WHEELCHAIR CONTROLLED BY HUMAN BRAINWAVE USING BRAIN-COMPUTER INTERFACE SYSTEM FOR PARALYZED PATIENT

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

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PUAN FOUZIAH BINTI MD YASSIN

I dedicate this thesis to my lovely mom and my late father, who throughout his lifetime etched in the walls of my heart the importance of education and become the pillar of my strength. For my siblings (Bro Azman, Sis Leez, Sis Ana, Bro Azri, Bro Ajiem and Bro Hadi). And last and the most important to Allah SWT, for your rizq and guidance to your servant. Thank you for everything and may Allah bless my family.

"The seeking of knowledge is obligatory for every muslim"
-Prophet Muhammad-

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ABSTRACT

Brain-Computer Interface (BCI) is a direct communication pathway between a human and external device. Integrated wheelchair controlled with human brainwave using a BCI system was designed and studied to help people with disabilities, especially for people who suffer from motor disorders such as peripheral nerves and muscles. The invention aims to develop an integrated wheelchair which can be controlled by a paralyzed person using only a single electrode. In this research, the efficiency of the brainwave integrated wheelchair has been improved using human attention value, blink detection and eyebrow movement of the user to control the wheelchair. An encephalography (EEG) device called Mindwave Mobile Plus (MW+) has been employed to obtain attention value for the wheelchair movement, eye blink to change the mode of the wheelchair to move forward (F), to the right (R), backward (B) and to the left (L). Eyebrow movement was used to stop the wheelchair when using human brainwave as the signal quality value of 26 or 51 is produced. Analysis on the human attention value in different gender and age category also has been done. Male is easier to focus compared to the female. Teenagers have the highest attention value followed by the children while the adults have the lowest attention value among all age categories studied. The EEG of the human were analyzed by using Arduino Integrated Development Environment (IDE) software. The development of the integrated wheelchair is improved by using human's attention value, blink detection and eyebrow movement and the threshold value of the attention level was set according to the gender and age category of the user. From the results and analysis, the threshold value for male children is 60, male teenager (70), male adult (40) while for the female children is 50, female teenager (50) and female adult (30).

ABSTRAK

Brain-Computer Interface (BCI) adalah laluan komunikasi terus antara manusia dan peranti luaran. Kerusi roda bersepadu yang dikawal oleh otak manusia dengan menggunakan sistem BCI yang telah direka bentuk dan dikaji untuk membantu orang kurang upaya, terutama bagi mereka yang mengalami gangguan motor seperti saraf persisian dan otot. Ciptaan ini bertujuan untuk membangunkan kerusi roda bersepadu yang boleh dikawal oleh pesakit yang lumpuh dengan menggunakan satu elektrod tunggal sahaja. Kecekapan bagi kerusi roda bersepadu otak telah diperbaiki dalam penyelidikan dengan menggunakan tahap perhatian manusia, pengesanan kerlipan mata dan pergerakan kening pengguna untuk mengawal kerusi roda. Peranti *electroencephalography* (EEG) yang dikenali sebagai *Mindwave Mobile Plus* (MW+) digunakan untuk mendapatkan data bagi tahap perhatian untuk pergerakan kerusi roda, kerlipan mata untuk menukar mod pergerakan kerusi roda ke hadapan (F), ke kanan (R), belakang (B) dan ke kiri (L). Pergerakan kening digunakan untuk menghentikan kerusi roda semasa menggunakan gelombang otak di mana nilai kualiti isyarat 26 atau 51 terhasil. Analisis terhadap nilai perhatian manusia dalam kategori jantina dan umur juga telah dilakukan. Lelaki lebih fokus berbanding perempuan. Kategori remaja memiliki tahap perhatian yang paling tinggi diikuti oleh kanak-kanak manakala kategori dewasa mempunyai tahap perhatian yang paling rendah dalam semua kategori umur. EEG yang dihasilkan oleh manusia dianalisis dengan menggunakan perisian Arduino *Integrated Development Environment* (IDE). Pembangunan kerusi roda bersepadu telah diperbaiki dengan menggunakan tahap perhatian, kerlipan mata dan pergerakan kening dan nilai ambang untuk tahap perhatian boleh ditetapkan mengikut kategori jantina dan umur pengguna. Berdasarkan keputusan dan analisis, nilai ambang bagi kanak-kanak lelaki ialah 60, remaja lelaki (70), dewasa lelaki (40) manakala kanak-kanak perempuan ialah 50, remaja perempuan (50) dan dewasa perempuan (30).

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LIST OF SYMBOLS AND ABBREVIATIONS

m	-	milli/meter
mA	-	milliampere
ms	-	milliseconds
A	-	Ampere
AD	-	Analog digital
ADHD	-	Attention deficit hyperactivity disorder
ALS	-	Amyotrophic lateral sclerosis
AN	-	Analog input
ANOVA	-	Analysis of variance
B	-	Backward
BCI	-	Brain-Computer Interface
BLE	-	Bluetooth Low Energy
BMI	-	Brain Machine Interface
DC	-	Direct current
DIP	-	Dual inline package
DNI	-	Direct Neural Interface
DOF	-	Degree of freedom
ECoG	-	Electrocorticography
EEG	-	Electroencephalography
EMG	-	Electromyography
EPWs	-	Electric powered wheelchairs
F	-	Forward
FFT	-	Fast Fourier Transform
fMRI	-	Functional Magnetic Resonance Imaging
GND	-	Ground
GUI	-	Graphical User Interface

Hz	-	Hertz Connector
IN	-	Digital input
I/O	-	Input/Output
IP	-	Internet Protocol
IDE	-	Integrated Development Environment
L	-	Left
LCD	-	Liquid Crystal Display
LED	-	Light emitting diode
MCU	-	Microcontroller unit
MEG	-	Magnetoencephalography
MMI	-	Mind-Machine Interface
MW+	-	Mindwave Mobile Plus
PC	-	Personal computer
PWM	-	Pulse width modulation
R	-	Right
RAM	-	Random access memory
RC	-	Radio control
REM	-	Rapid eye movement
RX	-	Receiver
S	-	Stop
SDK	-	Software development kit
SLA	-	Sealed Lead Acid
SMR	-	Self-myofascial release
SPSS	-	Statistical Package for Social Sciences
SW	-	Switch
TGAM	-	Think Gear Asic Module
TGC	-	Think Gear
TX	-	Transmitter
UART	-	Universal asynchronous receiver-transmitter
USB	-	Universal serial bus
V	-	Volts

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CHAPTER 1

INTRODUCTION

1.1 Research background

Normal people can manage their daily activities by their own without using any supporting system compared to the disabled people as they need some other assistive device to enhance their mobility performance.

For today's increasingly sophisticated technology, the world of technology has influenced human life. The evolution of integrated robot in order to be controlled by users has also been rapidly generated. Electric-powered wheelchairs have also been established to assist disabled people in their daily activities (Achkar et al., 2015). However, they still need to use their limbs to control the wheelchair such as hand, to control the wheelchair joystick.

This will limit the patients who fully paralyzed or suffer a spinal cord injury to control the wheelchairs. In recent years, a lot of research have been done to produce controlled electric wheelchairs only by using brainwave signals through a Brain-Computer Interface (BCI) system in order to improve their quality of life (Dumec & Kevric, 2018).

BCI is a system that communicates between human mind and physical devices by translating different patterns of the brain activity into commands in real time (Ramesh et al., 2014). Through this system, people can move machines or computers without using their limbs and this system is especially useful for handicapped people or paraplegic patients, such as paralysis and stroke (Devi et al., 2014).

Brain Computing is a technology that uses human brainwaves as an input before accessing it to produce output. Humans can send signals to an object or mechanism by utilizing only the force of mind or rather the brainwave. Every brain situation is often associated with the characteristics of the brainwave. Brainwaves can be detected using sensors located along the scalp. The brainwaves will vary according to what we perform and the feelings we face. The mental states and condition of the person can be configured by determining the brainwave type that is being produced.

Several types of waves can be classified as alpha, beta, gamma, delta and theta waves based on their frequency range. The electrical activity of the brain is monitored in real time using an array of electrodes, which are placed on the scalp in a process known as electroencephalography (EEG) (Sinha & Kanthi, 2016). The analog brainwave signal has been converted into digital form to evaluate the speed and attention. The EEG is the first non-invasive neuron imaging technique used to measure brain electrical activity (Ismail et al., 2016).

In this research, an EEG device called Mindwave Mobile Plus (MW+) has been used to acquire data of brainwave signals in terms of attention level, blink detection and eyebrow movement to control the integrated wheelchair's movement by human brainwave using BCI system for helping a paralyzed patient. The analog human brainwave has been converted to produce the digital value of attention level (range 0-100), eye blink detection (0-255) and signal quality value (0-200). The attention level has been converted by using EEG technique while eye blink detection has been acquired using Electromyography (EMG) technique.

The attention level was categorized into five levels, which are "poor attention" (1-19), "less attention" (20-39), "neutral" (40-59), "good attention" (60-79) and "great attention" (80-100). The attention level of neutral was considered as normal concentration level. The attention levels of less and poor were lower than normal attention level. The attention level higher than the neutral level indicated the person has a higher concentration level at the moment.

Mindwave Mobile uses the EMG technique which will detect the muscle contractions that occurs while blinking the eye and this contraction will generate a unique signal. Eye blinks are akin to a standard on/off binary system and therefore are valuable for controls that require definitive responses.

The signal quality value is between 0-200 which 0 are the best while 200 are the most defective. The signal quality will not detect when the user is not wearing the Mindwave Mobile, poor if almost no contact is made by the forehead skin with the dry sensor, medium if partial contact is made by the forehead skin with the dry sensor, and good if the dry sensor makes firm contact with the forehead (Bharali et al., 2018).

These values were used to control the brainwave integrated wheelchair in terms of movement (attention level), mode (eye blink) and stop for emergency alert (eyebrow movement). Based on the analysis, the threshold value for the human attention value was set differently according to the gender and age category of the user, the mode of the wheelchair changed in sequence of forward (F), to the right (R), backward (B) and to the left (L) when the blink strength value is above 110 and below 250 is detected. As an added safety precaution when using human attention level to move the wheelchair, eyebrow movement has been used to execute the stop mode as the signal quality value of 26 or 51 is produced.

1.2 Problem statement

There are many technologies that have been developed to help the disabled person but it is still limited, particularly for the paralyzed patient like quadriplegic or sometimes known as tetraplegic who cannot move their both legs and arms due to severe motor impairments such as amyotrophic lateral sclerosis (ALS). It is specifically for the paralyzed patient, that has no significant damage to their sensory nerve cells. Thus, sensory neurons still can be used to transmit the brain signal to control external devices. Human brainwave constantly emits the electrical signal as a way of sending information to all parts of our body. The procedure of sending signal never ceased even for the paralyzed and the physically handicapped.

Nowadays, there are many types of research about BCI that have been considered to help the disabled people for example, mind-controlled wheelchair. Yet, when brainwave is used to control the integrated wheelchair, it requires a longer time for the wheelchair to move due to unstable signals in time response due to different types of human brainwaves being produced. Besides that, the accuracy of the wheelchair from the previous works need to be improved as the wheelchair move continuously when using only human attention value as an input. Therefore, the efficiency of the brainwave controlled wheelchair can be improved using human brainwave in terms of attention value, blink detection and eyebrow movement. Besides that, the reduction in cost also can be done when using modification of the manual wheelchair into the electric wheelchair and using the cheapest brainwave sensor which consist only single electrode. Thus, it is possible to help the physically disabled person to move. Analysis on human attention for different gender and age are crucial in ensuring the efficiency of the integrated wheelchair could be optimized and improved.

1.3 Significance of study

This research has been studied to examine the human brainwave pattern by using MW+ in terms of attention level, blink detection and eyebrow movement to improve the quality of signal and the accuracy of wheelchair's movement regarding the requirement of brainwave signal produced by the human. Besides that, compare to another research, the main focus of this research is for the development of integrated wheelchair controlled by human brainwave using a BCI system in which it utilizes a user's level of attention and brain signal artifacts such as facial movements to provide mobility to the individuals who find it impossible to use a powered wheelchair due to motor disorder such as paralyzed patient.

1.4 Research aim

The aim of this research to improve the development of integrated wheelchair controlled by human brainwave using a BCI system depending on the ability individual brain attention level.

1.5 Research objectives

The objective of this study is to:

i. Design an electronics circuit and coding formation for various mode of wheelchair movement including stop mode controlled by Mindwave Mobile Plus (MW+).
ii. Construct an integrated wheelchair with Brain-Computer Interface (BCI) complete system.
iii. Analyze the efficiency of the system based on level of attention and facial movement at different gender and age category.

1.6 Scope of study

The scope of study in this project is to transfer the human brainwave signals in terms of attention level based on beta wave which is related to concentration produced as an input and being transformed into the digital output, which signals for controlling the movement of the integrated wheelchair by using an EEG device called MW+ that can be shown in Figure 1.1. By using the Arduino microcontroller, the movement of the integrated wheelchair can be manipulated by applying the force of mind. The mode of wheelchair's movement is selected by blink detection to go forward, to the right, backward and to the left. When the user raises the attention level over the threshold value, the wheelchair will move accordingly to the selected mode. For the stop mode, it can be taken by using eyebrow movement as when the user lifts up the eyebrow, the signal quality which is equal to 26 or 51 will be produced. The brainwave signals of the user will be analyzed by using Arduino Integrated Development Environment (IDE) software for every aspect of the movement. Light emitting diode (LED) and Liquid Crystal Display (LCD) are used to indicate the value of attention level of the user and the mode of the wheelchair in real time.

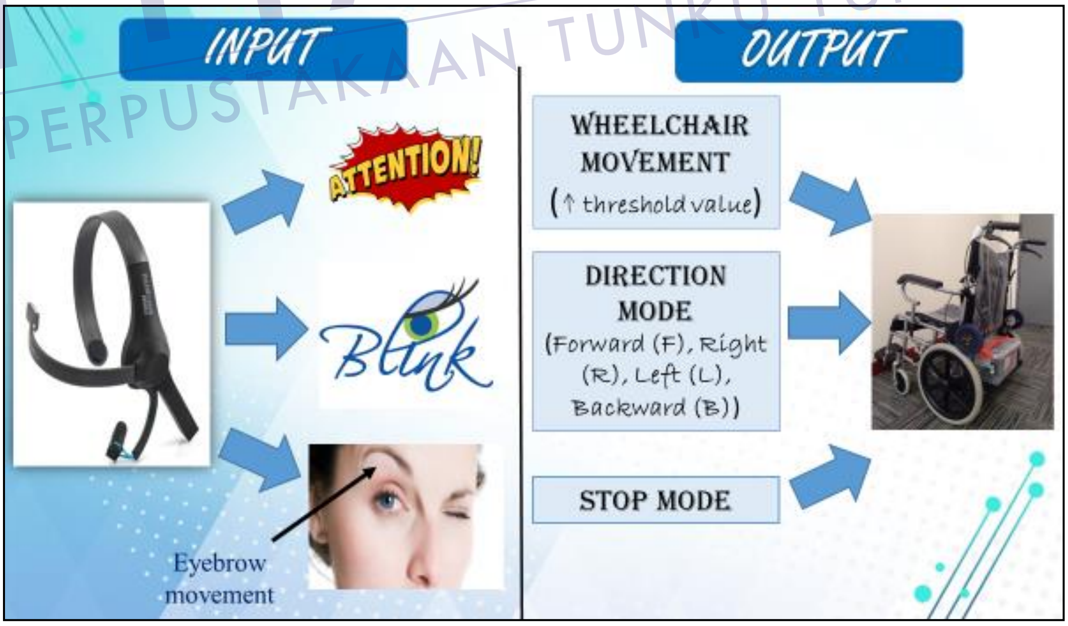

Figure 1.1: The scope of project

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter overview three main subtopics that discuss the theoretical study, explanation on hardware and software evolution and previous works that are related to this project to develop a better understanding in term of the procedure and technique used in each section of the task.

2.2 Human brain

Brain is an organ that plays an important role in the human body. Neurons found in the brain are closely related to the ability of learning and mental abilities of an individual. Glia is a place of neurons. Neuron consists of two parts, dendrite and axon. Dendrite works in receiving neurotransmitter from another neuron through the axon. This relationship is known as the nervous system (Singh, 2006). The brain can be divided into four parts, namely cerebrum, cerebellum, brainstem and limbic system.

Cerebrum which is also known as Cerebral Cortex is the largest part of the human brain. It makes man possesses the ability to see, think, analyze, and remember. Cerebellum works in controlling balance, muscle coordination and body motion. If this part is damage, it can cause lack in the movement of human muscle. Brainstem plays a role in controlling the respiratory system, the body temperature and the digestive procedure. The brainstem also can be found inside the animal brain. The limbic system works in expressing feelings, arranging hormone production, preserving homeostasis, creating a feeling of thirst and hunger, metabolism and even the long-term memory (Nowinski, 2011).

While in the womb, the brain has a larger size compared to the other body organs. The maturation of nerve cells in the brain grows rapidly during the initial development. The changes that occur in the brain are also more progressive compared to the other part of the body organs. For the change in brain weight, it is very clear that its growth is very fast happening in the first five years. During infant, the brain weight can go up to 750 grams. At the age of five, the brain weight reaches 1200-1250 grams and at the age of 18, there was a slim gain in the brain weight up to 1300-1500 grams (Kolb & Whishaw, 2001).

2.2.1 Cerebrum

Cerebrum is the most important part in awareness for human. This region of the brain leather is darker and is called as grey matter because it contains many nerve cells or neurons. It consists of four parts which are Frontal Lobe, Parietal Lobe, Occipital Lobe and Temporal Lobe (Figure 2.1). Each lobe has its own features and functions.

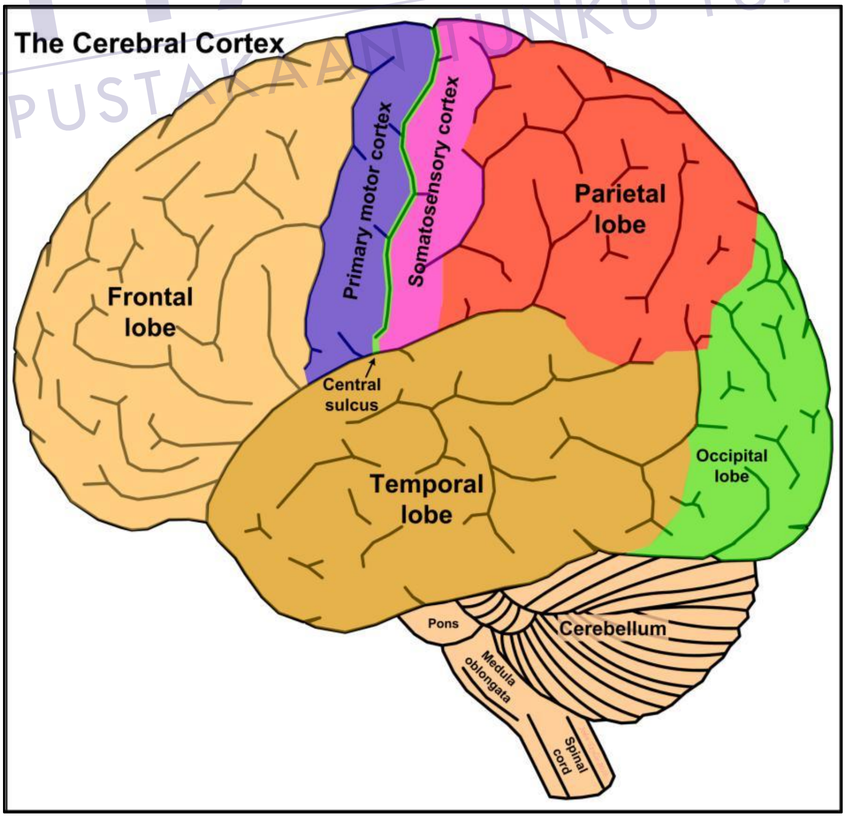

Figure 2.1: Human brain

Frontal Lobe is the most forward part of the brain. This lobe is separated from Temporal Lobe by laterally sulcus and also separated by Parietal Lobe by central sulcus. This lobe plays an important role in motor movement. It plays in controlling the ability to act. In addition, it has a role for memory as it can hold the memory in a long period of time, or long-term memory (Frebeg, 2009).

Parietal Lobe is the top part of the brain. The main role of parietal lobe is to process somatosensory which is the sense of touch, but at a very precise level. The error in analyzing by parietal lobe can lead to delusional or perception thought. It is categorized into three parts, namely primary somatosensory cortex, superior parietal lobule and inferior parietal lobe. The front part of the parietal lobe (anterior) is the sense of tactile, pain, position of limbs and temperature. Meanwhile, the back of parietal lobe is closely related to vestibular, visual and auditory system (Boutros et al., 2010).

Temporal Lobe functions as a listening ability and analyzing information transmitted through voice forms. It is divided into three parts, namely the superior, middle and inferior temporal gyri. Superior temporal gyri work in receiving hearing input and middle temporal gyri to detect movement in visibility, while inferior temporal gyri are used for facial recognition (Sapru & Siegel, 2010).

Occipital Lobe is located in the back and related to visual development. If this part of the brain is damaged, it can cause man to be blind (Ibnu Aqasha, 2015).

2.3 Brain-Computer interface

Brain-Computer Interface (BCI) system is a system that can bypass conventional channels of communication (ie., muscles and thoughts) to provide direct communication and command between the human mind and physical devices by translating different patterns of brain activity into output commands in actual time. BCI is also known as Mind-Machine Interface (MMI), Brain Machine Interface (BMI) or sometimes sent for as Direct Neural Interface (DNI).

This can be done by placing the electrode along the head to notice the signal or more accurately the brainwaves generated and then transported to the computer to analyze the information (He et al., 2013).

Philip Kennedy and Roy Bakay established a brain implant on humans that produce high quality signs to simulate motion (Devi et al., 2018). The implant was

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