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Study on EEG Signal Processing and Feature Extraction Techniques

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Abstract- The brain is the focal point of all activities performed in the human body, the state of which can be monitored by recording the related signals. The electrical signals generated by the brain named electroencephalogram, which shows the effective functions of various organs and further mental turmoil. EEG readings stress upon certain diagnostic applications for example to detect Epilepsy, sleep disorders etc. A brain computer interface (BCI) is communication system which associates the outside world using EEG signals. In this paper we discuss about a portion of work related on various techniques like signal acquisition, feature extraction and signal classification.

Keywords: BCI, EEG signals, Epilepsy, Feature Extraction, Signal processing

1. INTRODUCTION

The human brain is been studied since the time of ancient Egyptian to 18th century scientific research on neurons. In this 21st century neuroscience is advancing in technologies possibilities of the human brain. EEG records the electrical activity of the brain by capturing signals with neuron activity. EEG is an instantaneous and continuous indicator of brain function, which has led to its extensive use in the field of biomedical signal processing [1].
A brain computer interface (BCI) is communication system in which a person can use their generated EEG signal to control the external environment. A BCI system comprise of four parts: signal acquisition, signal pre-processing signal, signal classification and computer interface.

2. SIGNAL ACQUISITION

Brain electrical signals are obtained by using various non-invasive techniques like EEG, MEG, FMRI and FNRIS

2.1. *Electroencephalogram (EEG)*

EEG was recorded an animal brain in 1875 by Richard Caton. It absolutely was 1st recorded on human brain by Hans Bergen in 1929. EEG is used for signal acquisition technique attributable to the high temporal resolution, safety and an easy use 10-20 standard electrode is employed in EEG signal acquisition. EEG has low spatial resolution and is non-stationary in nature. EEG signals are vulnerable to artifacts caused by eye blinks, eye movements, muscular activities and the power line interference.

2.2. *Magneto-encephalography (MEG)*

MEG is a non-invasive brain imaging technique based on magnetic fields. MEG measures magnetic signals generated by electrical activities in the brain [2]. MEG provides wide range of frequency and exceptionally maintains spatiotemporal resolution. MEG equipment is expensive and heavy sized.

2.3. *Functional magnetic resonance imaging (FMRI)*

FMRI is a hemo-dynamically based technique. FMRI uses BOLD (Blood Oxygenation Level Dependent) methodology to observe the level of hemoglobin or Oxygenation fluctuations due to abnormal brain activities. In 1995, BOLD fluctuations were investigated since oxygenation patterns are identified in blood flow [3]. It has high temporal and spatial resolution depending upon the time required to acquire signal pixels.

2.4. *Functional Near infrared spectroscopy (FNIRS)*

FNIRS measures the brain activity through hemo-dynamically based technique. FNIRS is combined with EEG to construct hybrid BCI i.e. low cost and produce low noise signals [4]. FNIRS also utilizes BOLD to obtain signal data. This technology has low temporal resolution.

3. SIGNAL PROCESSING TECHNIQUES

Signal preprocessing occurs after the signal is acquired. When EEG signals are acquired, they are contaminated at many points during recording and transmission process. Signals are known to be very noise and artifact, as they can be easily affected by the electrical activity of the eyes or of the muscles. To remove the noise and artifacts, there are different techniques which can be applied to identify the original signal such as Wavelet transform (WT), Independent component Analysis (ICA), Principal component analysis (PCA), Common average referencing (CAR), Surface Laplacian (SL), common spatial patterns (CSP), Single value decomposition (SVD), and common spatio-spatial patterns (CSSP), Frequency Normalization (freq-norm), local averaging Technique (LAT) Robust Kalman filtering, common spatial sunspace decomposition (CSSD)etc. the most commonly used techniques are SL ,WT, ICA, PCA, CAR.

3.1. *Independent component Analysis (ICA)*

ICA was first preprocessing technique applied to EEG signals by Makeig et al. in 1996. ICA separates the artifacts (generated from physiological noises) from EEG signals into independent components based on the characteristic data without relying on the reference channel. The defining characteristics for ICA can change depending upon the type of ICA used- temporal or spatial. Temporal ICA (tICA) corrects overlapping spatial distributions of different signal sources by identifying the temporally independent signals. tICA has high performance but is rarely used due to complexity of the computation required and limited amount of data points available to perform calculations[5]. Spatial ICA (sICA) cannot accomplish the same task, but its calculations are simpler. EEElab supports various types of ICA algorithms (20 algorithms) and most frequently used algorithms are Joint Approximate Decomposition if Eigen matrices (JADE), fixed point ICA, Infomax.

3.2. *Principal component analysis (PCA)*

PCA was invented in 1901 by Karl Pearson and later developed by Harlod Hotelling in 1930. The PCA transforms the correlate vectors into linearly uncorrelated vectors. These uncorrelated vectors are known as "*principle components*" [6]. This is a classical method of Second Order Statistics. It depends upon decomposition of covariance matrix .PCA removes physiological noises and motion artifacts and performs feature dimensionality reduction, allowing for singular decomposition to be applied, creating the principal components to be used in ICA. The application of PCA in a BCI system gives best classification results.

3.3. *Common average referencing (CAR)*

This technique removes the noise by subtracting the common activity from the position of interest. The common activity can be noise and artifacts present in the EEG signal. This method enhances the signal-to-Noise Ratio (SNR). The presence of artifacts in EEG signals results in low SNR. The results in [7] prove that CAR outperforms all referring techniques and shows best classification accuracy results.

3.4. *Surface Laplacian (SL)*

It estimates the electrical current density leaving or entering the scalp through of the skull. It only considers the outer shape of the volume conductor and does not require any details of volume conduction [8]. For large artifacts ranging from 50microV(>50 microV) visual inspection is required and by considering shape of the artifacts the gradients of activities are obtained [9].SL is robust against artifacts generated uncovered regions by the electrode cap and it solves the electrode reference problem- identifying the noise present on all channels to subtract it out [10]. SL is insensitive to motion artifacts because there are no underlying muscles.

4. FEATURE EXTRACTION

Feature extraction occurs after obtaining the noise free signals from raw signals. Feature Extraction Techniques highlight signals characteristics of biomedical events. For EEG signals feature extraction techniques are used like Adaptive Auto Regression Parameter (AAR), bilinear AAR, Multivariate AAR, Fast Fourier Transform (FFT), PCA, ICA, Genetic Algorithm (GA), WT, and Wavelet Packet Decomposition (WPD). Among these PCA, ICA, WT, AR, WPD, FFT are mostly used as feature extraction techniques and some of them are also applicable as signal pre- processing techniques.

4.1. *Independent component Analysis (ICA)*

ICA also can be used as feature extraction technique. ICA forms the components that are independent to each other and form those components essential features were extracted using ICA. An important application of ICA is Blind Source Separation (BSS) [11]. It's an approach to estimate and recover the independent source signals using only the information of their mixture observed at recording channels. BSS of acaustic signals are also referred to as the 'Cocktail Party Problem' means separation of individual components from set of uncontrolled records.

4.2. *Principal component analysis (PCA)*

PCA is a signal pre-processing method as well as feature extraction technique. It is a robust tool for analyzing and for reduction of data dimension without any loss of information. With the use of PCA the information present at the entire series multichannel is extracted as principal components. By eliminating the artifacts and forming the principal components PCA reduces the signal dimensions.

4.3. *Wavelet transformation (WT)*

Wavelet transformation is used as feature extraction technique was expressed by Grossman and Morlet in 1984. Scottet.al suggested a method to perform the feature extraction with the B-Spline parameter in [12]. This function acts as low pass filter as well high pass filter and these filtering characteristics it stood as B-Spline Clients. WT has the advantage of performing a multi-resolution analysis meaning that is processes different frequencies in a different way. WT plays an important role in the recognition and diagnostic field: it compresses the time varying biomedical signal, which comprises many data points into a small parameter that represents the signal.

4.4. *Autogressive (AR)*

AR system is employed for feature extraction in time domain analysis. AR technique yields better frequency resolution and don't have problem spectrum density of the EEG using parametric methodology. There are two types of AR modeling styles: Yale walker Algorithm and Burg Algorithm. Among the two the Burg Algorithm has been proved the best for AR modeling.

4.5. *Wavelet Packet Decomposition (WPD)*

WPD will extract features in each time and frequency domain with the coefficients mean of WT. Beginning features are taken as the power at unique subsets and the separabilities were estimated by using Fisher's paradigm. In Fisher's criterion, the coefficients with higher separability were considered effective and formed as conclusive vector. It divides the original signal into 2 subspaces supported frequency. Wavelet packet tree demonstrates the decomposition of low frequency wavelets. The results of Ting et al. demonstrates that WPD shows higher performance results and it's superior to AR model [13]. It shows smart performance within the extraction methods of non-stationary signals like EEG.

4.6. *Fast Fourier transform (FFT)*

FT was formulated by Joseph Fourier in 19^{th} century. This method employs mathematical tool to EEG data analysis. It extracts the signal feature and transform signal from time domain to frequency domain. The frequency based analysis is named as discrete Fourier transform and also terms as power spectral density [14].

5. CLASSIFICATION OF FEATURE

After the feature extraction the signals are classified into various classes utilizing various classifiers. Classification methods are used to organize the processed signal and its feature into understandable sets to split the desirable from undesirable. There are two different types of classifiers: linear classifiers-linear Discriminant Analysis (LDA), Support Vector Machine (SVM) and non-linear classifiers- Artificial neural network(ANN), Non- Linear Bayesian classifiers, Nearest Neighbour classifiers.

5.1. *Linear Discriminant Analysis (LDA)*

LDA is stable classifiers. LDA have a low complexity. They are said to stable as small variations in the training set doesn't affect their performance. LDA is to hyper-planes to separate the data representing the different classes. It requires a very low computation and simple to use. LDA creates models of the probability density function and from each class to generate data [15].

5.2. *Support Vector Machine (SVM)*

SVM was proposed by Vapnik and was driven by statistical Learning theory following principle of structural risk minimization [16]. SVM realize a hyper-plane to separate the data set with clear gap as wide as possible to classify them in applicable category. It gives excellent results even with high dimensional feature vector and small training set [17]. SVM have high performance and more computational complexity.

5.3. *Artificial Neural Network (ANN)*

Artificial Neural Network are non-linear classifiers. These are composed of large number of simple interconnected elements called neurons and performs simple computational task. The most commonly used Neural Network is Multilayer Perceptron Neural Network are composed of three sequential layers: input layer, one or several hidden layers and an output layer [18]. The MLPNN with one hidden layer is preferred as classifiers. Large no. of neurons in the hidden layer can increase the computational complexity and processing time. Small amount of neurons can lead to the classification errors [19].

5.4. *Non- linear Bayesian classifier (NBC)*

Bayesian Classifiers produce non- Linear decision boundaries. It aims at assigning a feature vector to the class with highest probability. They are generative in nature and enables perform more efficient rejection of uncertain samples than discriminant classifiers [20]. Using Bayes rule *a- posteriori* is computed. Hidden Markov model is an example of NBC are popular dynamic classifiers in the field of speech recognition.

5.5. *Nearest Neighbour classifiers (NNC)*

NNC assigns a feature vector to a class depending upon its nearest neighbours. In k- nearest Neighbours (KNN) case neighbours could be a feature vector from training set. In [21] KNN are proved to be efficient with low dimensional feature vectors. For example, NNC can be applied to EEG signals in the form of a Weighted Adaptive Nearest neighbour (WDNN). WDNN is applied to determine the quality of the EEG signal segment by assigning different weights to classify task.

6. CONCLUSION

This paper gives a brief idea about various EEG/BCI signal processing techniques: Signal acquisition, feature extraction, classification of signal. With the sufficient knowledge of these new and effective techniques are involved to attain better performance in the field of EEG/BCI. The hybrid techniques can further used for applications like detection of mental turmoil, epilepsy, thought based operating system.

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