of linearly independent source components (IC) that can be separated by ICA, visually examined, and classified as artifact or EEG signal components. Once the artifact components have been identified, they can be removed and the remaining EEG signal components can be projected back to the original time domain. This procedure yields the reconstruction of an artifact-free EEG [10]. ICA uses linear decomposition method.

ICA assumes that time series recorded on the scalp are spatially stable mixtures of the activities of temporally independent cerebral and artifactual sources, that the summation of potentials arising from different parts of the brain, scalp, and body is linear at the electrodes, and that propagation delays from the sources to the electrodes are negligible. In EEG analysis,EEG signals recorded at different electrodes contributes to the rows of the input matrix, X, and the columns are measurements recorded at different time intervals. For artifact removal, ICA finds an `unmixing' matrix, W, which decomposes or linearly unmixes the multi-channel scalp data into a sum of temporally independent and spatially fixed components. The rows of the output data matrix, U = WX, are time courses of activation of the ICA components. The columns of the inverse matrix, inv(W), give the relative projection strengths of the respective components at each of the scalp sensors. These scalp weights give the scalp topography of each component, their physiological origins [11]. One of the ICA algorithms used for EEG cleaning is EWASOBI.

Epilepsy an overview: Epilepsy is one of the age old neurological disorders that has been identified in human beings. It is characterized by recurring seizures in which abnormal electrical activity in the brain causes the loss of consciousness or a whole body convulsion. Patients may not be aware that they are having seizures due to the random nature of them which may increase the risk of physical injury. Epileptic seizures are caused by disturbed brain activity – which simply means that the normal activity of the brain is suddenly interrupted and changes. EEG waveforms can be used to identify preictal stage which is the stage before the actual seizure occurs. This stage can go on for few minutes to more than a day. The next stage is the ictal stage that is the stage when the seizure occurs. The third stage is postictal stage that is the stage after the seizure has seized. The stage between the postictal and preictal stage is called interictal stage.

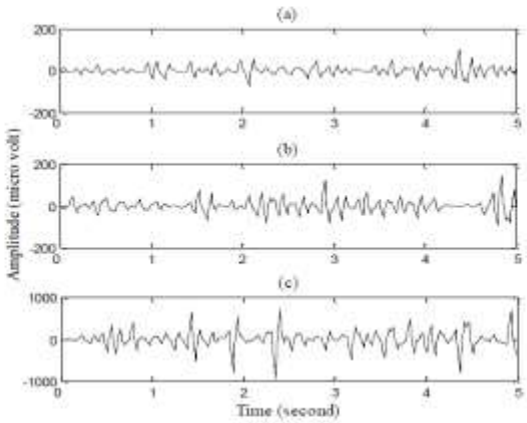


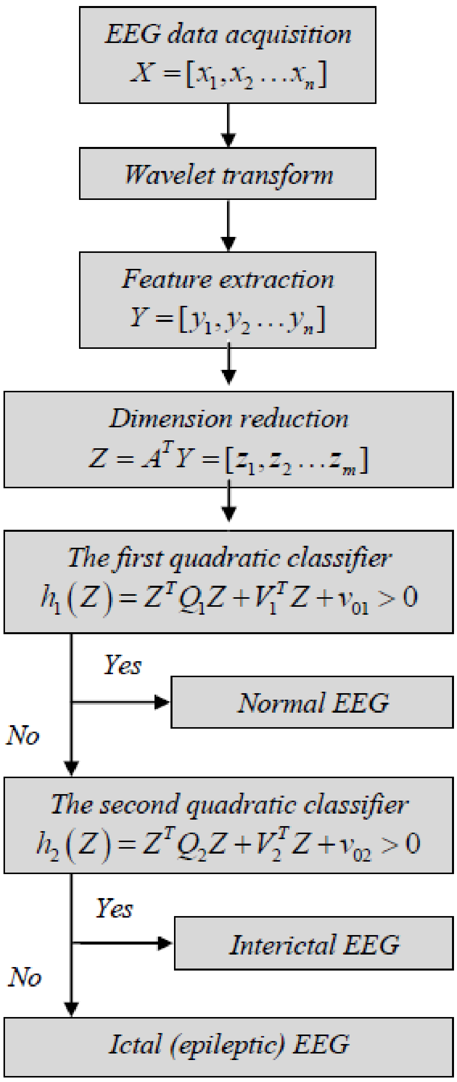
Figure 6: Normal, Interictal and Ictal EEG signals.

The above diagram shows normal, interictal and ictal EEG signals [12]. Sudden change in brain activity creates sudden difference in the rhythm of EEG signal. When a seizure happens during an EEG recording, the normal pattern of brain activity that is seen in the EEG reading, changes. In partial seizures the change in brain activity is seen only on the electrodes on the part of the brain the seizure happens. The readings from the rest of the electrodes remain the same as activities of normal brain. In generalized seizures the altered activity can be picked up by all the electrodes, from all parts of the brain.

Algorithms for detecting Epilepsy using EEG

Wavelets and Statistical Pattern Recognition: In their work, Gajic D., Djurovic Z., Di Gennaro S. and Gustafsson F has used wavelet and statistical pattern recognition for epilepsy detection [12].

Following is the flow chart of the proposed logic:



Wavelet transformation is a linear approach can decompose a signal into several frequency sub bands using wavelet functions and scaling functions. These sub bands so created helps in better understanding of EEG signals. After wave transformation, feature extraction is used to lower the dimensionality space and extract the feature vector $Y = [y_1, y_2 \dots y_n]$. Having dimension too large might pose problem in designing a classifier. Quadratic classifier is used because the EEG signal is classifies into 3 sections, i.e., normal, ictal, interictal. 2 classifiers are used.

1st Classifier: Separates normal from (ictal + interictal)

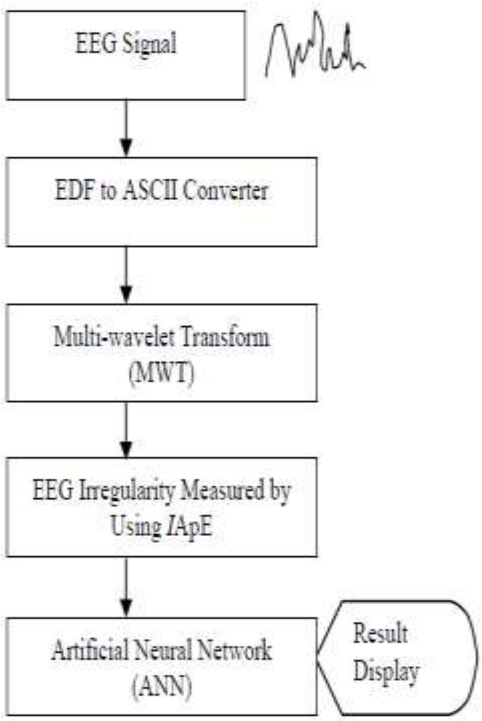
2nd Classifier: Separates interictal and ictal

The algorithm is robust and simple. As per the author, the algorithm gives quite accurate result and it provides an automatic, objective procedure that addresses all available features in a specific way and also makesa decision based on data, but because it also allows insight into the severity of the brain state. The algorithm should also consider the non- linear analysis of the data and from the flow chart, it can be said that the algorithm does not deal with the preictal stage of the seizure.

Improved Approximate Entropy and Artificial Neural Network

Sharanreddy, Kulkarni P.K., has used improved approximation entropy along with artificial neural network for seizure detection [13].

Following is the flow chart of the proposed logic:

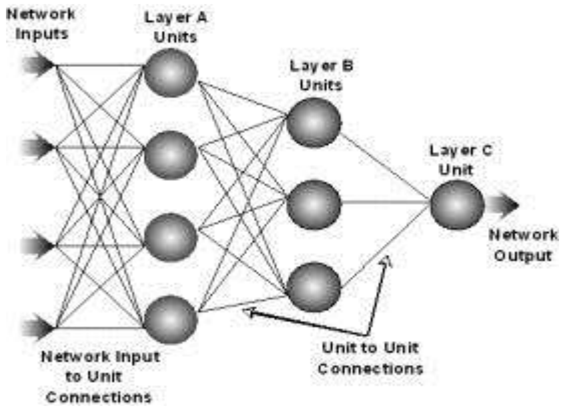


Above method also uses wavelet and scaling for feature extraction of EEG, but the difference with the previous method is that this method uses not one, but multiple wavelet and multiple scaling functions for feature extraction. In this method, the irregularity of the EEG signal has been measured using Improved Approximate Entropy. According to the paper, the accuracy is less in Approximate Entropy method for the method uses fixed length window. In this method, IApE has been calculated as:

$$\textit{Improved Approximate Entropy (IApE)} = \frac{\textit{Total window length}}{\textit{Total window size}}$$

The paper uses a feed forward neural network for analyzing the EEG signal.

Following is a diagram of feed forward neural network [14].



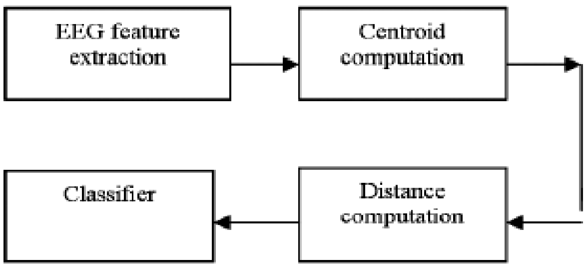
A neural network is an artificial intelligence system that can be trained in a set of input data. It consists of neuron like structures. It can have any number of layers of such neuron like structures, any number of neurons per layer. The input to the system is through network inputs, and out is through network outputs. Above diagram is an example of 3 layer neural network. Each unit in a layer is connected to all the neuron units in its previous layer. The connections have different strength indicating the knowledge of the network. Back propagation algorithm is used to train the neural network with specific data series. In the mentioned algorithm, the neural network is trained for various EEG signals and is used to detect epileptic EEG signals. Artificial neural networks carry advantage of features like adaptive learning, robustness, self-organization, and generalization capability.

In the above algorithm, training of the neural network can very time consuming. The network needs to be trained for thousands of epochs or data series. Therefore, training can be time-consuming, depending on the network size, number of examples, epochs limit, and error limit. Secondly, such training is only possible if adequate data for training is available.

Nearest Neighbor Classification

Nayak P.K. and Niranjan U.C has used nearest neighbor classifier for epilepsy detection [13].

Following is the flow diagram of the proposed logic:



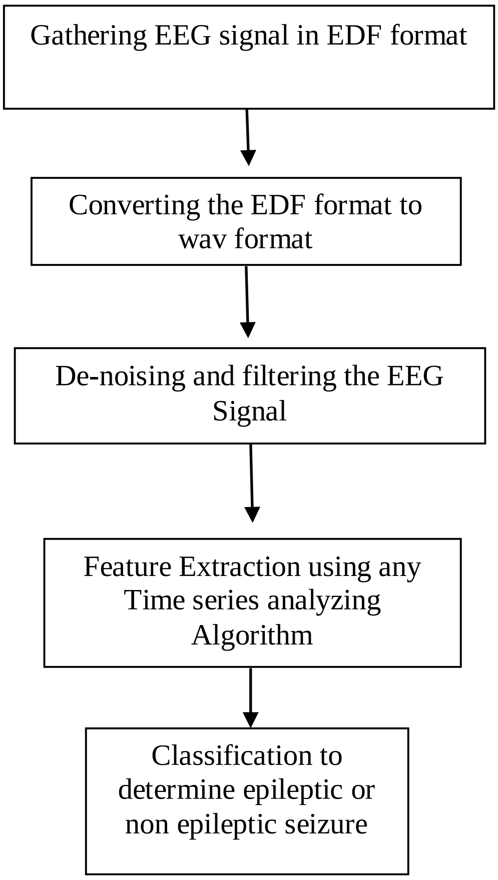
In this algorithm, feature extraction is followed by centroid computation.

EEG signal is normalized -> mean calculation of each channel -> median of each channel.

This median is considered centroid in the algorithm. In this method, centroid of normal and epileptic waves are already known. A reference is created for the normal by calculating the mean of centroids of all normal waves. Similarly, a reference is calculated for epileptic waves. Using nearest neighbor rule, a wave is classified either as epileptic or normal. The nearest neighbor algorithm uses the technique called "tell me who your neighbors are, and I'll tell you who you are".

CONCLUSIONS

On reviewing the above three methods of epilepsy detection, it can be concluded that epilepsy detection using EEG has the following general steps:



Prior knowledge of the normal and epileptic wave forms are required for classifying the classified waves into epileptic or normal waves.

The accuracy of most of epilepsy detection algorithms mainly depends on:

- How precisely the normal and epileptic waves have been categorized
- How accurately the waves in question can be classified into one of the reference categories.

In this context, it should also be kept in mind that some people have 'abnormal' EEGs but do not have epilepsy. Many people who do have epilepsy will only have 'abnormal' activity on the EEG if they have a seizure at the time the test is happening. This is why having an EEG that shows no sign of epilepsy cannot diagnose whether the person is epileptic.

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