Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 11, Issue 4, November 2020: 1341-1349

Feature extraction of EEG Signal based on Savitzky-Golay filter

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Abstract. EEG is a technique that enables the extraction and processing of brain signals. This study is important to observe the complex behaviour of the brain signals in order to categorize the signals based on the patterns. This plays a pivotal role in early diagnosis and prediction of brain disorders. The objective of this paper is to design a system to analyze EEG signals. This system will be useful in real time and medical diagnostic environments. The foremost stage is filter designing. It is a crucial step as the obtained brain signals are infiltrated by noise. The filter should be designed such that the noise is removed without affecting the quality of the signal. Initially in this work, synthetic EEG signals are tested on various filters. This is followed by extracting features from the filtered signal. By observing the values of these extracted features, a decision is made as to which filter is best suited for the study of EEG signal. It is found that Savitzky-Golay (SG) filter yields the best results. Following this, normal EEG signal and epileptic EEG signal is filtered by SG filter followed by feature extraction. Various features such as energy, entropy and band power are determined for both the classes.

1 Introduction

Studying brain signals by understanding their functional and cognitive nature provides a solution to numerous neu- rological disorders. The patterns exhibited by these signals are studied to check abnormalities indicating prospective brain disorders. Brain signals are extracted using various techniques such as Computed Tomography (CT), Mag- netic Resonance Imaging (MRI), Positron Emission To- mography (PET). One such method is Electroencephalog- raphy and the signals obtained using it are called Elec- troencephalograms or EEG signals. In the EEG signal ex-tracted from the brain, there are numerous artifacts and noise present due to transmission process, instrumentation noise and also EMI [1][2]. For accurate study of these signals it is important to de-noise them before studying them. EEG signals are classified based on signal frequen-cies. The aim of signal processing is to remove noise, 6 to provide quantification with accuracy, to perform feature extraction and to predict any potential neurological disor-ders. An entire EEG analysing system will consist of var-ious stages such as data acquisition, filtering, feature ex- traction and classification. Therefore , filters are designed in the first stage of EEG signal processing that is pre- processing step to purify the extracted signal from noise and to meet the frequency requirements [7]. The filter should be designed such that the noise is removed without affecting the quality of the signal and should not introduce any distortion. We implemented various filters to check which one works best.

Based on the comparative study of the results obtained from each, the filters we consider for this research are Savitzky-Golay filter, Moving Average Filter and Elliptic filter. Initially, we use synthetic EEG signal for our analysis. White Gaussian noise is added to this synthetic signal and is passed through these filters. After filtering, this signal is used to perform feature extrac- tion using Discrete Wavelet Transform (DWT)[3][7][10]. Various features like SNR, Signal Distortion, Cross Cor- relation Co-efficient, SNRI are examined. Based on the results, the best and the optimum filter is selected. It is found that Savitzky-Golay filter gives the best results. Two classes of real EEG signal are obtained from the MIT chb1 database. These real signals are then passed through the SG filter for de-noising. After filtering, features such as energy and entropy are extracted from each class[7][8].

2 Literature Survey

In biomedical signals, filtering and analysis of the siganls play a very important part. For better diagnosis of any ailment and its treatment, analysis of the signals must be accurate[1]. There are several stages in the EEG Signal Analysis system which include acquiring the data, pro- cessing (filtering) it, extracting its features and provid- ing these features as an input to the classifier. With the proposed methodology, the accuracy of the results and the speed of the system is increased during diagnosis[7]. Amongst various filters, Savitzky-Golay filter yeilds the best results while processing biosignals. It preserves the peaks of the EEG signals and also improves the detection of QRS in ECG signals and proves to be a better replace- ment for Moving Average Filter[11].

Recognizing the difference between the patterns of the signals is an important technique and for this pur- pose many methods have been proposed such as Discrete Wavelet Transform (DWT), Continuous Wavelet Trans- form (CWT), 2-D Wavelet Transform[6]. Along with these methods, Relative Wavelet Energy (RWE) technique was also used for classification of EEG signals which gave better results when used with Artificial Neural Network (ANN)[8].

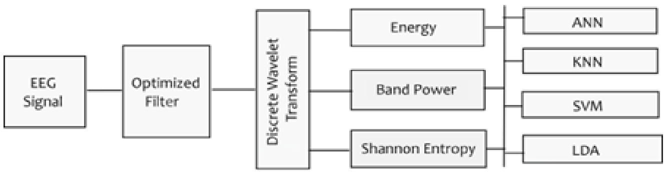

Figure 1. Genral Block Diagram of EEG Analysis System

Table 1. SGF Filtering Results

Noise	SNR	SGF COR	SD	SNRI
5	6.9313	0.9540	-3.7304	2.0112
10	11.6245	0.9851	-7.0727	1.7102
15	16.9777	0.9951	-11.1057	1.5558
20	21.6100	0.9986	-16.2689	1.4710
25	26.4827	0.9995	-20.9888	1.4446
30	31.2752	0.9998	-25.7514	1.2462

Table 2. MAF Filtering Results

	MAF			
Noise	SNR	COR	SD	SNRI
5	3.0404	0.8663	-2.4725	-1.9073
10	7.1910	0.9494	-3.9094	-2.7420
15	11.7118	0.9814	-7.0783	-3.3577
20	15.6110	0.9914	-10.4903	-4.3031
25	18.7426	0.9949	-13.2956	-6.3210
30	20.4547	0.9960	-14.9260	-9.5705

3 Description of Dataset

3.1 Dataset 1

The first set is obtained from MIT chb database. It is the normal brain activity signal of a 11 year old female.

3.2 Dataset 2

The second set is also obtained from MIT database. It is the interval of the brain activity of the same person with seizures occurring.

4 Filtering

4.1 Synthetic EEG signal

Filtering the EEG signal is the most crucial step. For this

Table 3. Elliptic Filtering Results

		Elliptic		
Noise	SNR	COR	SD	SNRI
5	4.3329	0.9665	-0.1134	-0.7531
10	8.2884	0.9888	-3.1580	-1.7525
15	11.3528	0.9960	-5.4470	-3.6654
20	13.1071	0.9984	-7.0924	-6.8523
25	13.8544	0.9992	-7.8148	-11.1173
30	14.1213	0.9994	-8.0691	-15.8407

Table 4. Real EEG Filtering Results

	with Real	G at N=2
SG F F	EE SNR	COR
17	0.9893	0.9954

19	0.98620.9951
21	0.99680.9989

Table 5. Real EEG Filtering Results at N=4

we are using three types of filters and performing com- parative study on the results obtained to find the best fil- ter. The three filters we are using are Savitzky-Golay filter,Moving Average Filter and Elliptic filter. Synthetic EEG signal is used for this comparative study. The observations are as shown in the table. It is concluded that Savitzky-Golay filter yields better results. Therefore we use SG fil-ter to de-noise or real EEG signal.

4.2 Real EEG Signal

On the basis of the above results, it is concluded that SG filter is the best for optimal filtering. Now, real-time EEG signal is served as an input to the SG filter for efficient filtering. Since it is a real signal, its SSNR is calculated instead of SNR. For the analysis of real-time data filtering, parameters such as SSNR, COR will be observed. The results are as follows.

Table 5. Real EEG Filtering Results at N=4

SGF with Real EEG at N=4		
F	SSNR	COR
17	0.9937	0.9975
19	0.9926	0.9969
21	0.9920	0.9962

Table 6. Real EEG Filtering Results at N=6

SGF with Real EE(at N=6		
F	SSNR	COR
17	0.9965	0.9989
19	0.9856	0.9984
21	0.9945	0.9980

Table 7. Real EEG Filtering Results at N=8

with Real	G at N=8	
SG EE	SSNR	
F F		
17	0.9981	0.9992
19	0.9975	0.9992
21	0.9968	0.9989

5 Savitzky-Golay Filter

The Savitzky-Golay Filter is a type of FIR filter. It is de- signed for polynomial smoothing of the data. The main purpose of the filter is smoothing the given data based on the technique of least-squares approximation of polyno- mials. This method was proposed by Savitzky and Golay. It can also be referred as polynomial smoothing filter or least-square smoothing filter. When data is filtered by SG filter, the shape of the waveform and its peaks are main- tained because of the least-square smoothing process. The data or signal which is highly corrupted by noise when fil-tered preserve the height and width of the original data or signal. SG filter gives signal distortion at its least value along with maximum rejection of noise. As compared to other filters, there is no delay introduced in the signals and it also holds the higher frequency components[11].

In real-time processing of EEG signals, sharpness of the signals must be preserved and be accurate as it is the most important feature of the signal for its analysis. The process of detection of peaks is improved because of the smoothing operation which helps in removing the un-wanted noise from the signal at every instant. Thus by fil-tering the signal through SG filter, the peak detection that is the spike detection in the signal is possible as the higher frequency components of the signal are preserved[9].

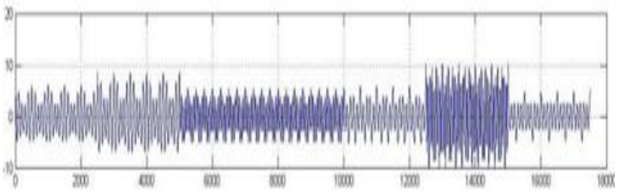

Figure 2. Synthetic EEG signal

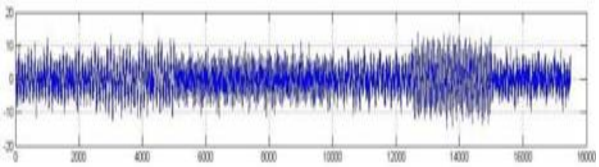

Figure 3. White Guassian Noise added to Synthetic EEG signal

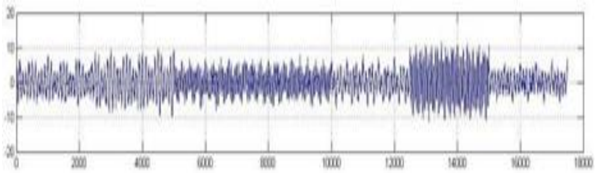

Figure 4. EEG Filtered by SG

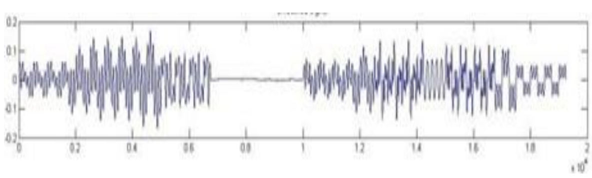

Figure 5. EEG Filtered by MAF

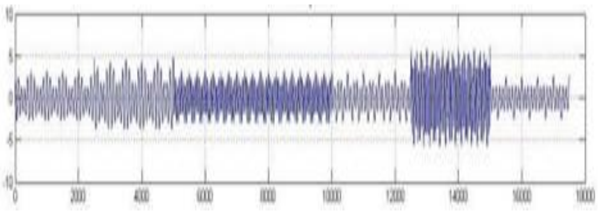

Figure 6. EEG Filtered by Elliptic

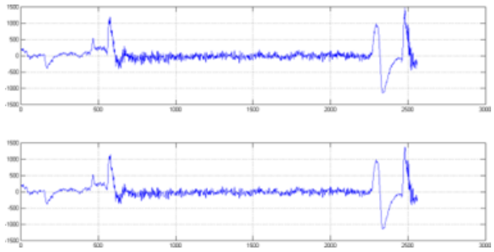

Figure 7. Real EEG Signal Filtered by SG

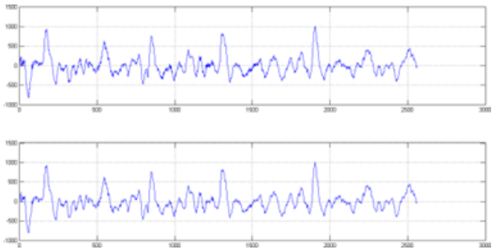

Figure 8. Real EEG Signal with Seizure Filtered by SG

6 Feature Extraction

For the classification stage, there are certain parameters required. These parameters are obtained by feature ex- traction. Since for accurate analysis of the EEG signal it is necessary to have the instantaneous information in the time and frequency domain so as to know which spike occurs when, we use Discrete Wavelet Transform as the method for feature extraction. In addition to this, DWT is preferred because EEG signal is non-stationery.

6.1 Discrete Wavelet Transform

DWT is an essential tool for analysis applied on a large scale in signal processing, image analysis, and various classification systems. Combined with classification tech- niques such as SVM, KNN, ANN, LDA yields improved results[3][10]. Feature extraction is performed to simplify the amount of resources necessary to describe a huge size of data accurately.[14]

DWT captures miniscule changes in the signal by rep-resenting the signal in time-frequency domain. DWT de- composes the filtered EEG signal into various frequency sub-bands with a wide spectral range. This representation is done in terms of Approximate Coefficient (Ax) and De- tail Coefficients (Dx). For this study, we are making use of six-level decomposition based on the Daubechies 4 (Db4) wavelet. It is necessary to represent the EEG sub-bands in the 0- to 32-Hz spectral range. Therefore, only the D3, D4, D5, D6, and A6 coefficients are used for feature ex-traction.[7][13]

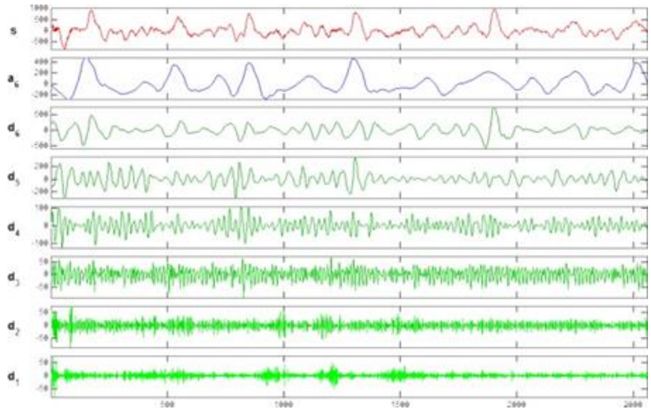

Figure 9. Sub-bands of Real EEG Signal

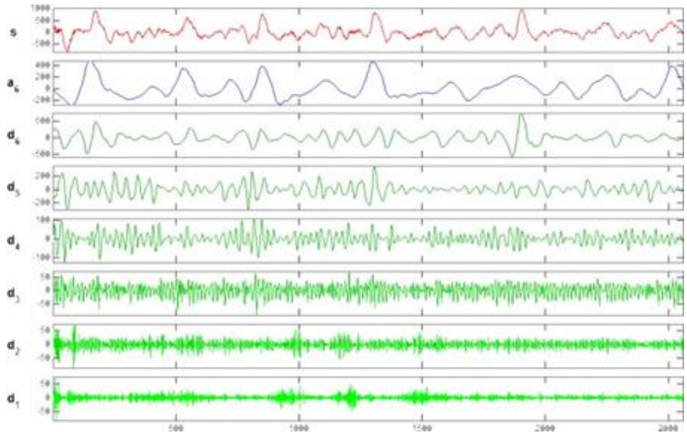

Figure 10. Sub-bands of Real EEG Signal with Seizure

6.2 Features Extracted

Using DWT various features are extracted for the purpose of classification. This is done for both the data sets. Later, these features are fed to the classifier. In this experiment, we study features like relative energy of each sub-band and Shannon entropy [7]. These features give useful infor- mation about the characteristics of the EEG signal which helps detecting the abnormalities in the signal. The be- haviour of the signal in their respective frequency sub- bands gives information of the signal at a particular instantin time-frequency domain.[14]

Feature extraction is performed for both the data sets, one with normal brain functioning and the other exhibit- ing epileptic behaviour. Features obtained from Normal

EEG signal are used as the trained signal and features ob-tained from Epileptic signal are used as the test signal[14]. This is fed as an input to the classifier. The classifier gives the output about the signal behaviour on the basis of these features.

Table 8. Features of EEG Signal

Real EEG Signal			
Levels	Energy	Relative Energy	Shannon Entropy
A	44.1693		
D1	0.0999	9.7825	2.5847
D2	1.6193	0.0016	-1.2910
D3	2.4527	0.0103	-6.5538
D4	1.3306	0.0286	-0.8245
D5	8.8284	0.2215	1.4511
D6	41.5052	0.7842	5.4501

Table 9. Features of EEG Signal with Seizure

Real EEG Signal with Seizure			
Levels	Energy	Relative Energy	Shannon Entropy
A	44.1970		
D1	0.0135	9.1307	-18.9963
D2	0.2848	0.0015	-15.1687
D3	0.6888	0.0098	-20.8642
D4	1.5098	0.0273	0.0118
D5	11.7383	0.2117	1.0507
D6	41.5678	0.7496	6.1985

7 Results and Discussion

To examine the performance of SG Filter in this analysis system, it was tested on to types of signals, synthetic EEG signal and Real EEG signal. The results were obtained by varying the order of the filter and window length for the Real signal. The main task is the selection of N and M for application of SG filters, where N is the filter order and M is the sample interval. The window length F is given by F=2 M+1. N is varied from 2 to 8 for various values of

F. F takes only odd values 17, 19, 21, etc. After rigorous experimentation it is seen that the filter performs best at N=8 and M=8 i.e. F=17. These parameters are used for the optimized filter. [11] 5.

8 Conclusion

This work has been presented for the pre-processing and feature extraction of EEG signal. The filter selected i.e SG filter is realized on MATLAB and its verification is per- formed on the basis of parameters like SSNR, COR, SD, SNRI. In the next stage DWT is used for the process of feature extraction for extracting features such as entropy, energy of the decomposed frequency sub-bands.

These features will be further used for the purpose of classifica- tion in future work.

9 Future Work

This system can further be used for classification. Various classification algorithms like ANN, KNN, SVM, LDA are implemented and a comparative study is performed on the results obtained to find the best method with maximum accuracy for analysis and detection of abnormalities.

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