

**UNIVERSITI TEKNOLOGI MARA**

**CHARACTERIZATION  
OF  
EEG FRONTAL ENERGY RATIO  
AND KNN WITH  
ENTRAINED BINAURAL BEATS  
FOR  
MENTAL STATES  
CLASSIFICATION**

**HARYANTI BINTI NORHAZMAN**

Thesis submitted in fulfillment  
of the requirements for the degree of  
**Doctor of Philosophy**

**Faculty of Electrical Engineering**

**March 2020**

## ABSTRACT

A binaural beat is a form of auditory stimulation on which two pure tones with slightly different frequencies are generated simultaneously in the left and right ear. The frequency difference between the two tones is the beat perceived by the brain. A binaural beat is believed to be able to entrain our cognitive and neural activities to synchronize with the perceived tone. Most research has been done only on the effects of the binaural-beats during stimulation. This research is carried out to explore the potential contributions of binaural beats to the entrained frontal Energy Spectrum Density (ESD) of alpha and beta sub waves for stressed subjects. The protocols involved 40 volunteers answering Depression Anxiety Stress Scale (DASS) questionnaires, after which they were segregated into two groups, namely Calm and Stress groups. Their EEG signals were recorded during three different sessions, namely "Resting", "Listen to Noise" and "After Binaural Beats". The frequency of the Binaural Beats used in this study was 10 Hz, which was intended to induce relaxation to the subjects. The EEG signals were preprocessed using Fast Fourier Transform to derive the ESD. The behaviors of the raw ESD for all sub waves was observed before the Alpha Beta Frontal Energy Ratio (ABFER) was calculated from the raw ESD. The ABFER feature was used to observe the pattern of alpha and beta sub waves in left and right hemisphere in both groups, namely Calm and Stress subjects, during the three mentioned sessions. The features selected were used as input in k-Nearest Neighbor (k-NN) classification, and the performance measures were used to determine whether the selected features were able to distinguish between Calm and Stress subjects in the three different sessions. The results showed the k-NN model managed to rule out the Stress subjects with a high accuracy of 87.5% during all sessions except the "Listen to Noise" session. The classification results were then validated using K-Fold Cross-Validation, with the highest accuracy of 90% obtained during "After Binaural Beats" session. In summary, the findings have shown that ABFER feature has the potential to be a marker to identify stress subjects, while the k-NN technique managed to classify calm and stressed subjects based on this feature. The novelty of this research is the analysis on the behaviors of the frontal alpha and beta ESD during noise stimulation and post binaural beats of Stress subjects.

## ACKNOWLEDGEMENT

*In the name of Allah, the Most Gracious, the Most Merciful*

*All praises are due to Allah the Almighty, the Merciful*

Foremost, praise upon Allah for giving me this excellent opportunity to pursue my study in Philosophy of Doctorate and most importantly, able to complete it comprehensively. Without His blessings, none of my journey will ever being accomplished successfully. Secondly, my sincere gratitude to my supervisor Dr Norliza Mohammad Zaini and first co-supervisor Prof Ir Dr Hj. Mohd Nasir Taib for their patience, helps, guidance and ideas in supporting me during my journey. I would also like to thank my co-supervisors PM Dr Rozita Jailani and Dr Hasmila Akmar Omar for their encouragements, pieces of advice and ideas in assisting me along my colourful journey.

My deepest appreciation goes to my other half, my best friend, my teacher, Mr Mohammad Ashiq Mohd Yaqoob, who is also my husband. He is always there for me, through my ups and downs. His prayers and his motivations fuels my spirit to continue my journey and never give up.

This thesis is also dedicated to my dearest father and mother Hj Norhazman Bin Hj Jamaluddin and Hajjah Esah Binti Che Wan for their belief in me and never ending-prayers for my success. Not to forget, the journey I embarked can never be completed without sacrifices from my other members of family, my sisters and my children. All of you are the fragments of my heart. Thank you!

Special thanks to my colleagues and friends from ASP Lab at UiTM Shah Alam for your patience, ideas and guides during the whole process. My sincere appreciation also dedicated to staff of the Faculty of Electrical Engineering, Universiti Teknologi MARA and IPSIS for providing the facilities, knowledge and assistance.

May Allah make easy to all of you in this world and hereafter as how you make everything easy for me. I share this triumph with all of you.

Thank you very much. Alhamdulillah.

# TABLE OF CONTENTS

**CONFIRMATION BY PANEL OF EXAMINERS**

**AUTHOR'S DECLARATION**

**ABSTRACT**

**ACKNOWLEDGEMENT**

**TABLE OF CONTENTS**

**LIST OF TABLES**

**LIST OF FIGURES**

**LIST OF SYMBOLS**

**LIST OF ABBREVIATIONS**

## **CHAPTER ONE INTRODUCTION**

- 1.1 Research Background
- 1.2 Problem Statement
- 1.3 Objectives of the Study
- 1.4 Scope and Limitations
- 1.5 Significance of the Study
- 1.6 Thesis Organization

## **CHAPTER TWO LITERATURE REVIEW**

- 2.1 Introduction
- 2.2 Human Brain
  - 2.2.1 Frontal Lobes
- 2.3 Brainwaves
  - 2.3.1 Brainwave Entrainment
  - 2.3.2 Binaural Beats
- 2.4 Electroencephalogram (EEG)
  - 2.4.1 History of EEG
  - 2.4.2 EEG and Its Applications
  - 2.4.3 EEG Signals and Stress

2.4.4	EEG Affected By Noise	18
2.5	EEG Signal Processing	19
2.5.1	Feature Extraction	21
2.5.2	Energy Spectral Density (ESD)	22
2.6	Statistical Analysis	23
2.6.1	Graphical Test - Box Plot	23
2.6.2	Normality Test	24
2.6.3	Paired Sample t-Test	24
2.7	Selection of Classifier Techniques	24
2.7.1	k-Nearest Neighbour (k-NN)	25
2.7.2	K-Fold Cross-Validation	26
2.7.3	Performance Measure of Classification System	27
2.8	Summary	29
2.8.1	Summary Table	30
CHAPTER THREE THEORETICAL BACKGROUND		31
3.1	Introduction	31
3.2	Binaural Beats	32
3.3	EEG Signals Processing	32
3.3.1	Fast Fourier Transform (FFT)	33
3.3.2	Energy Spectral Density (ESD)	35
3.3.3	Alpha Beta Frontal Energy Ratio	36
3.4	Statistical Analysis	36
3.4.1	Box Plot	37
3.4.2	Normality Test - Shapiro - Wilks	38
3.4.3	Paired Sample t - Test	39
3.5	Classification And Validation Technique	40
3.5.1	k-Nearest Neighbour (k-NN)	42
3.5.2	K-Fold Cross-Validation	45
3.5.3	Performance Measure for Classifier	45
3.6	Summary	48