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A Review of the Recurrence Based Techniques for Detection of Various Neurological Disorders

Mohd. Suhaib Kidwai[1], S. Hasan Saeed[2]

Assistant Professor, Dept of Electronics and Communication Engineering, Integral University, Lucknow, India[1]

Professor, Dept of Electronics and Communication Engineering, Integral University, Lucknow, India[2]

Abstract: There are certain neurological disorders like Alzheimer's disease, epilepsy etc which are characterized by recurring patterns in EEG obtained from the patient. If this recurrence pattern is observed and the degree of repetition can be studied then we can detect the presence of a disease and moreover if the degree of the repetition or recurrence can be detected by any parameter then further the intensity or the stage of the neurological diseases can also be diagnosed. This work mainly focuses on developing the algorithm and then a program using MATLAB so as to detect the seizures occurring in humans. This program will take the EEG signals from the Subject as input and will detect the recurrence patterns in the subject by using the mathematical concept of recurrences. Moreover different schemes of recurrence detection will also be used and the results will be compared so as to find the best of all the recurrence methods. This paper aims at giving the understanding of the synchronization that occurs in various natural and biological phenomenons and paves the way and prepares a ground for utilising this synchronization to detect and diagnose the neurological disorders in humans like epilepsy, alzheimer's disease etc.

Keywords: EEG Waves, Synchronization Index, Coupling Index, Recurrences.

1. INTRODUCTION

Coupling takes place when two or more systems adapt(synchronize) some characteristic of their respective motions, due to an interaction between the systems or to a common external forcing.This coupling phenomenon exists in biological systems too.For example the breathing pattern has got a special synchronized pattern and this pattern repeats itself perpetually. Any changes if found in the breathing patterns, signals a problem. Similarly there is a specific pattern of EEG signals. Any discrepancy in the pattern of this EEG signals may signal a neurological disorder like epilepsy, parkinson's disease etc.

This paper discusses about synchronization in natural and biological processes and gives an insight of the previous works done in this field

2. SIGNIFICANCE OF DETECTION OF COUPLING IN BIOMEDICAL SYSTEM

Natural systems are typically highly complex, and so also are the signals derived from them. This is especially true of the cardiovascular system and brain, and an enormous amount of effort has been made in recent years to develop time series analysis for diagnostic applications, i.e., to find ways to determine the physiological state by analysis of the corresponding complex signals. Synchronization and related phenomena in coupled complex systems have been found to occur, not only in physical, but also in many biological systems, e.g., the cardio respiratory interaction and neural signals. Measures of complexity have been developed that distinguish between regular, chaotic, and random behaviors, and can try to predict a heart attack or epileptic seizure. It has been reported that complexity of heart and brain data can distinguish healthy and sick subjects and sometimes even predict heart attack or epileptic seizure.

3. TYPES OF EEG WAVES

- Delta waves have frequency less than 4Hz. These cycles are associated with deep sleep or in morbid conditions such as coma.
- Theta waves ranges from 4-7Hz and are recorded during sleep states. Theta waves have the greatest amplitude compared in all EEG waves/rhythms.
- Alpha wave ranges from 8-13Hz and are associated with relaxed states, recorded from occipital and parietal lobes.
- Beta/ Gamma waves have frequencies above 14 Hz. Beta waves (14-30Hz) and gamma waves (>30 Hz) are recorded from frontal areas or other cortical regions Positioning Of the Electrodes: The International System 10/20 Recording of EEG helps to detect brain diseases so it should be recorded with great precision, this can be achieved by correct positioning of electrodes on the scalp. Nowadays, the most commonly accepted system for electrode placement is the international system 10/20. The standard positions of electrodes on scalp are denoted by a letter and a number.

The letters are: F = frontal T = temporal C = central P = parietal O= occipital A = ear Letters described above have suffix that contains numbers (even or odd). Even numbers refers to the right hemisphere and odd number refers to the left. Letter Z refers to the center line and A1 and A2 are used as reference.[8]

Electrode connections are of 3 types namely unipolar, bipolar, and media connection. In unipolar connection one electrode A1 or A2 is chosen as common reference for all others. In media connection, averages of all electrode potential are connected to a resistive network and output of the network is taken as common reference. Bipolar connections don't have any reference electrode. It uses the voltage difference between two electrodes. This type of connection provides flexible localization of electrodes at the areas of activity.[8]

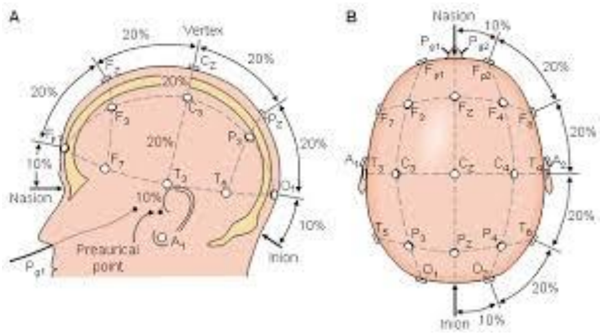

Fig 1: 10-20 Electrode system

Review of the work done till now:
The study of coupled systems goes back to the 17th century and begins with the analysis of synchronization of nonlinear periodic systems. Well known examples are the synchronization of two pendulum clocks that hang on the same beam it was through this system, that Huygens discovered synchronization, the synchronized flashing of fireflies, or the peculiarities of adjacent organ pipes which can almost annihilate each other or speak in unison. But the research of chaotic synchronization does not begin until the eighties where it was shown that two chaotic systems can become completely coupled, i.e. their time evolution becomes identical. This finding has had very important consequences for the design of secure communication devices. The synchronized chaotic trajectories can be used to mask messages and prevent their interception. In the notion of complete synchronization of chaotic systems was generalized, allowing the non identity between the coupled systems. And some time later, Rosenblum et al. [4] considered a rather weak degree of synchronization between chaotic oscillators, of which their associated phases become locked, whereas their amplitudes remain almost uncorrelated. Hence, they called this kind of synchronization, phase synchronization. Not only laboratory experiments have demonstrated phase synchronization of chaotic oscillators, such as electronic circuits, lasers and electrochemical oscillators, but also natural systems can exhibit phase synchronization. For example, the dynamics of the cardio respiratory system, an extended ecological system, and the electroencephalographic activity of Parkinson patients display synchronization features. On one hand it is important to investigate the conditions under which coupling of chaotic systems occurs, and on the other hand, to develop tests for the detection of coupling. In this work, it has been concentrated on the second task for the cases of phase synchronization (PS) and generalized synchronization (GS). Several measures have been proposed so far for the detection of PS and GS.

However, difficulties arise with the detection of coupling in systems subjected to rather large amounts of noise and/or non-stationarity, which are common when analyzing experimental data. The new measures that will be proposed in the course of this report are rather robust with respect to these effects. They hence allow to be applied to data, which have evaded coupling analysis so far. The proposed tests for synchronization in this work are based on the fundamental property of recurrences using order patterns.

The planned structure of whole work starts with concept given by Andreas Groth. His work mainly focusses on the visualization of patterns in time series by using the order pattern concept. Previous to this work in the analysis of coupled systems various techniques have been developed to detect cooperative behaviour from observed time series.One of the methods involve comparing the present sample with the previous and assigning a value 1 or 2 if the difference is positive or negative.This method is called as the method of order pattern.[7,4,2]

Depending on the nature of the systems, there are different requirements to the above methods. While linear methods based on correlations are not sufficient to deal with nonlinear dependencies, most nonlinear methods require sufficiently long stationary time series[10]. For the case that stationarity holds only for short observation time, cross recurrence plots CRPs were introduced.Cross recurrence plots focusses on finding the synchronization patterns between the two time series of signals.These signals can be mathematical,biomedical etc.Generally a sliding window method is used ,which means that number of signal samples that is to be compared at a time is fixed This ensures controllability and ensures accuracy.It also reduces redundancy.[5,6]

However, the method of CRP is based on taking distances of trajectories, which is conceptually difficult on physically different systems. A general problem in studying multivariate data from natural systems, for instance electroencephalogram EEG data, is that measurement conditions change with time. Among others offset and amplitude range can vary differently within the channels. To overcome this problem we consider a special symbolic dynamics of the system, where the time series is encoded by order patterns. This yields further symbol sequences, which are invariant with respect to certain distortions in amplitude.

The concept of symbolic dynamics suggested that the symbol sequence should come naturally from the time series, without further model assumptions, and that one should therefore take partitions as given by comparisons of neighbouring values of the series[3]. With this symbolic dynamics Bandt and a method of complexity measure and successfully applied to epileptic seizure detection. [8]
Following the idea of CRPs Andreas Groth introduce a visualization tool based on the recurrence of order patterns.

Thomas Schreiber in his paper, describes a method based on transfer entropy approach using the Markov property. The purpose of this paper is to motivate and derive an alternative information theoretic measure, to be called transfer entropy, which shares some of the desired properties of mutual information but takes the dynamics of information transport into account. With minimal assumptions about the dynamics of the system and the nature of their coupling one will be able to quantify the exchange of information between two systems, separately for both directions, and, if desired,conditional to common input signals. The concept of this is used in our work to generate a modified form of ORP and RP based on Markov property.
In addition to detection of coupling we have used symbolic dynamics and recurrences to find direction of coupling. The concept of recurrence has been used to detect relationships between interacting systems in , where the so-called synchronization likelihood has been introduced. This method allows for a multivariate analysis of generalized synchronization .Moreover, the concept of recurrence has been used to quantify a weaker form of synchronization, namely phase synchronization. Here, we extend these measures in order to detect the direction of the coupling. The proposed method is rather straightforward to compute, in contrast to the more complicated information theory approaches. Furthermore, it has the advantage that it is applicable to both weak and strong directional coupling, as well as to structurally different systems. For evaluating direction of coupling the literatures used are based on mean conditional probability of recurrence or directionality index based on mutual information.In these papers several methods have been compared from other literatures to estimate the direction of the coupling.

Use of the concept of recurrence to detect neurological diseases:
Going by the previously mentioned research papers, an idea of developing the algorithm and ultimately a program for the detection of neurological disorders comes into mind.
EEG signals can be used as an input .The entire idea is to use the mathematical concept of recurrence to determine the repetition patterns in the EEG signals.
Secondly, the degree or the intensity of repetition can also be determined by using the parameter called “synchronization Index (ℓ_π)”, where:

$$\rho_\pi = 1 - \frac{-\sum_{\tau=\tau_{min}}^{\tau_{max}} rr(\tau)\ln rr(\tau)}{\ln(\tau_{max} - \tau_{min})}$$

MATLAB can be used as a software tool for writing an efficient program, once the algorithm is developed.
Moreover once this is done various recurrence based methods can also be tested for diagnosing the neurological disorders and they can be compared so as to find the most efficient technique. The other synchronization parameters , which can be used are as follows:

Coupling Index $\rho_H(t)$: To define a coupling index the distribution of the instantaneous phase differences
$\Delta\Phi_H(t) = [\Phi^1_H(t) - \Phi^2_H(t)] \bmod 2\pi$
can be analyzed by means of the Shannon entropy S_H.
$\rho_H = 1 - S_H/S_{max}$
where S_H is the entropy of the distribution of $\Delta\Phi_H(t)$.
$S_{max} = \ln m$ the maximum entropy of m bins.
$z(t)=x(t)+i.\tilde{x}(t)=A(t).e^{i\Phi_H(t)}$, $\tilde{x}(t)$ is the Hilbert transform of x(t) and z(t) is the analytic signal for determining the phase of signals.
However, this interpretation of a phase using $\rho_H(t)$ holds only for narrowband signals. For this reason the EEG signals are band-pass filtered. Performing on the filtered signals in a sliding window of length L=1200 gives $\rho_H(t)$. Signals are band pass filtered (Butterworth Filter, 8-13 Hz for EEG signals) we get the qualitatively the same shape as with $\rho_\pi(t)$ i.e period of seizure is not reliable without filtering in case of $\rho_H(t)$.

Coupling Index $\rho_c(t)$: For non-phase-coherent oscillators an alternative method was introduced by the curvature of an arbitrary curve with $\emptyset(t)=\arctan \dot{x}(t)/\dot{y}(t)$. But this approach is restricted to systems where we are able to obtain at least two components.This idea was adopted to introduce a phase by the curvature of an analytic signal:
$\emptyset(t)=\arctan h\{\dot{x}\}/\dot{x}$; h{}→Hilbert transform
where just only a single component is needed. Analogously to ρ_H the coupling strength is calculated from the phase differences $\Delta\emptyset_c(t) = [\emptyset^x_c(t) - \emptyset^y_c(t)] \bmod 2\pi$ by means of Shannon entropy
$\rho_c = 1 - S_c/S_{max}$,
with Sc the entropy of the distribution of $\Delta\emptyset_c(t)$.
For order patterns CMI is:
$I_{X,Y}^\pi = I(\pi_x(t) ; \Delta_\tau \pi_Y \mid \pi_Y(t))$ and $I_{Y,X}^\pi = I(\pi_Y(t) ; \Delta_\tau \pi_X \mid \pi_X(t))$

4. CONCLUSION

To conclude, this work can be effectively and efficiently used over biomedical signals for finding short time dynamics and they can be more accurate in diagnosis of pathological condition that can be detected from strength of interactions between recorded signals obtained from two structurally different systems like ECG and heart rate variability, breathing patterns and EMG or in between different EEG channels for the patients of Parkinson disease ,epilepsy and it can also be used to analyze sleep

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disorders by studying EEG during various sleep stages. This work can pave the way for developing effective ways to diagnose the neurological diseases. This work can also be useful in understanding the interaction of brain and heart signal during dispensing of anaesthesia to patient for surgery. This work may help in understanding the nature of various biomedical signals and the effects of their interaction with each other.

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