

## TABLE OF CONTENTS

TABLE OF CONTENTS.....	viii
LIST OF TABLES.....	xi
LIST OF FIGURES .....	xiv
LIST OF ABBREVIATIONS.....	xviii
ABSTRACT .....	xix
CHAPTER 1 INTRODUCTION .....	1
1.1 Research Background .....	1
1.2 Research Problems .....	3
1.3 Research Objective .....	3
1.4 Research Contribution/Novelty .....	4
1.5 Research Assumptions and Limitation .....	6
1.6 Organization of the Thesis Writing .....	7
CHAPTER 2 LITERATURE REVIEW AND THEORETICAL BACKGROUND .....	8
2.1 Literature Review .....	8
2.1.1 Current Condition Mapping .....	8
2.1.1.1 Data Pre-processing.....	9
2.1.1.2 Feature Extraction .....	9
2.1.1.3 Feature Selection .....	9
2.1.1.4 Classifier.....	10
2.1.1.5 Dataset .....	10
2.1.2 Research Topic Position Mapping.....	10
2.1.3 Related Works .....	17
2.1.3.1 Feature Extraction, Feature Selection, and Classification Technique .....	18
2.1.3.2 Channel Selection Technique .....	21
2.2 Theoretical Background .....	22
2.2.1 Brain-Computer Interface (BCI) .....	22
2.2.2 Electroencephalogram (EEG).....	23
2.2.3 Motor Imagery .....	23
2.2.4 Feature Extraction on EEG Signal .....	23
2.2.5 Granular Computing.....	25
2.2.6 Hybrid Classifier based Ensemble Technique.....	25
2.2.6.1 Linear Discriminant Analysis (LDA).....	26
2.2.6.2 K-Nearest Neighbor (kNN) .....	27
2.2.6.3 Gradient Boosted Tree (GBT) .....	28
2.2.7 Voting Scheme .....	28
2.3 Research Problem .....	29
2.3.1 Inconsistent Detection Result in EEG-MI classification.....	29
2.3.2 No robust Channel Selection .....	29

2.4	Research Position .....	30
2.5	Research Hypotheses .....	36
CHAPTER 3	RESEARCH METHODOLOGY .....	37
3.1	Research Phase .....	37
3.2	Research Scope and Design .....	38
3.2.1	Research Scope .....	38
3.2.1.1	Selected Research Topic .....	39
3.2.1.2	Used Datasets .....	39
3.2.1.3	Method Improvement Efforts .....	40
3.2.2	Research Design .....	40
3.3	Dataset .....	40
3.3.1	BCI Competition III – Dataset IVa (2-class) .....	40
3.3.2	BCI Competition IV – Dataset 2a (4-class) .....	41
3.4	Research Apparatus .....	42
3.4.1	Hardware .....	42
3.4.2	Software/Tool .....	42
3.5	Data Pre-processing .....	43
3.6	Statistical based feature Extraction .....	44
3.7	Channel-Instantiation Approach .....	44
3.8	Hybrid Classifier based Ensemble Technique .....	46
3.8.1	Linear Discriminant Analysis (LDA) .....	46
3.8.2	K-Nearest Neighbor (kNN) .....	49
3.8.3	Gradient Boosted Tree (GBT) .....	52
3.9	Improvements to Detection Consistency across Subjects .....	58
3.9.1	Improvements to Detection Consistency on Two-class Classification (Proposed Method #1 – NWFE+kNN+VS) .....	58
3.9.1.1	Aim .....	58
3.9.1.2	Dataset .....	58
3.9.1.3	Step .....	59
3.9.2	Improvements to Detection Consistency on Multi-class Classification (Proposed Method #2 – NWFE+OvO-TSD) .....	62
3.9.2.1	Aim .....	62
3.9.2.2	Dataset .....	63
3.9.2.3	Step .....	63
3.9.3	Improvements to Detection Consistency on Two-class Classification with Various Dataset (Proposed Method #3 – LRFS+TSD) .....	64
3.9.3.1	Aim .....	64
3.9.3.2	Dataset .....	65
3.9.3.3	Step .....	65
3.10	Robust Channel Selection .....	70
3.10.1	Aim .....	70
3.10.2	Dataset .....	70
3.10.3	Step .....	70

3.11	Evaluation.....	73
3.11.1	Accuracy.....	74
3.11.2	Kappa Coefficient.....	74
3.11.3	Execution Time .....	75
3.11.4	Consistency Measure.....	75
CHAPTER 4	RESULTS AND DISCUSSION.....	78
4.1	Improvement to Detection Consistency across Subjects.....	78
4.1.1	Improvements to Detection Consistency on Two-class Classification (Proposed Method #1 – NWFE+kNN+VS) .....	78
4.1.1.1	Proposed Method #1's Overview .....	78
4.1.1.2	Proposed Method #1's Results and Findings .....	79
4.1.1.3	The Proposed Method #1's Comparison to Prior Research .....	81
4.1.2	Improvements to Detection Consistency on Multi-class (Proposed Method #2 – NWFE+OvO-TSD).....	86
4.1.2.1	Proposed Method #2's Overview .....	86
4.1.2.2	Proposed Method #2's Results and Finding.....	86
4.1.2.3	The Proposed Method #2's Comparison to Prior Research .....	88
4.1.3	Improvements to Detection Consistency on Two-class Classification with Various Dataset (Proposed Method #3 – LRFS+TSD) .....	94
4.1.3.1	Proposed Method #3's Overview .....	94
4.1.3.2	Proposed Method #3's Results and Findings .....	95
4.1.3.3	The Proposed Method #3's Comparison to Prior Research .....	98
4.2	Robust Channel Selection.....	103
4.2.1	Proposed Method #4's Overview .....	104
4.2.2	Proposed Method #4's Results and Findings .....	104
4.2.3	The Proposed Method #4's Comparison to Prior Research .....	109
4.3	Rationalization of the Improvement of the Proposed Methods....	114
CHAPTER 5	CONCLUSION AND FUTURE WORKS.....	118
5.1	Conclusion.....	118
5.2	Future Works .....	119
REFERENCE	.....	121
APPENDICES	.....	131