Anticipation of Epileptic Seizure in Advance and Localization of Seizure Onset Zone using Power Spectral Density

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***Abstract*— To have an accurate prediction of epileptic seizure and identification of the epileptogenic region is a difficult task. This paper utilizes scalp electroencephalogram to predict an epileptic seizure and detect an epileptogenic region. To detect epileptogenic region, the signals from five different regions of brain are taken into consideration. Forty-four non-linear features are extracted from eight frequency bands theta, θ, (4-8 Hz), alpha, α, (8-13 Hz), beta, β, (13- 30 Hz), gamma1, γ1, (30-50 Hz), gamma 2, γ2 (50-70 Hz), gamma3, γ3 (70-90 Hz), gamma4, γ4 (90-110 Hz) and gamma5, γ5 (110-128 Hz). Features include eight absolute spectral powers, eight relative spectral powers and twenty eight spectral power ratios. These features have been computed for ten seizure cases using a ten minute non overlapping window. From these forty four features the spectral power ratio from gamma band [30-128 Hz] [gamma1 (30-50 Hz) / gamma 3(70-90 Hz)] shows a prominent change for all the seizure cases during pre- ictal duration. The results also show that epileptic seizure is predicted in the second segment i.e. twenty minutes before the onset of seizure. Zone2 (temporal zone in this work) shows the highest change as compared to other zones so it is identified as the epileptogenic region in this work.**

Keywords- electroencephalogram (EEG); independent component analysis; power spectral density; seizure.

I. INTRODUCTION

Epilepsy is most common neurological disorder effecting around 2% of population. Various neurological disorders can be detected and forecasted by using the signals acquired from the brain [1]. There are different methods for acquisition of the brain signals. The brain signals can be acquired by using the scalp electrodes or by using the intracranial electrodes [2]. The intracranial electrodes are also called as in depth electrodes but the placement of these electrodes is a complicated procedure [3]. Scalp EEG signals are acquired by placing electrodes using 10-20 placement system on the surface of brain. The scalp EEG (sEEG) signals contains a lot of information about neurological disorders [4].The information stored in EEG signals gives a motive to search for pre-cursive changes in sEEG signals before seizure onset [5]. Pre –ictal state is before the onset of seizure. Any seizure free duration of the signals is called as inter-ictal state [6]. The seizure prediction problem can be perceived as classification problem in which one class consists of pre-ictal signals and other class consists of inter-ictal signals [7]. These EEG signals can be visually inspected by the neurologists for detecting an abnormality in brain function but the visual inspection of the scalp EEG signals is very time consuming task [8].

Based on common hypothesis that brainwave synchronization pattern is different in the pre-ictal and inter-ictal state most current seizure prediction techniques can be illustrated by extracting features from EEG and then data driven machine algorithm is used to classify them into pre- ictal and inter- ictal state [9,10]. The most commonly used feature for the seizure prediction are variance, complexity, Hurst exponent, entropy, accumulated energy, correlation and coherence [11-13]. It is known that power spectral density (PSD) of EEG signal is affected before and during the seizure [14].

The main drawback of using the power spectral density is that false prediction rate is high because the power spectral density shows the considerable amount of change in the inter-ictal period as well [15]. The other drawback is that the signal under consideration for analysis is the signal that is the average signal from all the channels.

The main contribution of this paper is that it develops a patient specific algorithm that can readily predict the epileptic seizure and identify the epileptogenic region. The EEG signals under consideration are the signals from different regions of the brain. Total forty four features are extracted in context of seizure prediction and the best is identified to predict the seizure.

This paper is structured as follows: Section II presents the complete methodology, the features calculated is explained in section III. Finally, results and conclusion are presented in Section IV and Section V respectively.

II. METHODOLOGY

A. EEG database

Database of epileptic patients in normal state (inter-ictal), before seizure (pre-ictal state) and during seizure (ictal state) are available on physionet website [16]. This database has been recorded by placing 10-20 electrodes on the human brain. The recordings are bipolar in nature and line noise has been

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removed from the database. In bipolar recordings, the potential difference between the pair of electrodes have been recorded. The detailed dataset on which analysis has been carried out is shown in Table. 1.

TABLE. 1 DETAILS OF DATABASE

S.No	File Name	Gender	Age(Years)
1	chb01_02	F	11
2	chb01_03	F	11
3	chb02_16+	M	11
4	chb02_17	M	11
5	chb02_18	M	11
6	chb02_19	M	11
7	chb04_05	M	22
8	chb04_05	M	22
9	chb04_08	M	22
10	chb04_08	M	22

B. Materials and methods

For physionet database 60 minutes recording preceding the seizure are categorized as pre-ictal duration, 3 minutes and 30 minutes duration during and after the seizure are categorized as ictal and post ictal duration respectively and any other duration of EEG signal is categorized as inter-ictal duration [17]. The main aim of the paper is to differentiate between pre-ictal and inter-ictal duration and the region of the brain showing the highest variation.

The complete methodology describes the pre-processing of EEG signals, division of brain region into five zones for extraction of five average signals, window based signal processing, separation of eight frequency bands, extraction of forty four non-linear features from eight frequency bands e different zones, selection of the best feature and zone showing the highest change. The complete methodology in the form of flow chart has been shown in Fig. 1.

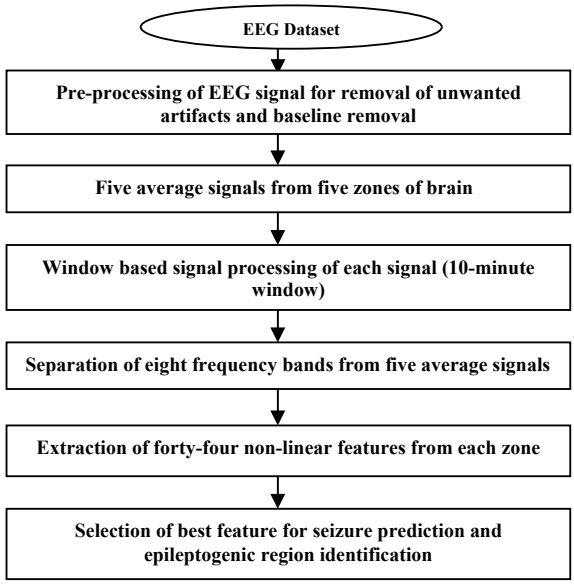

Figure 1. Flow chart of proposed algorithm

1) Pre-processing

Muscle and eye-blinks artifacts are removed from the EEG signals by using independent component analysis (ICA) [18]. The baseline correction to raw EEG signal is also applied during the pre-processing stage.

2) Averaging of Signals

For detection of epileptogenic region, the complete region of the brain has to be taken into consideration. The processing of 23 channels information simultaneously is a tough task. To reduce the complexity level the complete region of the brain is divided into five zones which are frontal (F), Temporal (T), central(C), Parietal (P) and occipital (O) [19]. Average of signals from five zones results into five average signals as shown in Table II.

TABLE. II ELECTRODE PLACEMENT AS PER 10-20 SYSTEM

Zones	Electrodes	Average Signal
Zone 1	FP1, FP2, FZ, FP3	s1
Zone 2	F7, T7, FT9	s2
Zone 3	C3, P3, C4, P4, C8,P8, Cz, Pz, P7	s3
Zone 4	F1, F8, FT10, FT8, T8	s4
Zone 5	O1, O2	s5

3) Window based signal processing of each signal

For prediction of the pre-ictal duration window based signal processing has been used. Input signal is divided into non-overlapping segments of 10-minute duration. Forty minute pre-ictal duration is considered as four segments of ten minutes duration each (10*60*256=153600 samples).

4) Separation of eight frequency bands from five average signals

Frequency bands of EEG signals contains a lot of information about the internal mental states of human brain. There are total four frequency bands theta, θ, (4-8 Hz), alpha, α, (8-13 Hz), beta, β, (13- 30 Hz) and gamma, γ, (30-128 Hz). The gamma band is further separated into five frequency bands namely $\gamma 1$ (30-50 Hz), $\gamma 2$ (50-70 Hz), $\gamma 3$ (70-90 Hz), $\gamma 4$ (90-110 Hz), $\gamma 5$ (110-128 Hz) using band pass filter [20].

The features extracted from these frequency bands can be used as a benchmark for the prediction of the epileptic seizure and detection of epileptogenic region.

5) Feature Extraction from different frequency bands

Total forty-four non-linear features are extracted from EEG signals in context of seizure prediction. These forty-four non-linear features include spectral power from eight frequency bands, eight relative spectral power and twenty-eight spectral power ratios.

6) Selection of best feature for seizure prediction and epileptogenic region identification

The absolute spectral power and spectral power ratios are not the promising features for the seizure prediction because these cannot discriminate between the inter-ictal and pre-ictal period for all the seizure cases. The spectral power ratio shows the strong predictability of the upcoming seizure.

III. Extracted Features from EEG Signal

A. Absolute spectral power

The absolute power from eight frequency bands have been calculated using (1):

$$P_i = \left| \frac{S_i(f)^2}{N} \right| \quad (1)$$

where P_i is the power from particular frequency band, S_i is the EEG signal of i^{th} segment and N is the total length of EEG signal.

The total absolute power from each frequency band has been calculated using (2):

$$P_{total(j)} = \log^*[\sum_i P_i] \quad (2)$$

where $P_{total(j)}$ is the total power in j^{th} frequency band.

B. Relative spectral power

Relative power from eight frequency bands has been calculated by using (3):

$$RP_i = \frac{P_{total}(i)}{P_{total}} \quad (3)$$

where $P_{total(i)}$ is the total power in particular band and P_{total} is the sum of powers from all the eight bands.

C. Spectral power ratio

This feature determines the ratio of power in different frequency bands. For eight frequency bands there will be twenty eight possible ratios. As there are eight frequency bands (θ, α, β, γ1, γ2, γ3 , γ4, γ5) so the twenty eight possible ratios are θ/α, θ/β, θ/γ1, θ/γ2, θ/γ3, θ/γ4, θ/γ5, α/β, α /γ1, α /γ2, α /γ3, α /γ4, α /γ5, β /γ1, β /γ2, β /γ3, β /γ4, β /γ5, γ1/γ2, γ1/γ3, γ1 /γ4, γ1 /γ5, γ2/γ3, γ2 /γ4, γ2 /γ5, γ3 /γ4, γ3 /γ5, γ4 /γ5. Power ratio has been calculated from powers of these frequency bands.

IV. Results

The methodology describes in section II has been implemented using MATLAB. Five average signals of different regions of brain are shown in Fig 2. All computations are based on these five averaged signals. The closer view of these five signals for a short duration is shown in Fig 3 for better visibility. The advantage of taking these five averaged signals is that all parts of the brain are investigated simultaneously with less computational complexity.

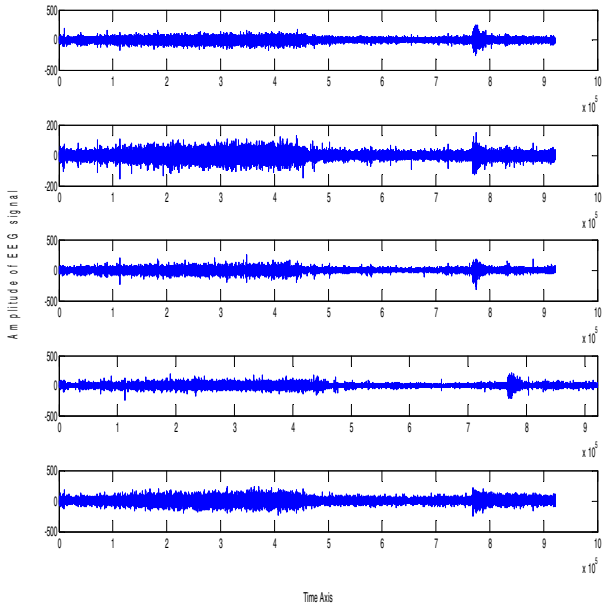

Figure 2. Averaged five signals from five different regions of brain by taking complete signal

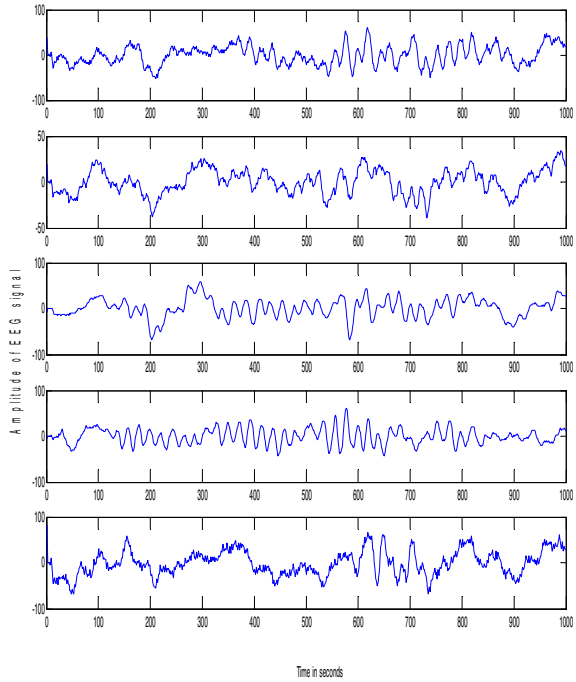

Figure 3. Averaged five signals from five different regions of brain by taking small duration signal

Forty-minute duration before the seizure is considered as pre-ictal duration [17]. For accurate prediction of seizure, a non-overlapping window of 10 minute duration has been used. So, the forty minute duration before seizure is divided into four segments. The analysis has been carried on the ten seizure cases of the database as mentioned in Table I. The average value (from ten seizure cases) of eight spectral powers from five zones for inter-ictal and pre- ictal recordings have been shown in Table III and Table IV respectively. From Table III and Table IV it can be observed that there is no uniformity between changes (increase or decrease) in spectral powers in inter-ictal and pre-ictal duration for all eight-frequency bands. In order to reduce the false prediction rate the relative spectral power and spectral power ratio has been calculated.

TABLE. III POWER IN EIGHT FREQUENCY BANDS DURING INTER-ICTAL STATE

Power calculations from five zones during inter-ictal state in decibels (dB)									
	Segments	**theta**	**alpha**	**beta**	**gamma1**	**gamma2**	**gamma3**	**gamma4**	**gamma5**
	Segment1	14.12	14.77	6.33	6.45	0.61	1.74	0.03	0.01
	Segment2	21.93	15.06	8.96	8.2	0.52	1.44	0.02	0
	Segment3	19.08	11.39	3.05	0.76	0.47	0.63	0.04	0.01
Zone 1	***Segment4***	10.37	4.42	3.37	0.76	0.25	0.61	0.01	0
	Segment1	5.97	3.17	1.2	0.47	0.08	0.17	0.02	0.01
	Segment2	8.55	2.77	0.93	0.38	0.07	0.13	0	0
	Segment3	10.35	2.43	1.04	0.61	0.08	0.23	0.06	0.02
Zone 2	***Segment4***	5.4	1.36	1.11	0.61	0.073	0.12	0	0
	Segment1	7.5	5.35	2.15	0.75	0.03	0.16	0.06	0.02
	Segment2	6.6	5.46	2.12	0.65	0.02	0.09	0.04	0.01
	Segment3	7.01	4.81	2.32	0.89	0.03	0.15	0.05	0.02
Zone3	***Segment4***	9.28	6.44	3.98	0.89	0.07	0.4	0.17	0.07
	Segment1	12	4.3	4.33	4.5	0.16	0.97	0.27	0.1
	Segment2	10.55	4.05	5.85	6.49	0.21	1.23	0.32	0.1
	Segment3	14.65	4.69	4.85	5.23	0.17	1.08	0.28	0.1
Zone4	***Segment4***	15.87	5.42	5.91	5.23	0.2	1.27	0.36	0.13
	Segment1	15.72	9.5	3.72	2.49	0.13	1.22	0.41	0.19
	Segment2	13.94	8.56	2.69	0.97	0.05	0.69	0.13	0.06
	Segment3	14.59	8.31	3.58	2.77	0.101	1.04	0.16	0.07
Zone5	***Segment4***	18.23	9.84	5.03	2.77	0.17	1.54	0.52	0.24

TABLE. IV POWER IN EIGHT FREQUENCY BANDS DURING PRE-ICTAL STATE

Power calculations from five zones during pre - ictal state in decibels (dB)									
		theta	**alpha**	**beta**	**gamma1**	**gamma2**	**gamma3**	**gamma4**	**gamma5**
	Segment1	19.12	7.04	11.72	14.31	0.43	2.35	0.92	0.36
	Segment2	22.41	3.78	13.09	17.52	0.43	2.15	0.76	0.29
	Segment3	18.06	4.02	15.24	19.23	0.55	2.83	1	0.37
Zone 1	***Segment4***	10.15	7.09	12.81	19.23	0.43	2.08	0.76	0.27
	Segment1	5.04	2.77	5.23	6.67	0.41	0.53	1.33	0.57
	Segment2	3.86	2.63	3.35	3.78	0.21	0.1	0.42	0.19
	Segment3	4.29	2.85	3.6	3.78	0.22	0.06	0.52	0.23
zone 2	***Segment4***	4.92	2.67	4.33	3.78	0.28	0.04	0.55	0.21
	Segment1	8.44	6.11	4.3	2.05	0.06	0.36	0.15	0.06
	Segment2	5.27	8.46	5.66	3.85	0.03	0.16	0.06	0.03
	Segment3	5.67	7.53	5.37	2.15	0.03	0.17	0.06	0.04
zone 3	***Segment4***	8.17	6.57	5.44	2.11	0.06	0.26	0.09	0.04
	Segment1	34.91	13.7	10.73	7.79	1.36	0.23	0.36	0.13
	Segment2	7.98	4.46	7.15	9.48	1.56	0.27	0.46	0.17
	Segment3	12.2	5.09	7.67	9.24	1.67	0.28	0.47	0.16
zone 4	***Segment4***	31.37	7.24	7.74	9.24	1.6	0.23	0.38	0.14
	Segment1	16.21	8.72	5.29	4.21	0.19	0.46	1.48	0.19
	Segment2	13.06	8.73	4.43	3.18	0.15	0.43	1.41	0.17
	Segment3	13.36	9.05	4.69	3.48	0.15	0.41	1.24	0.16
zone 5	***Segment4***	15.06	8.29	3.92	3.48	0.11	0.24	0.97	0.1

Table V shows the results for spectral power ratio (γ1/γ3) for inter-ictal and pre-ictal period.

TABLE. V SPECTRAL POWER RATIO DURING INTER ICTAL STATE AND PRE-ICTAL STATE

Spectral Power ratio from five zones				
		inter-ictal	pre-ictal	Increase
Zone 1	*segment1*	3.7	6.06	2.36
	segment2	5.68	9.22	3.54
	segment3	1.2	6.77	5.57
	segment4	1.24	8.13	6.89
Zone 2	*segment1*	2.7	12.37	9.67
	segment2	2.9	59.75	56.85
	segment3	2.58	35.81	33.23
	segment4	5.02	34.13	29.11
Zone3	*segment1*	4.51	10.32	5.81
	segment2	6.73	23.35	16.62
	segment3	5.78	12.21	6.43
	segment4	2.22	8.07	5.85
Zone4	*segment1*	4.6	8.99	4.39
	segment2	5.27	14.34	9.07
	segment3	4.83	8.37	3.54
	segment4	4.1	7.3	3.2
Zone5	*segment1*	2.04	33.85	31.81
	segment2	1.4	38.61	37.21
	segment3	2.65	32.99	30.34
	segment4	1.79	34.64	32.85

From Table V it is evident that the ratio of power in (γ1/γ3) frequency band shows a noticeable increment in the pre-ictal state. In addition, the highest change in the feature is observed from the zone 2, which is the epileptogenic region of the brain. The epileptogenic region in this work is the temporal region as zone 2 is representing the temporal region.

The second notable point is that remarkable change in the pre-ictal and inter-ictal state is during segment 2. Segment 2 is twenty minutes before the onset of seizure. So, seizure is predicted twenty minutes prior to the onset.

V. CONCLUSION

In this paper an algorithm for seizure prediction and epileptogenic region identification using bipolar EEG signals from different regions of the brain has been proposed. Forty four non-linear features including absolute spectral power, relative spectral power and spectral power ratio are extracted from eight frequency bands of EEG signals. The results are based on the findings that the absolute spectral power and relative spectral power does not shows much relevance for seizure prediction and region identification because the features changes in inter-ictal duration also. The spectral power ratio (γ1/γ3) proves to be the most relevant feature for seizure prediction and region identification because the clear demarcation exists between the pre-ictal and inter-ictal state. The proposed algorithm also identifies zone 2 as epileptogenic region which is temporal lobe. The large sample size and the machine learning algorithms can help to generalize and validate the promising results obtained in this work. Future work will be carried out to identify the particular electrode from the set of electrodes. Similar methodology can also be explored for detection of other neurological disorders.

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