Phase Information Enhanced Steady-State Visual Evoked Potential-based Brain-Computer Interface

by

WONG, Chi Man

Master of Science in Electrical and Electronics Engineering

2011

Faculty of Science and Technology
University of Macau

University of Macau

Abstract

PHASE INFORMATION ENHANCED STEADY-STATE
VISUAL EVOKED POTENTIAL-BASED
BRAIN-COMPUTER INTERFACE

by WONG, Chi Man

Thesis Supervisor: Dr. WAN, Feng
Master of Science in Electronics and Electrical Engineering

In recent years, steady-state visual evoked potential (SSVEP) based brain-computer interface (BCI) has received more and more attention in the research of BCI systems due to its three advantages: good system performance, little user training and ease system configuration. However, there is much room for further improvement in current SSVEP-based BCI, such as solving the problems of harmonic frequency and insufficient flickers as well as boosting its accuracy.

For these reasons, we propose an improved visual stimulus generation method and to embed the phase information in the traditional feature detection algorithm. The former method is able to 1) generate the stimulus phases with a very high resolution of $360/nV$ (deg) while employing a monitor as visual stimulator, which overcome the problem of insufficient stimulus phases, 2) generate the suitable flickers' phases for evoking SSVEPs at harmonic frequencies with different phases which help overcome harmonic frequency problem. The latter one may boost the accuracy of SSVEP-based BCI beyond 10% against the traditional one. Furthermore, although the proposed feature detection algorithm only utilizes the single signal electrode, it can overcome harmonic frequency problem and achieve the improved accuracy as similar as the multi-channel technologies: canonical correlation analysis (CCA) and minimum energy combination (MEC).

Finally, the first online SSVEP-based BCI system based on both frequency and phase information is implemented. It may achieve the average online accuracy rate of

94.81% and ITR of 38.64 bits/min respectively in despite of employing the harmonic frequencies of 17.14, 8.57, 15 and 7.5 Hz and only one signal electrode. In addition, this performance can be comparable to the other analogous systems.

Keywords: brain-computer interface (BCI), steady-state visual evoked potential (SSVEP), phase information, harmonic frequency, feature detection algorithm.

TABLE OF CONTENTS

List of Figures viii
List of Tables xi
List of Abbreviations xiii
Chapter 1: Introduction 1
1.1 Why BCI? 1
1.2 What Is BCI? 2
1.2.1 How to Monitor the Brain Activity? 2
1.2.1.1 Introduction to SSVEP 4
1.2.2 Classification of BCI 5
1.2.3 Performance Measure of BCI 7
1.2.4 Why SSVEP-Based BCI? 7
1.3 Introduction to SSVEP-Based BCI 8
1.3.1 Information Coding 9
1.3.2 Feature Detection Algorithm 11
1.3.3 Decision Strategy 14
1.4 The Existing Problems for SSVEP-Based BCI 15
1.4.1 Harmonic Frequency Problem 15
1.4.2 Amplitude-Frequency Problem 17
1.4.3 The Solution to the Harmonic Frequency Problem 18
1.5 Objectives 19
1.6 Contributions 19
1.7 Thesis Organization 20
Chapter 2: Visual Stimulator Design for SSVEP-BCI 23
2.1 Introduction 23
2.2 Visual Stimulus Signal 23
2.3 Visual Stimulus Signal Generation Method 25
2.3.1 Traditional Visual Stimulus Signal Generation Method 26
2.3.2 The Solutions to the Insufficient Flickers 27

2.3.3 Improved Visual Stimulus Signal Generation Method 28
2.4 Experiments 29
2.4.1 Preliminary Experiment 30
2.4.2 Phase-Tagged Visual Stimulator Design 33
2.4.3 SSVEP Experiment 34
2.5 Discussion and Conclusion 37
2.5.1 A Comparison between Traditional and Improved Visual Stimulus Signal Generation Methods 37
2.5.2 Conclusion 37
Chapter 3: Using Phase Information in SSVEP-BCI 39
3.1 Introduction 39
3.2 Phase Information of SSVEP 40
3.2.1 The Relationship between Latency and Phase of SSVEP 40
3.3 Feature Detection Algorithm 43
3.3.1 Apply the Additional Phase Information 44
3.3.2 Flicker's Phase Adjustment 46
3.3.3 SSVEP Data Segmentation 46
3.4 SSVEP Offline Experiment 49
3.4.1 Overview 49
3.4.2 EEG Recording 49
3.4.3 Visual Stimulator 50
3.4.4 Experimental Paradigm 52
3.4.5 Offline Data Analysis Result 52
3.5 A Comparison of Feature Detection Algorithms 57
3.6 Discussion and Conclusion 59
3.6.1 Globally Optimal Electrode Selection 59
3.6.2 Feature Detection Algorithm 59
3.6.3 Conclusion 60
Chapter 4: Implementation of an Online SSVEP-BCI System 62
4.1 Introduction 62
4.1.1 Online System Parameters Selection 62

4.2 SSVEP Online Experiment 65
4.2.1 Overview 65
4.2.2 Visual Stimulator and EEG Recording 66
4.2.3 Experiment Paradigm 66
4.3 Online Experimental Result 67
4.4 Discussion and Conclusion 69
4.4.1 System Performance 69
4.4.2 Advantages and Disadvantages of the Proposed System 69
4.4.3 Idle State Detection 70
4.4.4 Conclusion 70
Chapter 5: Conclusion and Future Work 72
5.1 Conclusion 72
5.2 Future Work 73
5.2.1 Electrode Configuration 73
5.2.2 Feature Detection Algorithm 74
5.2.3 Idle State Detection 74
Bibliography 75
Publications 83