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FINAL YEAR PROJECT

DEVELOPMENT AND ANALYSIS OF HEAD TRACKING SYSTEM FOR ROBOTIC WHEELCHAIR CONTROL

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Bachelor of Electrical Engineering (Control, Instrumentation & Automation)

2016

“I hereby declare that I have read through this report entitle “Development and Analysis of Head Tracking System in Robotic Wheelchair Control” and found that it has been comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation).

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VINCENT YAP KINN SHENG

A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

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2016

I declare that this report entitle "Development and Analysis of Head Tracking System for Robotic Wheelchair Control" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………….

Name : VINCENT YAP KINN SHENG

Date : 8.6.2016

Dedicated to my lovely father, mother and sister

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ABSTRACT

Quadriplegia patients have restricted limb movements due to injuries in spinal cord or brain. Most of them only able to move their eyes and head partially depends on the level of damages. This project is aimed to develop a hands-free motorized wheelchair controlled by head movement of users to assist the patients for daily movement without the help from others. An Inertial Measurement Unit (IMU) will be attached on user's head to sense and track user's head orientation. Inertial Measurement Unit is an electronic device that normally consists of an accelerometer and gyroscope. Different head orientation represents different command such as accelerate, stop, turn right, turn left, and reverse. NI myRIO will be used as controller while LabView software will use to program NI myRIO in this project. Inertial Measurement Unit will be connected to NI myRIO for signal processing before sending command to the wheelchair motors. Algorithm for this project is a signal processing filter named Complementary Filter to process raw signals obtained from Inertial Measurement Unit into a less noisy and more precise data. Signals obtained from the devices will be further analyzed, compared and discussed.

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CHAPTER 1

INTRODUCTION

1.1 Background

Statistics revealed that approximately 11,000 new spinal cord injuries occur each year in United States. Among them, 52% of spinal cord injured individuals are considered paraplegic and 47% quadriplegic [1]. Quadriplegia is a disease that cause major losses of human's limbs mainly shoulder and below by spinal cord and brain damages. There are a few levels of spinal cord injuries such as from C1-C7 that leads to quadriplegia. The loss is usually sensory and motor, which means that both sensation and control are lost [2]. Great people like Stephen Hawking and Max Brito have been suffering from this crippling phenomenon [3]. Thus, people who suffers from quadriplegia have very restricted movement in their daily living.

1.2 Motivation

A wheelchair is very crucial for quadriplegics as they relies on it to move around in their entire life. They can choose to use a normal wheelchair with the help of another person, or a motorized electric wheelchair that does not require hand control due to restricted hand movement. The price of a hands-free motorized wheelchair is high and not affordable for normal families. In past few years, there are plenty of new technologies applied to develop a hands-free motorized wheelchair by controlling the movement of wheelchair using head part of quadriplegics. For example, eye-tracking method – by using number of eye blink and eyeball movement to control wheelchair [19], EEG method – by using brain attention level to move a wheelchair [5], Head orientation method – by using a camera to capture and differentiate user's head position. [8] By considering the limitations of other wheelchair systems, this project will be proposing a head tracking system by using an Inertial Measurement Unit emphasizing low cost, more robust and higher stability to assist quadriplegics for their daily movement.

1.3 Problem Statement

Conventional motorized wheelchairs are usually controlled by users using a joystick. However, it is not suitable for Quadriplegia patients who have restricted limb movements that only able move their eyes and head partially. Recently, there are plenty of new technologies being invented to design a wheelchair system mainly for quadriplegics. For instance, eye-blinking detection and head movement detection by using image processing technologies, or EEG headset by detecting brain signals.

There are a few disadvantages by using image processing method in detecting eye-blink or head movement, such as a camera need to be placed in front or behind the user to capture eye and head movement. This makes the system become bulky. Another disadvantage is that a camera could not capture user's image properly in a low light and dark condition. It causes the wheelchair unstable and fail to move smoothly in such environment. A better resolution or large sensor camera with an infrared might improve the system but it also increases the cost. [8][19]

On the other hand, an EEG headset that detects brain signal also leads to some disadvantages. For example, the signal from the headset is not as stable as image processing method. Human's brain signal fluctuates a lot and it cannot be detected accurately by an EEG headset. To control the wheelchair, users have to focus on something to increase the attention level detected by EEG headset. This will causes some problem because human tends to think or focus on something unintentionally. [5]

Thus, head orientation tracking by using an Inertial Measurement Unit (IMU) is proposed in this project. Data received from IMU will be processed by NI myRIO and send an ‘Accelerate’, ‘Stop’ , ‘Reverse’ and direction command to the wheelchair motor to replace conventional joystick navigation. Inertial Measurement Unit consists of accelerometer and gyroscope. However, accelerometer is sensitive to vibration that even small force working on the object will disturb its measurement completely. A low-pass filter is needed to filter out unwanted signals to minimize disturbance. [20] While a gyroscope outputs angular rate instead of absolute measurement. It is likely to drift and gives a value other than zero even though the object is in rest.

Hence, a filter is needed to correct the error that produced by both accelerometer and gyroscope. Complementary Filter is proposed in this project to overcome this problem so that a smooth signal can be obtained in NI myRIO to process and command a motorized wheelchair. The wheelchair is aimed to be implemented in a cost effective way which reduces the complexity in the design, and to be used as a human-friendly interface for a quadriplegia patient.

1.4 Objectives

1. To replace joystick control with head movement control in motorized wheelchair for quadriplegics.
2. To detect patient’s head orientation with a 5 DOF Inertial Measurement Unit (IMU).
3. To implement Complementary Filter to process data obtained from Inertial Measurement Unit (IMU).
4. To use National Instruments myRIO to implement and analyze the processed data.

1.5 Scope of Work

This project will be focus on the head part of human body to control a motorized wheelchair. Head orientation of user will be used command the wheelchair such as ‘accelerate’, 'stop', 'turn left', turn right', and 'reverse'. A 5 Degree of Freedom Inertial Measurement Unit (with 3 axes accelerometer and 2 axes gyroscope) is the only sensor proposed in this project to track user's head orientation. Signals and data obtained in the Inertial Measurement Unit will be sent to NI myRIO for signal processing. Complementary Filter will be implemented in this project by using LabView software and NI myRIO. Analysis and calibration of signals will be done to ensure safety and reliability in the operation of the proposed motorized wheelchair.

1.6 Thesis Outline

This thesis consists of 5 chapters which are organized as follows:

Chapter 1 presents the background, problem statement and motivation of the proposed technique. The objectives of this project are also presented followed by the outline of thesis.

Chapter 2 gives some overview of quadriplegia, reasons that causes quadriplegia and its categories. It also explains about modern motorized wheelchair and some of the method to control it, for example eye-blinking method, EEG method, image processing method and so on. Besides that, it focuses on the usage of hardware such as Inertial Measurement Unit (IMU) and the components inside, such as accelerometer and gyroscope.

Chapter 3 presents the methodology of the proposed head tracking system in motorized wheelchair. The proposed head tracking system uses an Inertial Measurement Unit (IMU) to distinguish the head orientation of users such as turning left, right, tilting forward and backward. This chapter also presents the algorithm used to filter signals obtained from Inertial Measurement Unit (IMU) to be processed by NI myRIO controller. Besides that, the parameters of components used in LabView software and are also presented.

Chapter 4 presents the results for the proposed head tracking system. Data obtained from Inertial Measurement Unit and the filtered data are analyzed and discussed. Several tests are conducted to determine the accuracy of the proposed system.

C**hapter 5** concludes the thesis by summarizing the project outcome and presents possible future works for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Quadriplegia

Quadriplegia, or Tetraplegia in Europe, is a disease caused by disruption to the spinal cord in cervical part of human body that results in partial or total loss in sensory and motor of their body limbs. It leads to the loss of body movement and sensation to their arms, body and legs. The difference of quadriplegia and paraplegia is that paraplegic still retaining the movement of arms. Other than that, quadriplegics will still able to move their head and depending on muscle strength and spinal cord injury levels. Spinal injuries are divided into a few levels and sections. For quadriplegics, their spinal injury level usually falls in section C1-C8. For section C1-C3, patients will only have limited head movement, while C4-C8 will retain full head and neck movement with good muscle strength in C5-C8 [4].

2.2 Motorized Wheelchair

A conventional motorized wheelchair usually consists of a pair of motors, battery, joystick and motor driver as shown in Figure 2.1. Joystick will act as a control unit to let users maneuver the wheelchair with ease. Signals from joystick will be send to a motor driver (usually under the joystick) to control the speed of the 2 motors so that the wheelchair can be moved and turn around [5]. Studies revealed that 81% of all motorized electric wheelchairs are controlled by joysticks. Among the users, 32% of them having problem in using the joystick while 9% of them could not operate the wheelchair without any assistance. On the other hand, 18% of new patients who wish to use a motorized wheelchairs are having difficulties in operating the joystick due to lack of muscle strength and skills. [6] Joystick controls should be replaced with other methods for patients that have limited strength and movement, such as head movement control or eye-blinking control [7].

Figure 2.1: A motorized wheelchair [6]

2.3 Methods in Controlling Motorized Wheelchair using Human Head

There are a few methods in controlling the movement of a motorized electric wheelchair. For instants, it can be a joystick control, head movement control, eye blinking control, brain signal control and etc. In this project, we will be focusing in using the head part of human to control and send command to a motorized wheelchair. By using human head, a few methods can be used as following:

1) EEG Headset to detect brain attention level

   Electroencephalogram (EEG) is a method to detect electrical activity in a brain. It uses metal electrodes to place along the scalp to capture and record electrical impulses that transmitted through brain cells. When a person focus on something, there will be some increase in attention level that will be detected by the EEG headset [8]. A consumer EEG headset such as NeuroSky MindWave EEG as shown in Figure 2.2 is suggested to control acceleration and brake of wheelchair by detecting attention level of brain. Brain-computer interface (BCI) is a system that able to convert brain activity signal obtained by EEG into control signals to control a wheelchair. If focusing level exceeds certain amount, controller will send an 'accelerate' or 'stop' command to the wheelchair [7].

Figure 2.2: A Neurosky MindWave EEG Headset [22]

2) <u>Eye-tracking method</u>

Patients who suffers quadriplegia level C1-C3 are unable to move their head flexibly. So, eye-tracking detection method is suggest to be used to control the movement of a motorized wheelchair. There are a few method to detect eye blink, for example using a camera to capture eye movement, or using an EEG headset that includes eye-blink detection such as NeuroSky MindWave EEG headset [39]. Eye-blinking technique can be combined with EEG signal to increase safety as human eye could accidently blink more than usual. Some of the eye blinking frequency or eye ball position could be used as a different command as shown in Table 2.1 [9]:

Table 2.1: Eye-blinking commands [9]

Wheelchair Status	Eye activities	Accuracy (%)
Forward	Blink 3 times	90
Reverse	Blink 4 times	90
Stop	Blink 2 times	90
Turn Left	Glancing Left	95
Turn Right	Glancing Right	86

3) Detect Head orientation using camera and image processing

   A small camera such as high-definition webcam is placed in front or behind the user to capture their head orientation and movement. This could be done by using image processing techniques such as pixels mapping to analyze different head orientation [10]. When camera images is first captured and send to computer, depth thresholding will be done by separating user's head from background. Pixels of top, left and right of the head will be lock-on so that when user tilts their head, the target pixels will follow and thus it detects movement of the head to a certain different area. The pattern of head movement will then be mapped into a preset pattern such as left, right, front, back. It user's head movement matches one of the preset pattern, the wheelchair will respond in terms of the command given such as turn left, right or go straight [11].

4) Detect Head orientation using an Inertial Measurement Unit

   The principle of head orientation control using an Inertial Measurement Unit (IMU) is similar with using camera image processing technique. Users are required to tilt their head to certain angle to operate a motorized wheelchair. Key difference between these two methods is the way it obtain and analyze data [11]. An Inertial Measurement Unit will use an accelerometer and gyroscope to measure head position and detect head movement, while a camera will be using image processing that runs in a computer to sense head orientation. Details of an Inertial Measurement Unit will be discussed in the next section.

The few methods are summarized and categorized as Table 2.2 below shows comparison between the methods in developing a hands-free motorized wheelchair:

Table 2.2: Comparison of different motorized wheelchair control method [5][8][19][20]

No.	Method	Advantage	Disadvantage
1	EEG Headset to detect brain signal	- Does not require user to have any body movement	- High cost for most EEG headset - Brain signal differ from users and not stable. - Requires training and practice before the wheelchair can be controlled smoothly. - Tiring for users who need to focus all the time to move the wheelchair. - Multi-channel EEG headset is bulky and uncomfortable for user.
2	Eye-tracking	- Easy to learn and use	- Not stable since human eye blinks frequently by its own. - Users unable to move their eyeball freely since it will move the wheelchair.
3	Detect Head orientation using camera and image processing	- Easy to control	- Unable to detect user's head

			orientation in low light or dark condition. - Requires high quality camera to increase stability.
4	Detect Head orientation using an Inertial Measurement Unit	- Easy to control - Can operate in dark - Low cost - System less complex compared to EEG or image processing method.	- Users required to attach an Inertial Measurement Unit on their head all the time.

2.4 Inertial Measurement Unit (IMU)

Inertial measurement Unit, also known as IMU, is an electronic device that consist of accelerometers and gyroscopes, while some also includes magnetometer and barometer. An IMU is capable of measuring linear acceleration and angular velocity with the aid of accelerometers and gyroscopes. It is often used in obtaining position, speed, altitude for navigation system in an aircraft, space shuttle, ships and etc [12]. Types of Inertial Measurement Unit is normally categorized by its Degree of Freedom (DOF). A standard Inertial Measurement Unit requires 6 axis (also known as 6 Degree of Freedom) to utterly sense a complete motion and position. 6 DOF Inertial measurement unit will consist of a 3 axis accelerometer (X, Y, Z axis) and a 3 axis gyroscope (Roll, Pitch, Yaw). To increase in calibration against orientation drift, a magnetometer will be added to an Inertial Measurement

Unit, and will makes it to become a 9 DOF IMU or more [13]. The output pin of an Inertial Measurement Unit usually falls into two categories: analog and digital. Analog output will gives a voltage reading and have to be converted to digital signal using ADC, while a digital IMU gives data in serial protocol such as I2C and SPI [14]. The main components in an Inertial Measurement Unit are accelerometers and gyroscopes:

2.4.1 Accelerometer

Accelerometer is an electromechanical device that measures acceleration force, also known as gravitational force (g-force). A common accelerometer contains 3 axes as shown in Figure 2.3:

1. X-Axis
2. Y-Axis
3. Z-Axis

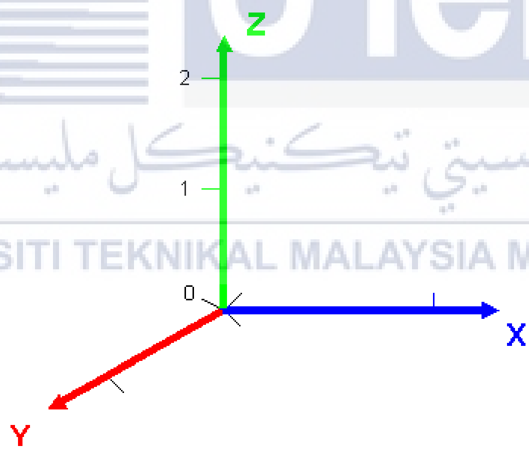

Figure 2.3: Axes of an accelerometer [12]

Data obtained in the above axes can be used to detect body motion and gesture by processing the data with suitable algorithms. [15] An analog accelerometer gives an output value in voltage that proportional to its acceleration. For example, by using an Analog Devices ADXL330 accelerometer with a range of ±3g, it gives 1.5V output when acceleration is 0g, and when acceleration increased, voltage will increase by 300mV/g. [16]

2.4.2 Gyroscope

A gyroscope, also known as gyro is illustrated as a fast spinning wheel on an axis which itself is free to change in direction. Tilting of the mounting will not affect the orientation of axis. Because of this reason, gyroscope is useful in calculating rotation and orientation. An electronic gyro sensor is an angular velocity sensor. Angular velocity is the change in rotational angle per unit of time [18]. It measures the rotation around an axis, in case it has 3 gyroscope that measures 3 axes (X, Y, and Z axis), according Euler Angles, the rotation is represented by the following terms [17]:

1. Pitch
2. Roll
3. Yaw

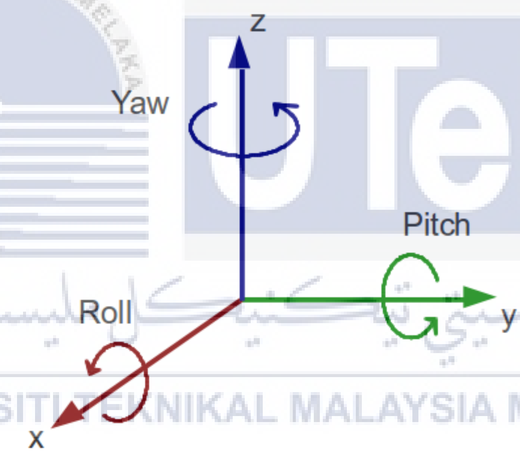

Figure 2.4: Pitch, Roll, Yaw of a gyroscope [12]

Figure 2.4 shows the rotation within the 3 axes that represents in Roll, Pitch, and Yaw according to Euler Angles. It is the basic concept of the measurement in a gyroscope to obtain angular velocity of the movement and rotation of an object [17]. Modern MEMS gyroscope comes with single, dual, or triple axes combined into a single chip.

2.5 Controller for Signal Processing

In this project, NI myRIO is proposed to be used as a controller programmed by LabView. A NI myRIO as shown in Figure 2.5 has a dual-core ARM® Cortex™-A9 real-time processing and Xilinx FPGA with 28,000 programmable logic cells, 10 analog inputs, 6 analog outputs, audio I/O channels, and up to 40 lines of digital input/output (DIO). Other than that, NI myRIO also includes onboard WiFi, a three-axis accelerometer, and several programmable LEDs in a durable, enclosed form factor. [21]

Figure 2.5: A NI myRIO [23]

This powerful tool will be used as a controller to process signals obtained from Inertial Measurement Unit with appropriate algorithm such as signal filtering. It will then send commands to both motor drivers to control each of the motor rotation. LabView software will be used to program NI myRIO and analyze obtained data.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

This chapter will be discussing the set-up of hardware such as the connection between an Inertial Measurement Unit, NI myRIO and motor driver. To execute the system, LabView is needed to be programmed by appropriate tools, connections, front panel user interface, block diagrams and algorithm. Procedures of building a proposed program in LabView will be elaborate in this chapter.

Figure 3.1 shows an operation flow chart of the proposed wheelchair system. At first, an Inertial Measurement Unit will be acquiring signal from user's head orientation, and signal obtained will then be sent and processed by NI myRIO to determine whether user's head is in which state. There are 4 states that will be declared in the program, such as tilt left, tilt right, tilt forward and tilt backward with a certain threshold. For tilting left and right, the wheelchair's turning radius and speed will be mapped according to the head tilting angle of user. If head movement other than the declared states is detected, the wheelchair will be in "Stop" mode.

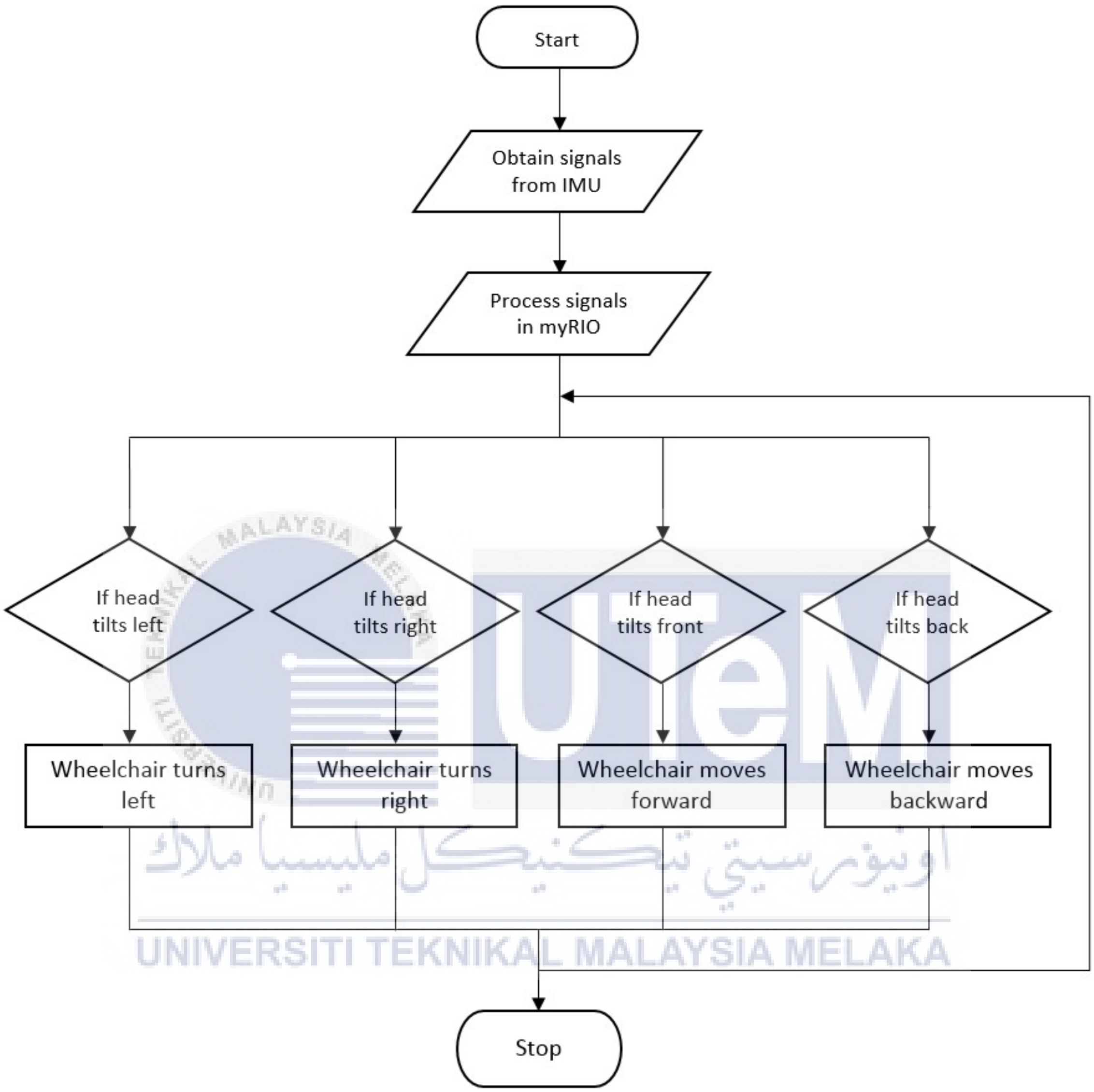

Figure 3.1: Flow chart of the proposed wheelchair system

3.2 Hardware Architecture

For the hardware section of this project, the hardware architecture is divided into three main module. It consists of sensor module, control module and also communication module. Sensor module is represented by an Inertial Measurement Unit that contains an accelerometer and gyroscope, while control module will be a NI myRIO microcontroller and a MDC30C PWM motor driver. To program or display status and data from the microcontroller, communication module does the job by connecting the microcontroller to a laptop or iPad wirelessly via onboard WiFi card in the microcontroller and also an external WiFi router.

Illustration of the hardware setup is shown in Figure 3.2 below. A Cytron 5 DOF Inertial Measurement Unit SN-IMU5D-LC gives an analog output, which means the output will be in Voltage. Other than V_{in} and ground pin, 3 output pin of accelerometer (X, Y, Z axis) and 2 output pin of gyroscope (X-Rate and Y-Rate) will be connected to analog input pin on NI myRIO. On the output side of NI myRIO, digital output pin with PWM will be connected to Cytron DC motor driver to move the wheelchair motor.

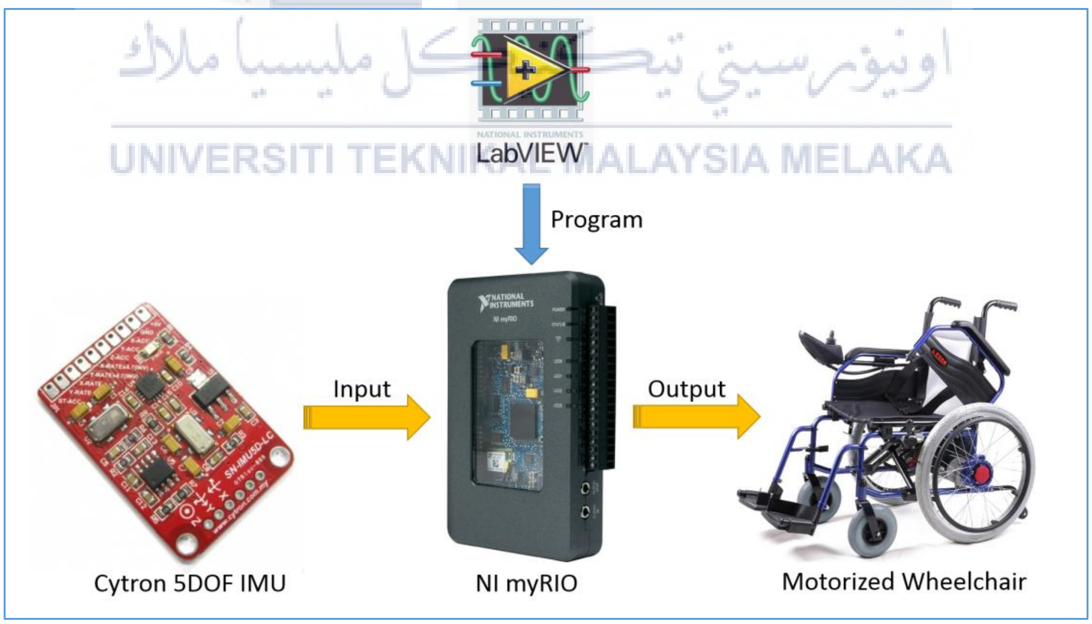

Figure 3.2: Illustration of hardware flow

Figure 3.3 shows a Cytron MD30C DC motor driver that will be used in the proposed wheelchair system. It will receive a digital PWM input that connected from NI myRIO. Two units of this DC motor driver will be connected to the right motor and left motor on the wheelchair. The function of motor driver is to obtain a low-current control signal from NI myRIO and turns it into a high current signal to drive a motor. In this proposed wheelchair system, two 24V DC motor is used to move the wheelchair and thus it needs two 30A motor driver to control the speed and drive the motor.

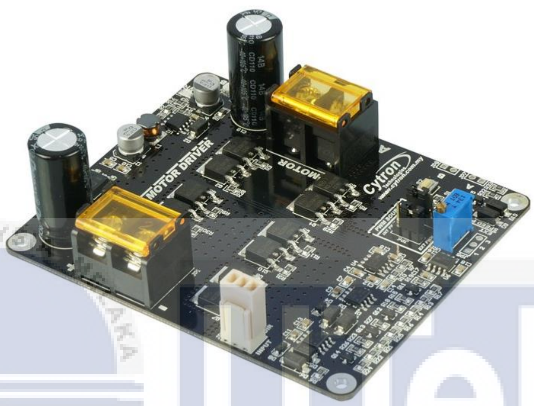

Figure 3.3: Cytron MD30C Motor Driver

A brief specifications of the three main devices are stated as below:

1. **Cytron IMU5D-LC Inertial measurement Unit**
   - 5-DOF (Gyro: Pitch & Roll Rate, Accelerometer: X, Y, Z).
   - Gyro: Murata ENC-03RC.
   - Accelerometer: Analog Devices ADXL335.
   - Powered by +5V with onboard 3.3V voltage regulator.
   - Analog output for all sensors.
   - Gyro Raw Sensitivity: 0.67mV/ °/s
   - Gyro Full Scale Range: 300 °/s
   - Onboard Amplifier for gyro output. Gain: 4.7x
   - Accelerometer Sensitivity: 300mV/g
   - Accelerometer Full Scale Range: +-3g
   - Dimension: 41.91mm x 27.94mm

2. **NI myRIO**
   - Processor: Dual-core ARM® Cortex™-A9 real-time processing
   - FPGA: Xilinx Z-7010
   - Memory: 512MB DDR3
   - Wireless: IEEE 802.11 b,g,n
   - Accelerometer: 3 axes
   - Multiple analog inputs, analog outputs, digital input/output

3. **Cytron MD30C 30A DC Motor Driver (Figure 3.3)**
   - Bi-directional control for 1 brushed DC motor.
   - Motor Voltage: 5V - 25V 30V
   - Maximum Current: 80A peak (1 second), 30A continuously.
   - Reverse polarity protection.
   - 3.3V and 5V logic level input.
   - Fully NMOS H-Bridge for better efficiency and no heat sink is required.
   - Speed control PWM frequency up to 20KHz (Actual output frequency is same as input frequency when external PWM is selected).

3.2.1 Inertial Measurement Unit

By referring to Figure 3.4, there are plenty of connections on the IMU. For powering it up, 5V will be supplied along with ground terminal from NI myRIO instead of 3.3V due to its onboard voltage regulator. The main outputs of this sensor that will be connected to NI myRIO is X-Acc, Y-Acc, Z-Acc from accelerometer and X-Rate and Y-Rate from gyroscope.

This whole unit of Inertial Measurement Unit will be placed in a small box tailor-made by 3D printer and attached on the side of a headset as shown in Figure 3.5 to be wear by user on their head. Outputs of the IMU will be in voltage value because it is an analog Inertial Measurement Unit. It will then be converted to digital form through the on board analog-to-digital converter in NI myRIO.

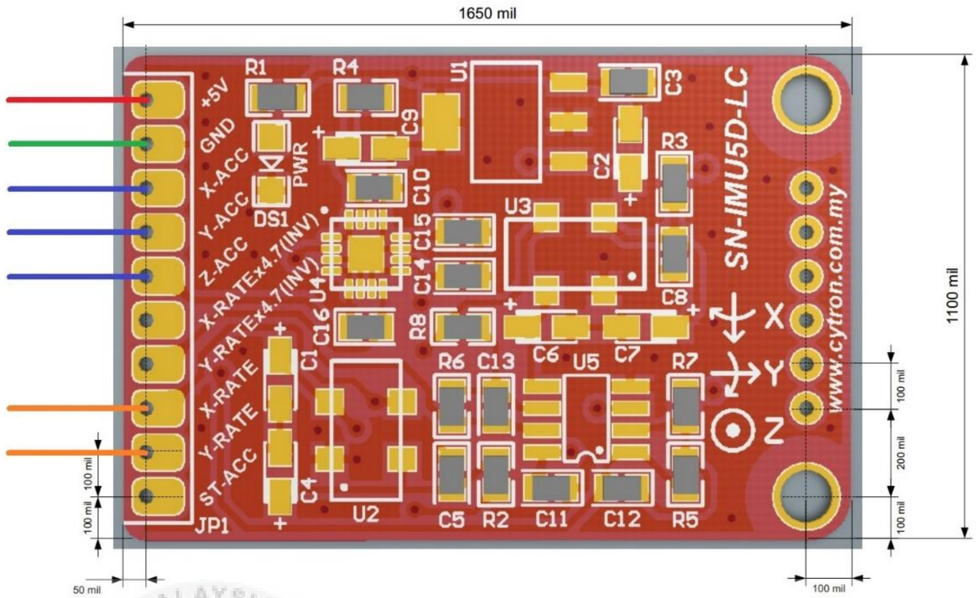

Figure 3.4: Front Panel of Inertial Measurement Unit

Figure 3.5: Front view of the placement of IMU

3.2.2 NI myRIO

There are 3 sets of Expansion Port (MXP) connectors on NI myRIO-1900 (A, B and C). In this project, we will be using only the left side of the connectors, A and B. Both of the connectors A and B carry identical sets of signals. The signals are distinguished in LabView by the connector name, as in ConnectorA/DIO1 and ConnectorB/DIO1. The following Figure 3.6 show the signals on MXP connectors A and B. Note that some pins carry secondary functions as well as primary functions such as PWM that will be used to control the speed of the wheelchair.

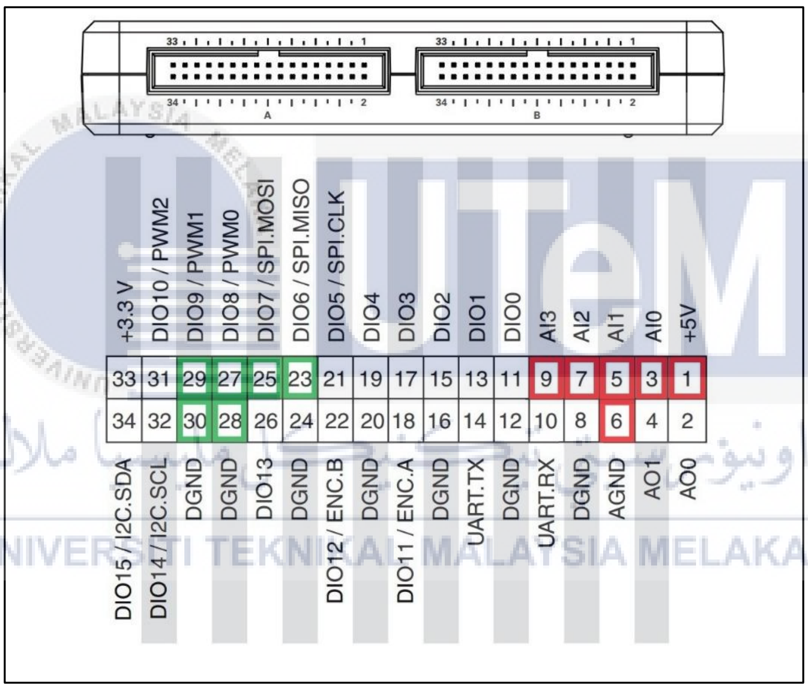

Figure 3.6: A and B MXP Connectors on NI myRIO

The jumper cables from Inertial Measurement Unit will be directly connected to the power supply (+5V, AGND) and analog input (AI0, AI1, AI2, A13, BI0) on the NI myRIO. While it outputs 2 digital signal to the motor driver to control the direction (DIO6, DIO7) and 2 digital signal with PWM to control the speed (DIO9, DIO9) as highlighted in Figure 3.6.

3.2.3 Cytron MD30C

Cytron MD30C is a DC motor driver with PWM speed control and 30A continuous current. Two identical Cytron MD30C are stacked together in the control box as shown in Figure 3.7 to supply power and control the speed of both left and right motor of the wheelchair. Battery of the wheelchair is connected directly to the motor driver and each motor driver is connected to one of the two motors.

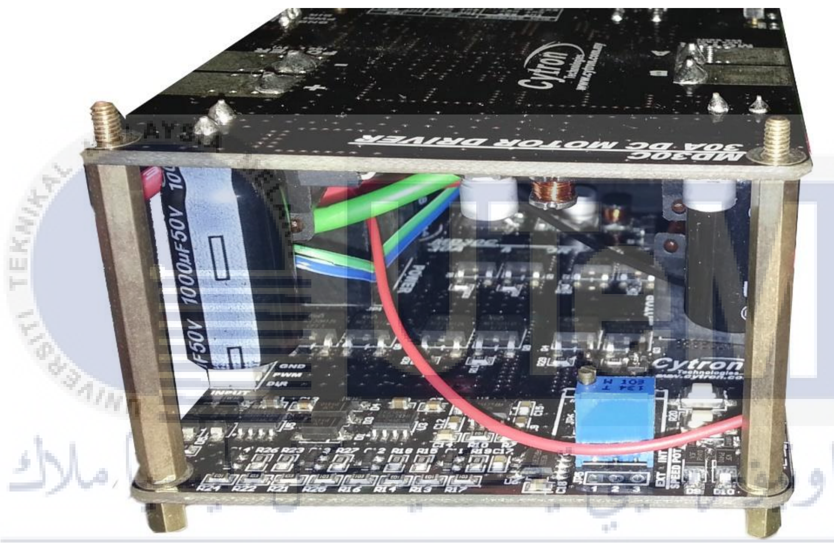

Figure 3.7: DC motor driver in control box

By referring to Figure 3.8, there are three sets of ports to be connected. The power port positive and negative is used to connect to the battery for supplying current to the motor and itself. Motor port A and B will be connected to the motor to control the speed and direction. Whereas the remaining ports is used to communicate with NI myRIO microcontroller. NI myRIO will supply PWM signal to the driver for speed control while the DIR port is for direction control (0 for forward and 1 for reverse).

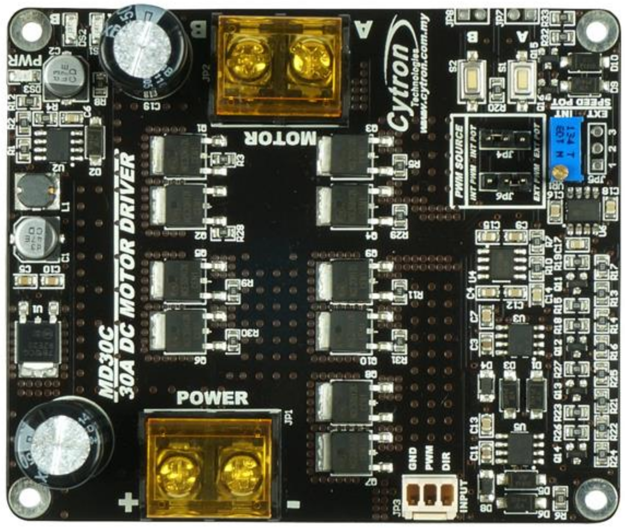

Figure 3.8: Front panel of Cytron MD30C

3.3 Software and Algorithm

LabView software will be the only software used in this project to program myRIO and display data. A VI is created under RT Target to communicate with myRIO. Analog inputs from myRIO will go through complementary filter for signal filtering and the result data will pass through case structure to set the threshold of head movement for controlling the wheelchair.

Another VI is created under host PC to create a 3D model for head movement illustration and also for data display from myRIO such as charts. Shared variable is used to transfer data in between RT Target and host PC. Figure 3.9 shows the diagram that constructed in LabView to display the data from IMU in 3D model form. The results of 3D model will be shown in result part of this report. This 3D plug-in that comes with LabView has the option to display a 3D box, sphere, cone and so on. The signal from IMU needs to be adjusted before it enters the 3D model VI to ensure accuracy of the 3D model movement and IMU signal.

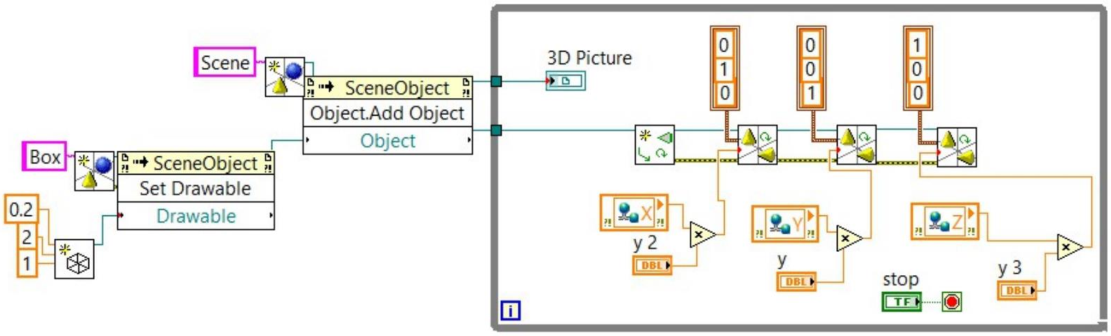

Figure 3.9: 3D Model VI diagram

For the filter, a formula node is used to program the formula for signal filtering. The reason to use signal filtering is because accelerometer is sensitive and it outputs a noisy data which is not very stable, while gyroscope tends to drift away from the actual value when time passes. This project will be using complementary filter, a filter based on low pass and high pass filter. The complementary filter is designed in such a way that the strength of one sensor will be used to overcome the weaknesses of the other sensor which is complementary to each other. It will make use of the gyro in short period, and then the low pass filtered data from the accelerometer is used to correct the drift of the angle over long period of time. Both of the filtered data will be combined to output a smoother estimated angle. The concept of complementary filter is shown in Figure 3.10 below.

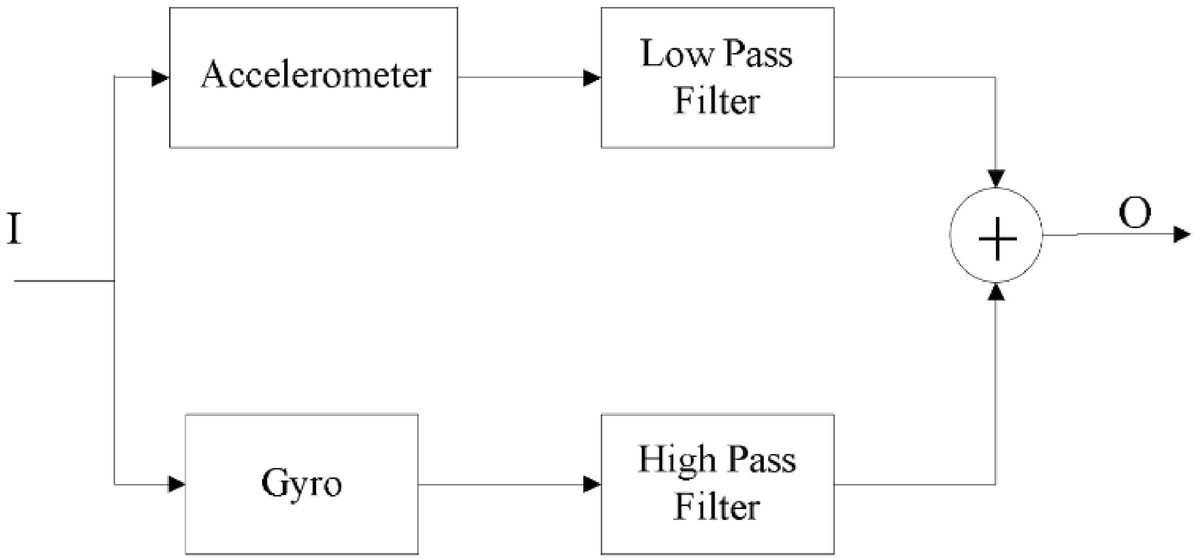

Figure 3.10: Complementary Filter block diagram

The offset of the gyro sensor will also be continuously updated and corrected. This will result in a drift free and fast responding estimated tilt angle. The main formula for the filter is shown below as equation 3.1.

$$\theta_n = \alpha \times (\theta_{n-1} + gyro * dt) + (1 - \alpha) * acc \quad (3.1)$$

According to equation 3.1, α is the filter coefficient, which we need to adjust by trial and error to obtain the best result. Sampling period (dt) is the amount of time passes between each of the program loop. θ_{n-1} is the last calculated angle while 'acc' is the data obtained by accelerometer and '$gyro$' is the data obtained by gyroscope.

$$\tau = \frac{\alpha \times dt}{1 - \alpha} \quad (3.2)$$

Time constant τ in equation 3.2 above defines where the boundary between trusting the gyroscope and trusting the accelerometer is. For time periods shorter than τ, the gyroscope integration takes precedence and the noisy horizontal accelerations are filtered out. For time periods longer than τ, the accelerometer average is given more weighting than the gyroscope. Once desired time constant and sample rate is chosen, filter coefficient α is picked.

$$\alpha = \frac{\tau}{\tau \times dt} \tag{3.3}$$

Larger α in equation 3.3 will trusts the integrated gyro signal for longer while smaller time constant merges the accelerometer signal faster.

Based on equation 3.1, the front part of the equation act as a high-pass filter for the gyroscope as in equation 3.4 below while the remaining as low-pass filter for the accelerometer as in equation 3.5. The filter equations will be set in a formula node in LabView to filter the signals.

$$\alpha \times (\theta_{n-1} + gyro * dt) \tag{3.4}$$

$$(1 - \alpha) * acc \tag{3.5}$$

Since the Cytron IMU5D-LC is an analog Inertial Measurement Unit that outputs data in Voltage, some mathematics has to be done to convert from Voltage to degree. Datasheet of the IMU is referred and the voltage at 90 ° and -90 ° is taken to calculate the angle for every voltage changes. A simple formula as in equation 3.6 is used to map the degree of head position to the left and right turning speed of the wheelchair by placing a formula node within case structure in LabView.

$$y = mx + c \tag{3.6}$$

Data obtained from Inertial Measurement Unit with complementary filter and without filter is compared and further discussed in the result part. Charts will be plotted by LabView front panel with each axis and also 3D model that will be displayed in a laptop wirelessly.

3.3.1 Wireless Monitor and Control

An iPad Mini is used to run a Data Dashboard application to monitor running data and control the system as an alternative way to LabView using PC. This is because NI myRIO has built in WiFi, it can be controlled by Data Dashboard app wirelessly without the need of running a full version LabView in PC. It would be inconvenient for researcher or user to monitor the statistics of Inertial Measurement Unit and motor condition by holding a Laptop on the wheelchair. Logo of this application is shown in Figure 3.11.

Figure 3.11: Data Dashboard application logo

3.4 Prototype Testing

After the completion of hardware installation and software design, a series of tests will be conducted to determine the functionality of the wheelchair system. There will be three main tests in this project. The first test is to determine whether the angle of head tilting matches with the result obtained in LabView after the signal is filtered. A chart of the signal will be plotted to illustrate the movement of signal in degree.

Second test will be the mapping of head tilting angle with the wheelchair turning angle. Initially, an unfiltered signal will be used to turn the wheelchair left and right. Head tilting angle should be fixed at an angle around 30 °and the wheelchair will turn left or right according to head tilting angle for 2 seconds and stop. The new position of wheelchair will be marked and the angle between its original position and new position will be determined. Next, the same process will be repeated with a filtered signal to make a comparison. There will be two types of left turn, with slight head tilt of approximately 20 ° and harder head tilt of approximately 50 °. Same test also goes to right turn.

Final test is a random movement test that take place in both indoor and outdoor. Head tilting angle will be turned randomly to the front, left, right, and backwards to determine the response of the wheelchair. A volunteer will be acting as a quadriplegic patient to simulate the usage of this wheelchair system to ensure the usability and safety of the whole control process.

3.5 Project Flow

The entire project flow is shown in a gantt chart as in Table 3.1 below. The 1st phase (FYP 1) of this project will be mainly focusing on research and literature review. Minor hardware and software testing will be done during this period to verify some results before proceeding into next phase. In phase 2 (FYP2), there will be design of algorithm (Complementary Filter) in LabView, hardware installing and testing. At the end of this project, a full thesis will be presented and submitted.

Table 3.1: Gantt chart of project flow

Tasks		2015 (FYP 1)					2016 (FYP 2)				
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	Project Understanding										
2	Research and Literature Review										
3	Thesis writing										
4	Design algorithm in LabView										
5	Produce and install hardware										
6	Hardware running and testing										
7	Data analyzing										
8	Final thesis writing										
9	Seminar preparation										
10	Final paper review										

CHAPTER 4

RESULTS

4.1 Software Development

The main VI created in LabView Real-Time Target is shown in appendix section. It consists of 3 main parts, such as complementary filter for X, Y and Z axis, unit conversion and case structure to set the threshold for different commands such as move forward, stop, reverse, turning left and right. There is also indicator that lights up the LED on the myRIO when the specific command is executed. The first part of the VI is an analog input that feeds data from Inertial Measurement Unit to a formula node that consist of the complementary filter equations to filter the input signal as shown in Figure 4.1. Then, the filtered signals will be send to a case structure in the next section.

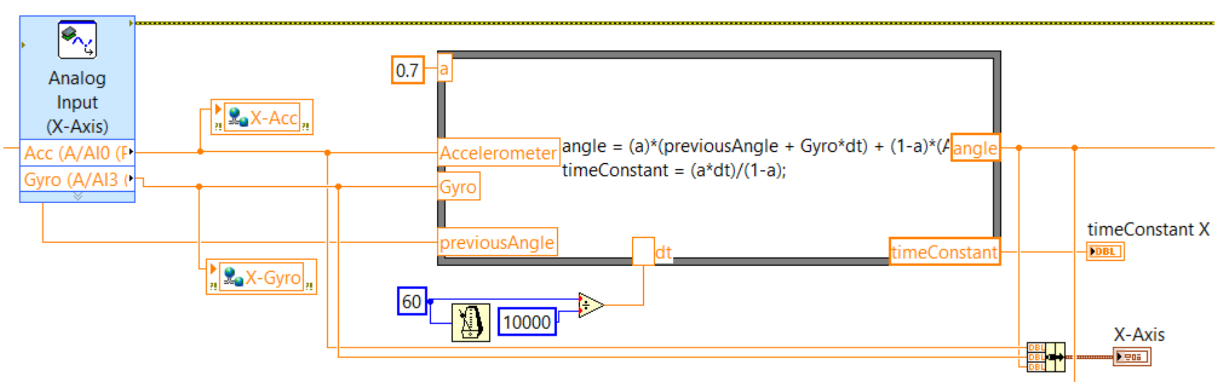

Figure 4.1: Complementary Filter in LabView

4.1.1 Case Structure

To convert the signal obtained from IMU into a wheelchair movement, a certain threshold were to be set to allow only certain degree of head tilting to move the wheelchair. In this case, a case structure function will be used in LabView as shown in Figure 4.2. It is the main part of the program to allow the microcontroller to differentiate the head movement of users such as tilting forward, backward, left and right. For this project, the threshold will be set to 35 degrees for each head tilting direction. If user's head tilts more than 35 degrees forward, the wheelchair will start to move forward, and if the user tilts to the left at the same time, the wheelchair turns left, same for other direction. The wheelchair will completely stop if the head tilting angle is less than 35 degrees.

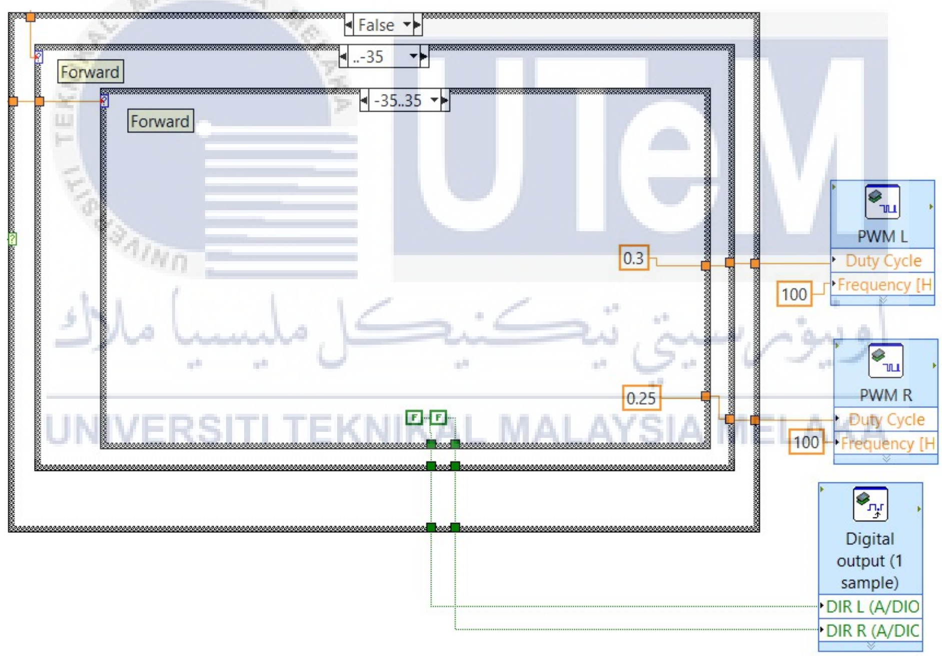

Figure 4.2: Case Structure (forward)

Upon adjusting the PWM value to determine the speed of the wheelchair, it is found that a maximum PWM value of 0.3 with frequency of 100Hz will be set for the motor speed to move the wheelchair at a speed of ±0.8 m/s in order to ensure user's safety. Both of the left and right motor have a slightly different speed when same PWM value is set due to its different internal factors. For forward speed, PWM value of left motor is set as 0.3 while right motor as

0.25 to move the wheelchair forward in a straight line. For reverse, the left and right motor is set to 0.21 and 0.18 respectively as shown in Figure 4.3. Reverse speed is slightly slower than forward speed for safety purpose. DIR output is set to 1 (true) so that the motor driver can reverse the polarity of the current supply to motor for opposite rotation.

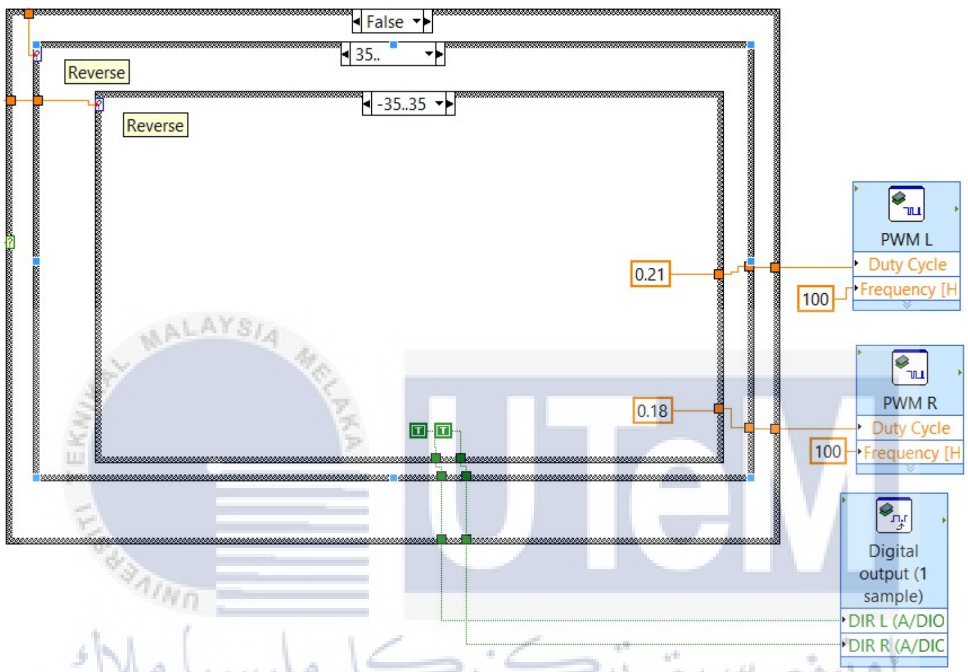

Figure 4.3: Case Structure (reverse)

4.1.2 Angle Mapping

For right and left turn of the wheelchair, turning radius and speed will be mapped directly with the degree of head tilting angle. For instance, the more user tilt their head to the left or right, the turning radius and speed will be greater, unlike forward and reverse speed which is fixed after the head tilting angle exceeds a threshold. This can be done if the speed of one of the motor is directly perpendicular to the degree of head tilting angle. To calculate the gradient of the mapping graph, a reference head tilting angle and PWM value is set. When user's head tilts 35 degree to the left or right, the PWM value will be 0.28.

$$y = mx + c \tag{4.1}$$

By using the equation 4.1 above, we found that the gradient of the curve is 0.008. A graph of the relationship between PWM value and head tilting angle is shown in Figure 4.4. Thus, a formula node is inserted in the right and left case to directly output PWM value according to the value obtained for Y-axis. For right turn command, the left motor will be fixed at PWM of 0.1 while right motor follows the Y-axis. Same applies to left turn with the right motor fixed at PWM of 0.1 as shown in Figure 4.5.

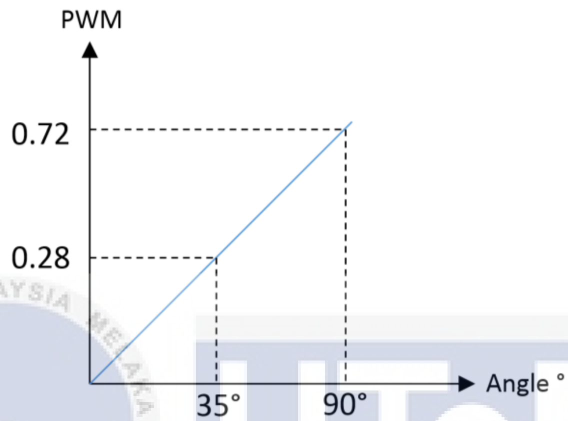

Figure 4.4: Graph of PWM VS angle

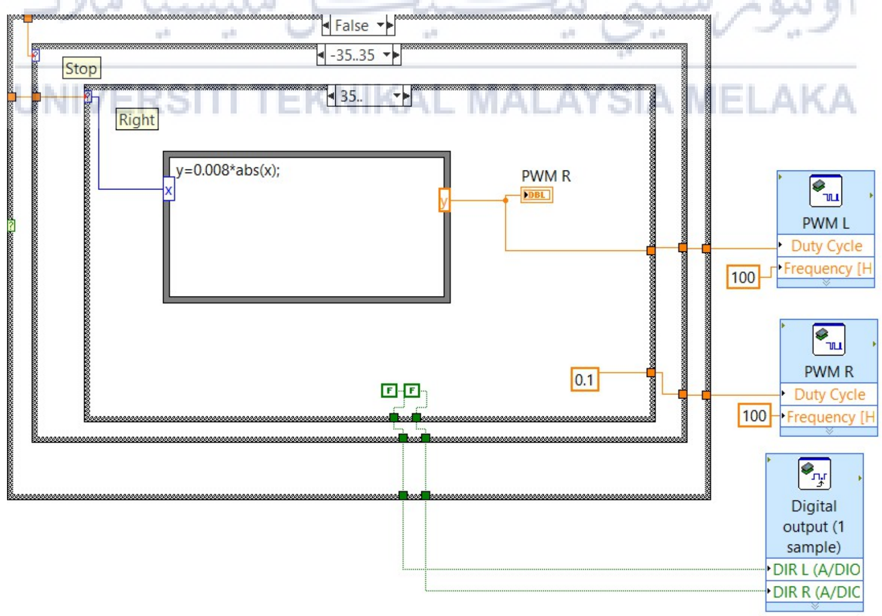

Figure 4.5: Case structure with mapping formula

4.2 Raw Data from IMU

Signals obtained from the Inertial Measurement Unit by NI myRIO was recorded. Figure 4.6 shows a chart with X, Y and Z axis of accelerometer in IMU without applying filter. Noises are very obvious even though the IMU is in rest as it has a high sensitivity. As the IMU moves, the signal fluctuates and not stable. If these signals were applied on the wheelchair, the motor will turn on and off irregularly when the signal is near to the threshold. This can cause damages to the motor and endanger the user.

As it is an accelerometer with analog output, signal obtained will be in Voltage. Result shows that when the IMU is at rest, it will receive an average of 1.6V for X and Y axis while 1.93V for Z axis. When the IMU tilts left, value of X-axis of accelerometer will increased from 1.6V, and it decreased from 1.6V when tilts right, while Y-axis stays still. When IMU tilts to the front, value of Y-axis increased and vice-versa for tilting backwards as shown in Figure 4.6.

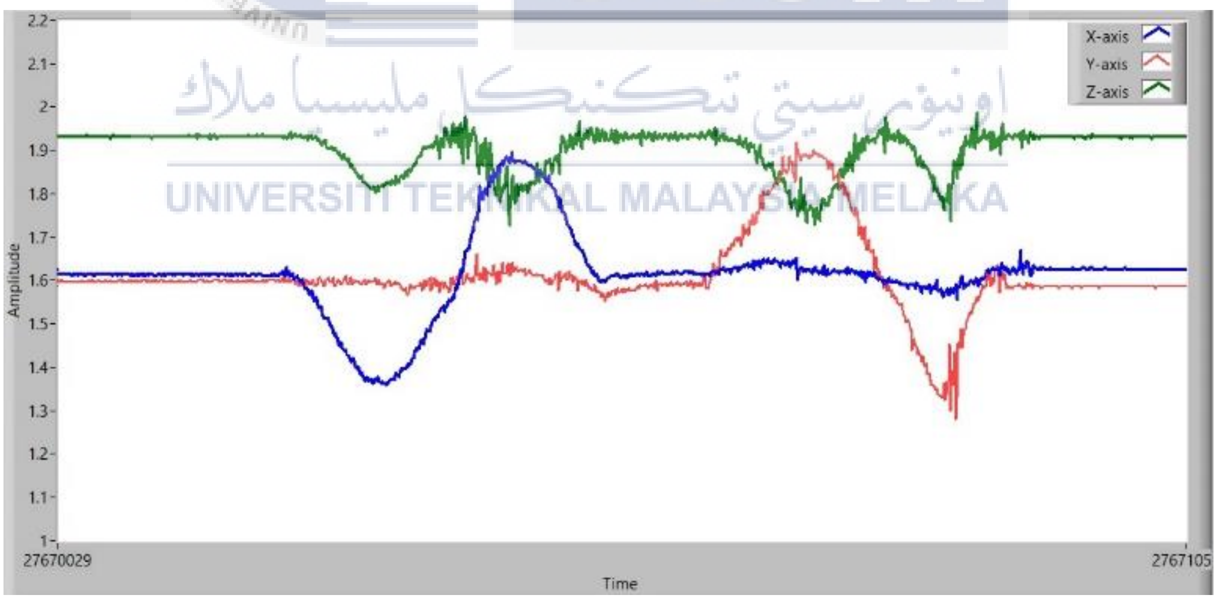

Figure 4.6: Accelerometer raw data without filter

On the other hand, Figure 4.7 shows an amplitude versus time chart with gyroscope signal obtained from Inertial Measurement Unit. The two axes plotted was roll and pitch. As similar with Figure 4.6, noise occurs in the output of gyroscope even it is in rest. Sometimes, a slight drift tends to occur in any gyroscope according to study. So, it is clearly proven that a signal filtering has to be implemented on the signal to remove unwanted noise, prevent drift and increase system stability. A Complementary Filter is implemented to avoid a faulty command to the wheelchair system and the results will be explained in the next section.

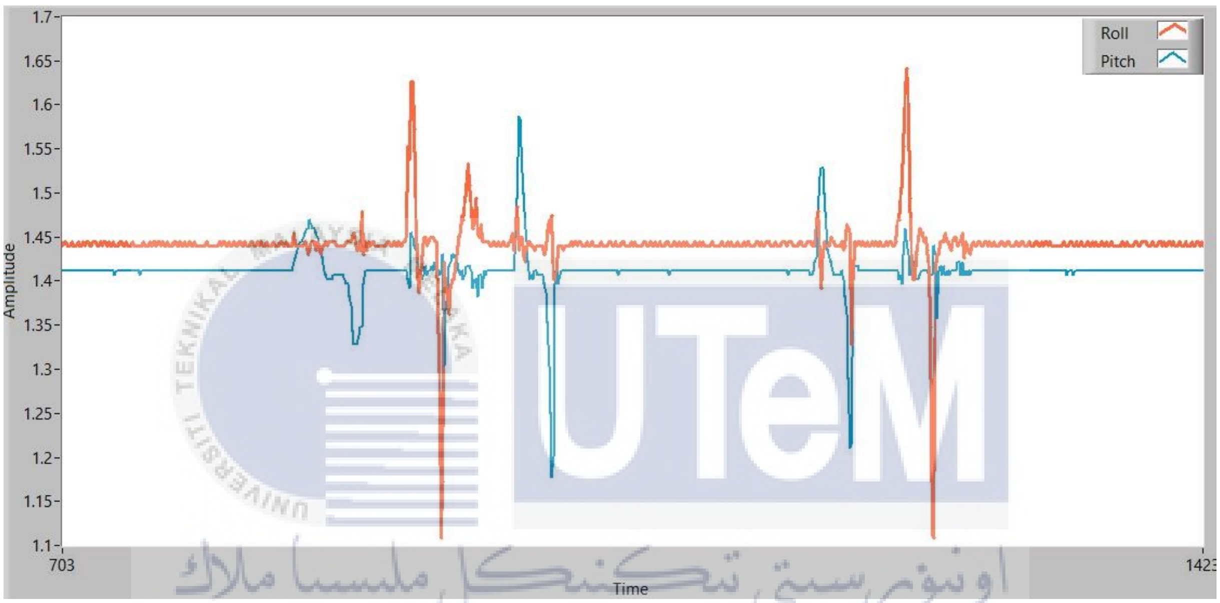

Figure 4.7: Gyroscope raw data without filter

4.3 Complementary Filter

4.3.1 Filter Coefficient

To design the filter, filter coefficient α should be determined. Time constant τ determines the time scale of the high-pass and low-pass filters, and is a value that can be tweak according to the Inertial Measurement Unit used. Larger filter coefficient α trusts the integrated gyro signal for longer. A smaller time constant merges the accelerometer signal in faster. Using the ADXL335 accelerometer from Analog Devices and ENC-03R angular rate sensor (gyroscope) from Murata, a filter coefficient of 0.7 corresponding to a time constant of 0.023 seconds gave good results. Like many other control situations, there is a trade off and the only way to really tweak it is to have multiple experiments. Calculation of time constant τ with a filter coefficient of 0.7 is shown in equation below.

$$\tau = \frac{\alpha \times dt}{1 - \alpha} \tag{4.2}$$

$$\tau = \frac{0.7 \times 0.01}{1 - 0.7}$$

$$= 0.023$$

When filter coefficient is set to a higher value such as 0.9, time constant will be greater. The ratio for the filter to trust the accelerometer will be higher, therefore larger delay occurs between the unfiltered and filtered signals. The result is over-filtered and can be illustrated in Figure 4.8.

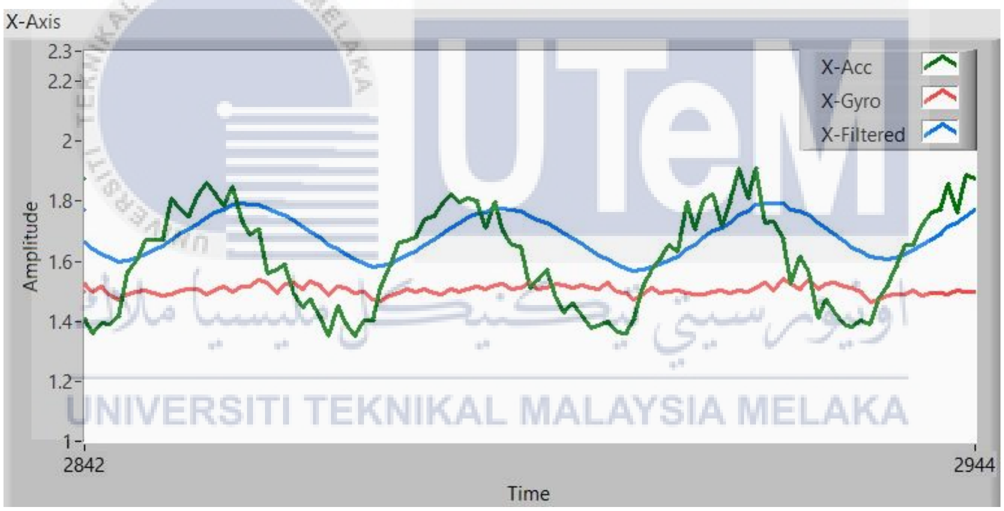

Figure 4.8: Signal obtained with filter coefficient of 0.9

If the filter coefficient is set to a lower value, for example 0.5, time constant will be smaller and it merges the gyroscope data too soon and did not emphasize much on the accelerometer data. This causes the filtered result to be less smooth and noises are still noticeable as in Figure 4.9.

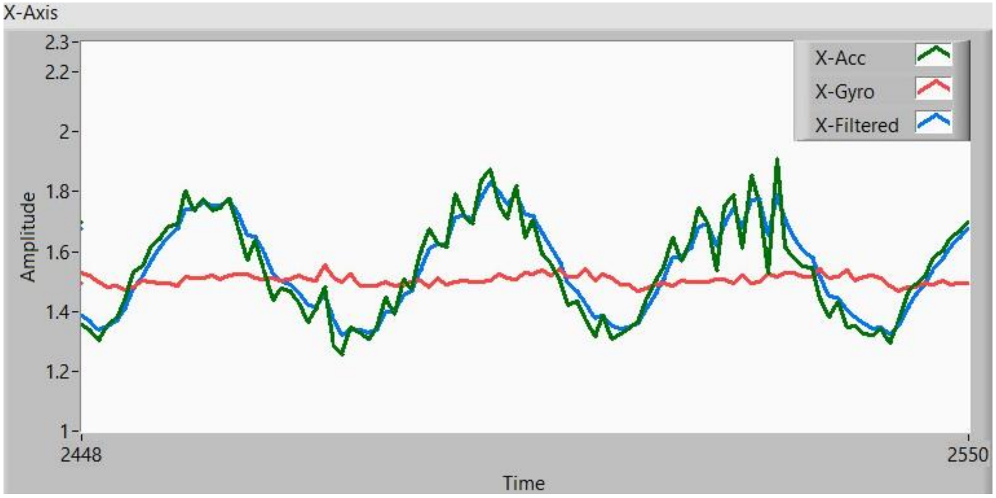

Figure 4.9: Signal obtained with filter coefficient of 0.5

4.3.2 Comparison with Non-Filtered Signal

After complementary filter was implemented to the program, each axis from accelerometer and gyroscope were compared by plotting 3 different charts. Figure 4.10 shows an X-Axis with green signal came from accelerometer and red signal came from gyroscope. Blue signal is the filtered signal combining both accelerometer and gyroscope data. It is much smoother than the original signal and noise are greatly reduced.

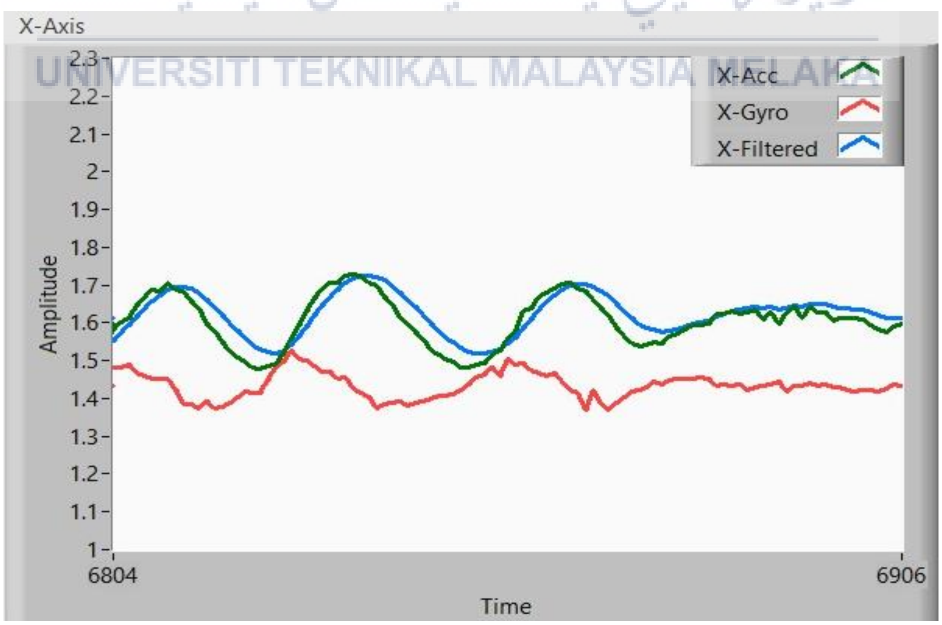

Figure 4.10: X-Axis of accelerometer (Green), Gyroscope (Red), Filtered (Blue)

Same goes to Y-Axis and Z-Axis in Figure 4.11 and Figure 4.12 respectively. This proves that complementary filter has the ability to combine both accelerometer and gyroscope data and elimited unwanted noise created by accelerometer and gyroscope drift.

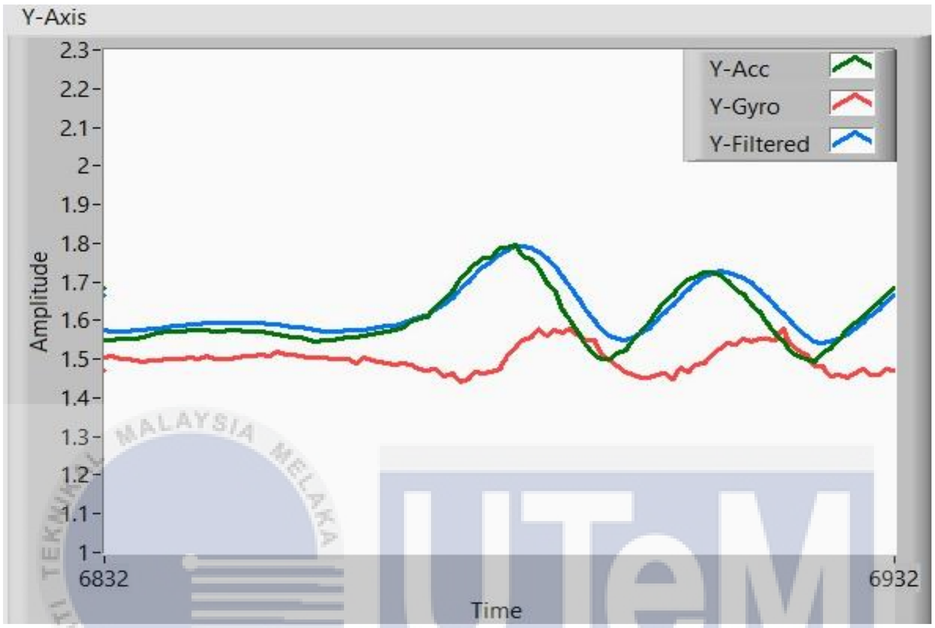

Figure 4.11: Y-Axis of accelerometer (Green), Gyroscope (Red), Filtered (Blue)

As it is a 5 degree of freedom Inertial Measurement Unit, there are only X, Y, Z axis from accelerometer and X, Y rate from gyroscope. So, Z-axis only contains data from accelerometer without gyroscope. Fortunately, complementary filter can still filter out unwanted noise from accelerometer but the signal is slightly delayed due to the lack of Z-rate from gyroscope as in Figure 4.12. A 6 degree of freedom IMU is suggested to overcome this problem.

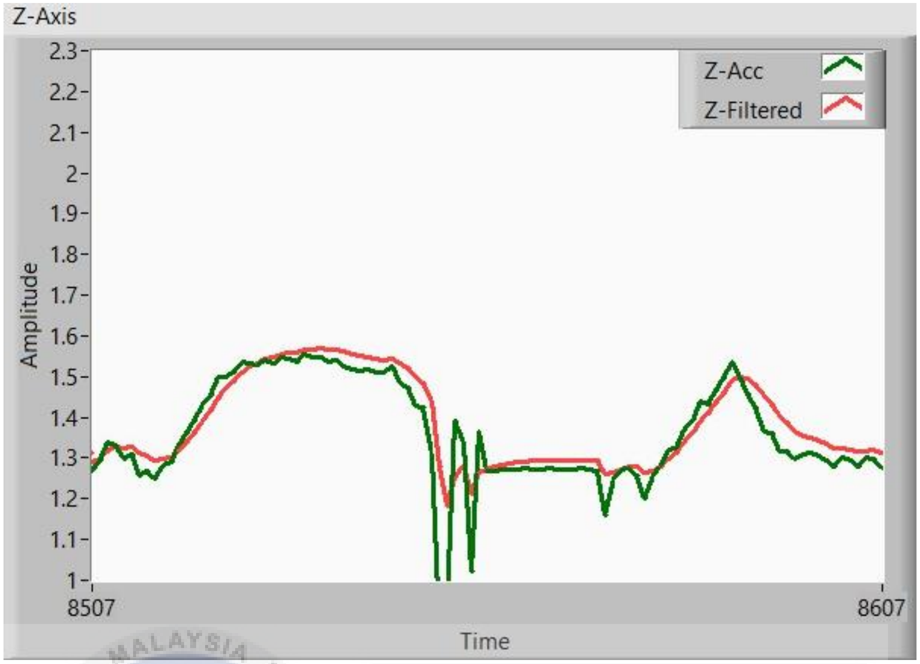

Figure 4.12: Z-Axis of accelerometer (Green), Filtered (Red)

Lastly, 3 filtered signal from X, Y and Z axis are combined together in a same chart in Figure 4.13 to be compared with the unfiltered signal from Figure 4.6. Signal in voltage value has also been converted to degree to detect user's head tilting angle. It is clearly proved that complimentary filter did a great job in estimating a smooth signal by the aid of both accelerometer and gyroscope. This makes the wheelchair system to be function well, stable and safer to use especially for Quadriplegia patients who have only limited body movement.

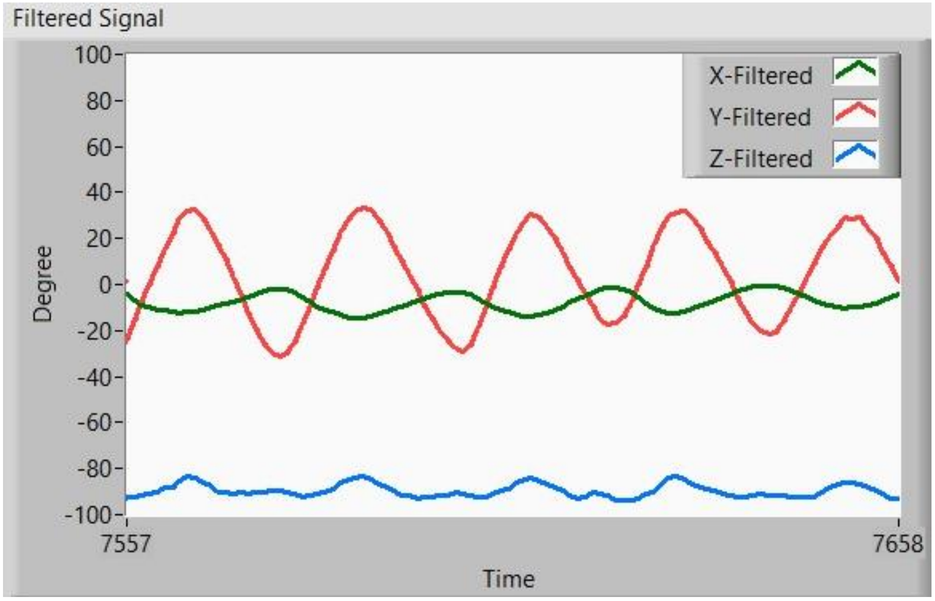

Figure 4.13: Filtered signal for all 3 axes

4.4 Accuracy Test for Filtered Signal

In this section, a test is conducted to determine whether the angle of head tilting matches with the result obtained in LabView after the signal is filtered. A chart of the signal will be plotted to illustrate the movement of signal in degree.

Figure 4.14: IMU is at 0 °

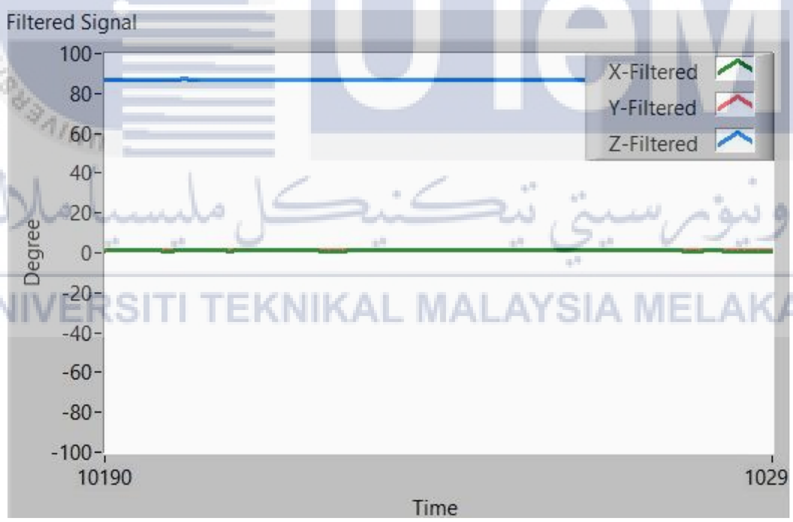

Figure 4.15: Result when IMU is at 0 °

At first, the Inertial Measurement Unit mounted on a headset is placed on a mannequin head as a replacement for human head. The mannequin head is positioned upright (0 °) for a few seconds as in Figure 4.14 and the results shown in Figure 4.15 proves that the angle of X and Y axis is in 0 ° while Z axis is at 90 °.

Figure 4.16: IMU is at 30 °to its right

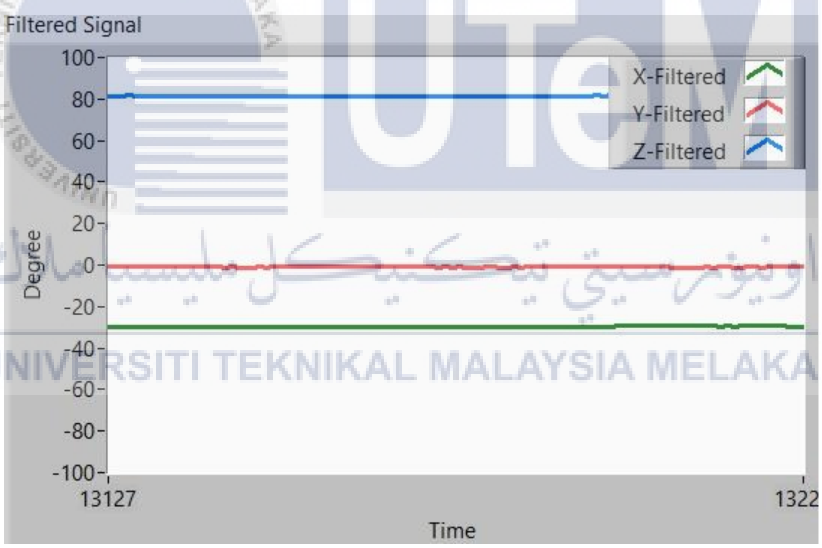

Figure 4.17: Result when IMU is at 30 °to its right

Next, the mannequin head is tilted 30 ° to its right and the position is hold for approximately 8 seconds as in Figure 4.16. According to Figure 4.17, it shows that the angle of measurement obtained by IMU is also at -30 °for X-axis while Y and Z axis remained the same. This tells that the angle of measurement obtained from IMU and filtered by complementary filter is correct.

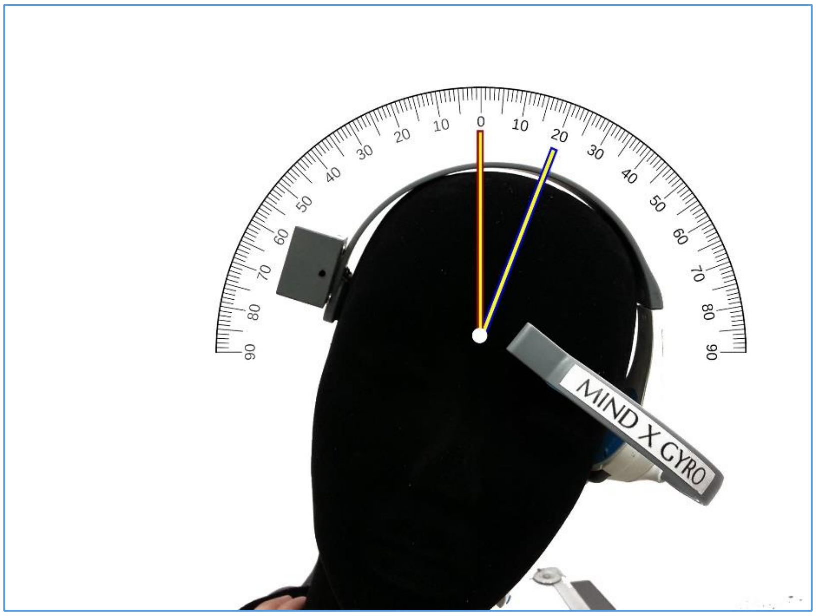

Figure 4.18: IMU is at 20 °to its left

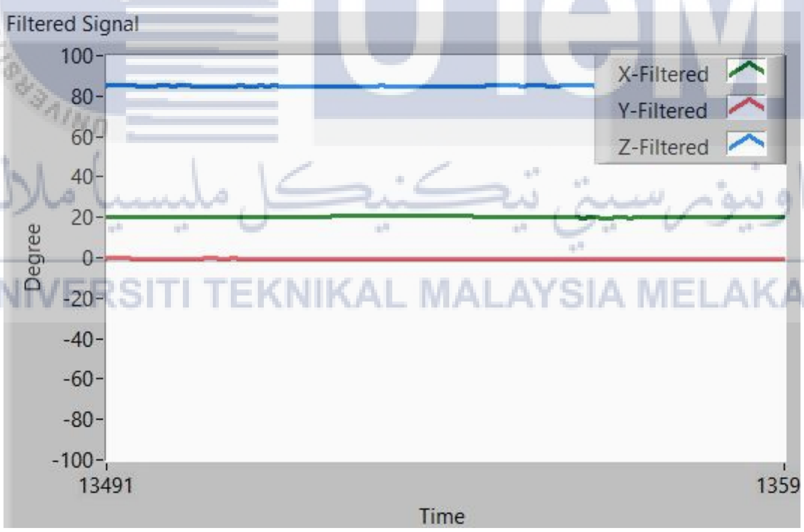

Figure 4.19: Result when IMU is at 20 °to its left

Lastly, the mannequin head is tilted to the opposite direction with an angle of 20 °to its left according to Figure 4.18. The position is remained for approximately 8 seconds. Result shown in Figure 4.19 clearly shows that the angle of X-Axis is at 20 °which is accurate and tally to the actual mannequin head angle.

4.5 Prototype Movement Test

The prototype wheelchair has been tested in both indoor and outdoor by volunteer for the four main command: forward, reverse, turn left and turn right. Turning radius to the left and right of the wheelchair can be controlled by the degree of head tilting. The system with both unfiltered signal from IMU and with complementary filter are tested on the same path. It is found that after applying filter, the movement of wheelchair is very stable and the response to the head movement is fast. Without the filter, the rotation of motor will jerk and vibrate as the degree of head tilt is near to the threshold due to the noise and fluctuation of accelerometer signal. For safety measurement, the value of PWM output to both of the motor is capped at 0.3 to ensure the wheelchair to move in a safe speed, about 0.8m/s.

Figure 4.20 shows the wheelchair system with an IMU attached on the right side of EEG headset to be wear by user. This EEG headset has only single channel, so it does not achieve good stability in moving the wheelchair. The attention level threshold of EEG is hard to achieve and requires training. Thus, IMU is fully utilized to control the wheelchair, and in case for some patient who unable to move their head forward and backward freely, this EEG headset will be used to control the forward and stop command. A laptop is used to monitor the signals from the IMU. As NI myRIO is a Real-Time microcontroller, the response of head movement to the wheelchair control is very quick and this increases the safety of this system.

Figure 4.20: Wheelchair prototype

Underneath the wheelchair is a black box (red circle) as in Figure 4.21 that contains the 2 motor driver that connects both of the motors. NI myRIO is placed inside the compartment behind the wheelchair and connects both the IMU and motor drivers as shown in Figure 4.22.

Figure 4.21: Motor driver underneath the wheelchair

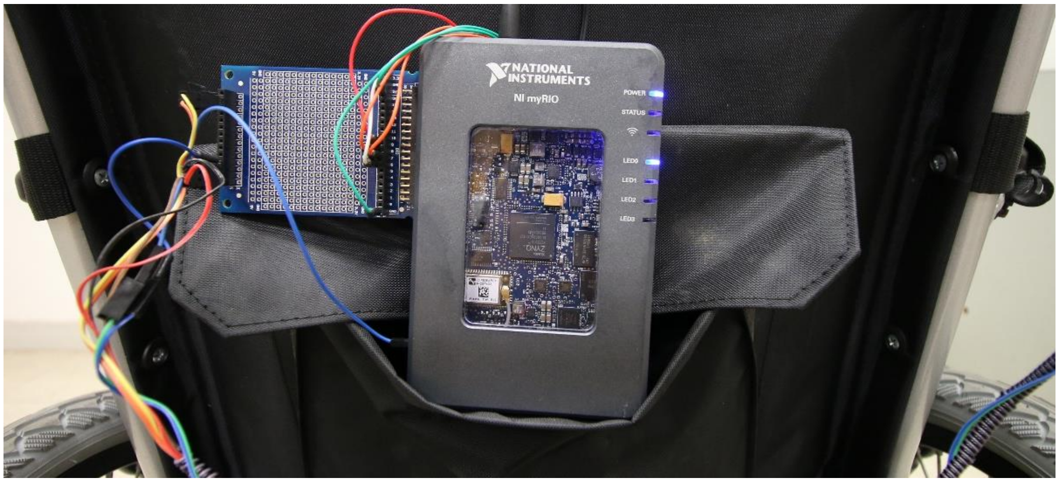

Figure 4.22: Placement of NI myRIO inside the compartment behind the wheelchair

4.6 Turning Angle Test

One of the features of this wheelchair system is that the turning angle of wheelchair are mapped into the tilting angle of user's head. User can simply control the wheelchair's turning speed and angle by just adjusting their head tilting angle to the left or right. For instance, the more user tilt their head to the left, the faster the right motor runs while left motor remains constant at low speed to perform a steeper left turn, and the same goes to right turn. To make things happen, a series of test on the turning angle of wheelchair has been performed.

4.6.1 Unfiltered Signal

At the outset, an unfiltered signal will be used to turn the wheelchair left and right. Head tilting angle has been fixed at an angle around $\pm 30°$ to the left and right and the wheelchair will turn left or right according to head tilting angle for 2 seconds and stop. The new position of wheelchair will be marked and the angle between its original position and new position is determined. Figure 4.23 shows the wheelchair at its original position before the test starts.

Firstly, a volunteer tilted his head to the left at approximately ±30 °, and the reading of angle in LabView shows an angle of 32 ° of X-Axis to the left. From the top view, the new wheelchair position is marked and it shows an angle of 38 ° from its origin as in Figure 4.24. It is a difference of 6 ° between the actual wheelchair position and the head tilting angle.

Figure 4.23: Wheelchair at its origin position

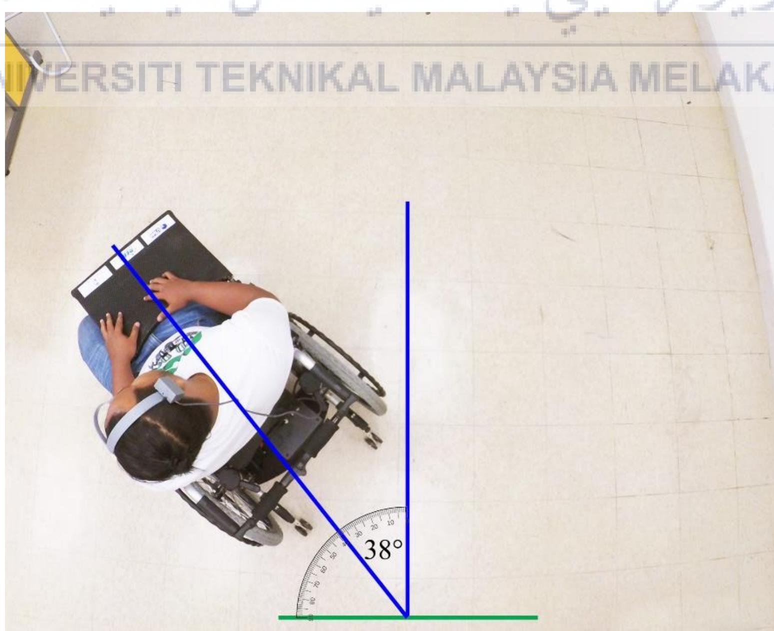

Figure 4.24: Wheelchair at 38 ° to the left

After that, the wheelchair has to be returned to its original position. For the second attempt, the same volunteer tilted his head to the right for about ±30 ° and LabView shows an angle reading of 32 °. While the wheelchair marked a position of 27 ° to the left instead of 32 °, a difference of -5 °. The top view of the wheelchair new position can be seen in Figure 4.25.

Figure 4.25: Wheelchair at 27 ° to the right

4.6.2 Filtered Signal

In this part, the same process will be repeated with a signal filtered by Complementary Filter to make a comparison with the raw signal. There will be two different angles to test of left turn, with slight head tilt of approximately ±20 ° and harder head tilt of approximately ±50 °. Same test also applies to right turn.

At first, the head position of the volunteer will be tilted to ±20 ° as in Figure 4.26. LabView records an angle of 21 ° to the left. The result of the actual wheelchair position is at 23 ° to the left, equals to a difference of 2 ° compared with the measured angle by IMU.

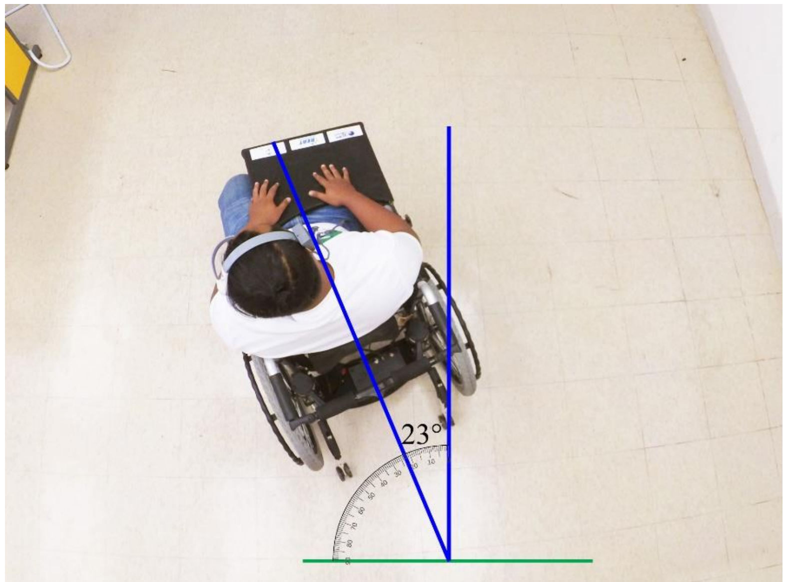

Figure 4.26: Wheelchair at 23 °to the left

After the position of wheelchair is reset, the head position of the volunteer will be tilted to ±50 °to the left as in Figure 4.27. LabView records an angle of 50 °to the left. The result of the actual wheelchair position is at 51 °to the left, equals to a difference of 1 °compared with the measured angle by IMU.

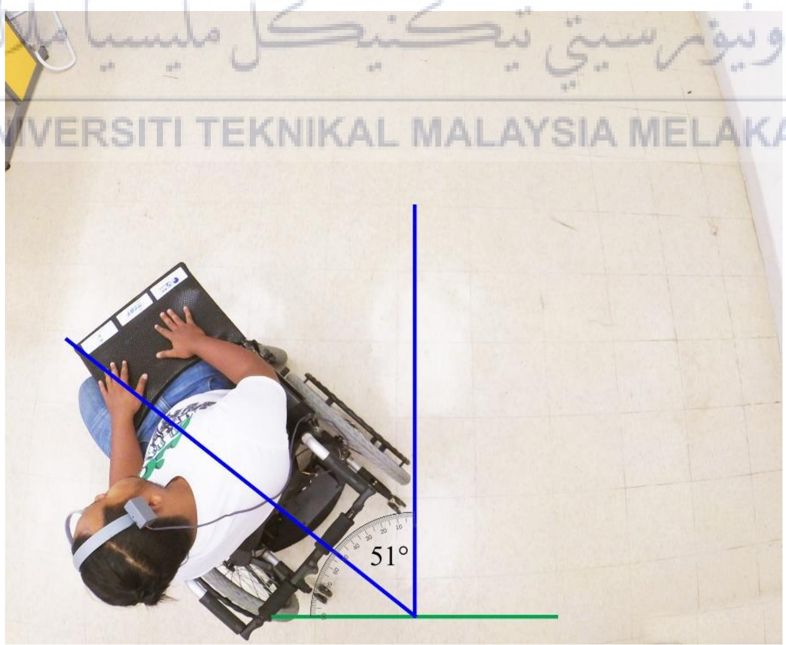

Figure 4.27: Wheelchair at 51 °to the left

For the right turn of the test, the head position of the volunteer will be tilted to ±20 °to the right as in Figure 4.28. An angle of 20 ° to the right is shown in the LabView for the measurement of IMU. The actual position of the wheelchair marked an angle of 19 °to the left, equals to a difference of -1 °compared with the measured angle.

Figure 4.28: Wheelchair at 19 °to the right

Last but not least, after the position of wheelchair is reset, the head position of the volunteer will be tilted to ±50 ° to the right as in Figure 4.29. Actual head tilting angle in LabView shows an IMU reading of 47 ° to the right. While the new position of actual wheelchair differs by 44 °from its original position, that is a difference of 3 °compared to the IMU angle reading in LabView.

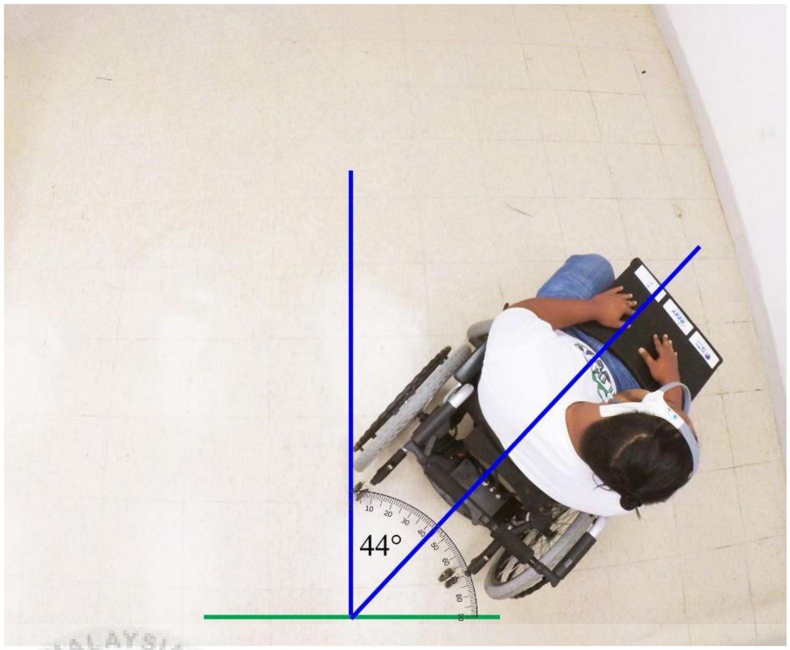

Figure 4.29: Wheelchair at 44 °to the right

Table 4.1: Results of Turning Angle Test with unfiltered signal

Unfiltered Signal		
Head tilt angle in LabView (°)	**Angle of wheelchair turn (°)**	**Difference (°)**
32 (Left)	38	6
32 (Right)	27	-5

Table 4.2: Results of Turning Angle Test with filtered signal

Filtered Signal		
Head tilt angle in LabView (°)	**Angle of wheelchair turn (°)**	**Difference (°)**
21 (Left)	23	2
50 (Left)	51	1
20 (Right)	19	-1
47 (Right)	44	3

Based on the result obtained from the several tests above in Table 4.1 and 4.2, it can be concluded that the signal obtained after applying filter is much accurate compared to an unfiltered signal. The difference between head tilting angle and actual wheelchair position is obvious, which is around 5 ° to 6 ° of error. It is also noticed that the wheelchair will jerk and the rotation of motor will change randomly. This is due to the raw signal from IMU that fluctuated a lot and noise that occurred even the IMU is at rest. To solve this, complementary filter is needed to create a smooth and stable signal to control the wheelchair system.

For filtered signal, the difference between head tilting angle and wheelchair position is around 1 ° to 3 °, which is better than using an unfiltered signal. There are a few factors that causing this error, for instance, the wear and tear of both motors, friction between the wheels and floor, and also the battery strength of the wheelchair. Two of the motors need to be programmed by different PWM value each due to both of it can't perform the same rotation while supplying the same PWM value. Fine tune of the PWM value is needed to improve the accuracy of the wheelchair rotation.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In this project, a head tracking system is proposed for a motorized wheelchair control. It uses both accelerometer and gyroscope embedded in an Inertial Measurement Unit to detect user's head movement. Raw signals directly obtained from Inertial Measurement Unit is not stable due to its high sensitivity that causes noise and drift to the signal. To solve this problem, signals from both sensors are combined and filtered by using Complimentary Filter to obtain a stable output to maneuver the wheelchair safely and accurately. By tilting user's head forward and backward, the wheelchair will be moving forward and also reverse respectively. Whereas tilting user's head right and left will also turn the wheelchair right and left respectively. The more the user tilt his/her head, the turning radius and speed will be increased according to the tilting angle by tracking user's head orientation. This can be done by mapping user's head orientation to the speed of motor. To stop the wheelchair, user have to maintain his/her head in upright position. By a series of tests, it shows that the head tracking system is reliable and have high accuracy. The actual angle of head tilting matches the angle that obtained in LabView after it is processed by Complimentary Filter. Moreover, the wheelchair turning angle can be mapped with the head tilting angle and it is proved by the result obtained. Slight difference between the measured and real angle of the wheelchair position is due to some external factors of the system. For user who unable to move their head forward and backwards conveniently, an EEG headset is proposed to be combined with this project to overcome this problem by detecting user's brain attention level.

5.2 Recommendation

The future work will be focusing on the development of an EEG headset to detect user's attention level more precisely to avoid too much head movement by Quadriplegia patients. By then, the wheelchair system can be used by more people especially for those who have a serious spinal cord injuries which have much limited neck movement. Other than that, a 6 degree of freedom Inertial Measurement Unit is suggested to replace a 5 degree of freedom Inertial Measurement Unit that used in this project to utilize the 'yaw' axis of the gyroscope. This can greatly enhance the head tracking system and reduce error of the angle detected from certain head movement direction. To operate the wheelchair in narrow places, a Pivot Turn can be used to turn the wheelchair on its original position without moving forward or backward by turning both wheelchair wheels in opposite direction at the same time as similar to a tank. Moreover, sensors such as ultrasonic sensor are suggested to be placed on each corner of the wheelchair, this can avoid collision to surroundings especially for user who have limited arm movement to stop the system by hand for a safer use, and without the need of the guardian of other people to use this wheelchair system.

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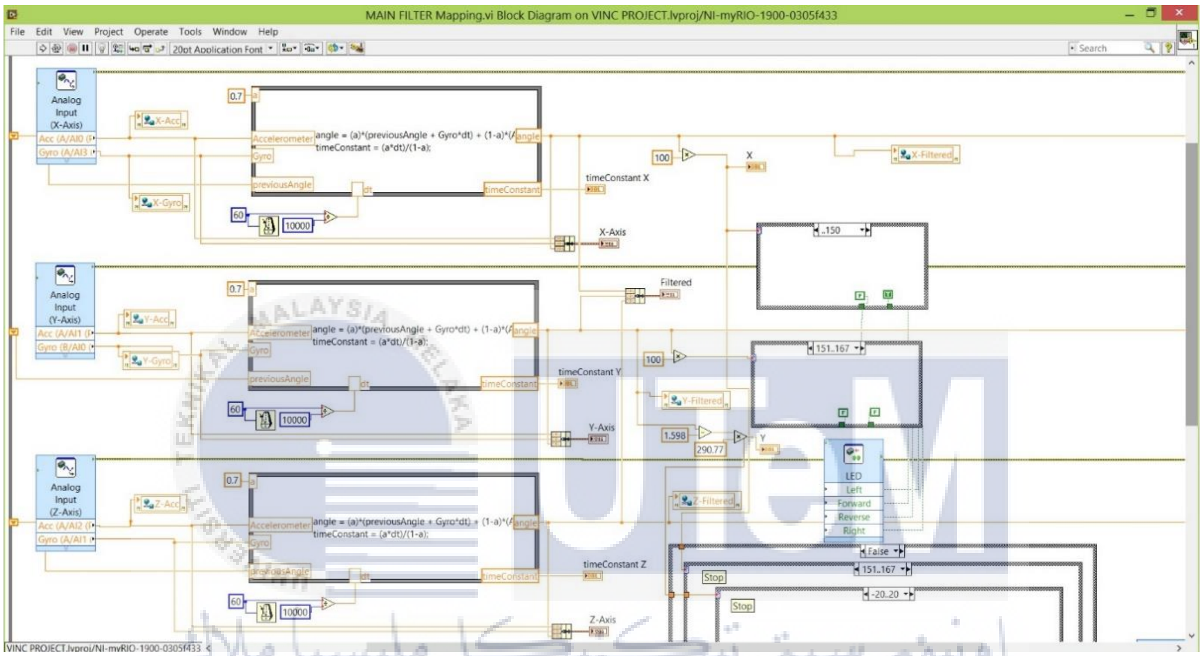
APPENDIX



A: Main VI program in LabView