Design and Development of BCI Application - Brain Painting Using SSVEP

LOH WAI YUEN

This Report Is Submitted in Partial Fulfillment of Requirements For The Bachelor Degree in Electronic Engineering (Industrial Electronic)

Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka

June 2017

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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Disahkan oleh:

DR. LOW YIN FEN
Pensyarah Kanan
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

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Student Name : LOH WAI YUEN

Date : 2 JUNE 2017

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DR. LOW YIN FEN
Pensyarah Kanan
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

Signature	: ....
Supervisor Name	: DR. LOW YIN FEN
Date	: 2 JUNE 2017

Thousand thanks to my beloved family and friends who gave encouragement and support for me to complete this project as well as my supervisor, Dr. Low Yin Fen who gave me a lot of guidance and advices throughout this project until complete.

ACKNOWLEDGEMENT

First, I, Loh Wai Yuen, would like to express my special thanks of gratitude to my supervisor, Dr. Low Yin Fen who gave me the golden opportunity to do this wonderful project on the BCI application using SSVEP, keep me on the correct path, as well as for provide it necessary information for my project. Thanks to her as she has also always encouraged me during difficult times.

Secondly, I would like to thanks to all my friends that helped me in doing the research and I came to know about so many new things and finally completed this project.

Lastly, I would also like to thank my parents and family who helped me a lot in finalizing this project with the support of spiritually as well as financially.

ABSTRACT

Steady-State Visual Evoked Potential (SSVEP) is a kind of EEG signal that acquired by visual stimulation through the human scalp. Some researchers have studied on providing mobility tools for disabled patients using the Brain-Computer Interface (BCI) method, however there are still limited applications using SSVEP. Therefore, the objective of this project is to develop a BCI application – Brain Painting using SSVEP. SSVEP signals were collected and analyzed to perform painting. In the first part, a stimulus with three different frequencies (10Hz, 12Hz and 15Hz) was developed using Cyberlink Power Director. The subjects were asked to gaze on the stimulus for two experiments. Next, the ENOBIO20 was used to acquire the SSVEP signals from the subjects, and it was sent to computer via Bluetooth and analyzed using the MATLAB. Filter process was done to remove unwanted signals. Finally, the peak frequency of the signal was determined using frequency analysis method and the frequency was associated with different shapes to display on a computer screen. In conclusion, a BCI application – Brain Painting has been successfully developed. In this project, stimuli with accuracies of greater than 90% was developed. This project is suitable for disabled patients, sustainable and able to improve human living lifestyle.

ABSTRAK

Steady-State Visual Evoked Potential (SSVEP) adalah sejenis isyarat EEG yang diperolehi oleh rangsangan visual melalui kulit kepala manusia. Penyelidik-penyelidik telah mengaji supaya menyediakan alat mobiliti untuk pesakit kurang upaya dengan menggunakan kaedah *Brain-Computer Interface* (BCI), walaubagaimanapun aplikasi yang menggunakan SSVEP masih terhad. Oleh itu, tujuan projek ini adalah untuk membina satu aplikasi BCI yang bernama "Brain Painting" dengan menggunakan isyarat SSVEP. Isyarat SSVEP telah dikumpulkan dan dianalisis untuk melaksanakan lukisan. Dalam bahagian pertama, rangsangan dengan tiga frekuensi yang berbeza (10Hz, 12Hz dan 15Hz) telah dibangunkan menggunakan Cyberlink Power Director. Subjek diminta focus pandangannya kepada rangsangan untuk dua eksperimen. Seterusnya, ENOBIO20 digunakan untuk memperoleh isyarat SSVEP daripada subjek tersebut, dan ia dihantar ke komputer melalui Bluetooth dan dianalisis dengan menggunakan MATLAB. Proses penapisan dilakukan untuk menghapuskan isyarat yang tidak dikehendaki. Akhirnya, frekuensi puncak isyarat akan ditentukan dengan menggunakan kaedah analisis frekuensi dan frekuensi tersebut akan dikaitkan dengan pelbagai bentuk untuk dipaparkan pada skrin komputer. Kesimpulannya, aplikasi BCI – "Brain Painting" ini telah berjaya dibangunkan. Dalam projek ini, rangsangan dengan ketepatan yang lebih daripada 90% telah dibangunkan. Projek ini adalah sesuai untuk pesakit kurang upaya, mampan dan mampu meningkatkan gaya hidup hidup manusia

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EEG	-	Electroencephalogram
SSVEP	-	Steady-State Visual Evoked Potential
NIC	-	Neuroelectrics Instrument Controller
O1	-	Occipital Area Left Side
O2	-	Occipital Area Right Side
Oz	-	Occipital Midline
TCP/IP	-	Transmission Control Protocol/Internet Protocol

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter presents the overview of the project. First, a short background which included some reviews of Brain-Computer Interface (BCI) will be given. Next, the objectives, problem statements and scope of the project are discussed. Finally, a report outline will be provided to show the overall organization of the report.

1.1 Background Study

Nowadays, human and technologies are literally inseparable. The study of BCI is a pathway communication between brain and external devices such as computer or machine. BCIs acquire brain signals, analyze them, and translate them into commands that are relayed to output devices that carry out desired actions. BCIs do not use normal neuromuscular output pathways. The main goal of BCI is to replace or restore useful function to people disabled by neuromuscular disorders such as amyotrophic lateral sclerosis, cerebral palsy, stroke, or spinal cord injury. In this field, one of the most used method is by using the Steady State Visual Evoked Potential (SSVEP).

In neurology and neuroscience research, SSVEP are EEG signals that are natural responses to visual stimulation at specific frequencies. When the retina is excited by a visual stimulus ranging from 5Hz to 60Hz, the brain generates electrical activity at the same (or multiples of) frequency of the visual stimulus. This technique is used widely with electroencephalographic research regarding vision and attention.

In SSVEP context, evoked potential is an electrical potential elicited by the stimulus that can be recorded from nerves system. As Visual Evoked Potential is the evoked potential elicited by using visual stimulation, steady-state means that the visual evoked potential was recorded at a frequency which is at least higher than 3.5Hz.

Nowadays, SSVEP-based BCI systems are gaining more popularity as this signal has higher accuracy and Information Transfer Rate (ITR) compare to others. There are many studies had try to optimize SSVEP-based BCI system using different kind of method, such as hybrid the P-300 Event-Related Potential (ERP) with SSVEP.

There are a few applications of SSVEP that are quite common nowadays especially for those paralysis victims. One of the application is text-based spelling system, which is uses flashing lights with certain frequencies to identify various words.

1.2 Objectives

This project consists of three objectives, which included:

i. To develop visual stimulator for eliciting SSVEP using monitor refresh rate.
ii. To analyze the SSVEP using frequency analysis method and translate it into control signal as the input.
iii. To develop a BCI application – Brain Painting using the SSVEP.

1.3 Problem Statement

Nowadays many equipment was invented to help those disabled persons. However, these equipment are quite expensive and not everyone can afford it. Hence, a BCI application using simple integration between computer and human are proposed since this system's cost is reasonable and it's effective to help disabled person too.

Besides that, there are still limited study about BCI applications using SSVEP. Nowadays the application of BCI involving SSVEP only focus in medical field. Therefore, it will be interest to develop an application in another field using SSVEP.

1.4 Scopes of Project

In order to accomplish this project, first the visual stimulator have to be developed. Monitor with refreshing rate of 60 Hz will be used as flickers. The stimuli will be operating from 10Hz to 20 Hz. Graphical User Interface (GUI) will also be designed and constructed to enable an interface to let user choose the operating frequencies of the stimuli. After that, the Brain Painting application by using the SSVEP will be developed. This application involves the transmission of SSVEP signal within the recording software and to perform drawing on display.

The hardware used in this project is ENOBIO20 device. This hardware can record the brain electric potential through scalp by using multiple channels (e.g. 8 channels) EEG measurement with water-free electrodes. The electric potential generated by brain, however, is too weak to process by normal approach. Therefore, this hardware capable with amplifier that sufficient to let the interface software pick up the signal and process it. Also, this device can record the signals wirelessly.

Meanwhile, the software used throughout this project included Cyberlink Power Director, MATLAB and Microsoft Visual Studio. Cyberlink Power Director was used to create the stimuli in video form, as the Cyberlink Power Director software contains a lot of features such as merge the audio and video at particular time. Besides that, MATLAB was used to perform data processing. The data processing is necessary to analyse the signal obtained to determine the accuracy of stimuli. Microsoft Visual Studio was used to create Graphical User Interface (GUI) to be user-friendly.

1.5 Report Outline

The first chapter covered introduction of this project which describes background study, objectives, problem statement and scopes of the project.

The second chapter is literature review that related to the project. It summarizes the concept of BCI as well as its paradigms. Also, a brief explanation of SSVEP application are discussed.

The third chapter of this report is methodology. Here described any method or approach used to develop the stimuli, set-up experiment, data acquisition, data processing and validation of data.

On the other hand, the fourth chapter is result and discussion which highlight the findings throughout the project such as data analysis for the SSVEP obtained.

The last chapter in this report concludes the overall progress of the project based on the findings and give recommendations of future works on the project. Sustainability and other impact of the project are discussed too.

CHAPTER 2

LITERATURE REVIEW

This chapter covers the review of previous research of Brain-Computer Interface (BCI) and its application. The main topics to be studied are development of BCI application. Furthermore, it will cover some examples of SSVEP-based BCI applications.

2.1 Brain-Computer Interface (BCI)

Brain-computer interface (BCI) is a communication technique that seeks to eliminate the middleman between users and applications, namely muscles through nondirect control. [1] While the growth of cognitive neurosciences has made large bounds through advances in several technologies, including electroencephalography, magnetoencephalography and functional magnetic resonance imaging, BCI research remains in its infancy. The prototype of this field was created in 1973 by Dr. Vidal, [2] with plans to adopt said system as a communication channel for the physical disabled, including but not limited to paralysis, amyotrophic lateral sclerosis, brain stroke and cerebral paralysis. [3] Continuation and acceleration of recent progress in BCI research and development have begun to address real world applications spanning activities of daily living, environment control, exercise, locomotion, and verbal communication. [4]

The BCI technology, combined with ambient assisted living (AAL) systems, can potentially make the home environment more intelligent and assistive, providing alternative communication means for supporting independent life of elderly people affected by impairments. The quality of life of persons suffering from severe motor disabilities can benefit from the use of BCI-based assistive technology. [5] In spite of advancements, a number of obstacles remain between us and a BCI system with high efficiency. Obstacles include accuracy, speed, price and usability. In terms of accuracy, current BCI systems are inaccurate with a low rate of information transfer, meaning the time where the user sends commands to the device is longer than expected. A further challenge is related to cost, as EEG equipment are costly, especially an EEG cap and amplifiers. [6] High sensor count systems require a long preparation time and on top of that are uncomfortable. With these challenges in place, commercial success of BCI systems are limited. Before design and implement attempts of a BCI system, several prerequisites include knowledge of the data acquisition process, characteristics of EEG waveforms, signal processing methods in terms of feature extraction and classification. Said points have been repeatedly pointed out by researchers in the BCI field as indispensable for the growth of BCI. [7] [8] [9]

Therefore, BCI technology still has many problems to be solved to transit to feasible assisted living [10] with minimal training effort and support required for independent use at home.

2.1.1 Overview of BCI Paradigms

A variety of BCI paradigms have been exploited, such as P300 [11], SSVEP [12], ERD/ERS [13], MI [14], slow cortical potential (SCP) based [15], and hybrid methods [16] [17] [18]. We review some of these paradigms in more detail in the following subsections.

2.1.1.1 Spontaneous Potentials

The methodology for defining spontaneous EEG is when the test subject is unstimulated. In subjects with no prior illnesses, spontaneous EEG is measured through a time span where brain activity converts constant waves into events with different frequencies. Within these spontaneous EEG waves, we can find and characterize different cognitive processes, mental states and activation processes. Band range limits defined as brain rhythms, in particular beta and gamma are sometimes contradictory and thus further divided into sub bands that can define brain activity with a frequency f, whereby f>30 Hz or f<0.5Hz is usually assumed to be limited in terms of clinical usage, though several papers proving the existence of cognitive processes in said area have been published in recent years, these papers are ambivalent regarding whether higher frequency activity with frequency of >30 Hz is due to cerebral activity. [19] The rhythms of EEG differ for different actions, thoughts and states of mind. An example would be the blocking or attenuation of mu rhythm when planning a movement. A BCI system is the logical extension of the fact that thoughts can change the rhythmic activity of the human brain.

2.1.1.2 Event Related Potentials (ERP)

Event related brain potentials (ERP) differs from the afore mentioned spontaneous potentials in terms of their method of appearing, while the subject is under stimulus, and is noted by fata analysis. Not only does the brain generate uninterrupted spontaneous activity all the time, but the brain also reacts with a characteristic potential change to external or internal stimulus. On repeated, episodic stimuli, event based activity is registered, but undisplayed provided no stimulation is presented. With an external stimulus (examples include sounds or light), specific reactions and EEG components should emerge in the ongoing EEG activity after the stimulus. Said ERP are analysed in the time domain through triggers, timestamps of stimulus presentation appearing in the EEG. The subject is presented with a periodic stimulus while their EEG is recorded. Data analysis is then performed on the data encompassing time after stimulus. The ERP that arises with amplitude of 0.1 of spontaneous brain activity is like noise and is barely noticeable in the date. But through computer analysis of time samples after stimulus and after averaging the signals, the resulting potential is visible. As most of, many of the oscillations are not what we are looking for, only certain frequencies are of interest by selecting a time window of 100ms to several seconds. The observed potential has an amplitude smaller than 10 µV and a duration of around 0.5 s. Its form is characteristic, with oscillations with very small amplitudes arising after a few milliseconds of stimuli. These potential differences can be positive or negative in terms of changes in brain potential, leading us to categorize them as cortical positivity or cortical negativity. [20]

Typically, in an ERP, a small positivity, called P1, is measured followed by a negativity called either N1 or N100, appearing after 100ms, and it is followed by a clear positivity P3, which arises after approximately 300ms after presentation of the stimulus, peaking at 300ms and is called a P300 wave. [21] Both P300 and N100 waves correlate to the stimulus, and are observed for medical purposes, that is, for patients with multiple sclerosis, the P300 wave lingers longer than in healthy patients. Another purpose is for diagnosis of mental illnesses such as schizophrenia or hyperactivity disorders. Other than sensory stimuli, ERP can be caused by different event-related actions, such as imaginative or physical motor activity, that is, the movement of arms or legs.

Modalities of stimulation are categorized into three [22]:

i. Auditory: Stimulus is done through signal tones of a specific frequency or even clicks.
ii. Visual: Light with a specific frequency of blinking is used as stimulus.
iii. Somatosensory: Through electrical stimulation of peripheral nerves, stimuli are elicited.

2.1.1.3 Steady-State Visual Evoked Potential (SSVEP)

Steady-state visual evoked potential (SSVEP) is the brain's electrical response to repetitive visual stimulation, which can be recorded from the scalp over the visual cortex, with maximum amplitude at the occipital region. In the human visual cortex, the firing of neurons synchronizes to the frequency of the stimulation and results in SSVEP, also known as a photic driving response characterized by sinusoidal-like waveforms at the stimulus frequency and its harmonics [23]. The frequency components in the SSVEP signals remain constant in amplitude over time, and therefore the stimulus frequency can be reliably recognized based on the measurement of SSVEP in the frequency domain. Due to the robust frequency character of the SSVEP, the frequency tagging technique, which encodes multiple visual targets with different flickering frequencies, has been widely used in the fields of visual neuroscience and neural engineering [24] [25].