FACULTY OF ELECTRONIC AND COMPUTER TECHNOLOGY AND ENGINEERING

DEVELOPMENT OF BCI FOR THOUGHT-CONTROLLED WHEELCHAIR USING ARDUINO

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Bachelor of Electronics Engineering Technology with Honours

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DEDICATION

To my beloved mother, and father,

and

To dearest friends, and lecturers

and

Miyamoto Musashi

and

people who believe in me

and

ME

ABSTRACT

A thought-controlled wheelchair utilising a brain-computer interface (BCI) is a type of wheelchair that can be operated through the use of human brainwaves. Individuals who have severe motor disabilities may encounter difficulties with mobility, especially those who are paralysed. The system is designed to cater to individuals with severe physical disabilities who are unable to operate conventional controls for mobility in a wheelchair. The primary objectives of this project are to conduct a thorough investigation and analysis of the brain-computer interface concerning controls driven by thought. Additionally, the project aims to develop an algorithm of brain signal acquisition from Neurosky Brainwave Mobile 2 device. Finally, the project seeks to design and construct a scaled-down model of a wheelchair that can be controlled by thought. The Neurosky BrainWave Mobile 2 EEG device is employed by the system to acquire brainwave signals that are predicated on beta wave frequencies. The Arduino microcontroller processes the digitised brainwave signals to enable real-time manipulation of the wheelchair's movement. The wheelchair's movement modes, such as forward, stop, left, and right, are chosen through blink detection. In summary, the thought-controlled wheelchair prototype has been successfully developed.

ABSTRAK

Kerusi roda yang dikawal pemikiran menggunakan antara muka otak-komputer (BCI) adalah sejenis kerusi roda yang boleh dikendalikan melalui penggunaan gelombang otak manusia. Individu yang mempunyai kecacatan motor yang teruk mungkin menghadapi kesukaran dengan pergerakan, terutamanya mereka yang lumpuh. Sistem ini direka untuk memenuhi keperluan individu yang mempunyai kecacatan fizikal yang teruk yang tidak dapat mengendalikan kawalan konvensional untuk pergerakan di kerusi roda. Objektif utama projek ini adalah untuk menjalankan penyelidikan dan analisis menyeluruh antara muka otak-komputer mengenai kawalan yang didorong oleh pemikiran. Di samping itu, projek ini bertujuan untuk mengembangkan algoritma pemerolehan isyarat otak dari peranti Neurosky Brainwave Mobile 2. Akhirnya, projek ini bertujuan untuk merancang dan membina model kerusi roda yang boleh dikawal oleh pemikiran. Peranti Neurosky BrainWave Mobile 2 EEG digunakan oleh sistem untuk memperoleh isyarat brainwave yang didasarkan pada frekuensi gelombang beta. Mikrokontroler Arduino memproses isyarat gelombang otak digital untuk membolehkan manipulasi masa nyata pergerakan kerusi roda. Mod pergerakan kerusi roda, seperti ke hadapan, berhenti, kiri, dan kanan, dipilih melalui pengesanan kedipan. Ringkasnya, prototaip kerusi roda yang dikendalikan oleh pemikiran telah berjaya dihasilkan.

ACKNOWLEDGEMENTS

I owe my achievement in finishing the thesis for the experimental work mostly to the Grace and Blessings of Allah SWT. Never forget those who taught me the fundamentals and helped me help others. I would like to begin by expressing my appreciation to my supervisor, Dr. Haslinah Binti Mohd Nasir, for their meticulous oversight and unflinching support of this report, as well as their insightful suggestions and advice.

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Finally, I'd want to express my gratitude to everyone at FTKEK who has been helpful and cooperative, from the administrative staff to my professors and fellow students who have helped make this report a success.

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CHAPTER 1

INTRODUCTION

1.1 Background

Disability is inherent to the human condition. Numerous individuals with disabilities lack equal access to health care, education, and employment opportunities, do not receive the disability-related services they need, and are excluded from daily life. The word "disability" is used to describe the negative effects of a person's health condition interacting with the person's surroundings and personality. This includes impairments, activity limits, and participation restrictions. It was estimated that around 15% of the population of the globe was living with some sort of disability that affects their mobility [1]. Individuals with mobility impairments necessitate diverse forms of assistance to enhance their standard of living.

Wheelchairs are among the most often used aids to help people with mobility issues have more independent and fulfilling lives. Wheelchairs help people with disabilities participate fully in society. The provision of suitable wheelchairs not only facilitates movement but also initiates a progression towards expanding opportunities for education, employment, and social engagement [2]. Moreover, the wheelchair has undergone advancements in conjunction with the expansion and progress of technology. Electric and battery-powered wheelchairs have become available in addition to the conventional manpower-driven ones.

1.2 Problem Statement

Individuals with severe motor disabilities often struggle with mobility particularly for those who are paralyzed, such as quadriplegics or tetraplegics, who experience severe motor impairments such as amyotrophic lateral sclerosis (ALS) [3], rendering them unable to move their limbsand independence due to their limited ability to operate traditional wheelchairs [4]. The system is made for people with serious physical disabilities who can't use regular controls to move around in a wheelchair. So, there is a great need for a way to control a wheelchair that is easier to use and doesn't depend on muscles. The utilisation of Electroencephalography (EEG) signals in the creation of a Brain-Computer Interface (BCI) controlled wheelchair has the potential to offer a more practical and effective means of mobility for individuals with disabilities. The task at hand involves developing a system that can effectively capture and interpret signals, and subsequently translate them into accurate commands for the wheelchair.

1.3 Project Objective

The main aim of this project are :

a) To study on brain-computer interface with regard to thought controlling.

b) To design an algorithm of brain signal acquisition from Neurosky Brainwave Mobile 2.

c) To develop a concept of miniature prototype of thought-controlled wheelchair.

1.4 Scope of Project

The scope of this project are as follows:

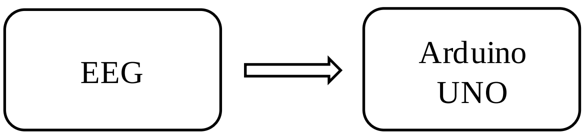

Figure 1.1 EEG signal transmission to Arduino

The EEG device will read human brainwave and transfer the brainwave signal in term as an input to the Arduino microcontroller for data processing of the algorithm to contol the movement of the miniature wheelchair.

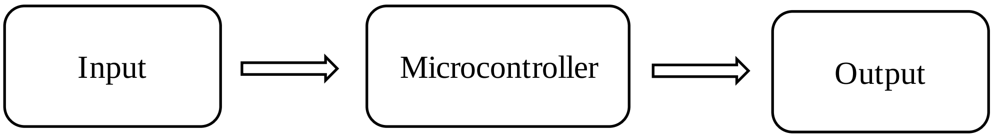

Figure 1.2 Flow diagram of input to output via Microcontroller

The EEG signal of human brainwave signals is converted to digital output using the Neurosky Brainwave Mobile 2 during the input process. The movement of the integrated wheelchair will be controlled by digital signals.

The Arduino UNO microcontroller is utilised to process digitised EEG signals and control the direction of movement of a miniature wheelchair. The movement direction can be manipulated to move forward, backward, right or left using attention level and blink detection through beta waves at a frequency range of 12Hz to 35Hz.

The resulting output will be the movement of the wheelchair where it is controlled by the motor, which receives signals from the microcontroller. The microcontroller interprets these signals based on the brainwave input from the Neurosky Brainwave Mobile 2.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of three major subtopics that examine theoretical research, an explanation on the development of hardware and software, and earlier works that are linked to this project. The purpose of this chapter is to establish a better knowledge in terms of the method an approach utilized in each portion of the assignment.

2.2 Electroencephalography

Electroencephalography, or EEG for short, is a medical diagnostic technology that does not need any invasive procedures and is used to record and analyze the electrical activity of the brain [5]. Berger H. Uber, a German psychiatrist, first developed EEG in 1929. It involves inserting electrodes on various parts of the scalp and brain in order to capture electrical neural impulses [6].The first human EEG recordings were made by a German doctor named Hans Berger in 1924 [7]. In 1910, he began using a string galvanometer, then switching to a smaller Edelmann model, and change it into a bigger model in 1924. Berger upgraded to the more sensitive Siemens double coil galvanometer (130 V/cm) in 1926. In 1929, he published the first report of human EEG recordings on photographic paper where lasting between one and three minutes [8].

EEG recording is a painless, non-invasive method that measures the electrical activity of the brain by putting electrodes on the head. EEG-based BCIs use a collection device like a headset or a cap with electrodes. The recorded scalp voltages are constantly generated with a continuous spectrum of amplitudes over time. The electrodes surface are made up of conductive plates of tin, silver, lead, or gold-plated fine silver metal coated with silver chloride (AgCl) and installed atop a headcap-like device, are the most practical and pleasant option [9]. Electrode-scalp contact impedance must be between 1 k and 10 k for accurate signal recording. The internal electronics of the collection unit consists of sensors, a bio-signal amplifier, and an analog-to-digital converter. The electrodes pick up brain signals that relate to specific brain activity, such as selective thinking or attention, motor movements, motor images, etc. The signals are sent from the EEG head electrode to the next stage, a bio-signal amplifier, which boosts the intensity of the recorded brain signals. Amplifiers are used to bring the microvolt signals from the electrodes into a range where they can be properly digitalized. Filters are used to remove unnecessary noise and interference from the signal, such as electrical noise from the surroundings or muscle action [10].

After being increased, data are sent to an analog-to-digital converter, which changes brain reactions from the analogue to the digital. In order to represent the voltage at any given time, the ADC takes samples from the continuous data stream and converts them into a binary code. Numerous modern recorders feature a sampling rate of 256 hertz per channel. Total transmission equals the number of channels multiplied by the sampling frequency. This yields a throughput of 5276 samples per second for a 21-channel EEG [11]. These digitalized brain messages are sent to an interfaced computer using a cable or wireless so that the computer could analyze the received brain data and generate control signals to operate a particular BCI application [9].

The signals that are picked up by the EEG electrodes placed on the scalp are representative of the electrical activity that is generated collectively by millions of neurons, and these signals may be separated into a variety of frequency bands each of which corresponds to distinct states of consciousness, tasks, or cognitive processes. This classification permits us to comprehend and interpret the fundamental brain activity. From low to high, these frequency bands are designated as delta (δ), theta (θ), alpha (α), beta (β), and gamma (γ), accordingly. Relevant features of these bands are described in table below:

Table 2.1 The characteristics of the five fundamental brain waves [12] [13].

Brainwave Type	Frequency Range (Hz)	Characteristics	Associations and Effects	References
Delta waves	0.5-4	Slowest frequencies, linked with deep sleep and unconscious awareness	Mainly observed in stages 3 and 4 of non-REM sleep. High levels in awake individuals may indicate neurological disorders.	[13], [14]
Theta waves	4 - 8	Common brainwaves, associated with imagination and calmness	Promote ease, intuition, and creativity. Linked with inward focus and well-being during meditation, and memory recall in conscious state.	[15], [16]
Alpha waves	8 - 12	Occur in various states of consciousness, promoting relaxation	Prevalent during daydreaming and extreme relaxation. High levels linked with good memory and quick recall. Suppression may cause anxiety and insomnia.	[17], [18], [19]
Beta waves	12 - 35	Associated with alertness and thinking process	Higher during awakening, linked with concentration and attention. Too much beta activity can lead to stress.	[20]
Gamma waves	Above 35	Highest frequency, often linked with attentive states	Associated with higher levels of intellect, compassion, and self-control.	[21], [22]

Electrodes are used in the recording of EEG. The electrodes were placed using the international 10-20 system that consists around 21 channel recordings which is a standard approach for describing and implementing the placement of scalp electrodes for neurophysiological measures such as an EEG [23], [24]. Electrodes are separated by either 10% or 20% of the skull's surface. These perimeters are then subdivided into 10% and 20% increments, which are used to establish the electrode positions. F denotes the frontal lobe, C the central lobe, P the parietal lobe, and T the temporal lobe. Z indicates a midline position for the electrodes.

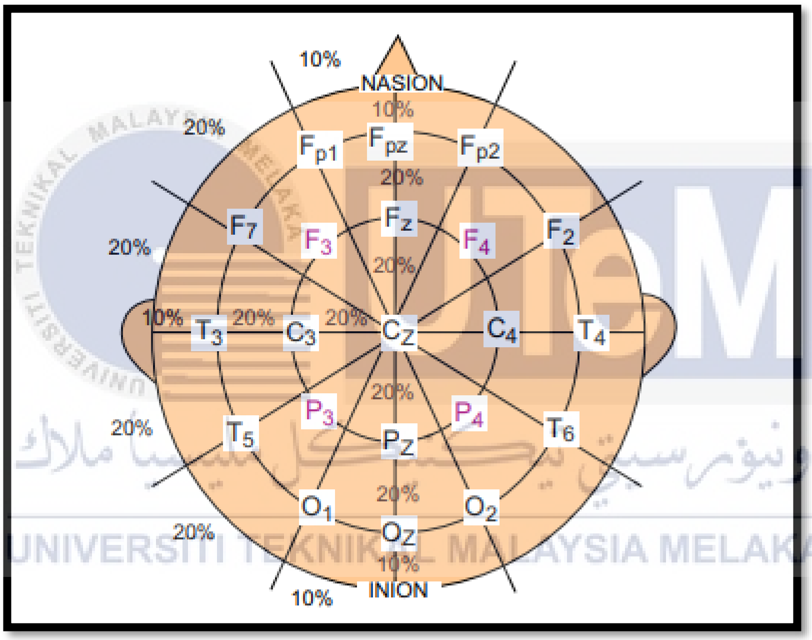

Figure 2.1 The 10/20 international electrode placement system [12]

2.3 Brain-Computer Interface

A brain-computer interface, often known as a BCI, enables a person to direct the operation of an external mechanical or electrical equipment via the use of just their thoughts. BCIs are able to interpret the signals that are read from the neurons of the brain thanks to the computer algorithms that power them [25]. Among the many uses for a computer-brain interface are the generation and regulation of stimulus signal, the measurement, recording, and processing of response signals, and the analysis of brain state [26]. BCI technology has the potential to facilitate mind-to-mind communication, device-to-brain control, and brain-to-device control [27]. However, BCIs are also being developed for practical uses, such as assistive devices that help people with severe motor limitations communicate and engage with their surroundings.

2.4 Background On Wheelchair Control Technologies

These days, consumers may choose from a wide variety of wheelchairs when they go shopping for one. It is a kind of design that takes into account a variety of forms and functions. In addition to its primary use, a wheelchair may also be utilized for a variety of physical activities. Wheelchairs may be broken down into conventional and nowadays technologies. The conventional wheelchairs, commonly referred to manual wheelchairs, are categorized as either self-propelled by the user through rotating the wheels, or attendant-propelled by another individual pushing from the rear. Some wheelchairs are equipped with sophisticated control systems, including joystick or Brain-Computer Interface (BCI) technology. The operating system and capabilities of each wheelchair are unique.

2.4.1 Conventional Approach of Wheelchair Technologies.

A manual wheelchair is a type of mobility aid that relies on the user's upper body strength for propulsion. This device is utilised by individuals with limited mobility to facilitate mobility and accomplish routine tasks. This paper provides an overview of various categories of manual wheelchairs, such as pushrim-propelled wheelchairs, crank-propelled wheelchairs, lever-propelled wheelchairs, geared manual wheelchairs, and pushrim-activated power-assist wheelchairs [28]. Wheelchairs that are operated manually often include two big wheels located in the rear with 24-inch diameter rear wheels and two smaller 8-inch diameter caster wheels located in the front. In certain configurations, the back of the chair may be equipped with anti-tip bars or wheels to forestall the chair from falling backwards over [29]. Manual wheelchairs come in a wide variety of styles and designs, some of which are intended for specific activities or terrain for example sports wheelchairs, lightweight wheelchairs and heavy-duty wheelchairs for larger users .Manual wheelchairs provide its users a measure of autonomy by eliminating their need on an external power source, as long as the user has the upper body strength and endurance to push themselves.

However, the loss of motor function in the lower limbs forces the upper limbs to execute the work of movement, which leads to a number of challenges for those who rely on manual wheelchairs for extended periods of time [30]. Furthermore, forces exerted to the pushrim during the first phase of wheelchair movement are much larger while going uphill or over uneven ground, as are rotating forces. Therefore, the risk of upper-extremity injuries may increase if the wheelchair is moved often across uneven surfaces [31]. Upper body strength limitations or other medical conditions impede a person from using a manual wheelchair properly. It may be challenging for someone with muscular dystrophy, spinal muscular atrophy, or another neuromuscular illness to push a manual wheelchair independently.

2.4.2 Modern Approach Of Wheelchair Technologies

Power wheelchairs, often known as motorised wheelchairs, are a major advancement in assisting persons with health issues move around. These high-tech devices have given individuals more flexibility to travel. Thus, those with weak upper bodies may move with easily. Electric power wheelchair controls are crucial. The joystick controls wheelchair speed and direction. The wheelchair's control system receives joystick commands to adjust speed and direction.

Due to the development of technology today, the conventional joystick could be replace with something more advance. Stated in “Motion control of joystick interfaced electric wheelchair for improvement of safety and riding comfort”, in order to improve the ease of use and security of the joystick type electric powered wheelchair, this study presents a new control system. The suggested system consists of a wheelchair's locomotion mode, a motion reference generator, wheelchair velocity controllers for both longitudinal and rotational motion, and a wheelchair motion observer based on the Kalman-Kucera Filter (KKF) where the system utilises the estimation of the motion state of the wheelchair, which is subsequently integrated into the control algorithm. [32].

However, in their 2018 study, Yassine Rabhi, Makrem Mrabet, and Farhat Fnaiech suggest control techniques and introduces a novel control system for a wheelchair that is operated through hand gestures. The proposed system utilises a visual recognition algorithm and artificial intelligence software. The system employs a camera that is affixed to the wheelchair to identify the movements of the patient's hand. The system then generates corresponding signals that are used to operate the wheelchair in real-time. Prior to conducting tests on the proposed control device, a three-dimensional environment simulator was developed to evaluate its performance under highly secure conditions. The new control interface of an electric wheelchair allow user to control wheelchair in new ways for the patients who are unable to use a wheelchair controlled by a conventional joystick [33].

Furthermore, Landu Jiang, Cheng Luo, Zexiong Lioa, Xuan Li, Qiuxia Chen, Yuan Jin, Kenzhong Lu, and Dian Zhang proposed an easy way for people and machines to work together to handle a robotic wheelchair directly which is called as SmartRolling. The system is capable of releasing operation commands by identifying various EEG patterns that are triggered by motor execution (ME) tasks. These tasks may include eye blinking, jaw clenching, and fist opening/closing.The system utilises inertial measurements and computer vision techniques to estimate the steering intentions of users based on their facing direction. Farnebäck's method is utilised to compute the dense optical flow, which estimates the displacement field between two consecutive frames. The method of least squares is employed for computing the coefficients. The outcome is derived by taking a weighted mean of all the coordinates in the vicinity [34].

Besides, in addition based on E Krishna, B Greeshma, N Reddy, and Y Reddy, they investigated the use of BCI for mobility aids. The study employs the Brainsense Headset, a non-invasive EEG headset, to capture artefact signals. The headset features a dry electrode for this purpose. The placement of the electrode is on the patient's forehead, specifically at the Fp1 location in accordance with the 10-20 electrode system. The Artefact detection method is a technique utilised to operate the wheelchair. An experimental configuration was established to assess the effectiveness of the system in executing user commands for carrying out intended actions.

The paper outlines a proposed system that utilises a headset to capture brain signals from individuals with disabilities. The aforementioned signals undergo processing to identify any artefacts and subsequently produce commands for the operation of a wheelchair. The signals are captured by the system through a dry electrode that is positioned on the patient's forehead. The study employed an experimental setup to evaluate the system's effectiveness in executing user commands to perform specific tasks [35].

2.5 Comparison Wheelchair Technologies

The following table presents a comparison of various methods of wheelchair technologies.

Table 2.2 Comparison wheelchair technologies

Authors	Method	Result	Advantage
Claire Flemmer and Rory Flemmer[28]	Relies on the user's physical strength for propulsion. The individual applies force on the hand rims, which are affixed to the sizable rear wheels. Manual wheelchairs have larger rear wheels, which provide stability when in use.	None mentioned	Manual wheelchairs are characterised by their lightweight construction, effortless steering, and exceptional indoor manoeuvrability.
Jung Choi, Younghun Chung, and Sehoon Oh. [32]	The system consists of two modes, the longitudinal mode, and the rotational mode, designed to control the wheelchair's motion. A motion reference generator was designed to set the joystick's sensitivity and response time independently in each direction. The Kalman-Kucera Filter (KKF) was used to estimate the wheelchair's motion state, and a feedback controller was designed to control the wheelchair's motion based on the estimated state. The system was evaluated through various experiments, and its validity was verified in terms of safety and comfort.	The control system significantly improved the safety and riding comfort of the user.	Improved safety and riding comfort of the user
Yassine Rabhi, Makrem	The paper proposes a new control system for a	The paper lacks an in-depth discussion of	The system provides a solution

Mrabet, and Farhat Fnaiech. [33]	hand gesture-controlled wheelchair using a visual recognition algorithm and AI software. A camera fixed on the wheelchair is used to recognize the patient's hand movements and derive corresponding signals to control the wheelchair in real-time. The proposed system was tested on real patients with diverse hand pathologies in a rehabilitation hospital in Tunis, and its validity was proved.	the outcomes achieved through the suggested control system. According to the authors, the "hand gesture-controlled wheelchair" device they designed is affordable and has undergone testing on actual patients, showing favourable outcomes.	for navigation assistance of intelligent wheelchairs for people with physical difficulties.
Landu Jiang, Cheng Luo, Zexiong Liao, Xuan Li, Qiuxia Chen, Yuan Jin, Kezhong Lu, and Dian Zhang. [34]	Uses EEG patterns from motor execution tasks such as eye blink, jaw clench, and fist open/close to issue operation commands. Estimates users' steering intentions based on their facing direction using inertial measurements and computer vision techniques. Calculates dense optical flow using Farnebäck's method with least square estimation and weighted averaging to estimate the displacement field between two adjacent frames.	The experiment shows that SmartRolling is effective and has great potential for promoting better health.The paper discusses improving system performance and possible extensions.	The consensus formed by the outputs of different decision trees trained on different subsets of the data can make the SmartRolling system more stable and reliable.
E Krishna, B Greeshma, N Reddy, and Y Reddy. [35]	Artifact detection method for operating the wheelchair.	An experimental setup was designed to evaluate the system's ability to execute user	The system is non-invasive, portable, and less expensive compared to other

	Non-invasive BCI-based EEG headset, Brainsense Headset, for artifact signal capturing with the help of a dry electrode in the headset. The electrode is placed on the forehead of the patient, exactly at the Fp1 location according to the 10-20 electrode system. An experimental setup was made to evaluate the efficiency of the system in processing the commands for performing desired actions by the user.	commands accurately. Different commands like 'front', 'back', 'left', and 'right' were sampled from healthy subjects across various age groups. 20 samples were collected from each person within a specific age group. In each age group, samples were collected from four different subjects . Accuracy was individually calculated for each subject within their respective age groups, resulting in values denoted as p1, p2, p3, and p4. The paper does not provide further explicit outcomes.	BCI-based systems.

2.6 Summary

The literature review section of the proposal examined various important areas of prior research to establish an appropriate foundation for the proposed project. The discussed topics mainly revolved around BCI, the analysis of brainwave patterns and the distinct features of EEG technology.

In conclusion, the literature review offered a deep understanding of the essential concepts, technologies, and methodologies that will play a major part in the successful completion of the intended project, which is the creation of a miniature wheelchair that can be controlled by thoughts. The insights obtained through these investigations will function as a directions reference point across various stages of project advancement, promising a technically strict and important result.

CHAPTER 3

METHODOLOGY

3.1 System Architecture

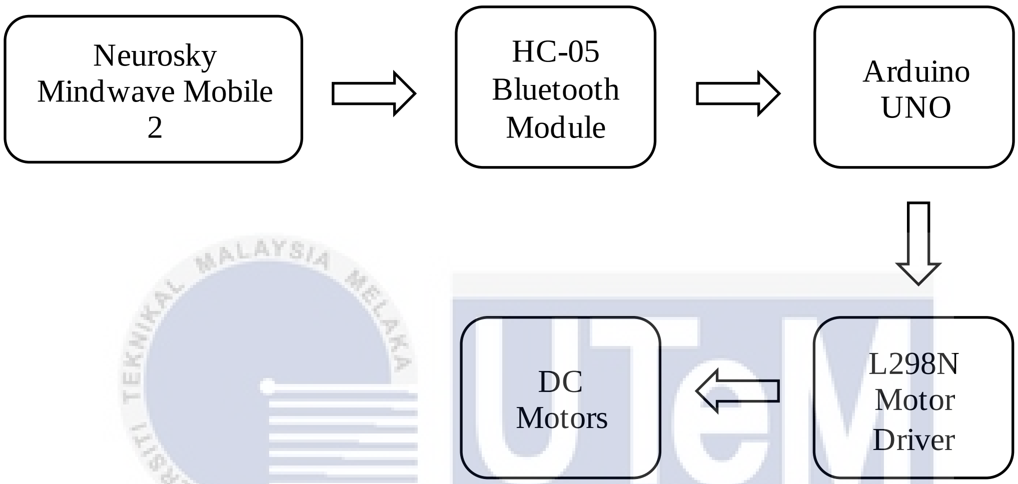

Figure 3.1 The block diagram of the hardware

The system begins with the utilisation of a Neurosky Mindwave Mobile 2 device that is specifically designed to capture and process the brainwave data of the user. After undergoing processing, the data is transmitted wirelessly through Bluetooth to HC-05 Bluetooth Module. The HC-05 Bluetooth Module serves as an intermediary to facilitate the transfer of information between the Mindwave Mobile 2 and the Arduino microcontroller that is integrated into the wheelchair.

The data is transmitted from the Arduino to the L298N motor driver, which is responsible for controlling the movement of the wheelchair. The motor driver is responsible for controlling two DC motors by adjusting their speed and direction based on the input data. This enables accurate management of the wheelchair's movement

3.2 Stage Development

To achieve the goal of creating a thought-controlled wheelchair, the development process has been divided into three main stages. The three stages are Algorithm Modelling and Hardware Development. The successful completion of each step-in sequence is crucial for the development of the system.

3.2.1 Algorithm Modelling

The mentioned stage serves as the fundamental structure of the wheelchair that is controlled by the user's thoughts. The first step is to develop an algorithm that can accurately process the input received from the Neurosky Brainwave Mobile 2. The objective of the algorithm is to identify distinct patterns in brainwave activity which attention and detecting eye blinking that correspond to the user's intended direction of movement, including forward, backward, left, or right. The process involves attention level (eSense) and eye blinks and their corresponding frequencies with distinct commands.

The miniature wheelchair's movement is governed by the algorithm, which is illustrated in the flowchart shown in Figure 3.2. This algorithm forms the basis for the wheelchair's operation. Regrettably, the code that was developed does not perform as anticipated. Although it accurately detects the user's degree of attention and blinking, the performance of tasks does not adhere to the specified conditions stated in the Arduino IDE. In addition, ineffective coding hinders the collection of data for future analysis.

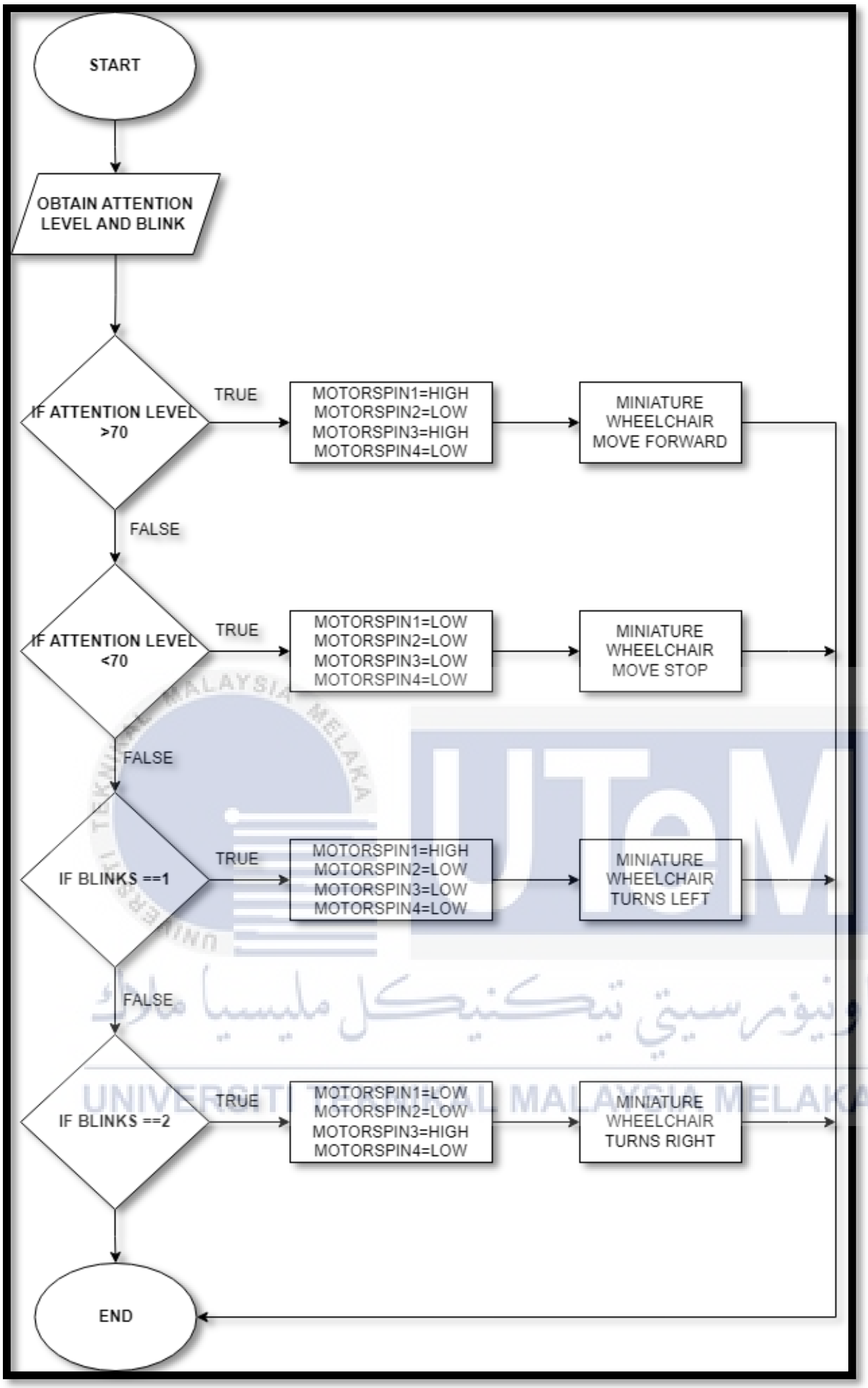

Figure 3.2 Condition for movement of miniature wheelchair

Figure 3.3 Neurosky Brainwave Mobile 2

3.2.1.1 eSense Meters(Attention & Meditation)

The metre value for all the different types of eSenses (such as Attention and Meditation) is reported on a relative scale of 1 to 100 but attention level has been utilize for modelling the algorithm. In this context, a value ranging from 40 to 60 is considered "neutral" and can be compared to the "baselines" used in traditional EEG measurements. However, it's important to note that the method for determining a ThinkGear baseline is unique and may differ from conventional EEG techniques. A value from 60 to 80 is considered “slightly elevated” and may be interpreted as levels being possibly higher than normal (levels of Attention). Values from 80 to 100 are considered “elevated”, meaning they are strongly indicative of heightened levels of that eSense.

On the opposite side of the spectrum, a value ranging from 20 to 40 suggests decreased levels of the eSense, while a value between 1 to 20 indicates significantly reduced levels of the eSense. These levels may suggest different states such as distraction, restlessness, or irregularity, based on the opposite of each eSense.

A value of 0 on the eSense meter signifies that the ThinkGear is unable to accurately calculate an eSense level. This may be (and usually is) due to excessive noise as described in the POOR_SIGNAL Quality section above.

The value of the unsigned one-byte indicates the user's current eSense Attention meter, which gauges their level of mental focus or attention. The data presented in the report demonstrates the user's high level of focus and consistent ability to think. The range extends from 0 to 100. Factors such as distractions, daydreaming, difficulty concentrating, or anxiety can lower the levels of the Attention meter.

3.2.2 Data Processing

After establishing the algorithm, the next step involves real-time processing of the data for controlling the wheelchair. The Arduino microcontroller is utilised for this specific purpose. The signals from the EEG device are sent into the Arduino system, which utilises the previously developed algorithm to interpret these signals into precise instructions. In the event that the algorithm detects the brainwave pattern that corresponds to a forward movement, it will proceed to analyse this information and generate a directive to advance the wheelchair in a forward direction. The Arduino Integrated Development Environment (IDE) software serves as the platform for data processing, facilitating the real-time control of the wheelchair in response to the user's thoughts.

Figure 3.4 Arduino IDE

3.2.3 Hardware Development

The last phase of the process is to put together every physical component of the system. The EEG device, Arduino microcontroller, wheelchair, and other essential hardware has been integrated. The components carefully arranged and assembled to ensure best compatibility.

3.2.3.1 Bluetooth Setting

The hardware development was started by configuring the HC-05 Bluetooth Module in order to able it to connect with the Neurosky Mindwave Mobile 2 headset for data transfer.

For a smooth and easy Bluetooth setup and pairing between the Neurosky Mindwave headset and the HC-05 module, it is crucial to follow a systematic sequence of steps. Starting with obtaining of the Neurosky Mindwave Headset address.

Figure 3.5 Neurosky Mindwave Headset address

The next steps involve uploading Arduino code for HC-05 configuration.

```
BT.begin(38400);
Serial.println("Bluetooth AT command mode");
```

Figure 3.6 Bluetooth serial AT command code

It is crucial to ensure that the connections are made correctly, with the Rx connected to PIN 11, Tx connected to PIN 10 on the Arduino, and a proper VCC pin connection.

To enable Command Mode on the HC-05 module, simply press the button on the module while the Arduino is starting up. The serial monitor acts as the channel for sending AT commands to the HC-05 module.

The sequence of commands starts with the basic "AT" command. For the technical setup, make sure to set the UART baud rate to 57600 without any parity or flow control. Set the Bluetooth role as peripheral and use the password "0000". Adjust the communication mode to 0 and utilise the AT+BIND command with the provided address (1234,56,ABCDEF) E07D,EA,E60374. Configure the AT+IAC to 9E8B33 and execute the AT+CLASS=0 command. Lastly, enter the AT+INQM=1,9,48 command.

i. AT
ii. AT+UART=57600,0,0
iii. AT+ROLE=1
iv. AT+PSWD="0000"
v. AT+CMODE=0
vi. AT+BIND=<Address> (1234,56,ABCDEF) E07D,EA,E60374.
vii. AT+IAC=9E8B33
viii. AT+CLASS=0
ix. AT+INQM=1,9,48

Figure 3.7 List Of AT Command

Expect a "OK" output as confirmation after sending each AT command.

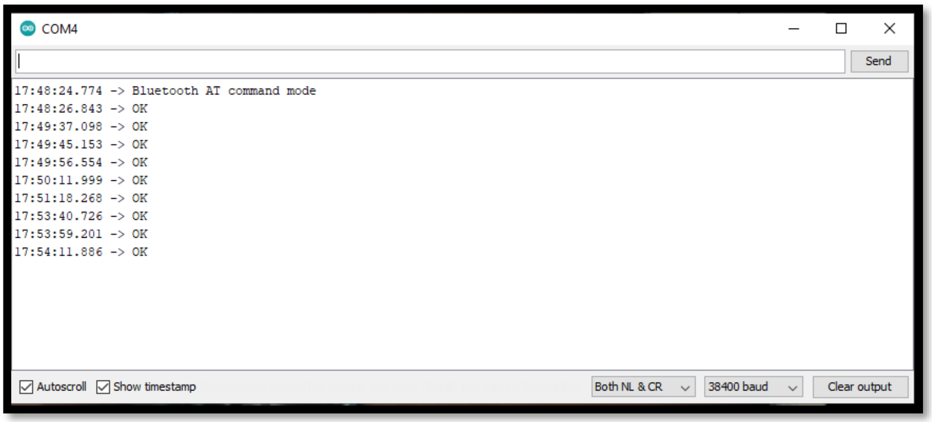

Figure 3.8 Serial Monitor Output

After successfully executing all commands, it is recommended to disconnect the Arduino from the PC in order to exit AT command mode. Reconnect the Arduino to the computer and turn on the headset to complete the setup process for the HC-05 module and establish a smooth connection with the Neurosky Mindwave headset. The HC-05 module will blink rapidly if the Neurosky Mindwave headset is not connected. Once it is connected, the LED on the HC-05 module will blink every two seconds.

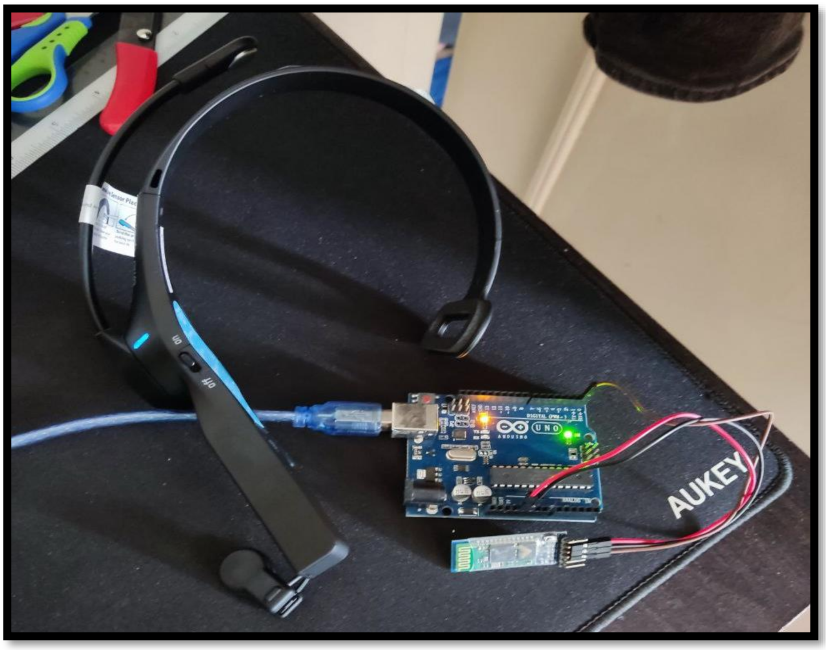

Figure 3.9 Neurosky Mindwave Mobile 2 successfully connected to HC-05

3.2.3.2 Miniature Wheelchair Development

The development process of a miniature wheelchair starts by acquiring necessary components like Arduino, two DC motors, L298N motor driver, and a power supply. After obtaining these items, the next step is to connect the different elements in a methodical way.

The Arduino to L298N Motor Driver Connection involves the allocation of specific pins for various functions. Pin 5 on the Arduino Uno is connected to the ENA pin on the L298N Motor Driver. Pin 9 is connected to IN4, pin 8 to IN3, pin 7 to IN2, pin 6 to IN1, and pin 10 to ENB. This wiring setup enables the essential communication channels between the Arduino and the motor driver.

When establishing the connection between the Arduino and HC-05 Bluetooth Module, it is important to note the pin connections. The VCC pin on the HC-05 Bluetooth Module should be connected to the 5V pin on the Arduino Uno. Similarly, the HC-05 TX pin should be linked to the Arduino RX pin, and the HC-06 GND pin should be connected to the

Arduino GND pin. This connection facilitates communication between the Arduino and the Bluetooth module, allowing for remote control.

A battery cable is used to connect the Arduino Uno to the 9 Volts battery in the Arduino power input setup. A switch is included in the circuit, providing easy control over the power supply to the Arduino.

To connect the L298N Motor Driver to DC motors, you need to link the OUT1 and OUT2 terminals on the driver to the positive and negative terminals of the motor. In addition, OUT3 and OUT4 are linked to the positive and negative terminals of another DC motor. This setup guarantees optimal motor control via the motor driver.

Finally, the connection between the L298N Motor Driver and the 12 Volts Power Supply is made by linking the 12V pin on the motor driver to the positive terminal of the power supply. Similarly, the GND pin on the motor driver is connected to the negative terminal of the battery holder. A switch has been incorporated into the circuit to facilitate power management.

In summary, this detailed setup serves as the basis for a fully operational miniature wheelchair, demonstrating the seamless integration of electronic components to achieve precise control over mobility.

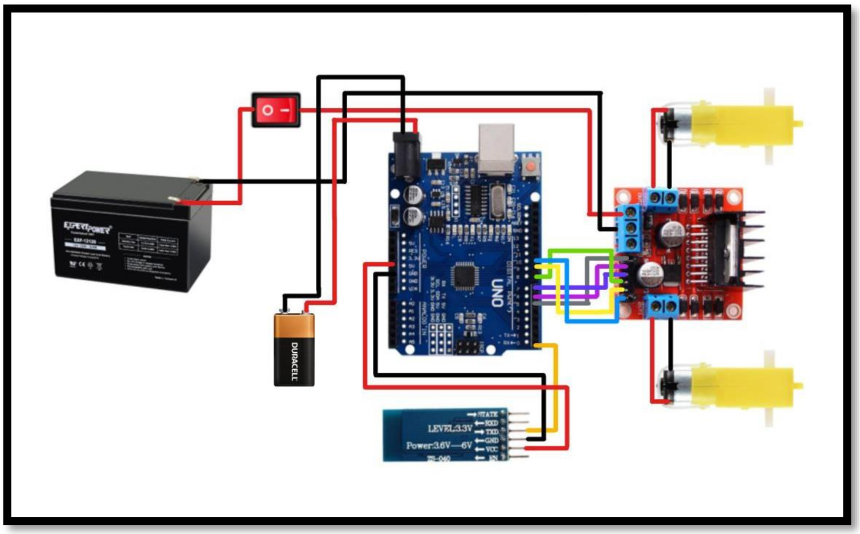

Figure 3.10 The circuit of miniature wheelchair

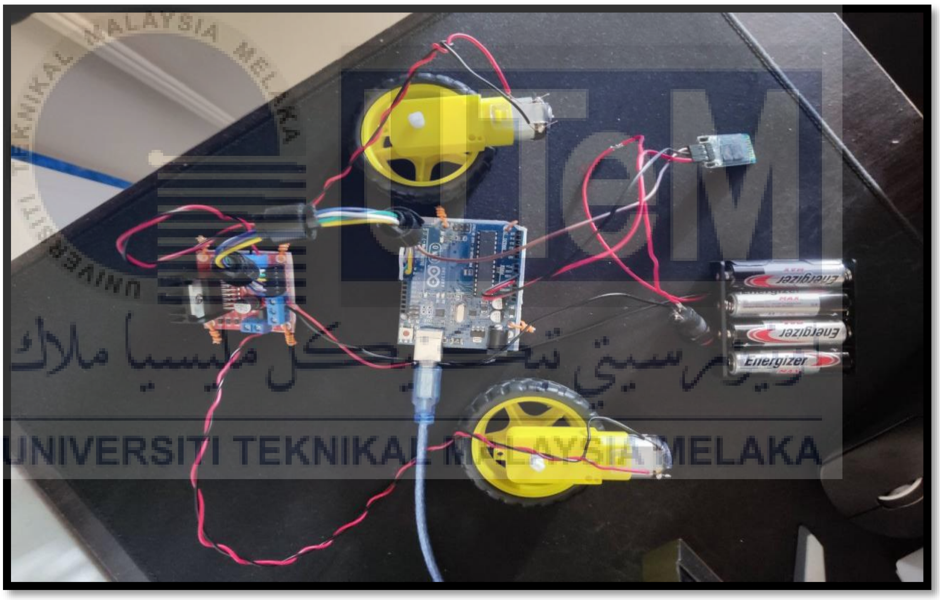

Figure 3.11 Hardware development

3.3 Testing

Prior to uploading the code onto the Arduino Uno, a comprehensive testing step was conducted to verify the code's integrity and functionality by compiling the code using Arduino IDE. After the code was uploaded, the hardware showed some unexpected operational errors, despite the initial debugging efforts that were made. In response, a comprehensive analysis of the code was conducted, during which various issues were explored. In terms of how functions were triggered, a thorough examination of the program's execution was carried out to ensure its accuracy. In addition, the investigation covered the confirmation of proper function usage, the validation of parameter and pin declarations' accuracy, and the verification of the Arduino library's integration into the code. Through a thorough examination, the aim was to pinpoint and resolve any variations that might obstruct the smooth interaction between the code and the Arduino Uno, as well as its connected components.

Despite making several adjustments to the hardware, it still experiences functionality problems. Afterwards, a thorough examination of the hardware was carried out to confirm that there was no damage. The hardware specifications were reviewed to ensure the compatibility of the components.

As part of the evaluation process, a thorough analysis was conducted to determine the optimal voltage needed for the successful operation of the DC motor. It was determined that the DC motor has a voltage range of 3 to 12 Volts. The power supply of 6 Volts should, in theory, be adequate for the motor to function.

Tests was conducted on both DC motors by directly connecting them to the power supply. Based on the test results, it can be concluded that the performance of both DC motors was satisfactory, indicating their excellent condition.

As a result, the power supply was upgraded from 6 Volts to 12 Volts. Next, the positive pin of the 12 Volts supply was connected to the input pin of the L298N Motor Driver.

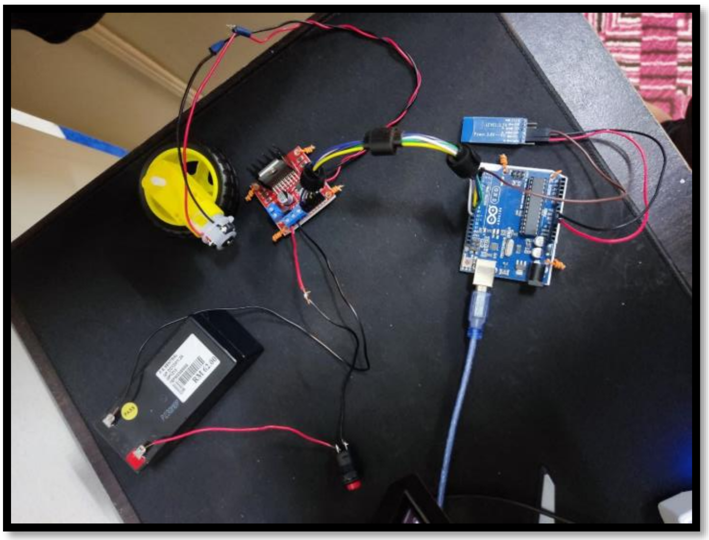

Figure 3.12 Hardware testing process

Afterwards, the hardware testing process was repeated to confirm if the hardware would now operate in line with the programmed system. The constant conclusion indicates that the problem is not caused by the hardware, but rather by the programming. The code seems to be lacking optimization, resulting in the Arduino's inability to operate the associated DC motor.

3.4 Summary

To summarise, the process involved setting up the HC-05 to enhance accessibility for the Neurosky Mindwave Mobile 2, allowing for data transfer via communication. Despite the careful and detailed configuration process, the construction of the small wheelchair was ultimately unsuccessful. The code's inefficiency in controlling the miniature wheelchair's movement presented a major challenge. This constraint underscores the necessity for additional improvement in the coding element to guarantee smooth communication and efficient control, emphasizing the complex problems faced during the development process.

CHAPTER 4

RESULTS

4.1 Introduction

Throughout the testing phase, the output from the Arduino IDE serial monitor is relied upon as the only source of results. The results can be divided into two main aspects: firstly, the findings regarding the identification of attention levels and blink detection, and secondly, the outcomes of integrating these identified attention levels into the wheelchair movement system.

4.2 Identification Of Attention Level and Blink Detection

The code provided extracts the attention value from the payload data transmitted by the NeuroSky Mindwave headset to determine the level of attention. The attention value is an essential part of the payload structure transmitted by the headset during communication.

```
case 4:
  i++;
  _attention = _payloadData[i];
  break;
```

Figure 4.1 Attention value retriving from payload

Within this section, when the payload type is 4 (hexadecimal 0x04), the code proceeds to increment the index (i) and retrieve the attention value from the payload data. It then proceeds to store this value in the _attention variable.

The attention value is a metric that quantifies the user's level of focus, as detected by the Mindwave headset. The value ranges from 0 to 100, with higher values generally indicating greater levels of attention. The headset analyzes EEG signals to determine the level of attention, with a specific focus on brainwave patterns associated with mental states related to attention.

Figure shown the analyse of the signal quality received by the sensor and assess the amount of attention using the ‘onMindWaveData()’ function. This function allows Arduino to obtain data from the sensor using a Neurosky-developed algorithm. When the user is not wearing the headset, the Quality and Attention values are left blank, indicating that the sensor is unable to detect any brainwave signals at that time.

```
void onMindwaveData() {
  Serial.print("Quality: ");
  Serial.println(mindwave.quality());
  Serial.print("Attention: ");
  Serial.println(mindwave.attention());
  Serial.println();
}
```

Figure 4.2 ‘onMindwaveData()’ function implimentation

When the headset is worn, the brainwave readings become detectable, and their values are displayed on the Serial Monitor. During this phase, users are given specific objectives to concentrate on, making it easier to observe changes in attention levels between periods of focus and distraction. Based on the data, an attention level close to 100 suggests a high level of focused engagement. Methods like numerical counting or participating in reading exercises are recommended to improve levels of focus, as indicated by the recorded data.

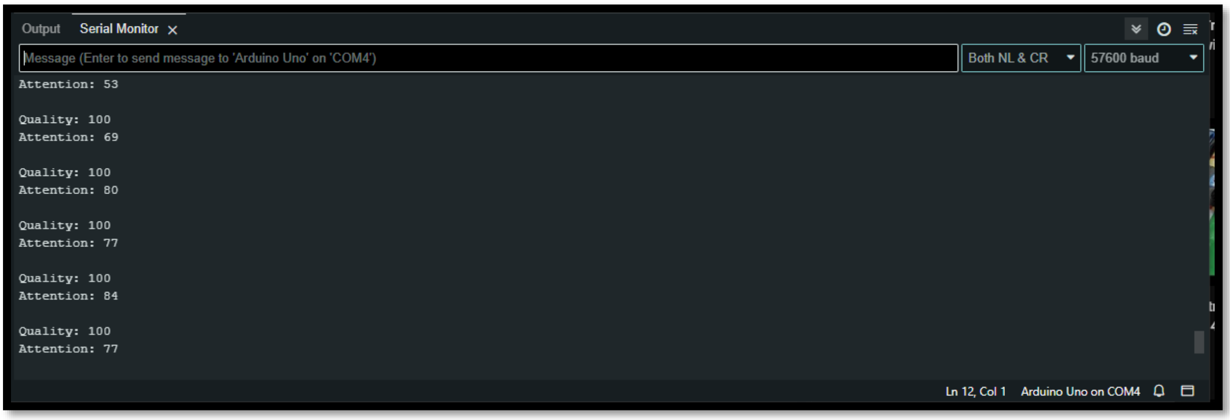

Figure 4.3 Attention level while in focus

Upon further examination of the data displayed on the serial monitor, it became apparent that there was a decrease in the attention level value. This decrease indicates a lack of focus, possible stress, or outside disruptions encountered by the user. An almost zero value indicates that the user is in a state of distraction. The extracted values, to some extent, provide evidence that supports the feasibility of creating a wheelchair that can be controlled based on an individual's level of attention.

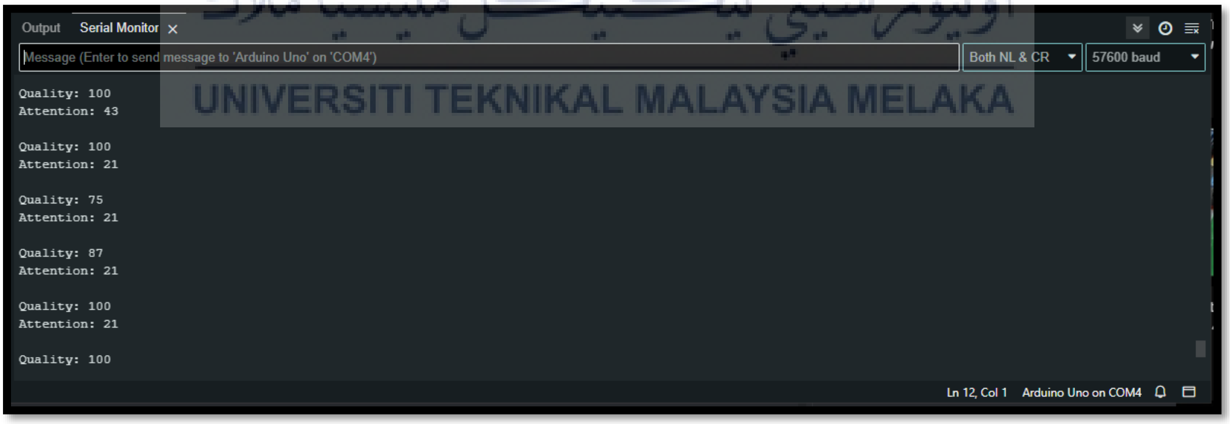

Figure 4.4 Attention level Attention level while distracted

The blink detection technique in the given code utilizes the unprocessed EEG data delivered by the NeuroSky Mindwave headset. Upon detecting a blink event, the headset incorporates this data into the payload, assigning it a specific payload type (0x80). The algorithm retrieves the unprocessed EEG data linked to eye blinks and turns it into a signed integer. A sliding sum (PiekP) is subsequently computed over a set of 50 EEG data points, spanning a time window of 71 previous values. The identification of eye blinks is accomplished by examining whether certain criteria are satisfied, which results in the detection of positive peaks in the sum. These requirements consist of the gliding total beyond a specific threshold, the lowest value in the sum being negative, and supplementary checks to prevent false detections. When a blink is detected, a counter (_n) is increased, and the piekDetected flag is set to true, indicating the occurrence of an eye blink. In order to avoid detecting blinks too frequently, the algorithm resets the blink detection after a designated time period of 450 milliseconds. In summary, the blink detection algorithm effectively analyzes the unprocessed EEG data to recognize significant patterns related to blinks, hence improving the accuracy of the detection procedure.

```
case 0x80:   // Raw data for blink
  if (_payloadData[i + 1] == 2) {
    Hilf = ((long)_payloadData[i + 2] * 256 + (long)_payloadData[i + 3]); // read the most significant two bytes and form a signed number of it
    if (Hilf > 32767) Hilf -= (long)(65535);
    Data[_i] = (int)Hilf;

    // PiekP is a gliding sum over 50 values of Data 71 values of Data in the past, 71 values are reserved for the minus peak PiekM
    PiekP += Data[(512 + _i - 71) % 512];
    PiekP -= Data[(512 + _i - 50 - 71) % 512];

    // Test, if PiekP exceeds a certain value and the youngest value of PiekP is negative and it has no huge values
    if ((PiekP > 3000) && (Data[(512 + _i  - 70) % 512] < 0) && (PiekP < 13000)) { // The next eye blink detection is enabled only after a certain elapse time

      if (millis() - piekTime > 100) { //time
        PiekM = 0;
        // After detecting a positive peak PiekP the following 70 values are summed up and tested, if more negative than a certain value
        for (int j = 1; j <= 70; j++)
          PiekM +=  (int)(Data[(512 + _i  + j - 70) % 512]);

        //Sometimes big negative numbers appear, which are suppressed by a limit for the negative values, if they are to huge
        if (PiekM < -3000 && PiekM > -11000) {

          if ((millis() - piekTime) < 400)_n++; else _n = 1;
          piekTime = millis();  // piekTime is the time at which the eye blink has been detected
          piekDetected = true;  // piekDetected is set true, when an eye blink has been detected

        }// end if PiekM (eyeblink detected)
      }//end elapse time
    }// end PiekP detect
    _i++;
    if (_i >= 512) _i = 0;
  }
  i = i + 3;
  break;
```

Figure 4.5 Blink detection algorithm

Blink detection can be effectively identified through the utilization of the 'onMindwaveBlink()' function. This function aids in discerning the value of the blink detection signal, offering a valuable mechanism for detecting instances of blinking.

```
void onMindwaveBlink() {
 if (mindwave.blink() == 1) {
    Serial.println();
    Serial.println("Single Blink!");
    Serial.println();
  }

  if (mindwave.blink() == 2) {
    Serial.println();
    Serial.println("Double Blink!");
    Serial.println();
  }
```

Figure 4.6‘onMindwaveBlink()’ function implementation

4.3 Miniature Wheelchair Movement System

Once the relevant data on attention level and blink values can be accessed via a designated function, the wheelchair can be controlled using this information.

```
// Check Attention Level
   if ((mindwave.attention() > 70) && (gosignal == 0)) {
      Serial.print("Go, ");
      Serial.print("\tattention: ");
      Serial.print(mindwave.attention());
      time = millis();
      Serial.print("\ttime: ");
      Serial.print(time);
      Serial.println();
      gosignal = 1;              // indicates going
      forward();          // motor move forward
      delay(4000);              // go for 4 seconds before checking
    // if attention has dropped
   }
```

Figure 4.7 Move forward condition

Figure 4.7 is a component of a larger program that interacts with the NeuroSky Mindwave Mobile 2 headset and manages a system, the miniature wheelchair, by analyzing the user's attention level. The conditional statement verifies if the attention level acquired from the Mindwave headset exceeds 70 and if a "go signal" has not been previously dispatched. This check is conducted to assess the user's level of focus and attentiveness before proceeding with a forward movement.

```
if ((mindwave.attention() < 70) && (gosignal == 1)) {
    Serial.print("Stop, ");
    Serial.print("\tattention: ");
    Serial.print(mindwave.attention());
    time = millis();
    Serial.print("\ttime: ");
    Serial.print(time);
    Serial.println();
    gosignal = 0;            // indicates stopped going
    stop();      // motor move stop
}
```

Figure 4.8 Stop condition

Figure 4.8 is a conditional statement to stop the miniature wheelchair. In this scenario, the condition verifies whether the attention level, derived from the Mindwave headset, is below 70, and if the system is presently in a situation where a "go signal" has been previously transmitted (gosignal == 1). If these conditions are satisfied, the miniature wheelchair should stop.

If both of the condition is satisfy serial output will print just like in Figure 4.9.

```
Go,     attention: 75   time: 118490
Stop,   attention: 41   time: 125481
```

Figure 4.9 Movement of miniature wheelchair for forward and stop

Figure 4.10 handles the task of determining the appropriate direction for the miniature wheelchair to turn, taking into account the results obtained from blink detection. To determine the occurrence of a blink, the program verifies if only one blink is detected (blinks == 1), it signifies a left turn. In the same vein, when it comes to a double blink, it verifies whether a double blink has been identified (blinks == 2), it signifies a right turn.

```
// Single blink to turn left
  if ((blinks == 1) && (blinksignal > 3)) {
    Serial.print("Left, ");
    Serial.print("\tSingle blink ");
    time = millis();
    Serial.print("\ttime: ");
    Serial.print(time);
    Serial.print("\tgosignal: ");
    Serial.print(gosignal);
    Serial.print("\tblinksignal: ");
    Serial.print(blinksignal);
    Serial.println();
    blinksignal = 0;           // reset for next blink(s)
    turnLeft();
    delay(2000);
  }
// Double blink to turn right
  if ((blinks == 2) && (blinksignal > 3)) {
    Serial.print("Right, ");
    Serial.print("\tDouble blink ");
    time = millis();
    Serial.print("\ttime: ");
    Serial.print(time);
    Serial.print("\tgosignal: ");
    Serial.print(gosignal);
    Serial.print("\tblinksignal: ");
    Serial.print(blinksignal);
    Serial.println();
    blinksignal = 0;           // reset for next blink(s)
    turnRight();
    delay(2000);
  }
}
```

Figure 4.10 Movement of miniature wheelchair for turn left and right

```
First blink     quality: 87     time: 162408    gosignal: 0     blinksignal: 0
        quality: 87     time: 162410    gosignal: 0     blinksignal: 1
        quality: 100    time: 163430    gosignal: 0     blinksignal: 2
        quality: 87     time: 164412    gosignal: 0     blinksignal: 3
        quality: 87     time: 164413    gosignal: 0     blinksignal: 4  time1: 2003     blinks now = 2
Right,  Double blink    time: 164427    gosignal: 0     blinksignal: 4
```

Figure 4.11 Miniature wheelchair being signal to turn left


```
First blink     quality: 87     time: 152429    gosignal: 0     blinksignal: 0
        quality: 87     time: 152431    gosignal: 0     blinksignal: 1
        quality: 100    time: 153435    gosignal: 0     blinksignal: 2
        quality: 100    time: 154444    gosignal: 0     blinksignal: 3
Left,   Single blink    time: 154445    gosignal: 0     blinksignal: 4
```

Figure 4.12 Miniature wheelchair being signal to turn right

4.4 Hardware Implementation

The Bluetooth module and the L298N motor driver are linked to an Arduino, which serves as the central processing unit for executing commands to control the prototype wheelchair's movements. These commands, written in code, enable the wheelchair to travel forward, stop, turn right, and turn left.

Figure 4.13 Neurosky Mindwave Mobile 2 headset connected to HC-05

The purpose of the Bluetooth module is to establish a link between an Arduino and the Neurosky Mindwave Mobile 2 headset. This connection enables the Arduino to analyze brain waves and translate them into instructions for miniature wheelchair, based on the predefined circumstances specified in the code.

Figure 4.14 The miniature wheelchair

The L298N motor driver regulates the motion of the motor and wheel, enabling forward, stop, right, and left movements. When the attention level surpasses 70, the Arduino transmits a signal to the motor driver, resulting in the forward rotation of both motors. Conversely, if the attention level falls below 70, both motors will cease spinning. To maneuver the miniature wheelchair to the right, the left motor will move forward while the right motor will travel backward. To move the wheelchair to the left, the right motor will move forward while the left motor will move backward.

Figure 4.15 Neurosky Mindwave Mobile 2 headset wear by a user

The Figure 4.16 and Figure 4.17 below portrays the miniature wheelchair moving forward as the user wears the headset and attempts to concentrate.

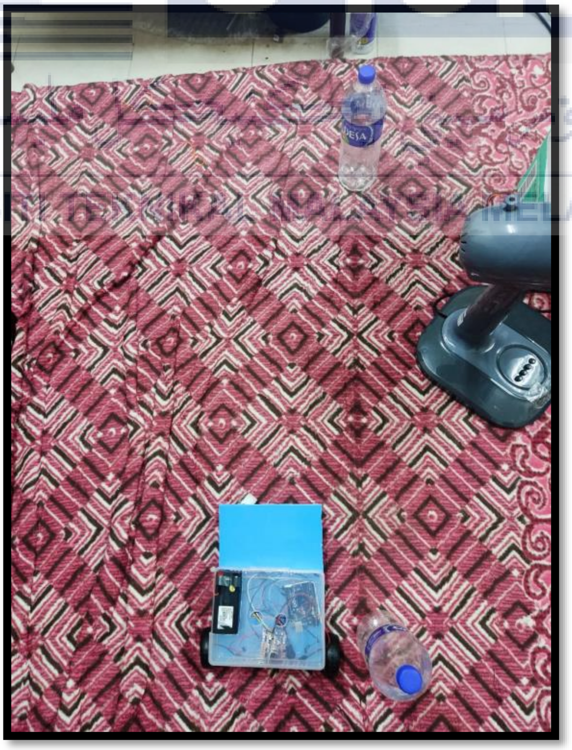

Figure 4.16 The miniature wheelchair before moving forward

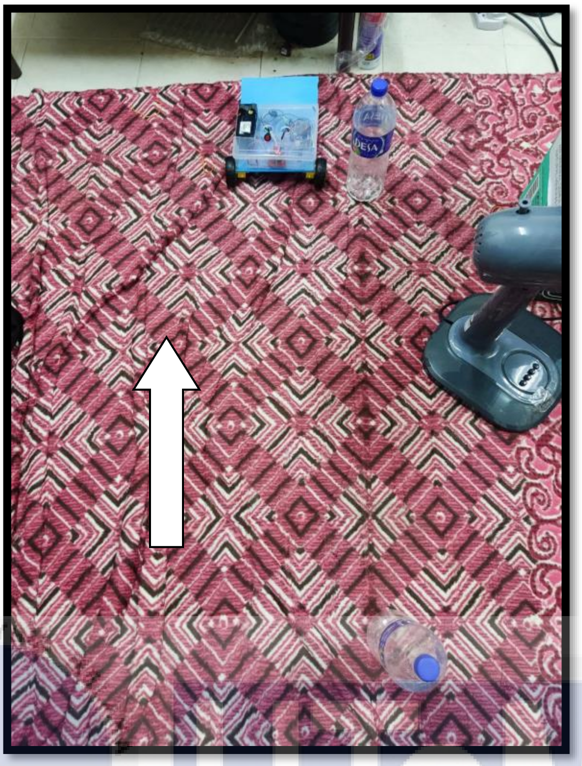

Figure 4.17 The miniature wheelchair moving forward

4.5 Result And Discussion

The data collection for this project relies on the time taken for data to be transmitted from the Neurosky Mindwave Mobile 2 headset to the Arduino UNO in order to control the wheelchair. The test conducted five times for each movement of the miniature wheelchair(forward, stop, turn right and turn left) to calculate the average time taken for the wheelchair to receive instructions from the headset.

Table 4.1 Miniature wheelchair movement analysis

Movement	Time taken for data to be transmitted from the Neurosky Mindwave Mobile 2 headset to the Arduino UNO(s)					Average(s)
	1st Trial	2nd Trial	3rd Trial	4th Trial	5th Trial	
Forward	10.46	6.56	10.44	4.64	8.09	8.64
Stop	7.69	6.61	6.77	7.12	12.02	8.44
Turn Right	6.30	5.31	5.43	4.88	4.34	5.25
Turn Left	3.84	4.40	3.24	3.49	3.81	3.96

The table provided contains important findings from experiments carried out on a small-scale wheelchair, highlighting different movements like forward, stop, turn right, and turn left. Every row in the table shows a different action, and the columns represent separate attempts, with the duration (in seconds) noted for each attempt. This dataset is essential for understanding how the miniature wheelchair performs during various activities.

Upon thorough examination of the data, significant variations are observed in the time taken for executing different movements across various trials. Notably, the "Forward" movement exhibits diverse durations, ranging from 4.64 seconds to 10.46 seconds, indicating fluctuations in the performance of mind-controlled forward movement. Similarly, the "Stop" movement demonstrates variability in execution times, with durations spanning from 6.61 seconds to 12.02 seconds, reflecting the challenges associated with halting the miniature wheelchair based on attention levels.

Moreover, the "Turn Right" and "Turn Left" movements, which are initiated by specific blink patterns, display their own sets of complexities. While turning right, the miniature wheelchair records times ranging from 4.34 seconds to 6.30 seconds, whereas turning left entails durations varying from 3.24 seconds to 4.40 seconds. These variations suggest nuances in interpreting blink signals for directional changes.

To determine the central tendency of the time taken for each movement, the average time from all trials is computed. This statistical measure offers valuable insights into the average time needed to complete each action. The average duration for the "Forward" movement is approximately 8.64 seconds, while for the "Stop" movement, it is around 8.44 seconds, “Turn Right” approximately 5.25 seconds and “Turn Left” for 3.96 seconds, demonstrating the typical performance standards for these activities.

This thorough examination assesses the consistency of the miniature wheelchair's performance during various movements and highlights the difficulties and complexities of mind-controlled navigation. Moreover, it emphasises the importance of improving the control algorithms to boost the efficiency and reliability of the miniature wheelchair's responses to user inputs, ultimately enhancing its usability in real-world situations.

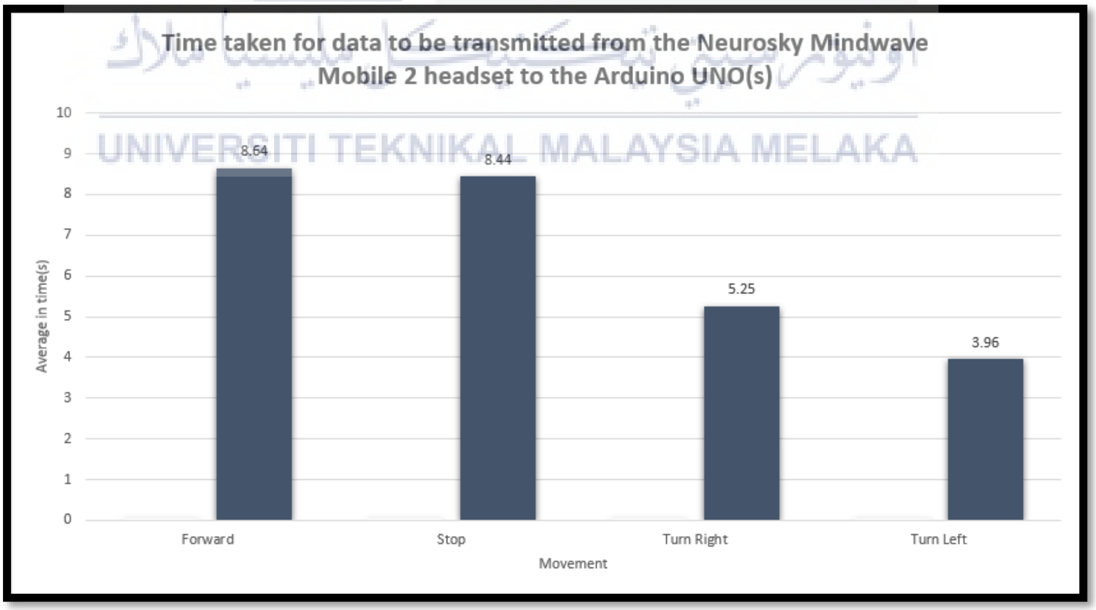

Figure 4.18 Bar chart for average time taken(s) for every movement of miniature wheelchair

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project has aimed to delve into the domain of brain-computer interface (BCI) technology, specifically focusing on thought control. The objectives centered on studying the feasibility of thought-controlled interfaces, designing an algorithm for brain signal acquisition using the Neurosky Brainwave Mobile 2 device, and conceptualizing a miniature prototype of a thought-controlled wheelchair.

Through this endeavor, significant insights have been gleaned into the potential and challenges of BCI technology in facilitating direct interaction between the human brain and external devices. Utilizing the Neurosky Brainwave Mobile 2 device, an algorithm has been devised for acquiring brain signals, laying the groundwork for further exploration and refinement of this technology.

Moreover, the development of a conceptual prototype of a thought-controlled wheelchair underscores the transformative prospects of BCI technology in augmenting mobility and autonomy for individuals with physical impairments. While the prototype represents an initial step in this direction, it emphasizes the necessity for ongoing research and innovation to enhance the efficacy and usability of such systems for practical implementation.

In summary, this project has provided valuable insights into BCI technology's potential to revolutionize human-computer interaction. Future endeavors in signal processing algorithms, hardware integration, and user interface design hold promise for unlocking new avenues to enhance the quality of life for individuals with diverse needs.

5.2 Potential for Commercialization

Brain-controlled wheelchairs, which aim to offer those with restricted mobility a novel method of navigation, have always been a fascinating topic in the field of assistive technologies. The utilization of brain signals, particularly attention levels and blinks, to govern the motion of wheelchairs signifies a pioneering convergence of neuroscience and engineering. Although the potential advantages are clear, there are currently multiple obstacles and restrictions that hinder the commercialization of these wheelchairs controlled by thought.

An essential challenge resides in the technological complexities of precisely decoding and converting brain impulses into dependable wheelchair motions. Although there have been improvements in brain-computer interface (BCI) technology, achieving the necessary level of accuracy for safe and efficient control still presents a significant obstacle. External considerations, such as ambient noise, user variability, and the requirement for consistent signal quality, impact the sensitivity of detecting attention levels and blinks.

The expenses involved in the development and production of brain-controlled wheelchairs are substantial, encompassing advanced hardware, software, and careful testing procedures. The aspect of affordability is essential in guaranteeing broad accessibility. Regrettably, the substantial expenses associated with research, development, and regulatory compliance may lead to a pricing level that limits the accessibility for those individuals who would gain the greatest advantage.

The concept of brain-controlled wheelchairs is undoubtedly revolutionary, but the process of transitioning from research and development to commercialization is filled with difficulties. In order to fully harness the capabilities of thought-controlled wheelchairs and ensure their availability to those who use them the most, it is imperative to tackle these obstacles as the field of brain-computer interfaces progresses.

5.3 Future Works

To enhance future advancements, it is advisable to refrain from performing all the processing using the Arduino IDE stand alone. Instead, make use of the complimentary developer tools given by Neurosky to develop software or applications that can enhance the signal processing, making it more efficient and accurate. A comprehensive understanding of how brainwaves can be translated into data, along with advanced signal processing and diligent data gathering, is crucial to effectively comprehend and ensure the successful growth of this effort.

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APPENDIX

DEVELOPMENT OF BCI FOR THOUGHT-CONTROLLED WHEELCHAIR USING ARDUINO

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