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Review Article

A Review of Electroencephalogram Signal as Clinical Decision Support System

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ABSTRACT
Computer Aided Diagnosis (CAD) systems have been helping us in various fields including the medical diagnosis of various diseases where the CAD generated output is taken as complementary to the doctor's view. EEG signals which pick up the electrical activity of the brain are fed into a CAD system to further analyze and confirm the underlying abnormality. Neurological disorders affect a person and can make one's day to day activities difficult which mainly deals with the brain's electrical activity. Autism and Epilepsy are two of the major neurological disorders which can be analyzed through CAD systems. Alzheimer's disease can also be diagnosed with the help of a CAD system. Signal processing is used to take the input EEG signal and then process or decompose it to help us in analyzing. Few of the many processing techniques include FFT, DCT, DWT etc., Four features are extracted from a processed signal like Shannon entropy, Band power, Standard deviation and Largest Lyapunov Exponent which enhance the study of the signal. The feature vector is formed which is then fed to different classifiers whose main purpose is to classify as a normal or an abnormal signal. Some of the classifiers used KNN, ANN, SVM and LDA in which KNN provides the best help in recognizing the abnormality in a short period of time. In this paper we study the usage of few techniques, features, classifiers and give emphasis to the advantages of using DWT, Shannon entropy and KNN which helps us get an efficient and better understanding of the abnormality.

Key words: ANN, CAD, EEG, KNN, LLE, LDA, SVM.

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INTRODUCTION

Computer Aided Diagnosis (CAD)

Computer aided diagnosis has been progressing through a long time. It was developed and the ideology began picking up speed since the 1960s. It plays a major role in medical field by giving a "second opinion" to the doctors which helps them in understanding the underlying disease and come up with better treatment and also reduces the time for the diagnosis.[1] The majority of the research was concerned with three organs – chest, breast and the colon – but other organs such as brain, liver and skeletal and vascular systems were also subjected to CAD research.

The CAD system when used long with PACS (Picture Archiving and Communication Systems) gives us more efficient results. CAD has two different modes of working. In the first one, the doctors analyze the disease and read the images without the computer's aid and then request for the computer output for making the final decision. This mode has two drawbacks when the doctor keeps the initial readings without taking the computer's output into consideration there is a possibility that the subtle changes in the reading, which would affect the diagnosis on a larger scale, are not detected at all. The time taken to analyze also increases which is undesirable. The second mode takes the computer's "opinion" prior to the doctor's. This method not only reduces the time of detection but also detects every subtle change in the image or signal that is fed. Using the latter mode in medical diagnosis has proven to give best results.

Electroencephalogram and Neurological Disorders

The electrodes can be placed in two ways, either invasive or non-invasive methods. The latter takes a lot of experience and must be placed carefully. Analyzing the abnormality in one's brain can be carried out by studying the EEG. The human brain consists of millions of neurons which play an important role in controlling our behavior. Understanding the cognitive behavior of the brain can help us detect any abnormality present.

The human behavior can be perceived in terms of motor and sensory states such as eye movements, hand movements, attention etc. The various frequencies in the EEG signal correspond to the numerous states of a human brain. The different bands acquired from an original EEG like alpha, beta, delta, gamma etc., ranging from 0.1 to 100 Hz as shown in Figure 1. These bands of EEG tell us a lot about the human activities and how they respond to activities. Epilepsy is being studied with the help of EEG primarily since a very long time. Even though EEG has low spatial resolution it has several advantages such as simplicity, low cost and high temporal resolution.

EEG signals are extracted from a person by different electrode placements. There are 64 and 128 EEG channels where every electrode is placed on the scalp at different points to obtain electrical activity of neurons. As shown in Table 1, the different bands obtained from an EEG signal after processing it are alpha, beta, gamma, delta and theta each having different frequency ranges.

Autism

Autism or Autism spectrum disorder is neurological disorder which can be seen in the early childhood of a person. It affects the memory, learning ability, behavior and communication of a person.[2] For the first few years of an autistic child, normal behavior like crawling, eating and walking would seem like farther milestones when compared to a normal child and it takes longer time than usual because of slow processing of signals in the brain. Research to diagnose ASD is a constant process because of

Table 1: The frequency range of various EEG bands.

Name of the EEG bands	Frequency (Hz)
Delta	0-4
Theta	4-8
Alpha	8-16
Beta	16-32
Gamma	32-64

Table 2: Review on CAD, Autism, Epilepsy, Alzheimer's.

S. No	Title	Conclusion	Inference
1	Computer aided diagnosis in medical imaging: Historical review, Current Status and Future Potential (2001), Kunio Doi	CAD is used along with PACS (Picture archiving communication system) to help in producing an enhanced output. CAD is used in clinical work for the detection of breast cancer by use mammo-grams, but it is still in application in different fields	CAD output is used as "Second opinion to make final using decisions. The role of Physicians and computers. CAD is used to assist the physicians in the daily detection of breast cancer. Lateral chest images to improve overall performance Many other neurons, Vertebral fractures Can be detected.
2	Alzheimer's disease: models of compu -tation and analysis of EEG (2005)	In experimental stages the chaotic analysis is used and new mathemati -cal models are also used	Different analysis approaches including chaos analysis and the combination of wavelet analysis evolves more efficient output.
3	The role of epilepsy: A critical review (2009)	Both invasive and non-invasive methods are used in detection of epilepsy	Invasive is more complex and needs more skill. Non-invasive is used by surface testing
4	Automated EEG ana -lysis of epilepsy: a review (2013)	EEG signals can be used to study mental ailments of the human brain. EEG is highly non-linear. Focus on epilepsy detection and stage	Stages of epilepsy, normal or abnormal can be determined with the help of extracted features.
5	Automated diagnosis of autism (2014)	(t,f,t-f and nonlinear dynamics are used)	Various domains were discussed which give the most effective approach.
6	Wavelet based EEG processing for compu-ter aided seizure de-tection and epilepsy diagnosis (2015)	Additional feature extrac -tion methods are necess -ary for efficient output with the help of dwt and not cwt	Wavelet transform captures subtle changes in the EEG signal in time, frequency and space

various behaviors of the neurons of one's brain. The complexities, various patterns and detection of abnormalities in autistic children is given in.[3-5]

Epilepsy

Epilepsy is a neurological disorder which is caused due to abnormality in the electrical signals that are transmitted through neurons of one's human brain. Epilepsy is not easily analyzed by just visually inspecting the EEG signals. They are analyzed using CAD systems. The automatic detection of epileptic disorder can be done with signal processing techniques like wavelet transform and the calculation of entropies to analyze more effectively. EEG analysis can differentiate epileptic from normal data and also distinguish these different abnormal stages/patterns of a seizure, such as pre-ictal (EEG Changes preceding a seizure) and ictal (EEG changes during a seizure). When patients have more than one seizure in a small duration, there is a stage called the inter-ictal stage. Pre-ictal is the stage before the seizure, while inter-ictal is the stage between two seizures.[6] The placement of electrodes for picking up the electrical activity from one's brain can be done in two methods, either invasive or non invasive. The non-invasive method involves the placement of electrodes on the scalp and in invasive it involves insertion of electrodes into the regions of brain for clear understanding of the neuron activity during an epileptic seizure.[7]

Alzheimer's

Alzheimer's is a neurological disorder which causes memory impairment temporarily (short term or long term). It interferes with day to day activities which makes a person lose a bit of memory and it is related to dementia. The research is still in its experimental stages where chaos analysis is used and different analysis methods like time-frequency and wavelet methods with the combination of various parameters would yield a more efficient output.[8] Table 2 shows the review on CAD, Autism, Epilepsy, Alzheimer's.

DATA ACQUSITION

The different EEG signals are taken with help of single channel and multi channel electrodes where the multi channel electrodes because they do not miss any small but crucial data. Once the EEG signal is obtained then a suitable signal processing method can apply for further analyzing the abnormality.

Fourier transform

The discrete Fourier transform gives a relationship between the time representation and the frequency representation of signals.[9] The Fast Fourier Transform (FFT) is simply a fast (computationally efficient) way to calculate the Discrete Fourier Transform (DFT) which reduces the number of computations needed for N points from N^2 to $(N/2)\log_2 N$.[10] Fast Fourier transform (FFT) is commonly used in analyzing the spectral content of any deterministic bio-signal (with or without noise).The amplitudes and phases of the sinusoidal components can be estimated using the DFT and is represented mathematically as

$$X(k) = 1/N \sum_{n=0}^{N-1} x(n) e^{-j2\pi kn/NT} \quad (1)$$

where k = 0……N-1

Discrete cosine transform

This transform is commonly used in encoding and decoding signals where a signal is expressed in terms of sum of cosine terms. It allows data reduction without losing any important data.

Discrete wavelet transform

The discrete wavelet transform expresses a signal in terms of different wavelets each corresponding to different frequency ranges where the transform captures every subtle change in an EEG signal in time,

frequency and space. DWT is more useful than CWT and additional features when calculated and combined with the different wavelets can provide an efficient and easier analysis of the EEG signal.[9,11] DWT is commonly used for the diagnosis of epilepsy with CAD because of its efficient outputs and detection of every minor change in an EEG signal and an advantage of removal of maximum artifacts.[12]

FEATURE EXTRACTION

Different features of an EEG signal can be extracted which significantly help in analysis and further processes of classification.

Band power

It is the power corresponding to a particular band of an EEG signal

It can be calculated using,

$$\text{Band Power} = \frac{1}{M}\sum_{m}^{M} = 1(s_m)^2 \quad (2)$$

where, *Sm* is the discrete time series of data

Standard deviation

It is a number which is calculated to show how measurements of a group are spread out from the average or expected value and is calculated as follows,

$$\text{Standard Deviation} = \sqrt{\frac{1}{M}\sum_{m=1}^{M}(s_m - \mu)^2} \quad (3)$$

Where, μ is the mean and *Sm* is the dataset containing *M* values

Largest Lyapunov Exponent (LLE)

The LLE is calculated simultaneously with the correlation dimensions[13] which is an accurate method and a fast one because it uses a simple measure of exponential divergence and works well with small data sets.

Shannon Entropy

Entropy is calculated to measure the disorder or uncertainty in a given signal. Shannon entropy calculates the average information of a set of data.

$$\text{Shannon Entropy} = -\sum_{k=1}^{i} p_k \log_2(p_k) \quad (4)$$

where i - the number of unique values in the discrete data (S_m)

pk - the probability or normalized frequency of the unique values.

There are three types of entropy calculated for finding out the complexities of the EEG waveform to quantify the patterns from wakefulness to depth of anesthesia, they are Sample Entropy, Approximate Entropy and Spectral Entropy.[14,15] The calculation of entropy and combining this feature with the wavelets provides efficient calculation or determination of presence of abnormality in a person.

The various entropies used and their significance in detecting the epileptic person from a non epileptic is given in[16] which justifies that the entropic activities of epileptic person is less compared to a non epileptic person and other results which shows that calculation of entropy is a powerful technique in non linear dynamics which proves to come with better results.

Cross correlation

In signal processing, cross-correlation is a measure of similarity of two series as a function of the displacement of one relative to the other. This

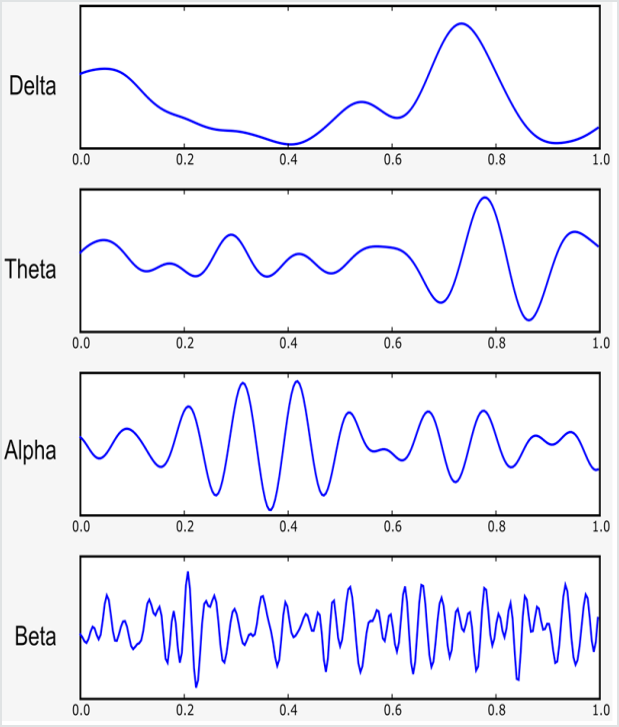

Figure 1: Different wave patterns of EEG bands.

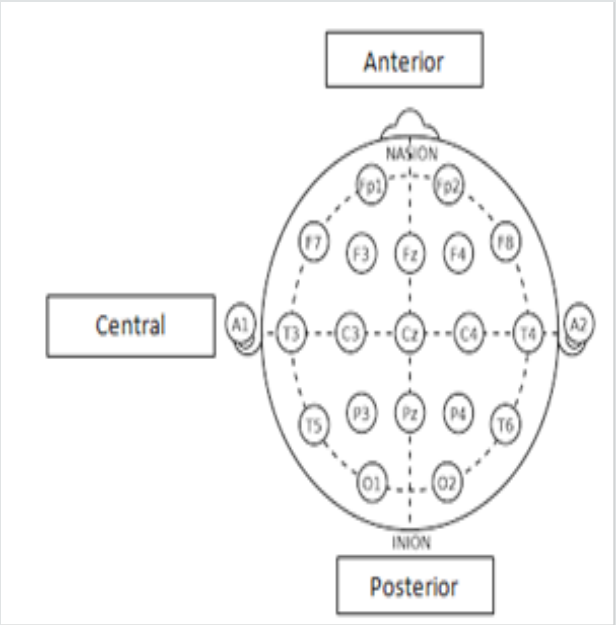

Figure 2: Brain regions and electrode placement.

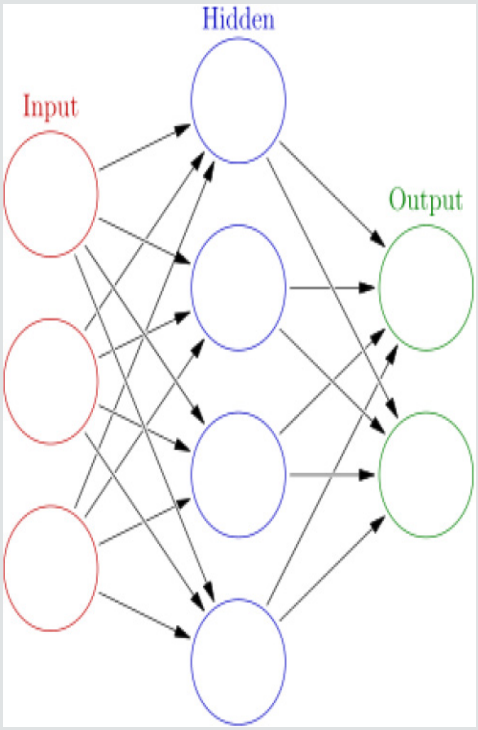

Figure 3: Different nodes in ANN.

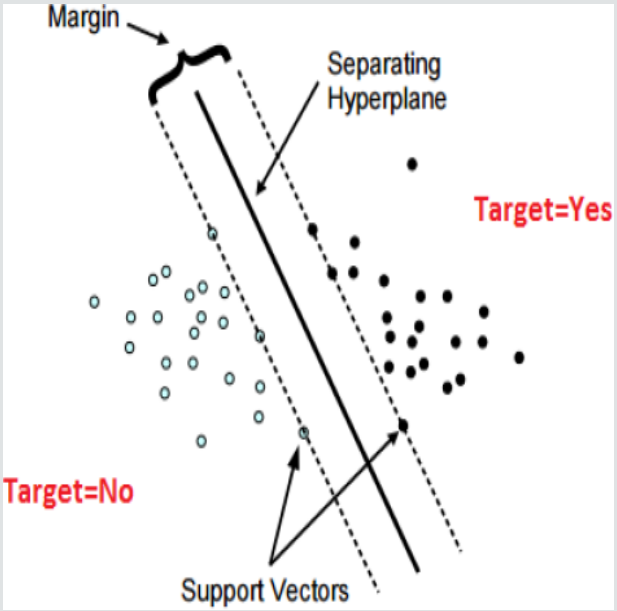

Figure 4: Support Vector Machine.

is also known as a sliding dot product or sliding inner-product. It is commonly used for searching a long signal for a shorter, known feature. It has applications in pattern recognition, single particle analysis, electron, tomography, averaging, cryptanalysis and neurophysiology. For discrete function, the cross correlation is defined as,

$$(x * y)\,|\,j\,| \stackrel{\text{def}}{=} \sum_{i=-\infty}^{\infty} \mathrm{x}^{*}\,|\,i\,|\,y[i+j] \qquad (5)$$

And measurement of synchronization of the three regions of the brain which are anterior, central and posterior as shown in Figure 2. The abnormal connectivity and synchronizations between brain regions may reveal certain brain disorders and tell us a bit about the electrical activity and helps to extract the features.[17]

CLASSIFICATION

Artificial Neural Network (ANN)

The main goal of the classification is automatically determine the class of the EEG segment based on the extracted features. Feed Forward Neural Network (FFNN) is applied in this work for classifying the EEG segment based the on extracted entropy value. The input features decides the number of nodes in the input layer, whereas the hidden layer uses log-sigmoid transfer function, while output later uses soft max transfer function as shown in Figure 3 FFNN must be trained before it is used for classification. This process adjusts the weights of the network. The performance of neural network depend on the 'epochs' process where epochs measure the number of iterations of the training vectors used to update the weights of neurons and the performance of neural network is increased when epochs is increased.[18]

K-Nearest Neighbor (KNN)

It is a non parametric method which does not make any assumption of the underlying data and which can be used for classification and regression. It is called as a lazy algorithm and it is very simple but also very effective with its training phase being very quick. Its purpose is to use a database in which the data points are separated into several classes to predict the classification of a new sample point. It is based on feature similarity where the new data is compared how closely related it is to the training set of data values. The method where Euclidean distances are taken as the distance metric for nearest neighbor classification is presented in.[19]

Linear Discriminant Analysis (LDA)

If the measurements made on independent variables of each observation are continuous quantities then LDA is applied. When dealing with independent variables of various categories, the equivalent technique is discriminant correspondence analysis

Support Vector Machine (SVM)

SVM is used in machine learning as a supervised learning method with added learning algorithms that is used for classification also regression analysis which analyze data. A Support Vector Machine is a classifier defined by a separating hyperplane which depends on pattern recognition Figure 4. In simpler words, the algorithm outputs an optimal hyperplane which categorizes new examples.[20] SVM can also perform non-linear classification along with linear classification. Table 3 shows the review on wavelet transform, entropies, LLE, SVM.

Data Sets

For autism the readings of the EEG are available in the KAU dataset which was recorded using 16-channel EEG at 256Hz from ten normal subjects and nine autistic subjects.[21] Epilepsy datasets it can be referred

Table 3: Review on Wavelet transform, Entropies, LLE, SVM.

S.No	Title	Conclusion	Inference
1	A tutorial on support vector machines for pattern recognition (1998)	SVM provides new approach for problem solving for clear connections to statist -ical learning theory and different from KNN and ANN	SVM makes a simple geometric pattern recognition for better investigation
2	Entropies for detection of epilepsy in EEG (2005)	Entropies of epileptic activity are less as compared to that of non-epileptic activity.	Entropy results can differentiate and classify normal and epileptic EEG.
3	EEG signal classification using wavelet feature Extraction and a mixture of expert model (2007)	It is a difficult task to diagn -ose epilepsy and requires observation of the patient an EEG and gatheri-ng of additional clinical information.	ME neutral structure achieved accuracy rates which were higher than that of the standard alone neural network.
4	Approximate entropy-based epileptic EEG detection using artificial neural networks. (2007)	Two types of neural networks ENs and PNNs employed for automated detection Overall accuracy as 100%	Seizure detection with high accuracy is possible with ANN
5	Resting state cortical connectivity reflected in EEG coherence in individuals with autism. (2007)	Robust patterns of over and under connectivity are apparent at distinct spatial and temporal scales and ASD subjects in the eyes closed resting state	The ASD group exhibited significantly greater relative power between 3 and 6 Hz and 13–17 Hz and significantly less relative power between 9 and 10 Hz.
6	Detection of abnormalities for diagnosing of children with autism disorders using of quantitative electro -encephalography analysis (2010)	Two kinds of significant differences in comparison of control children. The first, to decrease activity in left brain hemisphere, in alpha band, was detected by spectrogram criteria and the second, to increase connectivity of temporal lobes with other lobes, in gamma band, detected by coherence values.	Coherence values at 171 pairs of EEG electrodes indicated that there are more abnormalities with higher values in the connectivity of temporal lobes with other lobes in gamma frequency band.
7	EEG complexity as a biomarker for autism spectrum disorder risk (2011)	MMSE computed from revisiting state may be a useful for biomarkers for early detection of risk for ASD.	Using MMSE as a feature vector, infants were classified with over 80% accuracy
8	A practical method for calculating lyapunov exponents from small data (1993)	To calculate the correlation dimension simultaneously with embedding dimension, size of data set, reconstructtion delay and noise levels.	It is accurate and fast because it uses a simple measure to calculate LLE even for small data set.

Table 4: Comparison with several previous studies of epilepsy diagnosis.

Author	Feature extraction	Classifier	Accuracy (%)
Niqam *et al*. 2004	Non-linear filter	ANN	97.2
Kannathal *et al*. 2005	Entropies	ANFIS	92.2
Subasi *et al*. 2007	DWT	Mixture of expert (ME)	94.5
Srinivasan *et al*. 2007	Approximate entropy (Apen)	Elman ANN	100
Ocak 2009	Apen on DWT	ANN	96
Dhiman *et al*. 2014	DWT	GA-SVM SVM	100
Sutrisno Ibrahim *et al*. 2018	DWT + SE/SD/BP	KNN/SVM	100

from Bonn University[22] which contains five sets A-E recorded at 173.61 Hz with a spectral bandwidth of 0.5-85 Hz and MIT dataset at 256Hz, with a time gap 10 seconds. EEG dataset for invasive method (intracranial) is available in[23] in which recordings are made of 21 patients with 128 channel and 256Hz. More information for epileptic databases is available in[24] which give information about non linearity dependence and non-stationary of EEG signals of epileptic patients. Another set which tells about comparison of dynamical properties of brain electrical activity from different recording regions and from different physiological and pathological brain states with the help of nonlinear prediction error and an estimation of an effective correlation dimension with the method of iterative amplitude adjusted surrogate data. The samples are taken at 173.61Hz.[25] More clinical databases for various EEG recordings are given in[26,27] and comparison with several previous studies of epilepsy diagnosis[29-34] are shown in Table 4.

CONCLUSION

The process to automatically process and analyze the EEG signals using aided diagnosis has proven to be the best method to detect any abnormality with respect to a person's neurological state of the brain. The usage of proper signal processing methods and few features extracted from

numerous types of methods provides efficient and easy ways of understanding the patterns of an abnormal person. The usage of wavelet transform with the combination of entropy and classifying with the help of KNN classifier gives an easy way of analyzing epileptic signals, which are explained in.[28] Therefore developing adaptive learning and inclusion of other mathematical processes is to improve the system Performance and also help the doctors in analyzing various types of neurological disorders.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

ANN: Artificial Neural Network; **CAD:** Computer Aided Design, **DCT:** Discrete Cosine Transform; **DWT:** Discrete Wavelet Transform; **EEG:** Electro Encephalogram; **FFT:** Fast Fourier Transform; **KNN:** K-Nearest Neighbor; **LLE:** Largest Lyapunov Exponent; **LDA:** Linear Discriminant Analysis; **SVM:** Support Vector Machine.

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