SPATIAL ANALYSIS OF SIGNAL DURING EPILEPTIC SEIZURE ON FLAT ELECTROENCEPHALOGRAPHY

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To my beloved family, for your love and support. To my friends, for your wits, intelligence and guidance in life.

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ABSTRACT

The human brain is the most complex structure in the universe. It is made up of billions of nerve cells called neurons. Studies on human brain were started centuries ago whereby various diagnosis instruments and techniques have been developed to understand it. Epilepsy is the second most common brain disorder. Electroencephalogram (EEG) was invented and widely used for recording human brain electrical activities. It is considered as the best tool which has been used in epileptic analysis. However, the best visual inspection still highly relies on experienced electroencephalographers or neurophysiologists. Due to this restriction, extraction of the hidden information from EEG signal during epileptic seizure is important. In this work, a new spatial interaction model which is based on basic gravity model is developed and applied on flat Electroencephalography ($fEEG$). The model is used to study the interaction among clusters on $fEEG$. The images of these interactions are then verified and compared to interaction images of spherical domain model of charges in the brain. The strength of interaction force inside the spherical domain of charges' path is calculated. The results showed that the interaction of the clusters are not directly proportional to distance, potential difference of cluster and size of cluster's charge. This study concurs the chaotic behavior of epileptic seizure as advocated by Iasemidis and his fellow researchers.

ABSTRAK

Otak manusia ialah struktur yang paling rumit dalam alam semesta. Ia terbentuk daripada berbilion sel saraf yang dikenali sebagai neuron. Kajian terhadap otak manusia telah dijalankan sejak berabad-abad yang lalu dengan pelbagai instrumen dan teknik diagnosis telah dibangunkan untuk memahaminya. Sawan merupakan penyakit kedua yang sangat biasa dikaitkan dengan gangguan otak. Elektroensifalogram (EEG) telah dicipta dan digunakan secara meluas untuk mencerap aktiviti elektrik dalam otak manusia. Ia adalah peralatan terbaik yang diguna untuk menganalisa sawan. Namun demikian, pemeriksaan terbaik secara visual masih bergantung kepada pakar elektroensifalografi atau neurofisiologi yang berpengalaman. Disebabkan oleh kekangan ini, pengekstrakan maklumat tersembunyi daripada isyarat EEG semasa serangan sawan adalah amat penting. Dalam kajian ini, satu model ruang interaksi baru yang berasaskan model graviti asas telah dihasilkan serta diaplikasikan ke atas Elektroensefalogram Rata ($fEEG$). Model ini digunakan untuk mengkaji interaksi antara gugusan $fEEG$. Imej-Imej daripada interaksi ini seterusnya ditentusahkan dan dibandingkan dengan imej interaksi yang berdasarkan model domain sfera cas-cas di dalam otak. Kekuatan daya interaksi di dalam domain sfera laluan cas-cas ditentukan. Keputusan menunjukkan bahawa interaksi antara gugusan adalah tidak berkadar terus dengan jarak, beza keupayaan gugusan dan saiz cas gugusan. Kajian ini mendapati perilaku serabut daripada serangan sawan seperti dinyatakan oleh Iasemidis dan rakan penyelidiknya.

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LIST OF ABBREVIATIONS

EEG	–	Electroencephalogram
HUSM	–	Hospital Universiti Sains Malaysia
HKL	–	Hospital Kuala Lumpur
ILAE	–	International League Against Epilepsy
PSE	–	Photosensitive Epilepsy
SUDEP	–	Sudden unexpected death in epilepsy
SPECT	–	Single-photon emission computed tomography
fMRI	–	Functional magnetic resonance imaging
PET	–	Positron emission tomography
NIRS	–	Near-infrared spectroscopy
MEG	–	Magnetoencephalography
iEEG	–	intracranial EEG
EMG	–	electromyography
FTTM	–	Fuzzy Topographic Topological Mapping
MC	–	Magnetic Contour Plane
BM	–	Base Magnetic Plane
FM	–	Fuzzy Magnetic Field
TM	–	Topographic Magnetic Field
FRG	–	Fuzzy Research Group
C_{EEG}	–	Fauziah's EEG coordinate system
$fEEG$	–	Flat EEG.
PC	–	Partition Coefficient
CS	–	Compactness Separability
FCM	–	Fuzzy c-Means
PPA	–	point pattern analysis
NNA	–	Nearest neighbour analysis
RVT	–	Regionalized variable theory
NCGIA	–	National Center for Geographic Information and Analysis

TFL	–	Toblers First Law
MAUP	–	Modifiable Areal Unit Problem
ESDA	–	Exploratory Spatial Data Analysis
GIS	–	Geographic information system
CCG	–	Centre for Computational Geography
CSISS	–	Center for Spatially Integrated Social Science
USGIF	–	United States Geospatial Intelligence Foundation
CGA	–	Center for Geographic Analysis
IQR	–	Interquartile Range
i.e.	–	that is
e.g.	–	for example

LIST OF SYMBOLS

$\mathbb{R}$	–	set of real numbers
$\mathbb{R}^+$	–	set of positive real numbers
$\in$	–	is an element of
$\rightarrow$	–	is mapping to
$=$	–	is equal to
$\neq$	–	is not equal to
$\neq$	–	is greater than or equal to
$>$	–	is greater than
$<$	–	is less than or equal to
$\leq$	–	is less than
Σ	–	the sum of
$\mathbb{Z}$	–	set of integers
$\cup$	–	union
$A \setminus B$	–	belong to set A and not to set B
A^C	–	complement of set A
$\subset$	–	is subset of
$\vert$	–	such that

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Brain is the most magnificent organ of a human body that plays the character of controlling all of our thinking and movement. It is a neural network which built by billions of nerve cells, namely neurons. The neural activity of human brain starts between 17th and 23rd week of the prenatal development (Tyner *et al.*, 1983). In addition, all the building blocks of human brain, such as brain cells, brain molecules, neurotransmitters and synapses are almost identical in all animals. The question is: Does it mean that the larger brain is made of larger number of neurons? In other words, does larger brain process larger computational abilities than smaller brain?

Generally, an adult human brain's weight is between 1.2–1.5 kilograms, but elephant brain's weight is between 4–5 kilograms (see Figure 1.1) (Mink *et al.*, 1981). Human brain has the same general structure as the brains of other animals, especially mammals. Human is the only one can generate higher consciousness associated with ingenuity, such as writing, planning, and so on. Scientists believed that these abilities may come from humans that have a more developed cerebral cortex than others, thus human has the largest number of neurons in the cerebral cortex.

Even the human brain is taking an important role as centre of intelligence, interpreter of the senses, initiator of body movement, and controller of behaviour. It is only about 2% of a human's body weight. However, human devotes 20–25% of basal metabolism for it, whereby other vertebrate species use only 2–8% (Mink *et al.*, 1981). Centuries ago human did start to study on human brains, but to date, they still view the brain as nearly incomprehensible. In fact, the human brain is known as the most complex structure in the known universe.

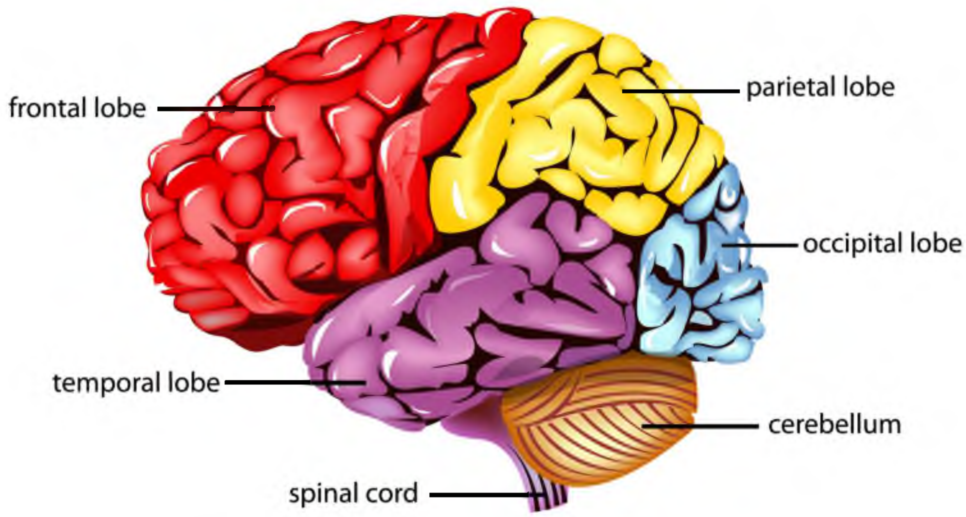

Figure 1.1: Human Brain. (From http://bricspl.com/human-brain/index.html)

Since the human brain is such important to an individual, when a disorder come to the brain, his normal living may be devastating. In general, brain disease may come in a few forms, such as infections, trauma, stroke, seizures, and tumours. The complexity of the human brain induces scientists fail to detect the cause of some brain diseases, for example Alzheimer's disease and epilepsy seizure (Bao *et al.*, 2009). There are some cases have resulted in the permanent damage. On the contrary there are treatments for other cases, which may involve surgery, medicines, or physical therapy.

While normal brain functioning, millions of tiny bioelectrical charges between nerve cells are produced for transmitting information. However if there is excessive and hypersynchronous activities of the neurons that causing a miniature brainstorm, the human may experience epileptic seizure (Sanei and Chambers, 2013). During seizure, patient may have uncontrolled muscle movements, sensory disturbances, loss or alteration in consciousness. In addition, if the seizure is recurrent and unprovoked, the patient is potentially having epilepsy.

1.2 Research Background

Life electrical signals are signals that generated by human brain, which resulted by the transportation of neurotransmitters from one neuron to another neuron (see Figure 1.2). It is believed that the signals not only presenting the brain function or motion, but also deliver messages about status of the whole body (Tyner *et al.*, 1983). This assumption has brought out the motivation to study the signal processes of human brain. A variety of techniques and instruments were invented for the study, including Electroencephalogram (EEG) (see Figure 1.3).

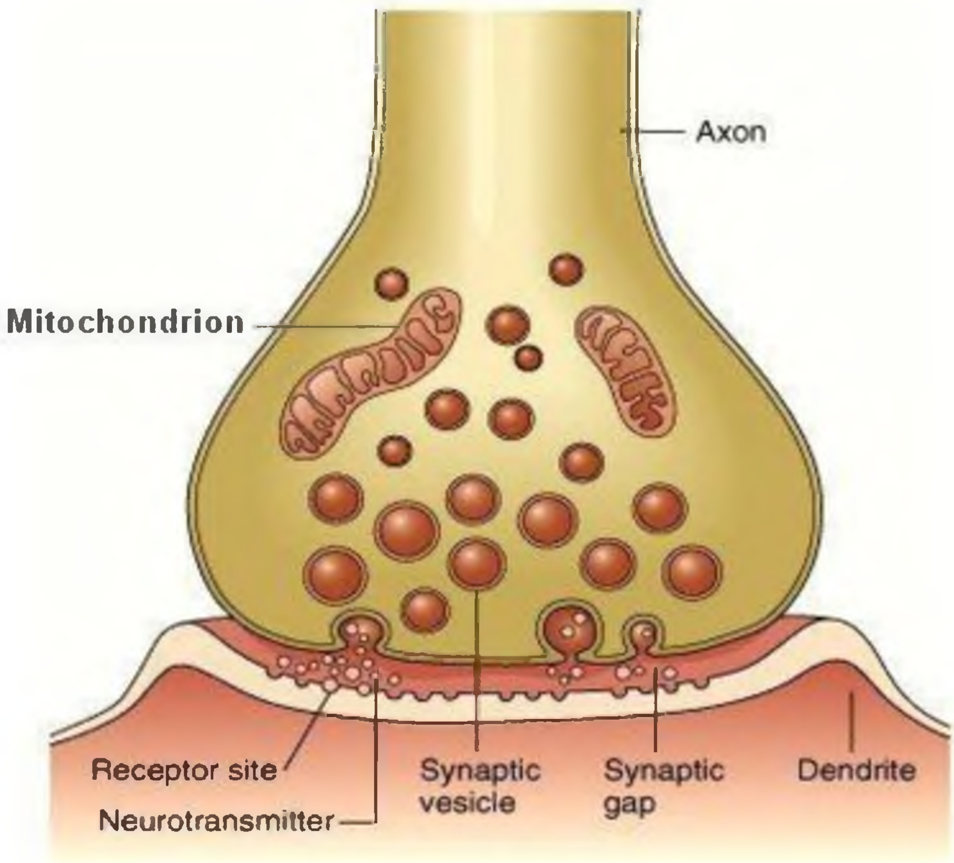

Figure 1.2: Release of neurotransmitters.
(from http://www.epilepsyresearch.org.uk/about-epilepsy/background-to-seizures/background_to_seizures_synapse/)

The first epilepsy surgery was on 25th May 1886, operated by Victor Horsley at National Hospital for the Paralysed and Epileptic at Queen's Square in London (Wolf *et al.*, 2001). The term of "epileptogenous focus" was first introduced by Horsley (1886). After that, the epilepsy surgery come to the first big wave. However the successfulness of the surgery was very limited, with a mortality of 5–7%. This result urged neurosurgeons to come up with another way to treat the epilepsy, such as the introduction of phenobarbital in 1912.

In the 1940s, EEG was developed to provide the necessary localization for diagnosis and treatment of brain lesions. This new development was brought the epilepsy surgery to the second wave, which started by Penfield and Flanigin (1950) with Bailey and Gibbs (1951). To date, EEG is still considered as the best method

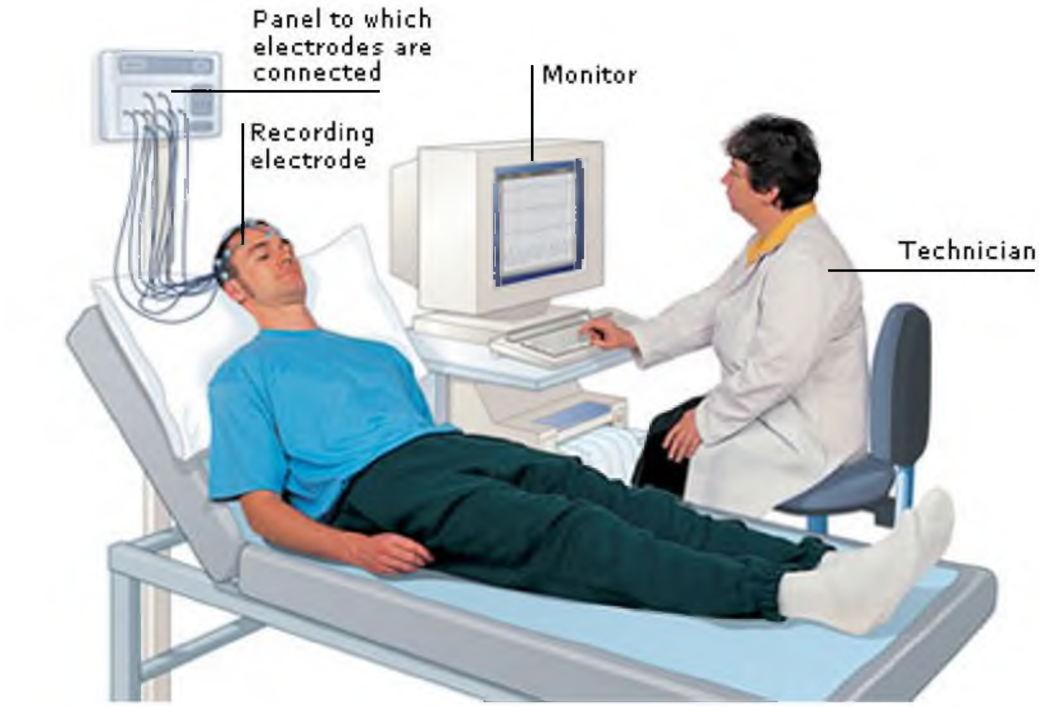

Figure 1.3: EEG system.
(from https://freudforthought.wordpress.com/2015/05/06/seeing-inside-the-brain/)

used in epileptic analysis.

Even though EEG can record all of the electrical activity in the brain during seizures epileptic, but the output is in the waveform, which makes the visual inspection become very subjective and hardly allows any statistical analysis or standardization. In order to overcome this problem, the transformation from high dimensional EEG signal to lower dimension of image form is conducted via flat EEG ($fEEG$) (Zakaria, 2007). This transformation allows EEG signals to be compressed and analyzed.

Researchers believe that through further improvement of this technique of Flat EEG, the origin of electrical activity inside the brain may be possible to be determined.

1.3 Problem Statement

The Universal Law of Gravitation states that a particle acts forces on every other particles in the universe. However, Coulomb's Law claims that the magnitude and sign of electric force are determined by the electric charge (Gregersen, 2011). According to Coulomb's Law, charges particles will repel each other and create electrical repulsive force when they are alike charges. This phenomena may be true also for life electrical signals that generated by human brain, which carry positive charges (+K and +Na). These information are hidden in transformed EEG Signal ($fEEG$). Therefore, this research will attempt to extract the interaction relationship (repulsion forces) through spatial analysis.

1.4 Research Objective

The main objective if this research is to identify the interaction relationship of clusters on $fEEG$. In doing so, a simulation model is first to be built to show the spatial interaction among clusters on $fEEG$ in image form. From there, the factor/factors which impact on spatial interaction forces of clusters will be identified. Furthermore, the model will be developed into three dimensional view and verify with Spherical Domain if Charges.

1.5 Scope of Research

In this research, the process of the clustering the EEG signal on Flat EEG was proposed by Zakaria (2007) and will be directly used as input data of spatial analysis. These data were obtained from Hospital Universiti Sains Malaysia (HUSM) and Hospital Kuala Lumpur (HKL).

1.6 Significance of Findings

The contributions of the findings in this study are:

1. a mathematical model that can describe the interaction relationship of clusters on Flat EEG;
2. introduce an application of fuzzy membership function into spatial interaction model;
3. a spatial interaction model that can represent the interaction among EEG data during seizure in image form.

1.7 Thesis Outline

This thesis contains seven chapters. Its framework is shown in Figure 1.4. Chapter 1 provides the general information about the research, including the research background, problem statement, research objectives, scope of research and the significance of the findings. It enables readers to have an overview on concept of the whole thesis.

Chapter 2 gives the literature review of epilepsy, seizure, electroencephalogram and flat electroencephalography. Some medical information such as definition of epilepsy and seizures, type of electroencephalography technique will be presented in this chapter. Also, the mathematical background of spatial analysis will be documented in this chapter. The history of spatial analysis will be discussed, where it expands the application from cartography and surveying to ecology, epidemiology, environmental resource management and many other criteria. Furthermore, the contentious of classifying spatial analysis techniques and general review of spatial interaction models will be presented.

The construction of the spatial interaction model on the platform of Flat EEG will be given in Chapter 3, which includes an introduction of a membership function on the gravity model. An example will be discussed in this chapter.

The implementation of the model will be given in Chapter 4, the output of the model is spatial interaction image for every single second, which is a greyscale image. In chapter 5, the model will be improved by standardising the image by introducing a simple statistical method, namely interquartile range. This standardised method will represents the output in a series of colour image.

The spatial interaction model will then be verified in Chapter 6 by the Spherical Domain Model of Charges. Additionally, the application of the model to the Spherical Domain Model of Charges will be carried out. The outputs of the projection of spatial interaction image from Flat EEG into Spherical Domain Model of Charges and the application of spatial interaction model on Spherical Domain Model of Charges will be compared. Besides, the intersection among Spherical Domain Model of Charges and Spatial Interaction Image will also be identified through slicing technique and analysis in Chapter 7.

Finally, Chapter 8 concludes this thesis which highlighting the significance of the research and providing some suggestions for future research.

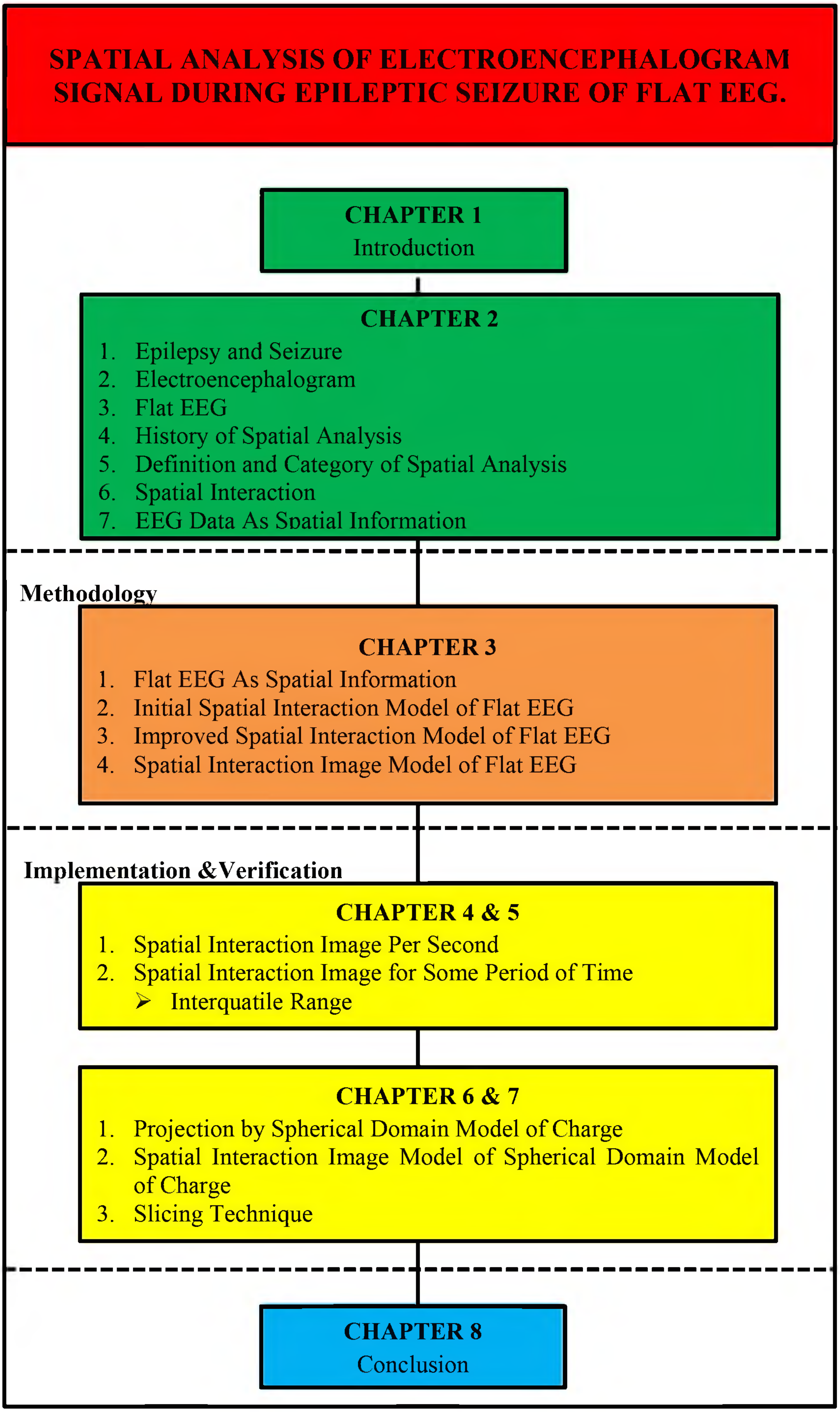

Figure 1.4: Research Framework.

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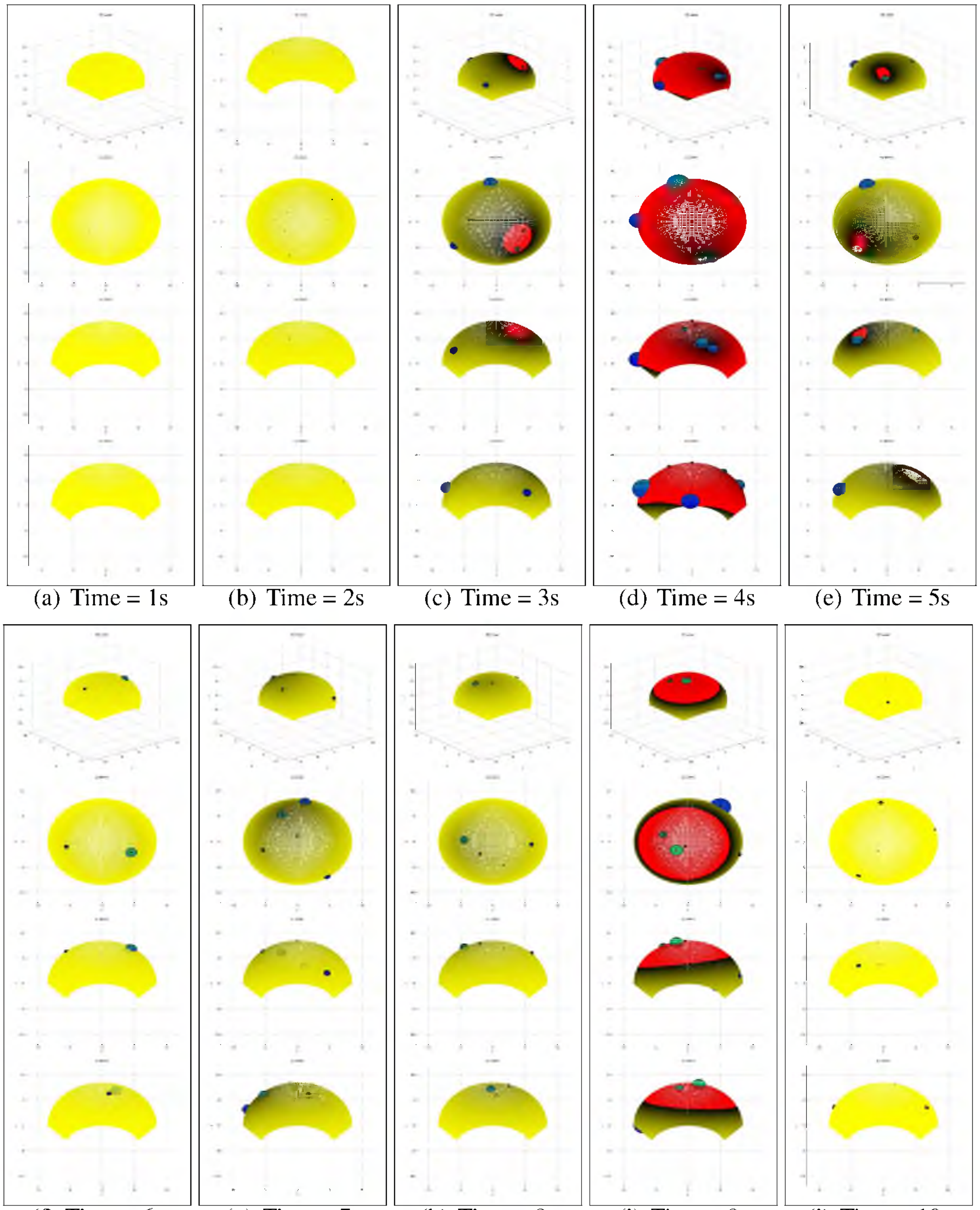
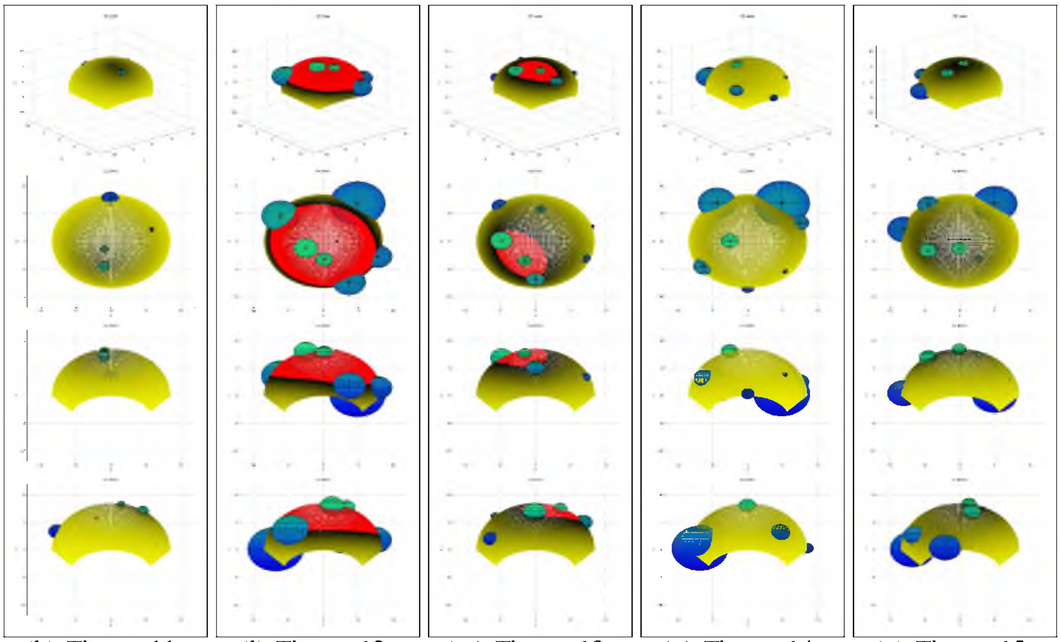


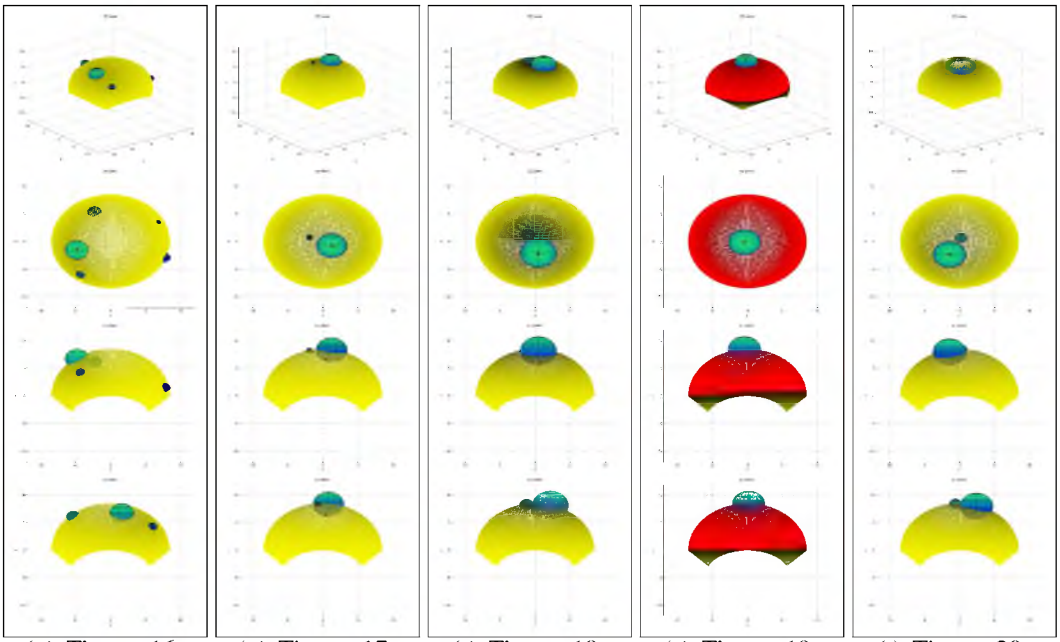
(a) Time = 1s (b) Time = 2s (c) Time = 3s (d) Time = 4s (e) Time = 5s

(f) Time = 6s (g) Time = 7s (h) Time = 8s (i) Time = 9s (j) Time = 10s

Figure B.2: Three dimensional projection of Spatial Interaction Image of patient B during epileptic seizure.

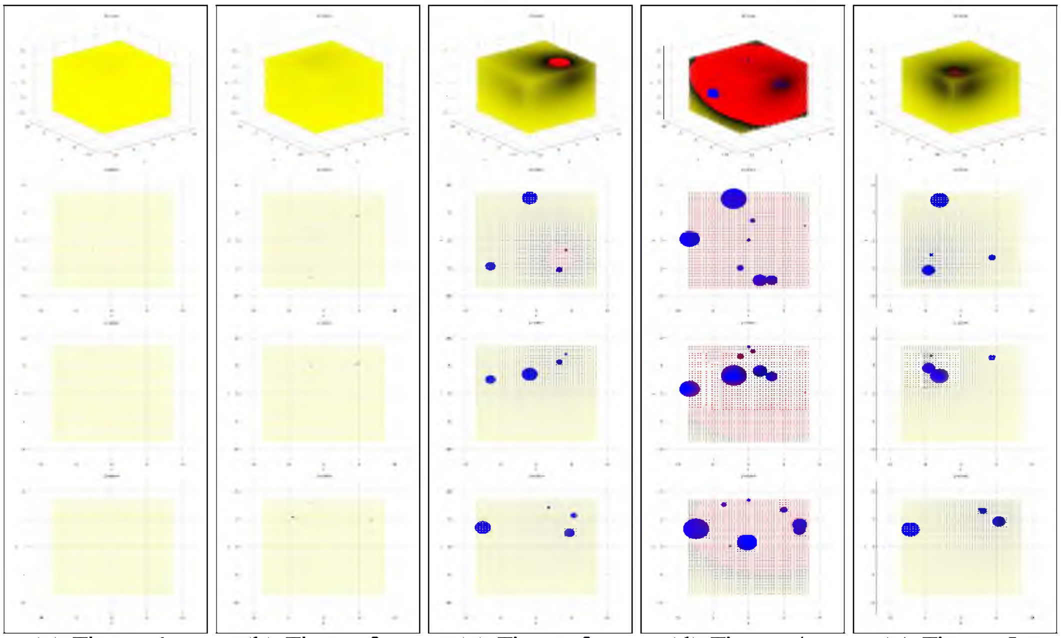


(k) Time = 11s (l) Time = 12s (m) Time = 13s (n) Time = 14s (o) Time = 15s

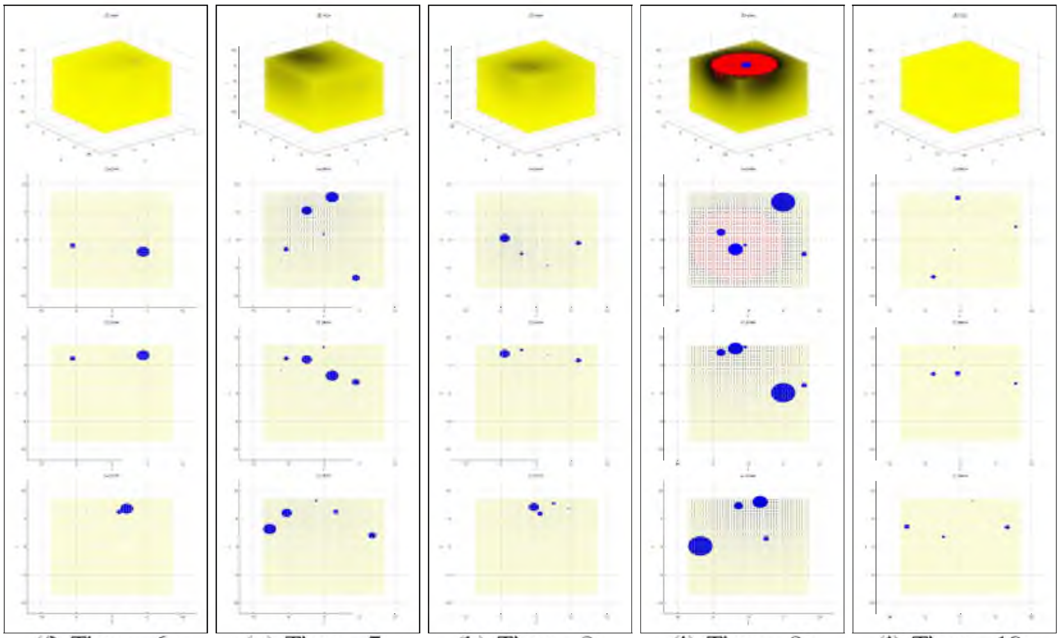


(p) Time = 16s (q) Time = 17s (r) Time = 18s (s) Time = 19s (t) Time = 20s

Figure B.2: Three dimensional projection of Spatial Interaction Image of patient B during epileptic seizure.



(a) Time = 1s (b) Time = 2s (c) Time = 3s (d) Time = 4s (e) Time = 5s



(f) Time = 6s (g) Time = 7s (h) Time = 8s (i) Time = 9s (j) Time = 10s

Figure B.3: Spatial interaction model on C_{EEG} of patient A during epileptic seizure.

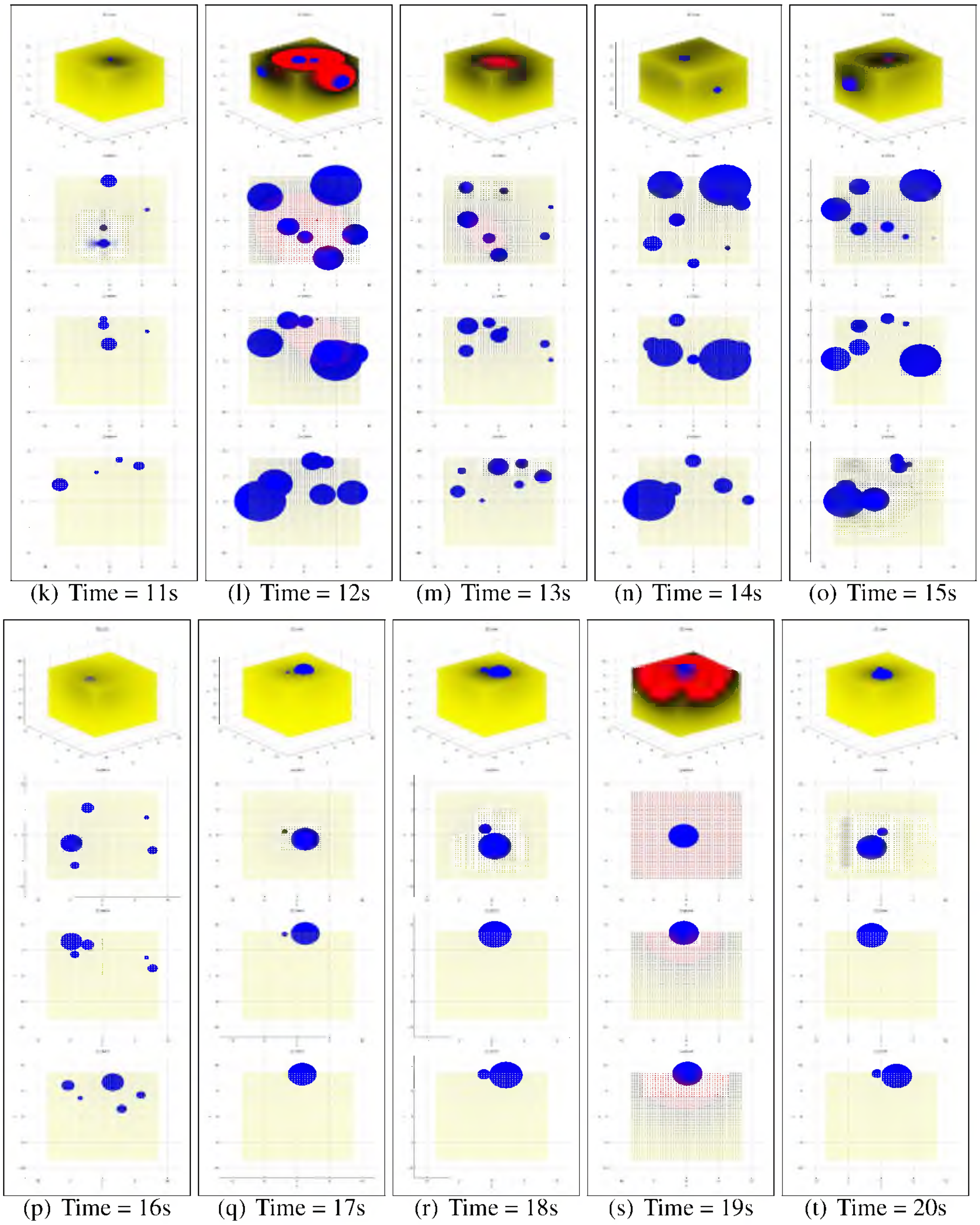


Figure B.3: Spatial interaction model on C_{EEG} of patient A during epileptic seizure.