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Early Detection Of Epilepsy Based On Synchronization Degree

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ABSTRACT

In this work, the synchronization degree is calculated using bi-spectral analysis in order to distinguish between three sets of electroencephalogram signals: normal, pre-ictal, and epileptic seizure cases. The obtained results are compared to six parameters which also extracted from the same analysis; such as the entropies, the mean of bi-spectral amplitude, and weighted center of the bi-spectrum. The obtained results using the proposed algorithm are very satisfactory compared to the other parameters, and show that the synchronization is high in normal cases, zero in pre-ictal cases, and low in epileptic cases, and it confirms the efficiency of the proposed algorithm.

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Introduction

The Electroencephalogram signal (EEG) is one of the most used tools for analyzing the electrical activities of the brain and for diagnosis of neurological diseases such as epilepsy. This disease is characterized by an abnormal functioning of the brain activity. It translates by the repetition of unpredictable seizures which is often very brief. These seizures can take different forms and vary in intensity. They can lead to brief loss of consciousness, a small muscle twitches, or might even lead to severe and prolonged convulsions.

The EEG compared to other investigative techniques, provides information in real time with a very good temporal resolution; in the order of millisecond. Indeed from the EEG signal some important parameters can be extracted; as a general rule, the frequencies, amplitudes, and the different shapes of waves are considered as indicators of the diseases under study. On the other hand, this type of record shows significant random, non-linear and non-Gaussian statistical properties, such as the presence of non-linear interactions of phase coupling between the frequency components of the EEG signal. So in order to study the behavior of this kind of signals and to differentiate between them, we find several works that have been realized. Some studies are based on the linear methods such as classical power spectra, or statistical parameters [1-5]. However these methods are considered as frequency and power estimators [6]. because it suppose that the phase is linear and the frequency components are not correlated between them.

Other studies are based on nonlinear methods such as wavelet and the neural network [7,8]. However, wavelet method wavelet transform needs to select a proper mother wavelet and to adjust the length of the sliding window, and the neural network is a black box [9]. it is difficult to derive a causal explanation of the results which are not guaranteed, even if the learning error is reduced to 0. Whereas the linear methods. In contrary, the bi-spectral analysis preserves the information on the phase and the interaction between the different frequencies.

This work, our contribution is using a new parameter which corresponding to synchronization degree to detect the epilepsy and to distinguish between the normal, pre-ictal, and epileptic seizure. The obtained results for the different sets were illustrated and discussed in detail. Then an evaluation of the proposed method was made using a statistical classifier that corresponds to the ANOVA test.

Method

The proposed approach is illustrated in the block diagram below (Figure 1) which includes four steps:

- Database
- Bi-spectral analysis
- Extraction of bi-spectral parameters (synchronization degree, entropy, square entropy, cubic entropy, the entropy of phase, mean of bispectral amplitude, the weighted center of the bi-spectrum).
- ANOVA test.

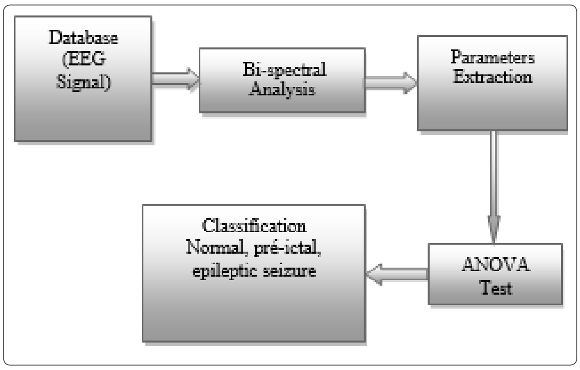

Figure 1: Block diagram of the proposed method

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Database
EEG signals were obtained from the database of the University of Bonn in Germany [10]. It groups together five sets (denoted A, B, C, D, and E). Each set contains 100 EEG signal records for a duration of 23.6 seconds. Groups A and B represent the acquired EEG signals of five healthy volunteers using a standard system where the electrodes are placed on the scalp. The volunteers were relaxed in an awake state with open eyes (group A) "beta waves," and closed eyes (group B) "alpha waves," respectively. Groups C, D, and E present pathological cases. Groups (C and D) represent pre-ictal signals that are recorded using intracranial electrodes, while group E contains epileptic activity using standard electrodes placed on the scalp.

After the 12-bit digital analog conversion, the data was recorded continuously on the disk of a computer data acquisition system with a sampling frequency of 173.61 Hz. The signals were filtered by a filter band [0.53-40] Hz. In this work group A was used as a normal case, groups C and D as pre-ictal cases, and group E as epileptic seizure cases [10].

Bi-spectral analysis of the EEG signal
Bi-spectral analysis is the study of nonlinear interactions [11-13]. It is defined as the Fourier transform of the third cumulant. Since the correlation function is an even function, and its FFT gives a symmetry spectrum (i.e the spectrum repeats twice "mirror effect"), we find that the bi-spectrum which represents the FT of the tri-correlation function, repeats itself four times. It is therefore sufficient to calculate the spectrum for the frequencies that lies in the non-redundant region Ω as it is illustrated in Figure 2. For more details see [14].

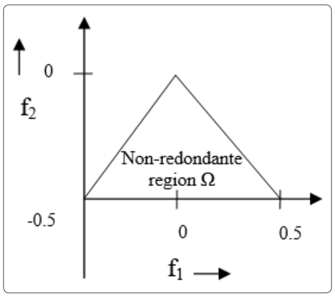

Figure 2: The non-redundant region for the calculation of bi-spectral frequencies

Extraction of characteristics
The bi-spectral analysis allows us to extract certain parameters, such as synchronization degree, the average amplitude, the standard bi-spectral entropy, the standard bi-spectral square entropy, the standard bi-spectral cubic entropy, the entropy of phase, and the weighted center of the bi-spectrum, which give us information on the distribution and dispersion of the signal.

Synchronization degree
The synchronization degree is defined as the ratio between the number of harmonics and all the sinusoids number of the bispectrum. We must indicate here that the number of harmonic and the sinusoids must be calculating n times if it is generated by n ways. The synchronization is close to 100 in awake subject, i.e.; the sinusoids components are all synchronous between them. It decreases with the deepening of unconsciousness.

The average amplitude
The average amplitude of the bi-spectral can be used for discrimination between similar power spectra.

The standard bi-spectral entropy
There are a number of concepts and analytical techniques directed to measuring the irregularity of the frequency spectrum of a stochastic signal, such as EEG. Entropy describes the irregularity, complexity, or unpredictability characteristics of a signal (1) [15].

The normalization in the above equations, shows that the entropy is calculated for a parameter which is between 0 and 1 and therefore the entropies (P1, P2 and P3) are also calculated between 0 and 1. P2 and P3 give information on the degree of variability.

The entropy of phase
The phase entropy would be zero if the process was harmonic and perfectly periodic and predictable. As the process becomes more random, entropy increases. In contrary to Fourier phase, the bi-spectral phase does not change with a time lag [14].

Weighted center of the bi-spectral (WCOB)
It gives us information on the distribution and the number of peaks in the ith line or in the jth column.

Results and discussion
The algorithm of the bi-spectral analysis is implemented and applied on the different sets of EEG records (healthy and pathological cases). The obtained results for the three cases: normal, pre-ictal, and epileptic seizure are illustrated in Figures 3 up 5. The color represents the relative variation of the amplitude of the bi-spectrum; the red color indicating the strongest increase and the blue color indicating the greatest decrease.

The bi-spectrum was estimated on the different frequency bands. The beta wave corresponding to the frequency 13 Hz, results from the state of an attentive subject, with open eyes. The alpha wave corresponding to the frequency [8 – 13] Hz, which results from a state of relaxed awakening. The theta wave corresponding to [4 – 8] Hz, results from a light sleep state, while, the delta wave corresponding to [0 – 4] Hz, results from a state of deep sleep.

Normal cases
The bispectral of normal case is shown in figure 3 (record Z048). It shows distributed peaks over the interval [0 - 27] Hz, with a predominance of the seven peaks: a1 around (0.695, 2.345) Hz, a2 around (1.65 , 4.7) Hz, a3 around (4.7, 11.7) Hz, a4 around (5.85 , 5.85) Hz, a5 around (1.65, 15.05) Hz, a6 around (1.345 , 17.4) Hz and a7 around (13.395, 18.1) Hz.

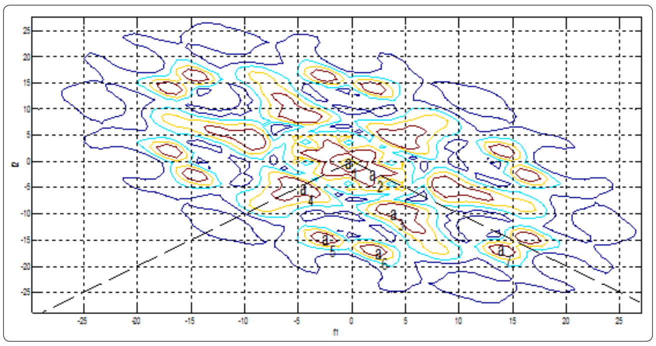

Figure 3: Bi-spectrum of a normal case (record Z048)

The frequencies 0.695, 1.65, and 2.345 Hz are interpreted by the presence of δ waves. While the frequencies 4.7, and 5.85 Hz are interpreted by the presence of the θ, however the frequency 11.7 Hz is interpreted by the presence of α waves. In the other hand, we are found 3 frequencies (13.395, 17.4, and 18.1) Hz which proving the waking state because it represent the β waves.

We clearly notice that the frequencies 1.345, 13.395, 15.05, 17.4, and 18.7 Hz are the nonlinear interaction between the frequencies (0.695 and 1.65), (11.7 and 0.695), (1.65 and 13.395), (15.05 and 2.345), (17.4 and 0.695) Hz respectively. However the frequencies 2.345, 4.7, 11.7 Hz are the quadratic interaction of the frequencies 0.695, 2.345, and 5.85 Hz respectively.

These results confirm that the interaction is nonlinear and lead us to conclude that the EEG signal in this case is nonlinear, non-stationary, and has a random appearance.

In the other hand, the synchronization degree indicates a high value 72.73%, because we have eight harmonics components (1.345, 2.345, 4.7, 11.7, 13.395, 15.05, 17.4, and 18.1 Hz) between eleven frequencies (0.695, 1.345, 1.65, 2.345, 4.7, 5.85, 11.7, 13.395, 15.05, 17.4, and 18.1 Hz). This result leads us to suggest that the both hemispheres of the brain manage to work together in a perfect harmony. Similar results have been obtained after the implementation of the proposed algorithm in all the records which represent a normal case, where we found a high values of synchronization degree which extend between 50.74% and 81.38%, except for the records (Z007, Z012, Z013, Z051, Z073, Z074), where a low value of synchronization degree is found which extend between (43.2% and 48.61%).

Pre -ictal cases

The bi-spectrum of the record N032 which represents the EEG signal recorded before the seizure (pre-ictal case), is illustrated in Figure 4.

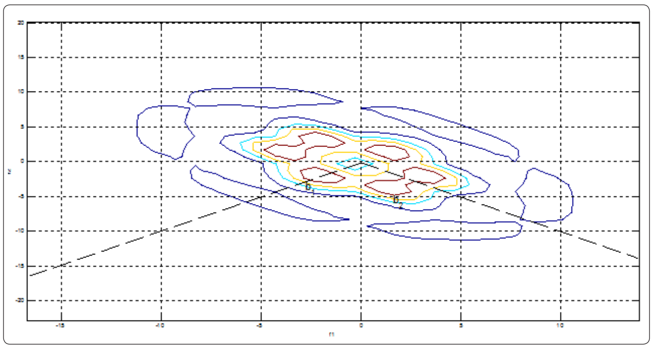

Figure 4: Bi-spectrum of the pre-ictal EEG signal (record N032)

The figure (4) shows a predominance of two peaks: b1 around (2.305, 2.305) Hz and b2 around (1.695, 4.9) Hz. As we remark there is no interaction between these frequencies i.e. that they are independent and the synchronization is zero. In addition, we Remarque that there is an abnormal drop in frequencies values; the frequencies 2.305 and 1.695 Hz corresponding to the delta rhythm (<4Hz), however the frequency 4.9 Hz corresponding the theta wave. This result shows that the patient is in sleep state, however in this case the signal have been recorded using deep intracranial electrodes, which required anesthesia; so we can suggest three probabilities of patient state: the first, is the deep sleep state, the second is the anesthesia state, the third is the unconsciousness state.

Similar results were obtained after the implementation of our algorithm on all the records of pre-ictal cases. (N001 up N100), and (F001 up F100). In all cases and without exception we have found a predominance of the wave δ and θ, and a zero degree of synchronization.

Epileptic seizure cases

The bi-spectral of the record S011 which represents the EEG signal during the epileptic seizure is illustrated in figure 5. It shows a predominance of four peaks: c1 around (4.3, 4.3) Hz, c2 around (7.3, 7.3) Hz, c3 around (4.6, 9.6) Hz and c4 around (6.2, 13.5) Hz. The frequencies 4.3, 4.6, 6.2, and 7.3 Hz indicate the presence of the θ wave.

The frequency 9.6 Hz indicates the presence of wave; however the frequency 13.5 Hz indicates the presence of β waves.

The frequency 13.5 Hz is the results of the nonlinear interaction between the frequencies (6.2 and 7.3) Hz, i.e. the synchronization degree equal (1/6=16.67%).

On the other hand, the appearance of the θ waves can be interpreted by loss of consciousness state, whereas the appearance of the β waves indicates that the patient is in waking state. From this result we can suggest that there is a transition between state and waking state in order to maintain the brain from an inevitable death, while the presence of α waves confirms this suggestion; because it translate the transition of brain state from loss of consciousness state to consciousness state.

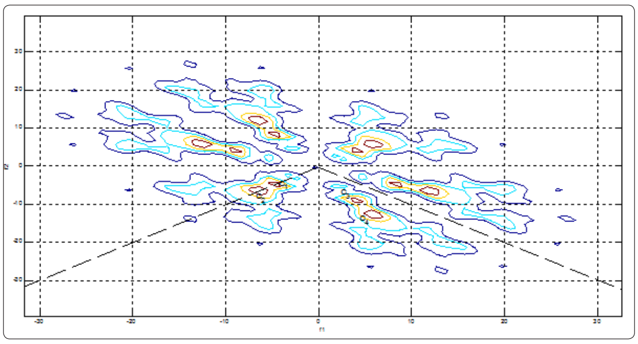

Figure 5: Bispectrum of the epileptic EEG signal (record S011)

In fact, these results show that there is an increase in the frequency from the frequency δ or θ which are already found in the pre-ictal cases to β wave. This may suggest that there is high mental activity and that the epileptic seizure represents a fast and abrupt transition from a neuronal activity that varies from an asynchronous oscillation of a small population of neurons associated with a decrease in frequencies of the EEG signal to a synchronized oscillation of a large population of neurons associated with a clear increase of frequencies of the EEG signal.

The implementation of the proposed algorithm on all the signals which represent the epileptic cases gives us similar results, except for the records (S002, S013, S017, S045, S061, S083, S084, S085); where a predominance of the β and α waves are found.

Evaluation

The bi-spectral analysis also allows us to extract six parameters which are: bi-spectral entropy (Ent1), square bi-spectral entropy (Ent2), cubic bi-spectral entropy (Ent3), and the bi-spectral phase entropy (EntPh), the average bi-spectral amplitude (mAmp), and the weighted centers of the bi-spectrum (wc1, wc2). The obtained results are shown in figure 6.

To evaluate the obtained results, the ANOVAT test was used. The P value is the measure used to identify significant statistical differences between the mean values of different groups. $p < 0.01$ are considered significant values, while values of $p < 0.001$ are considered very significant values.

According to the figure 6, the synchronization degree and the weighted centers wc1 and wc2 show a very significant values (p <0.001), but the Synch gives more precise values compared to WC1, and WC2. The bi-spectral entropies (Ent1), (Ent2), (EnPh) show a significant value (P<0.01). i.e. these parameters can distinguish between the three cases of the EEG signals however, the Ent3 and the mAmp can no longer distinguish between these different cases (p> 0.01).

In other hand, the parameters Ent1, Ent2, and EntPh show that EEG signals in normal cases are more random, more non-stationary, and more complicated, compared to epileptic signals that are in turn more random, and more complicated compared to pre-ictal signals because the dynamic processes are less complex for pre-ictal subjects than for normal subjects, it may be due to the biological systems which become functionally deficient, due to the death of nerve cells. While in the epileptic case there is an incredible increase of the amplitudes, this has resulted in a neuronal hyper-synchronous which can be considered as the responsible of the seizures.

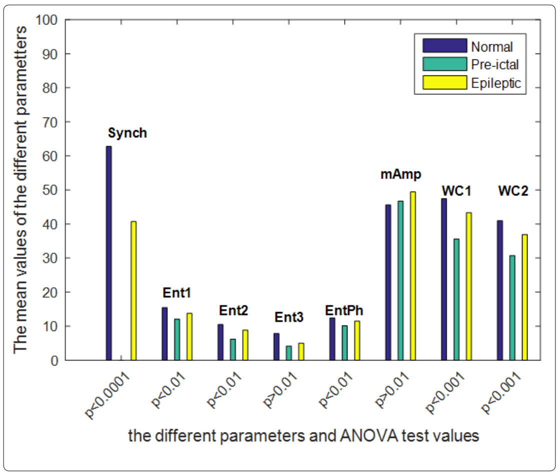

Figure 6: Histogram representing the mean and the ANOVA test for different parameters

Conclusion

In this work, the bi-spectral analysis is used to analyze the EEG signal in three cases: normal, pre-ictal cases, and epileptic seizure cases. The obtained results are very satisfactory and show a predominance of delta and theta waves in pre-ictal cases indicating that the frequency decrease during this phase, and a predominance of delta, theta, and beta high frequency waves during the epileptic seizure; indicating a high activity of the brain in order to save it from an inevitable death, while in normal cases, a predominance of beta waves was found which confirms the vigilance state. The synchronization degree gives a satisfactory results compared to the entropies (Ent1, Ent2, EntPh), weighted center of the bi-spectrum (wc1 and wc2), however no significant values were found in Ent3 and mAmp, i. e. the proposed algorithm is able to distinguish between the different cases; where a higher values of synchronization were found in normal cases compared to epileptic seizure; while in pre-ictal cases the synchronization is zero because during this phase, the EEG signals are more regular and less complex compared to epileptic activity. This means that the electrophysiological behavior of the brain has decreased during the pre-ictal phase and increases again during the epileptic seizure.

Compliance With Ethical Standards

- This study was not funded by any party: it is an academic PhD study
- No conflict of interest
- No animal or other used in this study

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