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Various Techniques for Denoising EEG signal : A Review

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Abstract: The Electroencephalogram (EEG) signal is a biological non-stationary signal which contains important information about various activities of Brain. Analysis of EEG signals is useful for diagnosis of many neurological diseases such as epilepsy, tumors, and various problems associated with trauma. EEG measured by placing electrodes on scalp usually has very small amplitude , so the analysis of EEG signal and the extraction of information from this signal is a difficult problem. EEG signal become more complicated to analyze by the introduction of artifacts such as line noise, eye blinks, eye movements, heartbeat, breathing, and other muscle activities. Proper diagnosis of disease requires faultless analysis of the EEG signals. The problem of denoising is quite varied due to variety of signals and noise. Discrete wavelet transform provides effective solution for denoising non-stationary signals such as EEG due to its shrinkage property.

Keywords:EEG(Electroencephalograph) signal; denoising; Discrete Wavelet Transform(DWT).

INTRODUCTION

Brain Signal Proceesing

Signal processing is the enabling technology for the generation, remodeling, and interpretation of information. At different stages of time our brain reacts differently. These brain signals are used for various purposes so that it is possible to study different functionalities of brain properly . This process is known as brain signal processing.

Brain waves and EEG

The analysis of brain waves plays an important role in diagnosis of different brain disorders. Brain is made up of billions of brain cells called neurons. The combination of these millions of neurons sending signals at once produces an enormous amount of electrical activity in the brain, which can be detected using EEG which measures electrical levels over areas of the scalp. The electroencephalogram (EEG) recording is a useful tool for studying the functional state of the brain and for diagnosing certain disorders. The combination of electrical activity of the brain is commonly called a Brainwave pattern because of its wave-like nature. An electroencephalogram (EEG) is the recording of the brain electrical activity. A set of electrodes are placed over the scalp . This technique is non-invasive as no surgery is required. The main drawback is that by recording the electrical activity far away from the source i.e. the neurons inside the skull, the signal we pick up is distorted and has reduced amplitude. EEG is one of the key tools for observing brain activity. Its main advantages are low cost, relative ease of use and excellent time resolution. For these reasons, EEG is widely used in many areas of clinical work and research. One of the biggest challenges in using EEG is the very small signal-to-noise ratio of the brain signals that is to be observed, contaminated by the wide variety of noise sources. EEG is used to record brain waves .It is one of the brain signal processing technique that allows gaining the understanding of the complex inner mechanisms of the brain and abnormal brain waves have shown to be associated with particular brain disorders. Ocular artifacts like eye movement, eye blinks,heart signals and line noise often produce large artifacts in EEG recordings. Rejecting artifacts with the EEG signal segment may result in lose of data because EEG signals contain neural information below 100 Hz so OAs and muscle artifacts that have spectral overlap with underlying EEG cannot be removed using conventional filtering[12].

Various frequencies of the human EEG waves are:

- **Delta**: has a frequency of 3 Hz or below and tends to be the highest in amplitude and the slowest waves. It may occur focally with subcortical lesions and in general distribution with diffuse lesions.

- **Theta:** has a frequency of 3.5 to 7.5 Hz and is classified as "slow" activity. It can be seen as a manifestation of focal subcortical lesions; it can also be seen in generalized distribution in diffuse disorders such as metabolic encephalopathy .

- **Alpha**: has a frequency between 7.5 and 13 Hz. It is usually best seen in the posterior regions of the head on each side. It seems once closing the eyes and restful, and disappears when open the eyes or alerting by any mechanism (thinking, calculating).

- **Beta:** beta activity is fast activity and has a frequency of 14 and greater Hz. It may be absent or reduced in areas of cortical damage. It is typically considered a standard rhythm. It is the dominant rhythm in patients who are alert or anxious or have their eyes open.

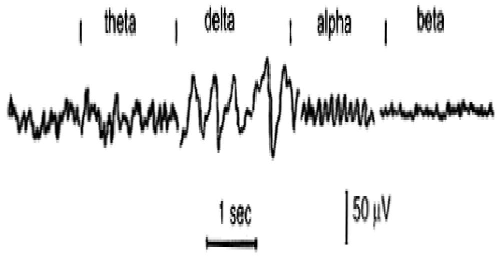

Figure 1: Various bands of EEG signal

The EEG signal identifying waves of the brain is oneof the most important biomedical signals . This signal is corrupted by various types of noise.These corruptions can be removed by using various denoising techniques. However, frequency domain filters could cause distortion in a transient interval of the signal and importantclinicalinformation may be lost because nature of the EEG signal is non-stationary. To protect the signal features,wavelet transform is the most popular method.

This paper is organized into fivesections. Section II explains the background for EEG Signal Denoising. Section III focuses on aspects of wavelet transform.Section IV explains the review of various techniques used for denoising of EEG signal. Finally,the conclusion is represented in Section V.

Background

The use of wavelet transform has attracted much attention recently for denoising EEG signal, and many different denoising techniques have been proposed to enhance the processing of signal. Some previous researchers are briefly described as follows:

Jeena Joy et al. [1] presented a comparative study of different denoising techniques.The denoising process rejects the noise by threholding in wavelet domain.Discrete Wavelet Transform has the benefit of giving a joint time-frequency representation of the signal and suitable for both stationary and non-stationary signals and is the most suitable method for signal detection.Discrete Wavelet Transform is a multiresolution analysis and provides effective solution.

Janett Walters-Williams et al. [2] proposed a new method for denoising artifacts in mixed EEG signals. To remove these artifacts the information theoretic concept of mutual information estimated using B-Spline was used for creating an approach for Independent Component Analysis (ICA) and tests showed that B-Spline Mutual Information Independent Component Analysis (BMICA) performs better.

Eleni Kroupi et al. [3] performed a comparative study on the performances of two methods namely, subspace projection and adaptive filtering using two measures mean square error (MSE) and computational time of each algorithm. ICA (independent component analysis) methods appear to be most robust but not the fastest one. Hence,they could be easily used for off-line applications. PCA (principal component analysis) is very fast but is less accurate so it could be used for real-time applications. Adaptive filtering appears to have most worst performance in terms of accuracy but it is very fast.

Muhammad Tahir Akhtar et al. [4] proposed a framework based on independent component analysis and wavelet denoising to improve the preprocessing of EEG signals and employed a concept of spatially-constrained ICA (SCICA) to extract artifact only independent components (ICs) from EEG recording, used wavelet denoising to remove any bran activity from extracted artifacts and finally project back the artifacts to be subtracted from EEG signals to get clean EEG signal.

V.V.K.D.V.Prasad et al. [5] introduced a new thresholding filter for purpose of thresholding in denoising EEG signals using wavelet packets. Wavelet packets have been found to be effective in denoising of biological signals. Wavelet based denoising methods employ hard and soft thresholding filters for denoising the signals.

Haslaile.Abdullah et al. [6] proposed wavelet based image processing techniques known as 1-D Double Density and 1-D Double Density Complex for denoising EEG signals at various window sizes nad performance is compared and evaluated using Root Mean Square Error(RMSE).1-D Double Density Complex was outperformed 1-D Double Density and was effective in EEG signal denoising.

Geeta Kaushik et al. [7] describes the method of wavelet transform for the processing and analysis of biomedical signals.One of the most important applications of wavelets is removal of noise from biomedical signals and is called denoising which is accomplished by thresholding wavelet coefficients in order to separate signal from noise A biomedical signal is a non-stationary signal whose frequency changes over time and for the analysis for these signals Wavelet transform is used.

P.Ashok Babu et al. [8] proposed wavelet based threshold method and Principal Component Analysis (PCA) based adaptive threshold method to remove the ocular artifacts.In comparison to the wavelet threshold method, Principle component analysis based adaptive threshold method will give better PSNR value and it will decreases the elapsed time.

Patil Suhas S. et al. [9] discussed that denoising of EEG signals is performed using wavelet transform that are acquired during performing different mental tasks. Appropriate analysis of EEG signal requires the elimination of noise due to facial muscle movements, eye blinking ,heartbeats etc.The problem of denoising is varied due to variety of signals and noise.The results are evaluated using the signal-to-noise ratio of the denoised signals.

Priyanka Khatwani et al. [10] concludes that wavelet method of denoising and its enhancement wavelet packet is best. various techniques that can be used for noise removal in EEG signals are discussed. As EEG signal is contaminated by various type of noises so to diagnose various brain related diseases ,the signal should be free from noise.

Weidong Zhou et al. [11] introduced methods of wavelet threshold denoising and independent component analysis (ICA). ICA is novel signal processing technique based on higher order statistics and is used to separate independent components from the measurements. The extended ICA method does not need to calculate high order statistics. The experiment results indicate the electromyogram (EMG) and electrocardiograph (ECG) can be removed by a combination of wavelet threshold denoising and ICA.

Wavelet Transform

In general, a wavelet is a wave like oscillation with amplitude that starts at zero, increases and then decreases to zero. One of the main functions of wavelet transforms is used to reduce the unwanted noise and blurring in the signals. Wavelet transform isone of the efficient technique used for decomposition of non-stationary signals like EEG [12].

Wavelet transforms can decompose a signal into different scales that represent dissimilar frequency bands. The Wavelet Transform provides a time-frequency representation of the signal. A signal is examined and expressed as a linear combination of the sum of the product of the wavelet coefficients and mother wavelet is wavelet transform. Wavelet transform provides both frequency and spatial domain of an signal. Unlike conventional Fourier transform, temporal information is retained in this transformation process. The original signal is transformed using predefined wavelets in wavelet transform. The wavelet transform is classified into Discrete Wavelet Transform and Continuous Wavelet Transform. Discrete Wavelet Transform (DWT) based de-noising is performed, to meet the mathematical criteria to obtain the discrete sequences as discrete wavelet function. If the analyzing function is waveform then DWT based de-noising can be performed better .Dividing the continuous time function into wavelets is referred to us Continuous Wavelet Transform (CWT).

Signal decomposition is referred as the way of decomposing a given signal into a sum of simpler signals. Decomposing a signal into scales with different time and frequency resolution is done by Multi-Resolution Analysis (MRA) algorithm. To decompose a signal ,wavelet transform uses some set of basic functions. There are many types of wavelets they are, daubechies wavelet which is described by a maximal number of vanishing moments for some given support. In Haar wavelet which is an order of rescaled square shaped function which together to form a wavelet family. Symlet wavelets are an improved version of Daubechies wavelets with increased symmetry. Coiflets wavelets have scaling functions with vanishing moments.

Signal reconstruction meansreconstructing the original sequence from the thresholded wavelet detail coefficients leads to a denoised version of the original signal. Inverse Discrete Wavelet Transform (IDWT) is used to reconstruct the original signal. Therefore wavelet transform is a reliable and better technique than Fourier transform technique.

Wavelet families

Daubachies: Daubechies family wavelets are signed dbN (N is the order).This wavelet belongs to orthogonal wavelet.

Coiflets :A discrete wavelets designed by Ingrid Daubechies to have a scaling function with vanishing moments. The scaling function and the wavelet function must be normalized by a common factor.

Symlet: The symlet family wavelets are signed symN (N is the order). The symlets are nearly symmetrical, orthogonal and biorthogonal wavelets suggested by Daubechies as modifications to the db family. The properties of the two wavelet families are similar.

Biorthogonal: Biorthogonal filters state a superset of orthogonal wavelet filters.The biorthogonal family wavelets are signed as bior. Biorthogonal wavelet transform has frequently been used in numerous image processing applications, because it makes possible multi -resolution analysis and does not produce redundant information.

Wavelet Filters

The time-frequency representation of DWT is performed by repeated filtering of the input signal with a pair of filters named as, low pass filter (LPF) and high pass filter (HPF), which decompose the signal into different scales.The coefficient of low pass filter is called as Approximation Coefficients (CA) and similarly, high pass filtered coefficients are called as Detailed Coefficients (CD). The CA is consequently divided into new approximation and detailed coefficients. This decomposition process is carried out until the required signal is achieved from the given input signal as shown in Figure 2:

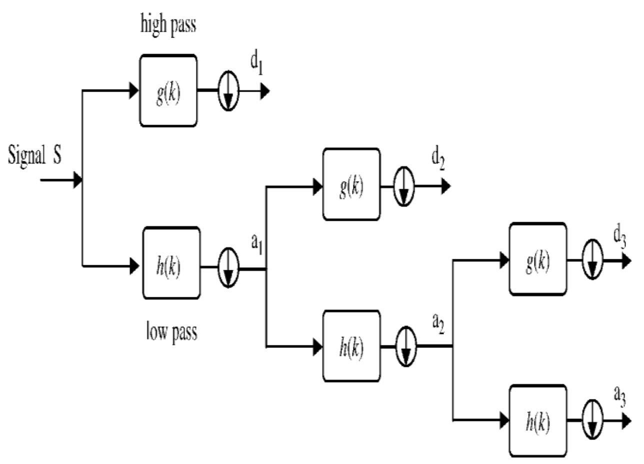

Figure 2: Block Diagram Representation of wavelet Denoising as Combination of Filter Banks

Wavelet Thresholding

Wavelet thresholding is the signal estimation technique that exploits the capabilities of signal denoising. Thresholding method is categorized into two types such as hard thresholding and soft thresholding. Performance of thresholding is purely depends on the type of thresholding method and thresholding rule used for the given application. The hard threshold function tends to have bigger variance and it is unstable and is defined as:

However, soft thresholding function is much stable than hard thresholding and it tends to have a bigger bias due to the shrinkage of larger wavelet coefficients and is defined as:

.

In general, most of the researchers have proved that, thesoft thresholding method gives the best results with other methods on denoising the EEGsignal.

Some Application of Wavelets : Wavelets are a powerful statistical tool which can be used for a wide range of applications, namely

- Signal processing
- Data compression
- Smoothing and image denoising
- Fingerprint verification
- DNA analysis
- Blood-pressure, heart-rate and ECG analyses
- Speech recognition
- Computer graphics and multifractal analysis

Review of EEG Signal Denoising Techniques

Various denoising techniques have been implemented for removal of artifacts from EEG signals. Some of the techniques are: ICA(independent component analysis) , PCA(principal component analysis), Wavelet transform, Wavelet packet transform and performance can be measured by parameters like PSNR, MSE, RMSE, SIR, SDR etc.

Principal Component Analysis (PCA)

Principal component analysis involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components.PCA is sensitive to scaling.The mathematical technique used in PCA is called Eigen analysis : we solve for the eigen values and eigen vectors of a square symmetric matrix with sums of squares and cross products[8].

Independent Component Analysis (ICA)

ICA components of many signals are sparse, so that one can remove noise in the ICA domain.ICA carries all the information in single component and mostly contain non-artifactual information which can result in information loss.The limitation of this method is that the signals can only be analyzed in time domain not in the frequency domain.

Discrete Wavelet Transform (DWT)

Discrete Wavelet transform (DWT) is a mathematical tool for hierarchically decomposing a signal[4]. The transform is based on small waves, called wavelets. Wavelet transform provides both frequency and spatial domain of a signal.. Unlike conventional Fourier transform, temporal information is retained in this transformation process. Wavelets are created by translations and dilations of a fixed function called mother wavelet. This section analyses suitability of DWT for signal denoising and gives the advantages of using DWT as against other transforms [9]:

1. The DWT requires less space utilizing the space saving coding based on the fact that wavelet families are orthogonal or biorthogonal bases , and thus do not produce redundant analysis.

2. The DWT is computed by passing a signal consecutively through a high pass and a low pass filter.

3. The DWT provides sufficient information both for analysis and synthesis of the original signal,with a significant reduction in computation time.

4. The DWT transforms a discrete signal from the time domain into time-frequency domain.The transformation product is a set of coefficients structured in the way that enables not only spectrum analysis of the signal, but also the spectral behavior of the signal in time.This is achieved by decomposing the signal,breaking it into two components,each carrying in information about source signal. Filters from the filter bank used for decomposition come in pairs- low pass and high pass.

Wavelet Based Denoising

The term 'wavelet' refers to an oscillatory vanishing wave with time-limited extend, which has the ability to describe the time-frequency plane, with atoms of different time supports [10]. The signal is decomposed into high and low frequency components using wavelet thresholding. A suitable threshold value is selected based on the signal characteristics. There are two thresholding methods : Hard Thresholding and Soft Thresholding and then wavelet is selected which decompose the signal and the signal is reconstructed. Wavelet transform is applied to low pass i.e approximation coefficients only.

Wavelet Packet Denoising

Wavelet Packets are linear combinations of wavelets. They form the bases which retain many of the orthogonality, smoothness and localization properties of their parent wavelets [5].The coefficients are obtained by making newly computed wavelet packet coefficient sequence the root of its own analysis tree. Wavelet Packet

Transform is applied to both detail and approximation coefficients [10].

Performance Measures:

- **PSNR** (Peak Signal to Noise Ratio):
  Peak signal-to-noise ratio, often abbreviated PSNR, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation.

- **MSE** (Mean Squared Error) :
  Mean squared error (MSE) of an estimator measures the average of the squares of the "errors", that is, the difference between the estimator and what is estimated.

- **SDR**(Signal to Distortion Ratio):
  We measure the quality of signal by separation of noise from the noisy signal.

Where x_i (n)is the original source signal and y_i (n) is the reconstructed signal.
The higher the SDR value,the better the separation of the signal from the noise.

- **SNR** (Signal to Noise Ratio) :
  It is defined as the ratio of signal power to the noise power, often expressed in decibels.

Conclusion

Various methods have been studied for denoising of the EEG signal. It is known that a denoised signal has high PSNR,SNR and low MSE.By taking into account various performance measures like SNR, PSNR, SDR, SIR calculated by various authors it is concluded that Wavelet based denoising gives better results. As Wavelet Transform is a multiresolution technique , a signal can be analyzed in both time and frequency domain and by decomposing the signal low frequency signal can be removed. ICA and PCA deals with only time domain, therefore frequency components could not be analysed.So,to analyse frequency components as well Wavelet Transform is used.

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