EVOLUTIONARY COHERENCE ON EEG SIGNALS FOR EPILEPTIC SEIZURE DETECTION

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Special thanks to

My beloved family members who always there for me,

My friends, who assists, accompanying me now and then,

And also to

My supervisors who guide me through the research's hardships

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ABSTRACT

Electroencephalogram (EEG) signal for epileptic seizure is nonstationary by nature. The onset of epileptic seizure is determined by the increase in synchronicity of firing neurons, and the spreading of epileptic seizure could be traced with investigating on the evolution of synchronicity across channels. However, there are only a few previous studies on utilizing evolutionary coherence in detecting epileptic seizure EEG events. Besides that, these researches also mostly focus on only a few channels for mere simple and quick comparison. There is also a lack of research in comparing coherence analysis from different non-parametric approaches. Therefore, this research aims to analyze the brain connectivity in EEG epileptic seizure using nonstationary coherence by applying specifically SLEX coherence, wavelet coherence and STFT coherence. The algorithm is tested on a real epileptic seizure patient with focal epilepsy seizure at the left temporal lobe. The coherence obtained is further plotted using Circos software package, which is advantageous in mapping complex links and relationships. In conclusion, evolutionary coherence on EEG signals for epileptic seizure detection has been performed using STFT, wavelet and SLEX coherence. It was found that wavelet and SLEX coherence are capable of epileptogenic focus localization and seizure prediction, with wavelet coherence showing slightly better performance.

ABSTRAK

Isyarat electroencephalogram (EEG) bagi sawan adalah bersifat. Permulaan sawan ditentukan oleh peningkatan dalam segerakan dalam penembakan saraf, dan penularan sawan dapat dikesan dengan menyiasat evolusi pegerakan antara saluran. Walau bagaimanapun, hanya sedikit kajian sebelum ini menggunakan evolusi konsisten dalam mengesan aktiviti EEG sawan. Di samping itu, penyelidikan dalam bidang ini juga kebanyakannya memberi tumpuan pada hanya beberapa saluran sahaja untuk perbandingan ringkas dan cepat semata-mata. Selain itu, penyelidikan juga kekurangan dalam perbandingan antara cara-cara yang tidak bergantung pada parameter. Justeru itu, kajian ini bertujuan untuk menganalisis perhubungan otak dalam EEG sawan dengan menggunakan konsisten nonstationary dengan menggunakan terutamanya konsisten SLEX, konsisten wavelet dan konsisten STFT. Algoritma diuji pada pesakit sawan sebenar yang mempunyai tumpuan epilepsi rampasan pada lobe temporal kiri. Konsisten yang diperolehi seterusnya dijadikan graf dengan menggunakan pakej perisian Circos, yang mempunyai kelebihan dalam pemetaan kompleks pautan dan hubungan. Secara kesimpulannya, evolusi konsisten pada isyarat EEG untuk mengesan sawan telah dijalankan menggunakan STFT, wavelet dan SLEX konsisten. Adalah didapati bahawa konsisten wavelet dan SLEX mempunyai kemampuan dalam epileptogenic fokus penyetempatan dan penyitaan ramalan, dengan konsisten wavelet yang menunjukkan prestasi yang lebih baik sedikit.

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LIST OF ABBREVIATIONS

BBA	-	Best basis algorithm
CWT	-	continuous wavelet transform
DWT	-	discrete wavelet transform
EEG	-	electroencephalogram
FFT	-	fast Fourier transform
fMRI	-	functional magnetic resonance imaging
GCV	-	generalized cross validation
ICA	-	independent component analysis
LDBA	-	local discriminant basis algorithm
MATLAB	-	Matrix laboratory
PCA	-	principle component analysis
Perl	-	Practical extraction and reporting language
SLEX	-	functional magnetic resonance imaging
STFT	-	short time Fourier transform
SWD	-	stationary wavelet coefficients

LIST OF SYMBOLS

a	-	Wavelet scaling parameter
A	-	A matrix
b	-	Wavelet translation parameter
$\mathbf{d}$	-	Coefficient vector
$\hat{f}$	-	Cross spectrum
$\mathbf{I}$	-	SLEX periodogram matrix
$\tilde{\mathbf{I}}$	-	Smoothed SLEX periodogram matrix
M	-	Wavelet smoothing window
r	-	SLEX steepness function
$S(j,b)$	-	SLEX library
t	-	Time
v	-	Bandwidth
W	-	Wavelet coefficient
X	-	SLEX coefficient
β	-	Complexity penalty parameter
ε	-	SLEX number of points overlapping
$\hat{\rho}$	-	Coherence
$\hat{\boldsymbol{\rho}}$	-	Wavelet coherence estimator

ϕ	-	SLEX vector
Ψ	-	SLEX window
ω	-	Frequency

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CHAPTER 1

INTRODUCTION

1.1 Background

Seizure is a neurological disorder which can be generally described as a series of uncontrollable convulsions. It can be divided into two major classes, which are epileptic and non-epileptic seizure. Epileptic seizures are caused by massive neuronal discharge in the brain. Meanwhile, non-epileptic seizures do not involve abnormal, rhythmic discharges of cortical neurons, but instead are caused by physiological or psychological conditions. Further classification of epileptic seizure is by the region of onset. In focal seizure, the source of epilepsy starts in one of the hemisphere while the generalized seizure the epilepsy starts in both hemispheres (Figure 1.1), both spreading to other regions after the initial onset. Epileptic seizure is usually investigated through acquisition of data in the form of electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI).

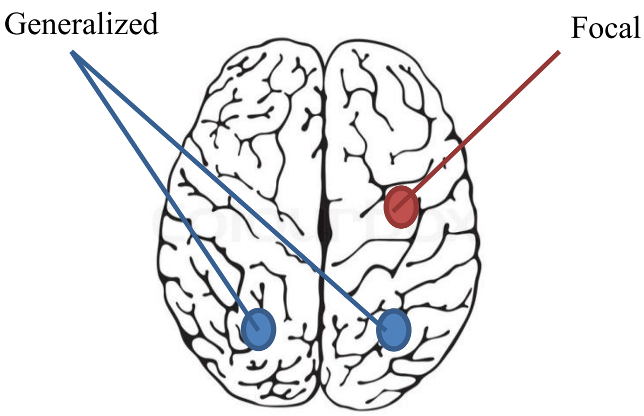

Figure 1.1: Location of onset for focal and generalized seizure.

The analysis of EEG is unique due to its nonstationary and voluminous properties. A signal is termed as nonstationary or evolutionary when its properties, such as amplitude and frequency, fluctuate outside periodical manners across time. Therefore, most of the signal properties are masked at first inspection by neurologist. One of the examples is the relations between channels. This is particularly important as the information on signal propagation is required for epileptogenic focus localization. Besides that, the properties of EEG signals vary greatly with the presence of epileptic seizures. Therefore, neurologists often use a lot of time for tedious analysis, which is also error-prone and subjected to inter-observer variabilities. This poses a great threat in interpreting the patient condition, especially that the natural stochastic process of EEG still remains unknown.

The analysis of epileptic seizures can be viewed from different ways. First of them is the domain in which the signals are looked into, which are time domain, frequency domain and also phase. Further inquisition involves techniques such as correlation and coherence which finds the relations between each channel. Secondly, the temporal structure of epileptic event is analyzed with reference to the onset of seizure. Ictal defines the duration where seizure occurs, while preictal is before the onset of seizure and postictal is after the onset of seizure. This is particularly important in the analysis since the characteristics of the signal (including amplitude, frequency and phase) changes dramatically in these different stages. Thirdly, different statistical analysis approaches are used to analyze the epileptic EEG signals. There are parametric method (such as autoregressive model and linear regression model), non-parametric method (such as smooth localized complex exponential (SLEX) transform, short time Fourier transform (STFT) and wavelet transform) and dimensionality reduction method such as principle component analysis (PCA) and independent component analysis (ICA). These analyses are then used for epileptogenic focus localization and also seizure prediction, which are the main applications in neural signal processing of epileptic seizure.

Other than the changes in spatio-temporal, epileptiform activity is also characterized by the synchronous activation of multiple large aggregates of neurons (Ahlfors *et al.*, 1999; Duckrow & Spencer 1992; Gotman, 1987). For longer stationary time series, frequency domain approach is computationally easier because it reduces the dimension of the problem. For nonstationary time series, the reduction in dimension is essential for computational efficiency.

Evolutionary coherence is a relatively new technique in analyzing epileptic seizure EEG data. It is an adaptation from correlation whereby the synchronization between channels is studied in predetermined frequency bands. (Brillinger, 1981; Brockwell & Davis 2009) describes coherence as “the frequency domain analog of the autocorrelation function” or the “correlation between the stochastic increments in the spectral representation”. This is essential in analyzing epileptic seizure as a few studies have reported that there is a shift of coherence across frequency bands during seizure (Ombao & Van Bellegem 2008). In addition to that, the nonstationary property of evolutionary coherence is also in congruent to the characteristic of epileptic seizure EEG.

SLEX transform (Ombao *et al.*, 2001a; Ombao *et al.*, 2001b) is a recent method developed for analyzing nonstationary signal. Its ability in analyzing coherence was tested in a few researches such as on seismic waves (Huang *et al.*, 2004) and speech signal (Ombao *et al.*, 2001b). It is an adaptation from STFT by applying double-window method to preserve the orthogonality of extracted features. The ability of SLEX transform in automatically segments bivariate time series into approximately stationary blocks and automatically chooses the smoothing parameter could produce optimal window for best feature representation. Besides that, SLEX transform is also complex valued, in which its phase can model the time lag between components in bivariate time series and useful in coherence analysis.

In this project, the characteristic of epileptic seizure is investigated through a 21 channels EEG, featuring a patient with focal epileptic seizure at the left temporal lobe. All preictal, ictal and postictal activities are analyzed through using three non-parametric methods (STFT, Wavelet transform and SLEX transform) for feature extraction then coherence analysis to obtain information on the correlation of channels at different frequency bands. This is followed by adapting the data into graphical representation using Circos, which is a graphical visualization method excel in modeling links and relationships between elements.

1.2 Problem Statements

The problems of the research are summarized as follows:

(1) Although there have been numerous researches on EEG signals, **there are only a few previous studies on utilizing nonstationary or evolutionary coherence in detecting epileptic seizure EEG events.** It was found that most of the previous studies use stationary analysis and also time domain correlation in studying the connectivity of epileptic seizure EEG. The usage of stationary analysis for epileptic seizure EEG is not appropriate as it is unable to characterize accurately for the nonstationary properties of the signal. While time domain correlation serves as the basic understanding of brain connectivity, it is unable to picture precisely the

connectivity pattern of epileptic seizure EEG with reference to specific frequency bands.

(2) In order to study nonstationary coherence properties of epileptic seizure EEG, **simultaneously high resolution in both temporal and frequency domain is required in feature extraction method**, as this is the most basic but crucial step in representing raw data in analyzable block. The conventional nonstationary approach such as STFT is unable to achieve this simultaneously due to its lack of flexibility and also non-orthogonality. Furthermore, the sinusoidal basis of conventional Fourier transform might not be able to capture the abrupt changes of the epileptic seizure event.

(3) Besides that, there is also **a lack of research in comparing coherence analysis from different non-parametric approaches**. This is especially true for the recently found method, SLEX transform which is not yet benchmarked with more popular method such as wavelet transform and also the conventional STFT.

1.3 Motivation

This project is motivated by recent researches which suggest that EEG is a nonstationary signal, and moreover, epileptic seizure EEG which shows dramatic changes even by mere direct observation. In this way, the findings fully support the notion of further investigation on the properties of epileptic seizure EEG by applying nonstationary analysis in order to be able to picture the real characteristics of the signal.

Besides that, change in frequency domain is also reported in various researches across the epileptic seizure event in EEG. Coherence, which is the correlation of signal at specific frequency band, also shows notable changes as well. Since epileptic seizure is nonstationary, evolutionary coherence is proposed as the main analysis method in this project.

Recent discovery of the utilization of Circos visualization tool in mapping the brain connectivity also sparks interest in this research. Its intuitive property and ability to map complex set of links originally catered for genome mapping are seen as a valuable asset to adapt in neural signal processing, especially in studying brain connectivity.

1.4 Objectives

Therefore, this research aims to analyze the brain connectivity in EEG epileptic seizure using nonstationary coherence by applying specifically SLEX coherence, wavelet coherence and STFT coherence. This will further insights to the characteristics of EEG epileptic seizure compared to the conventional spectral analysis or coherence analysis.

- To extract time-varying spectral features from raw EEG data using SLEX transform, wavelet, and STFT
- To perform nonstationary coherence analysis of the extracted features
- To compare SLEX and wavelet coherence with conventional sliding window technique such as STFT
- To present brain connectivity result in effective graphical representation

1.5 Scope

The research is limited by only focusing the brain connectivity analysis through coherence analysis. Phase coherence and time correlation is not investigated in this research. Besides that, techniques applied for feature extraction are of non-parametric approaches only, such as STFT, wavelet transform and SLEX transform. There are other ways of obtaining the features such as parametric and dimensionality reduction analysis but is not given attention in this research. Finally, EEG data used in this research is obtained through collaboration with Prof Hernando Ombao, University of California, Irvine.

1.6 Contribution of the Research

The research contributes in developing evolutionary coherence using STFT coherence, wavelet coherence and SLEX coherence in EEG signals for epileptic seizure detection. The result from the coherence analysis were plotted using Circos software package and the performance of each method was compared.

1.7 Overview

This report contains a total of five chapters, which are introduction, literature review, methodology, results and discussions, as well as conclusion and future work.

The first chapter Introduction serves as the basic background knowledge for the concept of this whole project, such as understanding what epileptic seizure is. This is followed by identifying the problem statements which later triggers the formation of motivation for this project. Aims and objectives are then listed as an end target. Scope and contribution of this research are listed as well. Lastly, the overview of this report is given.

The second chapter Literature Review lists out all of the literatures which are related to this research. Besides that, the basic concept for time-frequency spectral analysis of non-stationary signal is given as well, which includes short time Fourier transform (STFT), wavelet transform and smooth localized complex exponential (SLEX) transform. This is followed by the concept of evolutionary coherence analysis and the usage of Circos software package in brain connectivity.

The third chapter Methodology explains the systematic and theoretical analysis of the methods applied in this research. This starts with the system overview, data description and software packages. Following these is the time-frequency analysis of single channel, which includes the source of reference for the algorithm used, details on the theoretical analysis of the algorithm, the adaptation performed and also a link to the algorithm at the Appendix. Then, the methodology of evolutionary coherence is explained. Lastly, the operation of software package Circos for the construction of connectogram is explained in detail.

Chapter 4 Experimental Results and Discussions examine the outcome of this research. First, observations are made based on the generated connectograms. Then, the observations are discussed with the support of literatures as seen appropriate.

Lastly, this report ends with Chapter 5, which is Conclusion and Future Works. The finding of this research is concluded in this section followed by some suggestion of future works to be done in extension to this research.

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