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Recurrence Based Method to Determine the Neurological Disorders Through Electrical Signals of Brain

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Abstract: ***This paper talks about the phenomenon of recurrence and using this concept it proposes a novel and a very simple and user friendly method to diagnose the neurological disorders by using the EEG signals. The mathematical concept of recurrence forms the basis for the detection of neurological disorders and the tool used is MATLAB. Using MATLAB, an algorithm is designed which uses EEG signals as the input and uses the synchronizing patterns of EEG signals to determine various neurological disorders through graphs and recurrence plots***

Keywords: EEG Signals, Recurrence, Order Recurrence Plot, Coupling Index, Signal Processing.

I.INTRODUCTION

This paper gives the keen insight of the process of recurrence in human body and proposes a novel method to detect the neurological disorders like epileptic seizures, Alzheimer's disease etc. The proposed method uses the recurrence method and tells the degree of coupling or synchronism between the EEG signals taken from various different positions from the human brain. A parameter called the "synchronization Index", is used to detect the recurrence patterns in the EEG signals from various channels of EEG machine and a graph is plotted using MATLAB. It is seen that during neurological disorders the synchronism between EEG signals taken from different positions of brain increases. This can be visualized using the graphs [1-4].

1.1. Biomedical System and coupling: The various processes of human body works in synchronism i.e. in a body various systems like nervous system respiratory systems work in a certain rhythm. This can be seen through the patterns obtained from EEG and ECG machine. When there is any changes in the EEG signals or any variations, they can be used to diagnose the neurological or cardio related diseases. [3-5].

2. **1.2. Non Linear signal processing:** In this work,. Order patterns are being used to analyse the highly chaotic and unpredictable signals from brain. The order pattern method is used in analysis of EEG signals because it quantizes the value of signal to zero and one ,so this facilitates the analysis of EEG signals whose value keeps on changing frequently [6].

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II.RECURRENCES

The concept of recurrence was observed and discovered by Poincare, who proved that for any chaotic signal series after a certain time, the values start repeating or recurring.

2.1 Types of Recurrences: The types of recurrences can be explained briefly by the table given below:

Table 1: Types of Recurrences.

Recurrence Matrix	**Cross Recurrence Matrix**	**Joint Recurrence Matrix**
$R_{ij=}\Theta(\varepsilon - \parallel x_i - x_j \parallel)$	$CR_{ij=}\Theta(\varepsilon - \parallel x_i - y_j \parallel)$	$JR_{ij}^{xy} = R_{ij}^{x} * R_{ij}^{y}$

x_i, y_j are two different sample of signal series between which recurrence needs to found and CR_{ij} refers to the cross recurrence.

Recurrences in Bio Medical Signals: The biomedical signals like ECG and EEG are highly random in nature and vary very much even in short time duration. Superficially, it seems that there is no pattern in EEG signals, but when observed closely over the time limited samples which are obtained by digitizing and filtering one can find that, there are certain patterns of repetitions or recurrences in EEG signals taken from various positions of brain using EEG machine.The recurrence between any two time series of biomedical signals can be found by above mentioned methods.. Some of the methods that use the concept of recurrence to find the synchronism between biomedical signals are as follows:

2.2. Coupling Model

In this model,we divide the total coupling into the direct and the indirect couplings. Former is the measure of the direct effect that one signal exerts on the other and the latter , measures the shared effects of the two signal series. The coupling characteristic q1(ϕ1,ϕ2) may be expressed as:

$$q1(\phi1,\phi2) = P1(\phi1)P2(\phi2) \quad (1)$$

where P1(ϕ1) is the phase curve of first signal, whilst P2(ϕ2)is the phase curve of the second time series [7-8].

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2.3. Statistical analysis of Bio Signals

Firstly,the signals are analysed manually, and then they are processed by normal digital filtering [7-11].Then the coupling between the signals obtained from EEG machine is studied and compared with the standard values that are obtained mathematically. Following parameters are often used for understanding the repetitive pattern within the signals:

Determinism(DET): This is the parameter that is based on the histogram $P(l)$ of diagonal lines of length l. In case if the signals are uncorrelated or weakly correlated, smaller diagonals are formed .If the signals are strongly synchronised or correlated then it will lead to formation of longer diagonals.

Measures based on vertical lines(LAM)*:* Unlike the DET parameter,this method analyzes histogram of vertical lines of length v. The ratio between the recurrence points forming the vertical structures and the entire set of recurrence points is called laminarity [10,11].

THE PROPOSED METHOD

The method is based on the concept of recurrences in biomedical signals.It has been observed that in various neurological disorders like epilepsy, alzheimer's etc,the EEG signals taken from various position of brain are in a same state or in recurrence with each other So a method has been proposed which uses parameter called synchronization index ρπ. The high value of synchronization index between EEG signals taken from various areas of head(using EEG),ensures that a person is suffering with some kind of fits or seizures.These seizures are the characterstics of various neurological disorders.So basically this method gives the mapping of brain signals and helps the doctor to understand if a person is suffering from a neurological disorder. The graphs showing the synchronization are obtained in MATLAB which helps to understand the condition of brain in a better way. In this way the proposed work is a diagnostic method to diagnose the neurological disorders using EEG signals. Moreover these graphs are also easy to understand and analyse as they take and compare data between two different channel of EEG machine.[14]

Given below is the diagrammatical illustration of the method for better understanding. It shows the step by step working of algorithm through interconnected blocks.

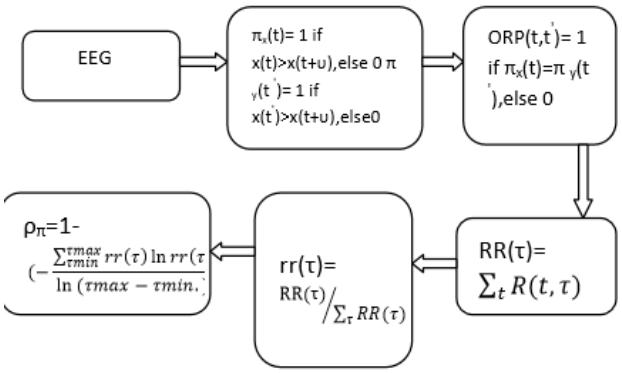

Figure1: Algorithm Based on MATLAB

The stepwise explanation of algorithm is given below:[14]

a. The EEG signals are taken from EEG machine and stored in the form of matrix.This matrix serve as the input for the propgram which is developed using the above mentioned algorithm

b. pie x(π_x) and pie y (π_y) are termed as the order patterns and they are found out by comparing a value of a sample at time 't' with the sample of same signal series at some other time instant.

c. Then with the values of order patterns of indivisual signal series the order patterns between the two signals taken from different channels of EEG machine is determined by using the formula given below:

$$\text{ORP}(t,\tau) = 1 \text{ if } \pi_x(t) = \pi_y(t+\tau) \qquad (2)$$

$$0, \text{ otherwise}$$

Following the above steps, Recurrence Rate and normalized recurrence rate are found : (3)

$$\text{Recurrence Rate } \text{RR}(\tau) = \sum_t \text{R}(t,\tau)$$

$$\text{Normalized Recurrence } \text{rr}(\tau) = \text{RR}(\tau) \Big/ \sum_\tau \text{RR} \qquad (4)$$

Then "synchronization index" (ρ_π) is found and plotted. The formula for synchronization index is as follows:

$$\boldsymbol{\ell\pi} = 1 - \left(-\frac{\sum_{\tau min}^{\tau max} rr(\tau) \ln rr(\tau)}{\ln (\tau max - \tau min.)}\right) \qquad (5)$$

This parameter "ρ_π", exhibits either low, moderate or high value. These values are further compared to find out the extent of repetition between the EEG signals recorded from various positions of brain. Moreover the recurrence plots are also plotted which helps in better understanding of synchronism between the EEG signals. [8-14].

a. Comparison with the Decomposition Model: Decomposition model for analysis of EEG signal,breaks the signals into their phases and compares the phase between the EEG signals attained from different channels of an EEG machine. To analyse the phase of such signals phase splitters and additional circuitry is required and moreover sometimes the phase differences are so small that they are hard to find out. Moreover ,the phase splitter devices and additional circuitry makes the method costly.

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On the contrary the developed method simply finds out the degree of synchronisation(ρ_π) to find out the neurological disorders.Since no additional circuitry except an EEG machine and a MATLAB software is required,this method is economical and accurate

b. Comparison with other algorithms: Their are few more algorithms like K-nearest neighbor algorithm,which compares a sample with k nearest neighbour,but the problem with such algorithm is that they are application specific i.e. for diagnosing various disorders,their source codes needs to be modified.In the case of the proposed method,it can be used effectively to diagnose neurological disorders like alzheimer's ,epilepsy etc,without making any changes,so it is far more versatile.

III.3. Results and Discussions

Through the proposed algorithm, certain programs have been made which takes EEG signals of patient (from different channels of same EEG machines), as an input. There has been a common observation in most of the neurological diseases that at certain point of time, the EEG signals show high degree of coupling or synchronization. This feature is ascertained with the help of recurrence plot and the plot of synchronization/coupling index to detect the disorders .The results for some of the neurological disease are as follows:

a. Epileptic seizure: Using the recurrence plot and the coupling index, one can easily detect the epileptic seizure and its intensity. The ORP and the coupling index graph of a person with epilepsy are shown under: Two EEG signals are taken from different channels and a sliding window is applied as shown in figure 8. These are RP of EEG at different moments. It is found that density of black dots is diminishing as we move towards seizure moments and eventually RP has very rare white black dots at the seizure activity in stage(IV&V).This is also shown through recurrence rate rr (t) and coupling index ρ_π in figure 9.

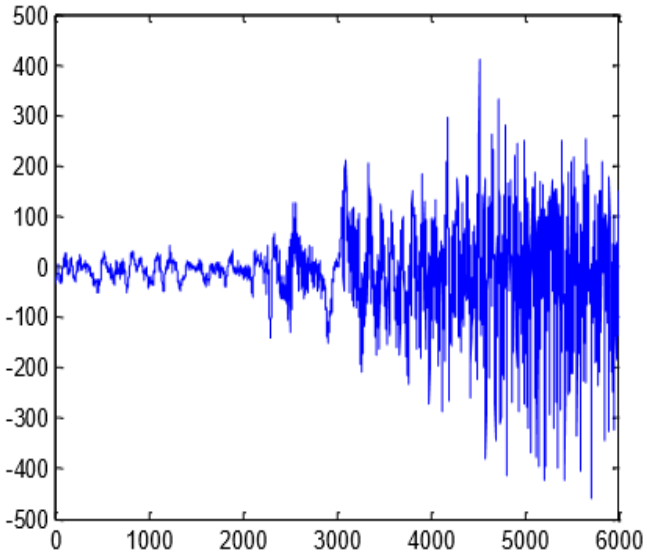

Figure 2: Epileptic EEG Signal from channel 1

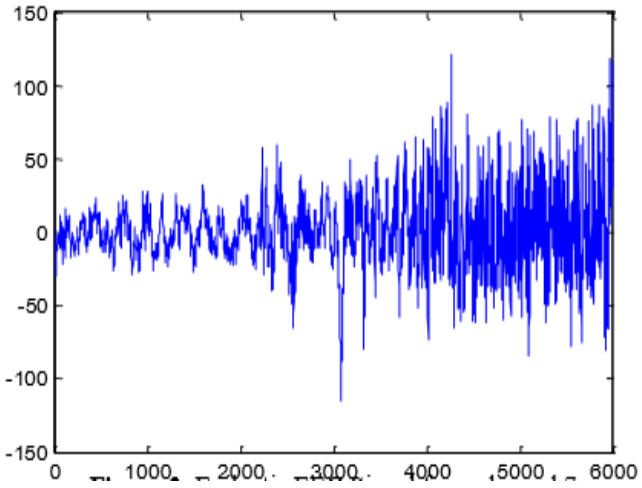

Figure 3: Epileptic EEG Signal from channel 7

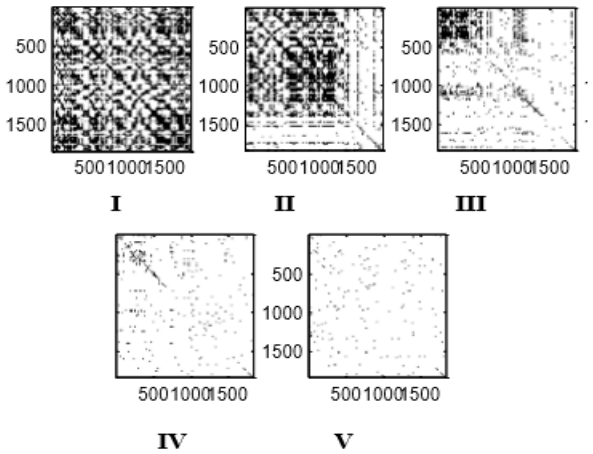

Figure 8: Stages of Recurrence Between Signals

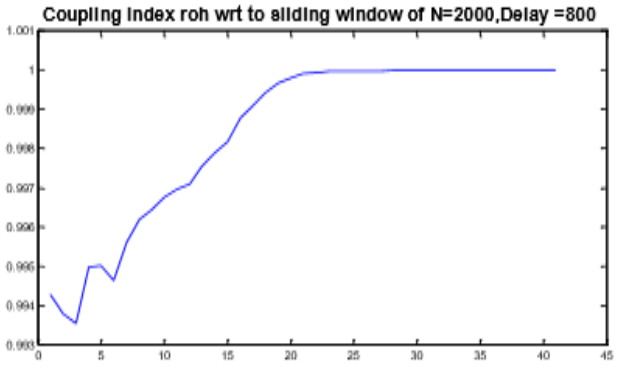

Figure 9: Coupling Index Graph

The increasing trend in the coupling index shows high degree of synchronization between EEG signals taken from channels [15-17].

This happens when the person is suffering from epileptic fits.

b. Bruxism: This is an involuntary activity which involves excessive grinding or clenching of teeth.

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This is also a neurological disorder and during this phenomenon, there is a high degree of phase locking or synchronization, hence the proposed algorithm can also be used to diagnose this disorder. In this process the EEG signals of the subject are taken routinely for at least a week and then using this algorithm, the synchronization index is plotted. The increasing trend in synchronization index ensures that the most probable reason out of the various reasons for teeth grinding is bruxism.The result of a patient, which is obtained by using this algorithm, is given below:

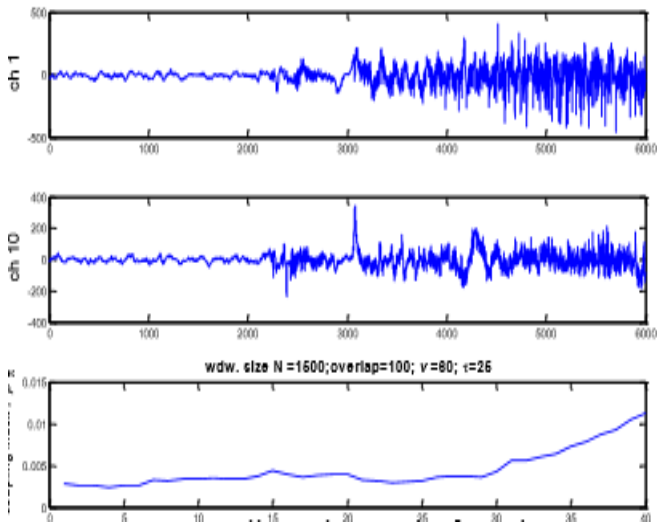

Figure 10: Coupling Index Graph of Bruxism

c. Alzheimer's disease: This is also a neurological disorder, which manifests itself in the phase locking or increased coupling between the EEG signals obtained from various regions of a patient's brain.

One result showing the increasing trends in coupling index in an Alzheimer's patient is given below:

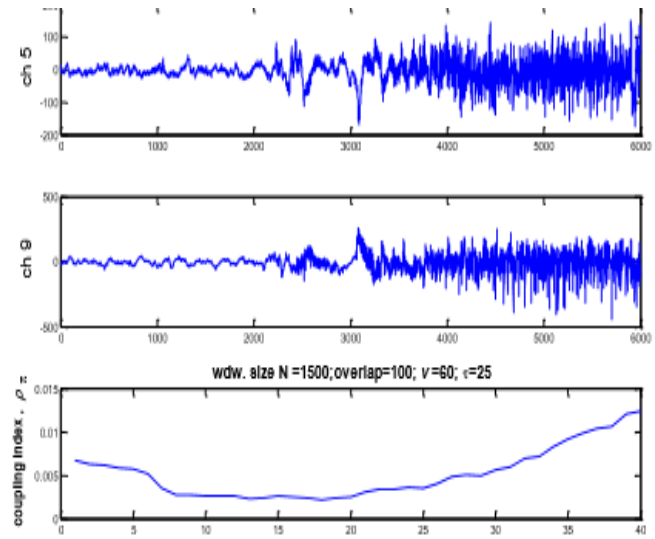

Figure 11: Coupling Index Graph of Alzheimer

Likewise, other neurological diseases like autism,dementia etc, that manifest themselves in coupling of EEG signals can effectively be diagnosed using the proposed method.

IV.CONCLUSION

To conclude, this method altogether presents a new approach for detection of neurological diseases that have certain degree of coupling or phase locking between them. Since the concept of order patterns is used which only compares the discrete values and creates a matrix of one and zero, the error probability in this method is very low.

Secondly, the algorithm used in this method is robust and not disease specific.Moreover, this method is a non invasive method so the chances of any kind of infection are nil.

This method also paves the way for developing the more efficient algorithms which can also use ECG and EMG signals to diagnose various disorders.

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Conflicts of interest

The authors do not declare any conflicts of interest.

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