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To my beloved son Adam Mikael and my family

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ABSTRACT

This study focused on contrast enhancement of Flat Electroencephalography (fEEG) image during epileptic seizure. The main interest is in visualizing the path of brainstorm in the brain that occur during seizure. Selected techniques that are involved ranging from classical, ordinary fuzzy, and advanced fuzzy namely the intuitionistic fuzzy sets (IFS). Different techniques may result in different output of fEEG image. The methods in classical approach are Power Law Transformation, Histogram Equalization, and Image Size Dependent Normalization. The intensifier operator is implemented in the fuzzy contrast enhancement technique. For the IFS approach, the Window Based Enhancement Scheme (WBES) and its revised version (RWBES) are applied. The RWBES gives better results compared to the WBES whereby the vague boundary of the cluster centres are reduced resulting in a smaller area of the vague boundary. The vague boundary represents the strength of the electrical potential of the foci of seizure. Next, the quality of the output image is measured via the objective measure such as mean squared error (MSE), peak-signal-to-noise-ratio (PSNR), universal image quality index (UIQI), and structural similarity index measure (SSIM). In IFS, the sum of membership and non-membership is not necessarily equal to one. Thus, there exists hesitancy in deciding the degree to which an element satisfies a particular property. Moreover, the sequence of enhanced fEEG images are demonstrated by varying the value of parameter, namely λ, that also influence the hesitation value π. In addition, the Sugeno type intuitionistic fuzzy generator which is used to compute the non-membership value ν has been extended to the concept of fuzzy limit. Hence, by implementing the definition of fuzzy limit, different values of ϵ will be tested in obtaining the values of integer N that will determine the value of λ and hence the value of hesitation π. The relationship between membership, non-membership, and hesitation values are also demonstrated graphically.

ABSTRAK

Kajian ini memfokuskan kepada penambahbaikan kontras bagi imej Elektroensifalografi Meleper (fEEG) semasa serangan sawan. Kepentingan utama adalah untuk menggambarkan laluan ribut otak dalam otak semasa berlakunya sawan. Teknik-teknik terpilih yang terlibat berbagai-bagai dari klasik, kabur biasa, dan kabur lanjutan iaitu set kabur intuisinistik (IFS). Teknik berbeza akan memberikan imej output fEEG yang berbeza. Kaedah pendekatan klasik adalah Transformasi Hukum Kuasa, Penyamaan Histogram, dan Normalisasi Berdasarkan Saiz Imej. Pengoperasi keamatan diimplementasi dalam teknik penambahbaikan kontras kabur. Untuk pendekatan IFS, Skim Penambahbaikan Berasaskan Tetingkap (WBES) dan versinya yang disemak semula (RWBES) digunakan. RWBES memberikan keputusan yang lebih baik berbanding WBES yang mana sempadan kabur bagi pusat gugusan dikurangkan, lalu menghasilkan kawasan yang lebih kecil bagi sempadan kabur tersebut. Sempadan kabur tersebut mewakili kekuatan potensi elektrik bagi pusat sawan. Seterusnya, kualiti imej output diukur menerusi ukuran objektif seperti min ralat kuasa dua (MSE), nisbah isyarat puncak kepada hingar (PSNR), indeks kualiti imej universal (UIQI), dan ukuran indeks kesamaan struktur (SSIM). Dalam IFS, hasil tambah keahlian dan bukan keahlian tidak semestinya bersamaan dengan satu. Oleh itu, keraguan wujud dalam menentukan darjah bagi suatu unsur memenuhi sesuatu sifat tertentu. Selanjutnya, jujukan imej fEEG yang telah ditambahbaik dipamerkan dengan mengubah-ubah nilai parameter, iaitu λ, yang juga akan mempengaruhi nilai keraguan π. Tambahan pula, penjana intuisinistik kabur jenis Sugeno yang digunakan untuk mengira nilai bukan keahlian ν telah dilanjutkan kepada konsep had kabur. Seterusnya, dengan mengimplementasi definisi had kabur, nilai ϵ yang berbeza akan diuji untuk memperolehi nilai integer N yang akan menentukan nilai bagi λ dan seterusnya nilai keraguan π. Hubungan antara nilai keahlian, bukan keahlian, dan keraguan turut dipamerkan secara graf.

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LIST OF SYMBOLS

Na^{+}	-	Sodium ion
K^{+}	-	Potassium ion
Ca^{++}	-	Calcium ion
Cl^{-}	-	Chloride ion
x_{ij}	-	Gray level at pixel (i, j)
$\mu_I(x_{ij})$	-	Membership value of the gray level x_{ij}
I	-	An image of $M \times N$ pixel
o	-	Object function that denotes the object or scene
p	-	Point-spread function
n	-	Additive noise-nondeterministic function
X	-	A set of element x_i
$\pi_A(x)$	-	The degree of non-determinacy or hesitation
$v_A(x)$	-	Non membership $v_A(x)$
N	-	Total number of pixel
σ_x	-	Standard deviations of x
σ_y	-	Standard deviations of y

r	-	Input pixel value
s	-	Output pixel value
c	-	Scaling constant
γ	-	Positive value
h	-	Frequency value
K	-	Enhancement variable
t_i	-	Time at i seconds
$\mathbb{R}$	-	Real number
$\leq$	-	Less than or equal to
$\in$	-	Member of
λ	-	Parameter value

LIST OF ABBREVIATIONS

EEG	-	Electroencephalography
C_{EEG}	-	EEG coordinate system
FTTM	-	Fuzzy Topographical Topological Mapping
IFS	-	Intuitionistic fuzzy set
IFIP	-	Intuitionistic fuzzy image processing
fEEG	-	Flat Electroencephalography
MSE	-	Mean square error
PSNR	-	Peak signal to noise ratio
UIQI	-	Universal image quality index
SSIM	-	Structural similarity index measure
WBES	-	Window Based Enhancement Scheme
RWBES	-	Revised Version of Window Based Enhancement Scheme
PET	-	Positron Emission Topography
MEG	-	Magnetoencephalography
I-EEG	-	Intracranial Electroencephalograph
ECoG	-	Electrocorticography
fMRI	-	Functional magnetic resonance image
CT	-	Computerized tomography
PSF	-	Point-spread function

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The human body functions are generally controlled by two most important systems which are the nervous system and the endocrine system. Human nervous system is a very complex system, well organized, highly sophisticated with estimated at least about 100 billion of neurons and 100 trillion of interconnections or synapses involve in its networking system. It can be divided anatomically into central nervous system (CNS) which comprises the brain and spinal cord, and the peripheral nervous system (PNS) which forms the cranial and spinal rootlets. It also can be classified base on the functional status into somatic nervous system which innervates the structures of the body wall such as skin, muscles and mucous membranes or the autonomic nervous system (ANS) which innervates the smooth muscles, internal organs, blood vessels and glandular system. These systems work together to maintain body homeostasis and internal milieu state within the acceptable normal physiological condition in order to allow the hormones, enzymes, metabolism and other vital functions for life able to operate in the most optimal condition [1].

1.2 Research Background

Epilepsy is a general term used for a group of disorders that cause disturbances in electrical signalling in the brain. It is not a disease but a symptom that originated in the brain. A seizure refers to a single event of abnormal and excessive electrical discharge of group of neurons. People with multiple seizures will experience chronic condition which is epilepsy. Epileptic foci refer to the location of the current sources that generate the corresponding magnetic fields. Electroencephalography (EEG) has been used as a system that measures and records electrical activity of the brain in graphic form [2]. It is a method of visualizing physiology to discover the hidden causes of epilepsy such that it reads voltage differences on the head relative to a given point [3].

In the preliminary study by Fuzzy Research Group (FRG) of Universiti Teknologi Malaysia (UTM) in 1999, the data sources is based only on the data collected from epileptic patients from Hospital Kuala Lumpur (HKL) and Hospital Universiti Sains Malaysia (HUSM) Kubang Kerian, Kelantan. Previous study by Zakaria [4] showed the transformation of the EEG signal during epileptic seizure into Flat Electroencephalography (fEEG) via flattening method. It is a mathematical technique that involved the mapping from high dimensional signal (i.e, EEG signal) into low dimensional space (i.e, fEEG) whereby clustering process was carried out in the study. Then the signals were transformed into discrete data by using Nicolet One software. The EEG signal was then processed by using Fuzzy c-means (FCM) clustering to cluster the discrete data at every second. Finally, the optimal number of clusters were obtained via cluster validity.

Moreover, previous study by Abdy [5, 6] showed the transformation of fEEG into digital fEEG and finally into image. Digitization process of fEEG by using the Voronoi digitization is implemented in obtaining the digital fEEG. Next, fuzzy approach is applied in assigning the membership value for each pixel via the quantization pixel process. Finally, the membership value is transformed into gray level value such that an image of fEEG is obtained. The main aim of the previous research by Zakaria [4] and Abdy [6] is to visualize and to trace the electrical pulses paths of the brainstorm event right from the scalp of the head to the point where they started (i.e. the foci).

In the literature, most of the images or specifically medical images are captured by using medical devices such as X-ray, MRI, CT scan, ultrasound, 3D imaging systems and so forth. The occurrence of noise in an image may be caused by the system devices or situation such as hand shaking or taking picture while moving. However the images of fEEG are obtained without using any image processing system devices. It is a challenging task since the abnormalities are detected non-invasively.

1.3 Problem Statement

In the process of imaging and transformations such as fEEG, it is hard to avoid the inheritance of different kinds of noise during recording of the EEG signals. Since the regions of clusters in fEEG are not always defined, uncertainty might arise within every transformations. In this study, the noise is defined as the uncertainty that occur in transforming the EEG signal into image. Furthermore, the digital fEEG itself is a fuzzy object which has been proven in details in Abdy [6]. In the process of determining the membership value, uncertainty might arise due to the lack of information or knowledge which lead to the unclear boundaries of the epileptic foci.

In Abdy [6], the boundary area of the epileptic foci which is represented in the shades of gray is not well-defined. The shades of gray spread out widely since it considered the electrical potential strength. Thus, in the presence of noise, pre-processing steps such as image enhancement is needed. The objectives of image enhancement are to remove noise, to smooth non impulsive noise, and to enhance the edges or other salient structures on fEEG.

Besides that, in order to have a clearer boundary, unwanted background or unwanted object in the scene should be eliminated. Hence, enhancement is carried out in order to obtain an improved image of fEEG. Since the focus of this study is to enhance the boundary of the epileptic foci, therefore, the unwanted object or background which is the electrical potential strength will be suppressed or reduced. Previous study by Abdy [6] has implemented fuzzy set in determining the membership value of the pixels. Therefore, it is more realistic to acquire a more comprehensive element rather than ordinary fuzzy set since the ordinary fuzzy set only considers the membership value of an element. The enhancement technique that is implemented in this study is based on the intuitionistic fuzzy set (IFS) approach which considered more parameters or uncertainties compared to the ordinary fuzzy set. The IFS aims to handling the inherent uncertainty carried by image pixels. Hence, in dealing with noise and to obtain more accurate results, more advanced techniques that considered more parameters other than membership value is needed.

1.4 Research Questions

Some of the research questions are as follows:

1. How to reduce the vague boundary of the epileptic foci?
2. How to measure the image quality of fEEG?
3. How does implementing different approaches might affect the fEEG output image?
4. To what extent the enhancement methods may help in visualizing the path of brainstorm during seizure?
5. How to determine the hesitation value via fuzzy limit?

1.5 Research Objectives

The main objectives of this study are as follows:

1. To enhance the contrast of fEEG input images in determining the epileptic foci by classical and non-classical approaches.
2. To investigate the fEEG output images by various methods such as classical and non-classical approaches.
3. To evaluate the quality of the output images via different image quality assessment.
4. To extend the concept of fuzzy generator into fuzzy limit in obtaining the hesitation parameter.

1.6 Scope of Research

The research focused mainly on enhancing the contrast of fEEG input images during epileptic seizures. The IFS approach is implemented on fEEG input images via Window Based Enhancement Scheme (WBES) and Revised Version of WBES (RWBES). Furthermore, the results are compared with selected classical and ordinary fuzzy approaches. Data that is used in this research is based on the secondary data of epileptic patients that obtained from Hospital Universiti Sains Malaysia (HUSM) and Hospital Kuala Lumpur (HKL).

1.7 Significant Contributions

In this digital era, everything is seemed to be computerized due to the rapid development in advanced technologies. The environment of medical imaging has changed dramatically from analogue to digital technology. It is important in assisting medical practitioners to diagnose different medical condition without having to undergo surgical procedure to look into various organs and areas in the body.

The contributions of the research particularly in the fEEG image is described briefly in Figure 1.1. Figure 1.1 begins with the technique of EEG whereby small and non-invasive electrode is placed on the patient's head. EEG is an aid in characterizing epilepsy and plays important role in localizing the damaged tissue. The type of the activity such as abnormal patterns (e.g. spikes and sharp waves) can be seen in the EEG signals recording.

This study has built on previous related work by Zakaria [4] and Abdy [6] which indicates the continuity of research work. Furthermore, this research adopts the techniques of image processing in enhancing the contrast of fEEG images in different domains which are the classical and non-classical. The non-classical are the ordinary fuzzy and advanced fuzzy approaches. Different contrast enhancement techniques show different fEEG output images. Fuzzy theory based technique is designed in this study to better detect epileptic seizures. The innovation of this study has brought together medical field, mathematics, signal and image processing. It is expected to contribute greatly in these fields. This study contains a mixture of theoretical development and practical investigation.

Besides that, the RWBES is proposed in obtaining better fEEG output images. In RWBES there are two different ways of fuzzification that have been done for the fEEG input images. The RWBES able to reduce the vague boundaries of the cluster centres. It also able to preserve information of the clusters as the value of λ increased. The outcome of the fEEG images may help in determining or improving the visibility of a sharp boundary of the epileptic foci. It is expected from the results that a clearer view of the path is able to be visualized during seizure. Moreover the Sugeno type intuitionistic fuzzy generator is extended to the concept of fuzzy limit which highlights the great impact in the field of real analysis application in image processing.

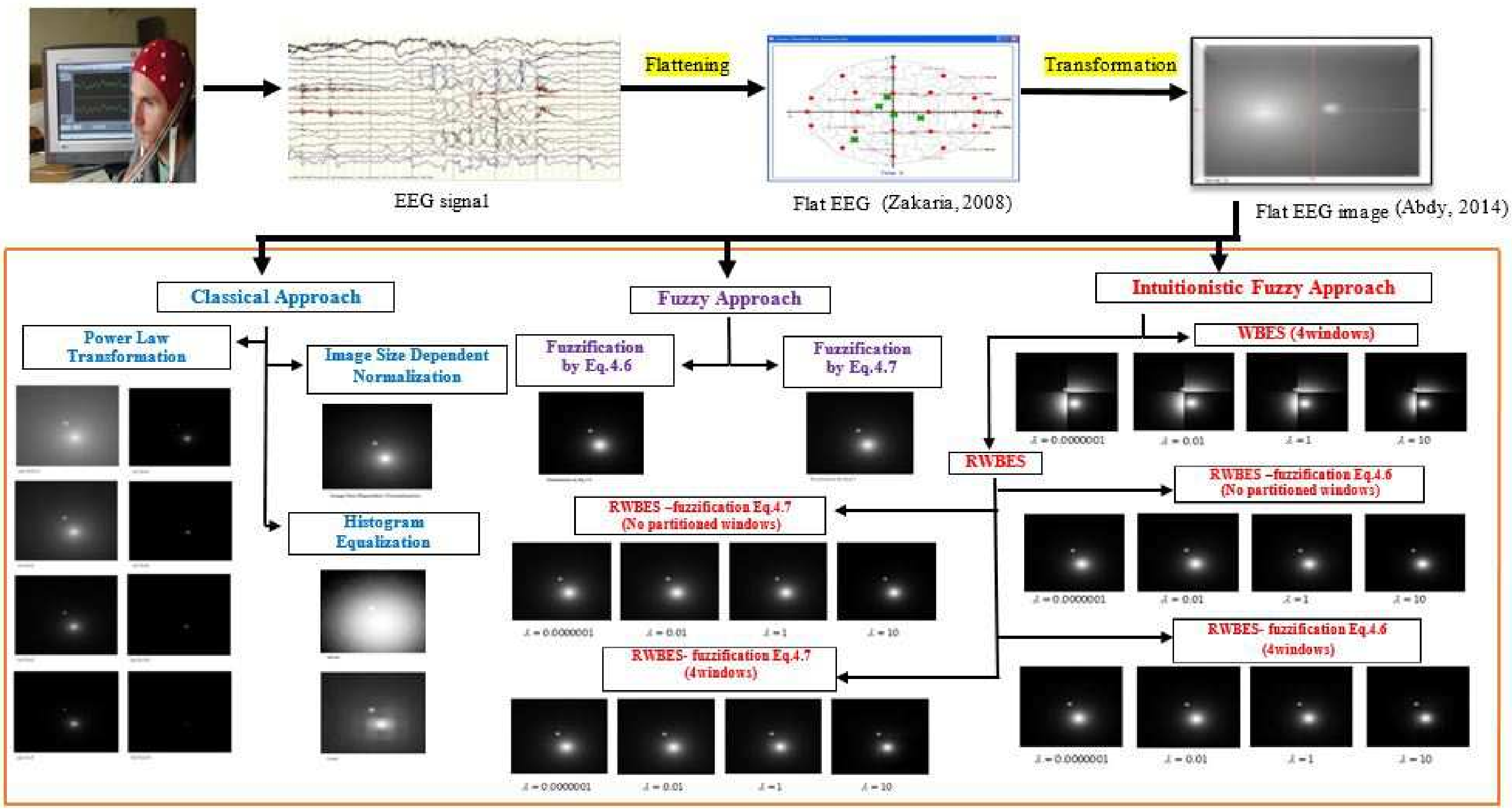

Figure 1.1 Research contribution on fEEG image

1.8 Research Framework

This research consists of eight chapters and the summary of framework is shown in Figure 1.2. The first chapter serves as an introduction to the whole thesis. This chapter provides the general information about the research background, problem statement, research questions, research objectives, scope of the research, and significant contributions. Chapter 2 presents the literature review of this research which contains of information on human brain, seizure, digital image processing, fuzzy image processing, intuitionistic fuzzy image processing, image enhancement, medical imaging, and electroencephalography.

The mathematical background of fEEG image is demonstrated in Chapter 3. Moreover, the mathematical concepts of classical set, fuzzy set, intuitionistic fuzzy set, sequence of fuzzy number, fEEG, digital fEEG, and image quality assessment are discussed in this chapter. The enhancement process of fEEG image is discussed in Chapter 4. It focused on contrast enhancement which covers the classical, fuzzy, and intuitionistic fuzzy approaches. The selected methods and algorithms are presented in details in this chapter. The implementation of the enhancement methods is given in Chapter 5. The fEEG input image that is presented in this chapter is for patient A at time $t = 1$ with size of 201×201, which is a grayscale image. Different enhancement methods will give different output images.

Chapter 6 demonstrates some image quality indices that are applied to the input and output images which consist of the error based and structural based metrics. Additionally, in Chapter 7, the concept of Sugeno type intuitionistic fuzzy generator in the non-membership function is extended to the concept of fuzzy limit. Some values of ε are tested to obtain the values of integer N. Hence the values of λ and hesitation π are also determined. Finally, Chapter 8 concludes the research outcomes which highlights the significance of the research and provides some suggestions for future works.

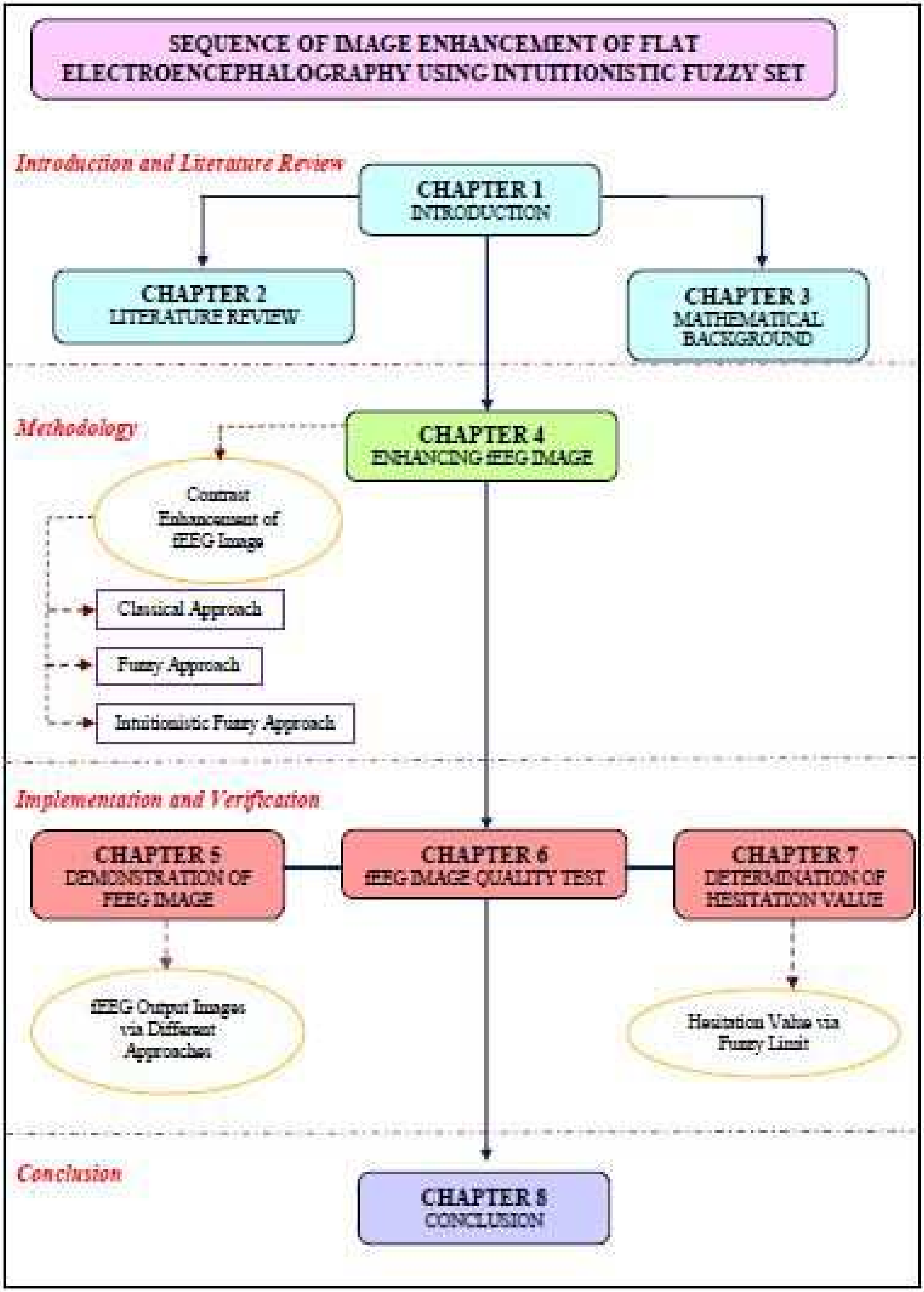

Figure 1.2 Research framework

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