DESIGN AND DEVELOPMENT OF AN INTELLIGENT HEARING ABILITY LEVEL ASSESSMENT SYSTEM USING SOMATOSENSORY STIMULI

by

KAMALRAJ SUBRAMANIAM
1040610532

A thesis submitted
In fulfillment of the requirements for the degree of
Doctor of Philosophy

School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS

2014

ACKNOWLEGEMENT

First and foremost, I would like to express my sincere thanks to the Vice Chancellor of Universiti Malaysia Perlis, Brigedier Jeneral Dato Professor Dr. Kamarudin Hussin for his constant encouragement and facilities provided at the university for the completion of this research work.

I would like to express my sincere gratitude to my advisor and mentor Professor Dr. Paulraj M P for the continuous support of my Ph.D study and research, for his patience, persistence, visualization, and immense knowledge. During the research, Prof Paul style of guidance had made me to gain knowledge on many aspects; Prof Paul will not give you answers for your research problems instead he will put you on a path to seek answers. I have been fortunate to have a supervisor who gave me the opportunity to develop my individuality and self-sufficiency during the study. I am indebted to him for sharing his vast knowledge and experience with me and for teaching me to write research papers. I am happy to say that one could not wish for a better or friendlier supervisor.

I would also like to extend my warmest gratitude to my second supervisor Professor Dr. Sazali Bin Yaccob for his motivational words, understanding and caring advices, convictions, and making me to realize my true potential. I extend my boundless appreciation to Prof Sazali for establishing the joint collaboration between UniMAP and Otolaryngology Department, Hospital Tuanku Fauziah, Perlis, from which my research work have been greatly benefitted.

I am also very grateful to my third supervisor Professor Dr. Abdul Hamid Bin Adom for his support and facilities provided at the school, for the completion of this work. I thank him for constantly encouraging me to complete this research work.

I also very grateful to Dr. Amirozi Bin Ahmed, Head of Otolaryngology Department, Hospital Tuanku Fauziah, Perlis, Malaysia, for his generous contributions of data inspection, fruitful suggestions, advices, and for sharing knowledge.

I wish to thank the Malaysian Ministry of Higher Education for providing the research grant: 9003-00278 under the Fundamental Research Grant Scheme (FRGS), which funded this research work. I also extend my sincere thanks to UniMAP for providing a financial support through a Graduate Assistantship.

I also would like to express my thanks to my close friends Mr. Sanjeev Kumar Nataraj, Mr. Divakar Purushothaman, Mr. Allan Melvin, Mr. Sathees Kumar Nataraj, Mr. Jeevan and Mr. Yogesh Chinnakalai for their friendly advices and encouraging words during this research work.

Finally, I owe my sincere thanks to my father Mr. P. Subramaniam, my mother Mrs. S. Santhamani, my brother Bharathraj Subramaniam for their unconditional love and support that motivates me to set higher targets.

Last but not least, I thank the Almighty for blessing me to successfully complete this research work.

To my beloved Professor Balasubramaniam R S and Professor Lakshmi Narayanan K who had given dreams to look forward to

TABLE OF CONTENTS

CHAPTER 3 RESEARCH METHODOLOGY

LIST OF ABBREVIATIONS

AABR	Automated Auditory Brainstem Response
AAEP	Automated Auditory Evoked Potential
ABHS	Abnormal Hearing Subject
ABR	Auditory Brainstem Response
AEP	Auditory Evoked Potential
AHG	Abnormal Hearing Group
ANOVA	Analysis of Variance
AR	Auto Regressive
ARMA	Autoregressive Moving Average
ARX	Autoregressive model with an Exogenous Input
ASHA	American Speech Hearing Association
BAEP	Brainstem Auditory Evoked Potential
BFF	Box-counting Fractal Feature
BP	Backpropagation
BM	Box-counting Method
CA	Classification Accuracy
DFA	Detrended Fluctuation Analysis
DFFF	Detrended Fluctuation Fractal Feature
EEG	Electroencephalography
ENN	Elman Neural Network
EP	Evoked Potential
ERP	Event Related Potentials
FD	Fractal Dimension
FFT	Fast Fourier Transform
HTR	Hearing Threshold Response
HPR	Hearing Perception Response
HFF	Higuchi Fractal Feature
HM	Higuchi Method
HL	Hearing-threshold Lower
HU	Hearing-threshold Upper
HPL	Hearing Perception Level
ISEF	Independent Spectral Energy Feature

ISENF	Independent Spectral Entropy Feature
ISEENF	Independent Spectral Energy Entropy Feature
ISI	Inter Stimulus Interval
ICA	Individual Classification Accuracy
LLAEP	Long Latency Auditory Evoked Potential
MFNN	Multilayer Feedforward Neural Network
MLAEP	Middle Latency Auditory Evoked Potential
MMN	Mismatch Negativity
MA	Moving Average
NHG	Normal Hearing Group
NHS	Normal Hearing Subject
NN	Neural Network
PSO	Particle Swarm Optimization
PSONN	Particle Swarm Optimization Neural Network
SBC	Spectral Band Combination
SBCEF	Spectral Band Combination Energy Feature
SBCENF	Spectral Band Combination Entropy Feature
SBCEENF	Spectral Band Combination Energy Entropy Feature
SD	Standard Deviation
SPL	Sound Pressure Level
SNR	Signal to Noise Ratio
STFT	Short Time Fourier Transform
TEAOE	Transient Evoked Oto-acoustic Emissions
VEP	Visually Evoked Potentials
WT	Wavelet Transform

NO.	LIST OF FIGURES	PAGE

LIST OF SYMBOLS

δ	Delta band
θ	Theta band
α	Alpha band
β	Beta band
γ	Gamma band
µV	Micro volt
T	Temporal Lobe
p	poles
z	zeros
Hz	Hertz
dB	decibel
HL	Hearing level
Ω	Ohm
ms	Milli second
µs	Micro second
KΩ	Kilo ohm
a(k)	AR coefficient
k	Gain factor
N	Data length
X_i^j	AEP signal corresponding to the i^{th} frame of the j^{th} channel
H(z)	Transfer function

Xn_i^c	Normalized data value
X_i^c	data to be normalized
$X_{\min}$	Minimum value
$X_{\max}$	Maximum value
d(z)	Characteristic equation
p, q	real roots, pair of complex roots
$M_{\max}, M_{\min}$	Maximum and Minimum magnitude of the roots
H_u, H_l	Upper and Lower hearing threshold factors
X_i	i^{th} Swarm particle
V_i	Velocity of i^{th} swarm particle
P_i	Best previous location of i^{th} swarm particle
P_g	Best global location of i^{th} swarm particle

NO.	LIST OF TABLES	PAGE