A FUZZY LOGIC CONTROLLER FOR TRANSLATIONAL AND ROTATIONAL CONTROL OF A COMMERCIALLY AVAILABLE MOTORIZED WHEELCHAIR

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A FUZZY LOGIC CONTROLLER FOR TRANSLATIONAL AND ROTATIONAL CONTROL OF A COMMERCIALLY AVAILABLE MOTORIZED WHEELCHAIR

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechanical Engineering

Faculty of Engineering and Science
UniversitiTunku Abdul Rahman

April 2013

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"A FUZZY LOGIC CONTROLLER FOR TRANSLATIONAL AND ROTATIONAL CONTROL OF A COMMERCIALLY AVAILABLE MOTORIZED WHEELCHAIR."** was prepared by **NG YAU JIA** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Degree (Hons.)Mechanical Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ___________________________

Supervisor : Prof.Dato' Dr.Goh Sing Yau

Date : 8/5/13

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the progress of this project. I would like to express my gratitude to my research supervisor, Prof.Dato Dr. Goh Sing Yau for his invaluable advice, guidance and his enormous patience throughout the whole development of the project. Even though he has busy with his job but he still insist to have a meeting every week to monitor my project progress and at the same time he also guide me to achieve the goal of this project.

Here I also would like to express my deep sense of gratitude and appreciation to Mr. Danny Ng who taught me a lot of necessary skill and knowledge that required for this project.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement.

Finally, I would like to thank again for those individuals who have shared their suggestions and opinion of this project.

A FUZZY LOGIC CONTROLLER FOR TRANSLATIONAL AND ROTATIONAL CONTROL OF A COMERCIALLY AVAILABLE MOTORIZED WHEEL CHAIR.

ABSTRACT

A Fuzzy Logic Controller (FLC) was developed to control the translational and rotational movements of a commercially available motorized wheelchair. The FLC enabled the wheelchair to travel between 2 locations with the shortest possible time without overshooting or undershooting the targeted destination. In addition, the FLC enabled the wheelchair to turn right and left as well as rotate in both directions on the spot at a comfortable speed without causing dizziness to the rider. The capabilities of the wheelchair were tested successfully unloaded (without a rider) and loaded (with a rider).

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LIST OF SYMBOLS / ABBREVIATIONS

Ω	ohms
F	Farad
R	nominal resistance
V	voltage
ADC	analog to digital converter
CPU	central processing unit
DC	direct current
DAC	digital to analog converter
FL	fuzzy logic
FLC	fuzzy logic controller
IC	integrated circuit
LED	light emitted diode
MF	membership function
Op Amp	operational amplifier
PC	personal computer
PCB	printed circuit board
POSxCNT	position counter
PIC	peripheral interface controller
QEI	quadrature encoder interface
SPI	serial peripheral interface
UART	universal asynchronous receiver transmitter

CHAPTER 1

INTRODUCTION

1.1 Background

A well-controlled self-navigating wheelchair would improve the quality of life of a paralyzed person such as a stroke or a motor neuron disease (MND) patient. In certain cases, the control system will be integrated with a brain computer interface (BCI). A Fuzzy Logic Controller (FLC) for the wheelchair is proposed in this project to enable the wheelchair to perform optimally when used by patients with different weights.

1.2 Aims and Objectives

The main objective of this project is to develop a FLC:

1. That will enable the wheelchair to travel between 2 locations with the shortest possible time without overshooting or undershooting the targeted destination.

2. That will enable the wheelchair to turn right and left as well as rotate in both directions on the spot at a comfortable speed without causing dizziness to the rider.

1.3 Scope and Limitations of Work

The scope of work is to establish a controller for the wheelchair using fuzzy logic algorithm.. Thus, the main skill requirements to achieve the scope are:

- EAGLE 6.1 Light for PCB design
- MPLab X IDE for dsPIC33
- Matlab for Fuzzy logic design
- SolidWorks for encoder mounting design

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this report, the reviews will emphasize on:

- The performance of fuzzification, defuzzification and inference of the fuzzy logic on the speed controller.
- The autonomous wheelchair.

2.2 Traveling Control of the Autonomous Mobile Wheelchair (Ohkita, 2004)

The aim of project is to develop and upgrade the previous wheelchair, namely DREAM-2 to DREAM-3. This wheelchair is designed to travel in the indoor environments such as in hospital or welfare facilities for their practical use and serve to take care of old people and physically handicapped people (Ohkita, 2004). The information on the surroundings of the wheelchair is acquired using 10 pairs of ultrasonic sensors, a gyroscope sensor, rotary encoder, 8 touch sensors, a landmark leader and a CCD camera. The environment map is preloaded on DREAM 3 and the initial position of the wheelchair is required to match with the real environment using ultrasonic data and camera image data. The existing of real environment such as a fixed wall, pillar, obstacle and boundary line are written on the environmental map and the wheelchair will keep update an environmental map by each values of each sensor during traveling. The obstacle recognition for this wheelchair is using ultrasonic and touch sensor. The touch sensor was installed in eight places of surrounding of the wheelchair to describe the obstacle information in the environmental map. In order to compensate the unstable operation of ultrasonic sensor, certain weight is added to the obstacle information acquired with each sensor.

2.3 Development of Intelligent Wheelchair System based on Stereo Omni-directional System (SOS)

This project utilized the Stereo Omni-directional System (SOS) which can capture omni-directional color and stereo images in real time with a full field of view of 360 × 360 degrees (Figure 2.3.1) to develop the functions of autonomous obstacle avoidance control. The three main advantages are acquisition of spatial information in the form of seamless, high resolution images captured from the surrounding environment by means of a configuration of multiple cameras; complete absence of blind spot in all directions by means of spherical camera setup; and simultaneous acquisition of color images and distance information in real-time.

Figure 2.3.1: 360 × 360 degrees Image

The SOS is mounted on an arm at an angle above the user. A block diagram of the system is shown in Figure 2.3.2. A single PC is used to integrate the control of the SOS and the electric wheelchair via an RS232C connection. Besides, the omni-directional information obtained by the SOS can be transmitted to a supporter at a remote location via a network.

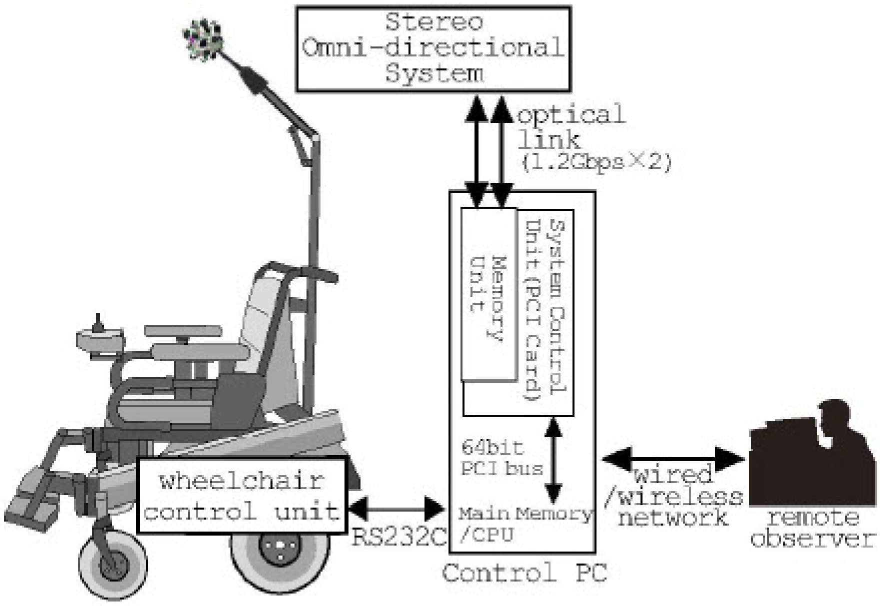

Figure 2.3.2: Block Diagram of SOS Wheelchair

The external appearance of the SOS is shown in Figure 2.3.3. This novel camera was developed by this author. The real time distance information about surrounding obtained from SOS can be utilized for obstacles avoidance. Figure 2.3.4 shows an example of a depth image acquired by SOS from the surroundings. The higher the brightness of the pixels, the closer the object is to the SOS system.

Figure 2.3.3: The Stereo Omni-directional System (SOS)

Figure 2.3.4: Omni-directional depth image

2.4 Study of the Defuzzification Methods of Fuzzy Logic (S.S.Saraf, 1996)

The purpose of this study is to evaluate qualitatively the performance of the different defuzzification techniques as applied to speed control of a DC motor. (S.S.Saraf, 1996) A typical fuzzy logic controller (FLC) composed of fuzzification, knowledge base, decision making and defuzzification. Various defuzzification techniques have been proposed in this journal. The efficiency of a FLC depends very much on the defuzzification process because overall performance of the system under control is determined by the controlling signal the system receives. (S.S.Saraf, 1996)

Basically, the defuzzification is a mapping from a space of fuzzy control actions defined over an output universe of discourse into a space of non-fuzzy control actions. The defuzzification technique is aimed at producing a non-fuzzy control action that best represent the possibility distribution of an inferred fuzzy control action (Kung, 1994). Few defuzzification techniques have been used in this study, described as below, Figure 2.4.1.

a) Center of Area / Gravity (Centroid) - A (S.S.Saraf, 1996)

   This is most commonly used defuzzification techniques in the design of FLCs. This method determines the center of the area of the combined membership function and takes into account the area of the union of the fuzzy sets.

b) Center of Sum – B (S.S.Saraf, 1996)

   This method is quite similar to center of area but faster defuzzification because it avoids the computation of the union of the fuzzy sets, and considers the contribution of the area of each fuzzy set individually. In term of mathematic, the center of area takes union of the fuzzy sets but the center of sums takes the sum of the fuzzy sets.

c) First of Maxima– C (S.S.Saraf, 1996)

   This method uses the union of the fuzzy sets and takes the smallest value of the domain with maximal membership degree.

d) Last of Maxima - E (S.S.Saraf, 1996)

   This method uses the union of the fuzzy sets and takes the largest value of the domain with maximal membership degree.

e) Middle of Maxima– D (S.S.Saraf, 1996)

   This method takes the average values of the first of maxima and last of maxima.

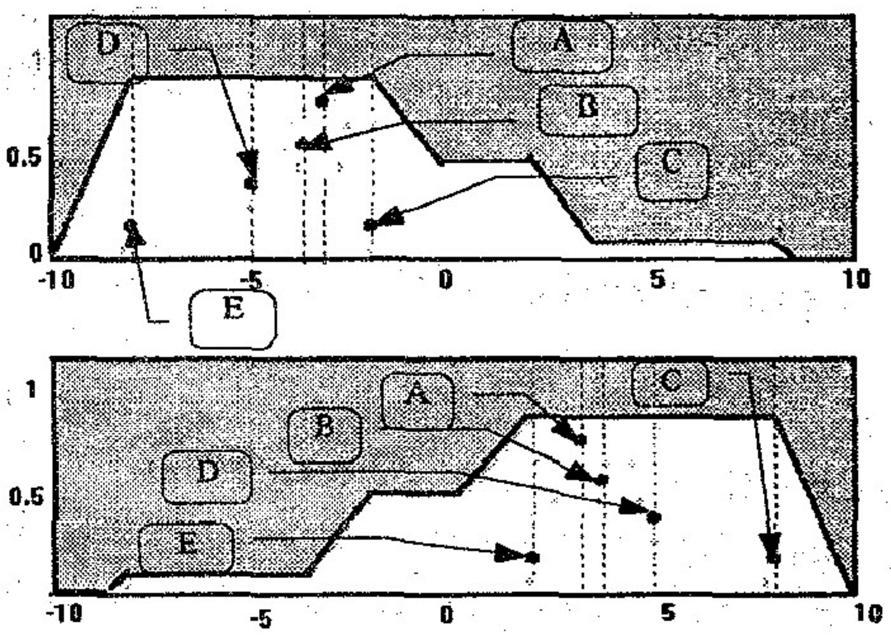

Figure 2.4.1: Defuzzification Methods

The fuzzy set definition for the input was kept similar for all defuzzification methods in order to study the effect of different defuzzification methods. The results of error versus iteration for different defuzzification methods is shown in Figure 2.4.2

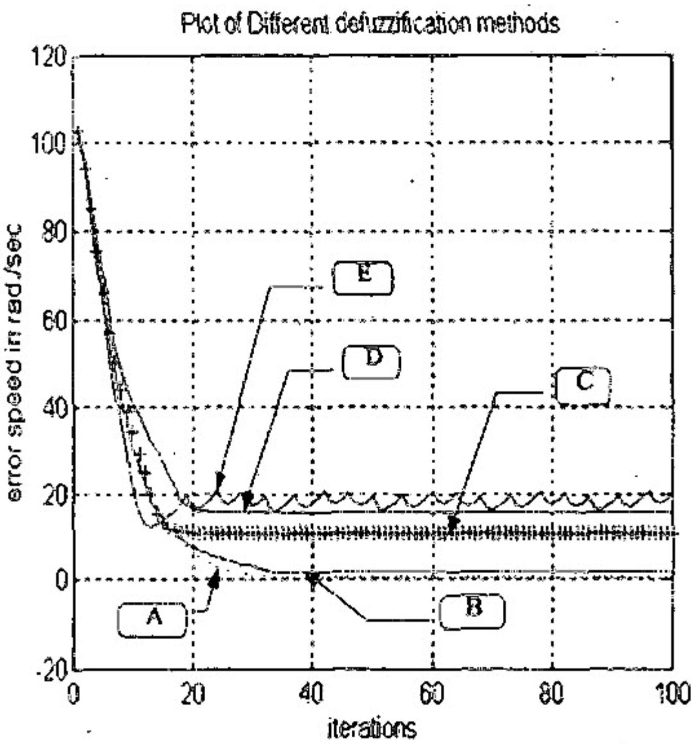

Figure 2.4.2: Results for Different Defuzzification Methods

From Figure 2.4.2 few observations can be made. The largest of maxima (E) has the fastest response but induce steady state error. Whereas the center of area (A) and center of sum (B) have slower response compared to largest of maxima, but have relatively small steady state error. (S.S.Saraf, 1996)

This paper also studied the possibility of combined defuzzification methods in order to have better defuzzification characteristics. This journal has proposed two combinations which is largest of maxima and center of sum (A); largest of maxima and center of area (B). The result of this combination defuzzification method is shown in Figure 2.4.3.The combination of largest of maxima and center of area is faster and has a small steady state error compare to the combination of largest of maxima and center of sum. Thus, from this simulation results it was observed that the synthesis of largest of maxima and centroid defuzzification techniques has the best defuzzification characteristics. (S.S.Saraf, 1996)

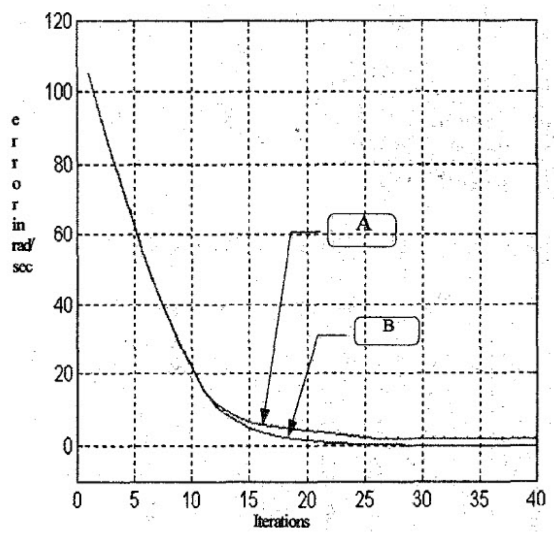

Figure 2.4.3: Results for Combination of Defuzzification Methods

2.5 PMDC Motor Speed Control with Fuzzy Logic Using PIC16F877 (Isik, 2009)

The aim of the paper is to study the speed of permanent magnet DC (PMDC) motor with Fuzzy Logic algorithm using PIC16F877. The membership functions used in this paper are called Negative (N), Zero (Z) and Positive (P) and the membership degree of the functions are defined from 0 to 255 which is 8 bit unsigned maximum value. The fuzzy logic based controller composed of 3 main parts, namely fuzzifier, rule base and defuzzifier, as shown in Figure 2.5.1. (Isik, 2009)

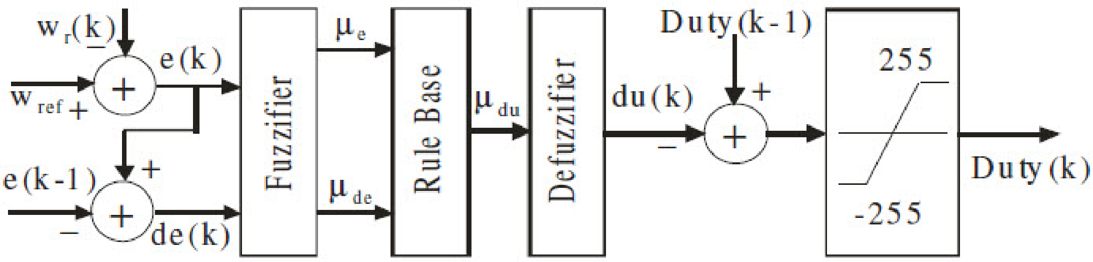

Figure 2.5.1: Block diagram of fuzzy logic controller

The fuzzifier is where the crisp values of the error (*e*) and change in error (*de*) are converted to membership degrees μ_e and μ_{de} respectively. The fuzzy sets represent the linguistic terms negative (N), zero (Z) and positive (P) and the shape of fuzzy set used in this paper is shown in Figure 2.5.2.

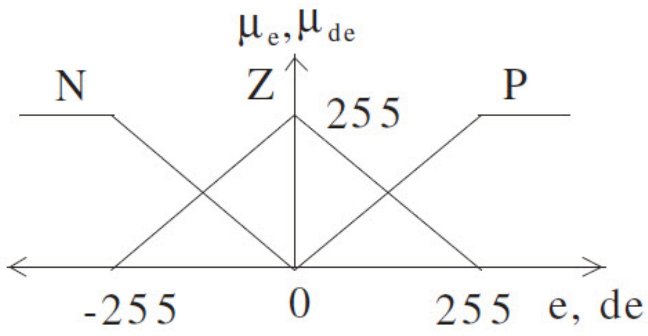

Figure 2.5.2: Fuzzy Sets

The next stage of fuzzy logic control is the rule base. The rule table is used to produce the output membership subset as a *du*. There are four combination which is du_1, du_2, du_3 and du_4 due to subsets of *e* and *de*. The Table 2.5.1 is the control rules that representing the control actions to be taken in terms of the linguistic variables N, Z and P.

Table 2.5.1: Fuzzy Control Rule Table

de\e	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

After the rule base, the defuzzification will be the next step. In this paper, the minimum function is used and the center of area (centroid) method is implemented to find to mean value of the output membership degrees. The formula for the center of area is shown inEquation 2.5.1.

$$Du = \frac{\sum_{i=1}^{n} \mu_i(du) \times du_i}{\sum_{i=1}^{n} \mu_i(du)} \qquad 2.5.1$$

The flow chart of the fuzzy logic algorithm written to the microcontroller is shown in Figure 2.5.3.

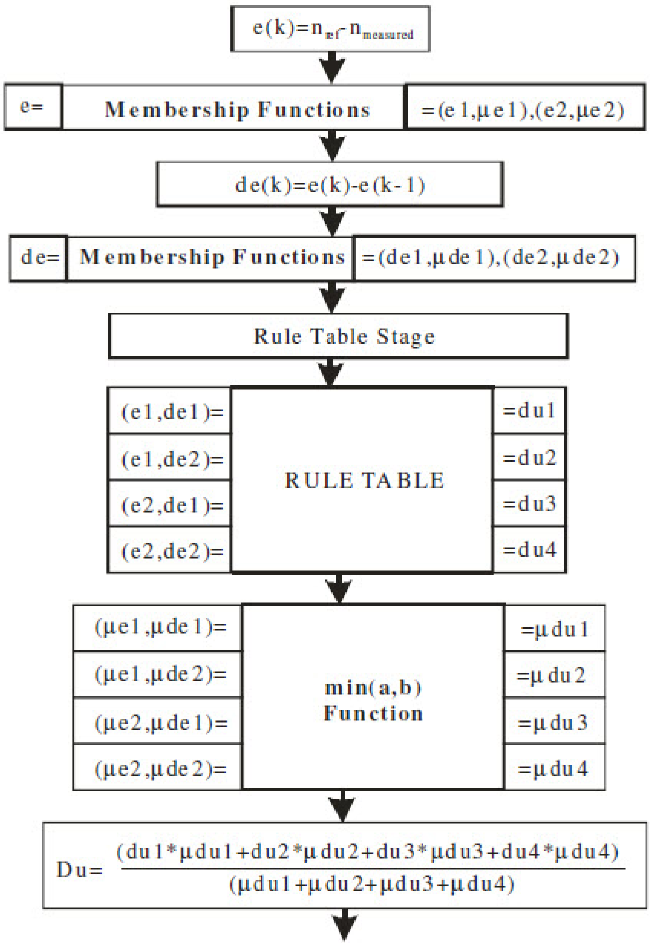

Figure 2.5.3: Flow Chart of Fuzzy Logic

CHAPTER 3

METHODOLOGY

3.1 Overview

In this project, the wheelchair movement and distance travelled will be controlled in a microcontroller. Two encoders will be used and mounted on the two wheels to provide the feedback on distance travelled. Besides, the joystick control is bypassed through the microcontroller system. The Fuzzy Logic algorithm was implemented and programmed into the microcontroller to control the distance travelled by the wheelchair with the minimum undershoot or overshoot. The printed circuit board (PCB) was fabricated.

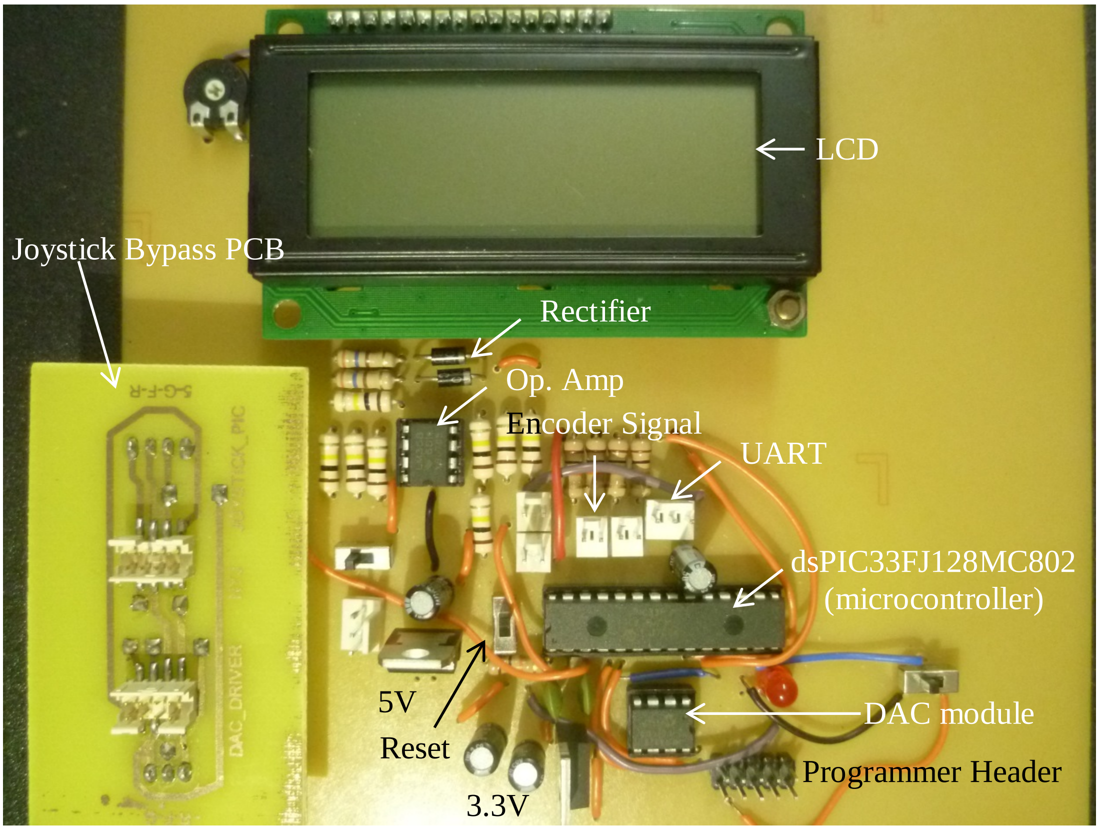

Figure 3.1.1: Microcontroller Printed Circuit Board

3.2 Hardware Overview

In the subtopic, the hardware design and configuration will be illustrated in details. The overall/flow chart of the board design is shown in Figure 3.2.1.This board is designed in such a way that the user can manually control the wheelchair without the needs for feedback from the control system. This provides some flexibility to the user when the user does not need the use of feedback control system.

The microcontroller model that was used in this project is the dsPIC33FJ128MC802, with operating voltage is of 3.3V. The operating voltage of the joystick is 5V, thus an operational amplifier (LM358) is needed to reduce the voltage before connecting with the microcontroller. The analog voltage from the operational amplifier is then digitized through the Analog to Digital converter (ADC) in the microcontroller. Next, a Digital to Analog converter (DAC) is needed to convert back the digital voltage into analog voltage before connecting to the wheelchair. The DAC used in this project is the MCP4822 (2 channel, 12bit resolution).

The two rotary encoders are mounted on the wheels to provide distance feedback to the microcontroller. The rotary encoder is able to produces 500 pulses in one revolution. Furthermore, a LCD on the PCB is used to display the real time parameters such as the distance travelled, the angular speed of the wheel, and the error of the distance between the target locations. The microcontroller is able to send data to the laptop/computer for data collection and testing. This is an important feature because it provides relatively accurate data collection during testing. It also can be used to give commands to the microcontroller for future action. This is important when the control system needs other feedback such as path planning, obstacle avoidance, localization from other systems.

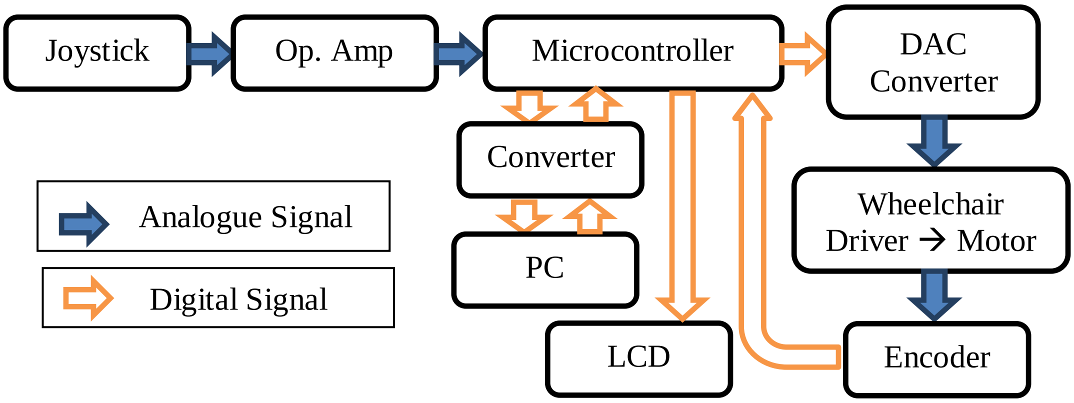

Figure 3.2.1: Overview/flow chart of board design

3.2.1 Joystick

The function of the joystick is to control the wheelchair moving direction as well as speed. The user can control the wheelchair movement by moving the joysticks. The operating voltage of this joystick is 5V. There are two output voltages from this joystick, which will be used to control the wheelchair to move forward or backward and turn right or left. At neutral position, both output voltage are approximate to

2.4V. The maximum and minimum outputs from the joystick are about 3.9V and 1.1V, Figure 3.2.2.

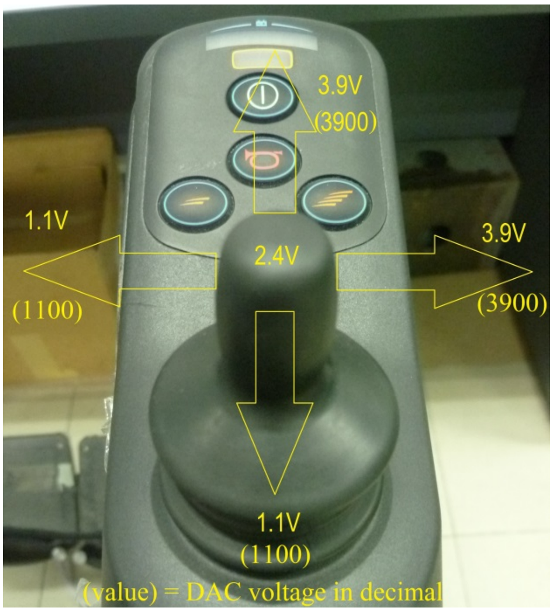

Figure 3.2.2: Joystick control

3.2.2 Operational Amplifier

The operational amplifier used in this project is a low power dual operational amplifier, LM358. The maximum input voltage to the microcontroller is 3.3V whereas the maximum output voltage from the joystick is 3.9V. This can spoil the microcontroller if the voltage exceeds 3.3V. Thus, an operational amplifier is needed to subtract the extra 0.7V from the joystick output voltage. The simplified schematic diagram is shown on Figure 3.2.3.

The function of the rectifier is to clamp the voltage of 0.7V into amplifier. The forward voltage of the rectifier can be adjusted by changing the current. The relationship between the voltage and current can refer to the datasheet. A resistor is connected in series with rectifier to get required current which will correspond to the forward voltage.

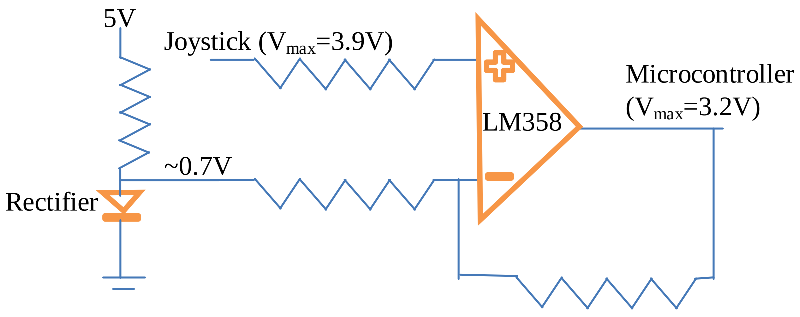

Figure 3.2.3: Schematic diagram of operational amplifier

3.2.3 Microcontroller

The microcontroller that is implemented in this project is the dsPIC33FJ128MC802, from Microchips Technology Inc. This is a 28 pin microcontroller which can be programmed to have different functions. There are different modules such as timer, analog to digital converter(ADC), quadrature encoder interface (QEI), serial peripheral interface (SPI), universal asynchronous receiver transmitter (UART) and so on, inside this microcontroller.

3.2.3.1 Analog to Digital Converter (ADC)

The ADC in this microcontroller is used to convert the analog voltage from the operational amplifier into digital signal. The ADC in this microcontroller can be programmed into either 12 bit or 10 bit resolution. The main difference between 12 bit and 10 bit is conversion error.

$$12bit: \frac{1}{2^{12}} \times 3.3V = 0.000806V \qquad \text{Equation 3.2.1}$$

$$10bit: \frac{1}{2^{10}} \times 3.3V = 0.00322V \qquad \text{Equation 3.2.2}$$

$$Difference\,\% = \frac{0.00322 - 0.000806}{0.00322} \times 100 = 75\% \qquad \text{Equation 3.2.3}$$

From this above calculation, it shown that 12bit ADC can provide finer voltage conversion up to 75% compare to 10 bit ADC. In other means, 12 bit ADC can responds to 0.000806V of voltage changes whereas 10 bit ADC only able to responds to 0.00322V of voltage changes. Thus, 12 bit ADC is implemented in this project.

3.2.3.2 Serial Peripheral Interface (SPI)

The SPI is one of the common communications in electronics devices. The function of SPI in this microcontroller mainly is to use to control the DAC output voltage. 12 bit data will be sending from the SPI to the DAC in order to control the output voltage from DAC, as shown in Figure 3.2.5 and Table 3.2.1.

3.2.3.3 Quadrature Encoder Interface (QEI)

The function of this QEI is to count the pulses from the encoder which will represent the distance travelled by the wheel. In each encoder, there is two wire will send the pulses, namely QEAx and QEBx, as shown in Figure 3.2.4. Two encoders will be mounted on right and left wheel. Therefore, these four wires will be connected to microcontroller. The pulses from the encoder will be processed by the QEI module and the number of pulses in one revolution is stored into a register, namely POSxCNT. The calculation of distance travelled is calculated inside the microcontroller based on the number of pulses. Besides, this QEI is also able to determine whether the wheel is rotating anticlockwise or clockwise. The rotation direction is important to make sure the wheelchair is moving in the correct direction.

Besides, QEI module is also able to be configured either only sensing the rising and falling edge of the QEAx signal or sensing rising or falling edge both QEAx and QEBx. Kindly refer to topic 3.2.5:Encoder for further illustration.

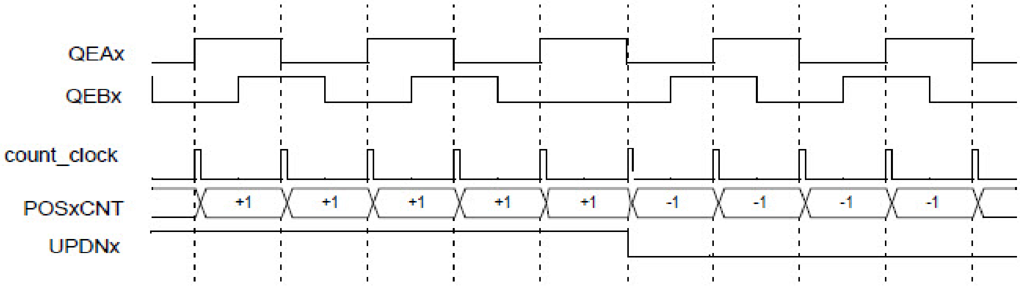

Figure 3.2.4: Quadrature encoder – pulse diagram

3.2.3.4 Universal Asynchronous Receiver Transmitter (UART)

UART is another common type of communication other than SPI. The function of UART in this project is used to communicate with laptop through serial-to-USB converter. The purpose of this is to send command to microcontroller and receive the experimental data from the microcontroller. All the data in the Appendix is received through this UART communication. This UART will send the 8 bit data with a start bit and a stop bit. The purpose of the start bit is to tell the devices such as laptop that data will soon be send. After sending the 8 bit data, another stop bit will be send to notice the laptop that sending has completed. The 8 bit data from UART is in ASCII format, which is the format that used in laptop.

3.2.3.5 Timer

The function of timer is to count the time lapsed. Besides, the angular speed on both wheel are calculated in the microcontroller. The angular speed of the wheelchair will be updated every 0.02 second. The angular speed will be monitored and to make sure that the wheelchair is always achieve the maximum speed with the minimum time to reach the desired distance.

3.2.4 Digital to Analog Converter (DAC)

After the signal is being processed in microcontroller, the DAC is required to convert the digital signal into analog voltage, which will connect to the wheelchair motor driver. The DAC model that used in this project is MCP4822 and it is a 12bit, dual voltage output DAC.The maximum and minimum output voltage from this DAC is about 3.9Vand 1.1V. This range of DAC voltage is to simulate the voltage range from the joystick. This is important because this DAC voltage will be used as a signal to control the wheelchair. If the conversion is not being done properly, the microcontroller might not able to control of the wheelchair.

Besides, this DAC also serves as the function of bypass the joystick control. The fuzzy logic system will send the digital signals to DAC and the DAC will convert the digital signals to analogue voltages to the wheelchair driver, Table 3.2.1. The graph is plotted for visualization of relationship between voltage A and voltage B, Figure 3.2.5.

To move forward, the microcontroller will need to send 3700 in decimal to channel 1 and 2400 in decimal to channel 2. The 3700 and 2400 of digital signal in decimal will converted to analogue voltage of 3.7V and 2.4V in respectively channel.

Table 3.2.1: DAC Controlled Voltage (decimal) for Wheelchair

	Digital Signal from Microcontroller	
Direction	Voltage A (channel 1)	Voltage B (channel 2)
Forward	2400 (slow) – 3700 (fast)	2400
Backward	2400 (slow) – 1300 (fast)	2400
Turn Right	2600 (slow) – 3000 (fast)	2600 (slow) – 3100 (fast)
Turn Left	2600 (slow) – 3000 (fast)	2200 (slow) – 1800 (fast)

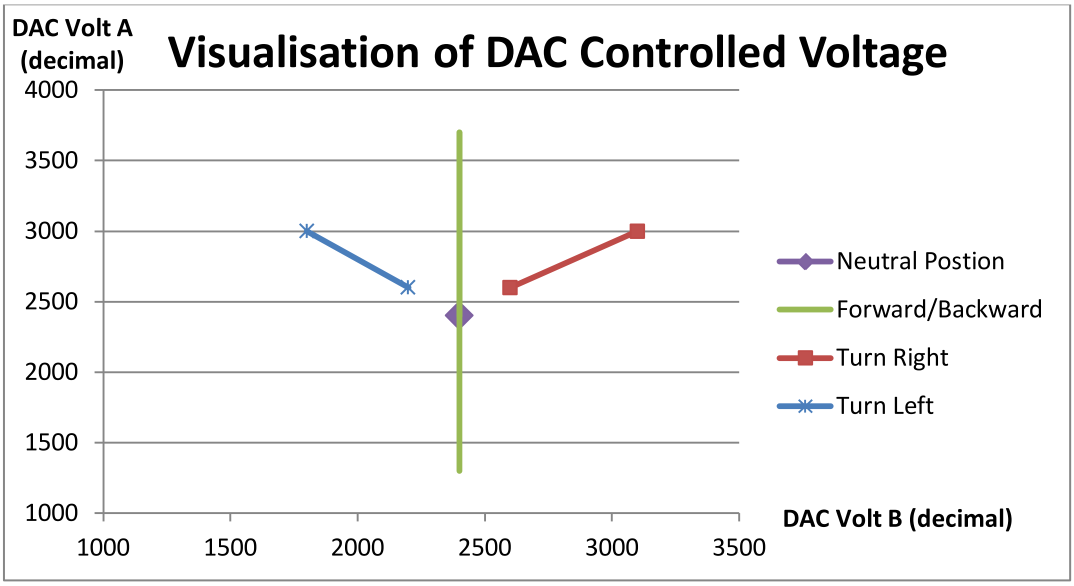

Figure 3.2.5: Visualisation of DAC Controlled Voltage

3.2.5 Encoder

The main function of the encoder is to provide feedback of the wheelchair travelled distance. Two encoders will be used and mounted on the right and left wheel, as shown in Figure 3.2.8. The technical drawing of the encoder mounting is attached on Section 6.3.The encoder will generate 500 pulses per revolution on two channels, namely channel A and channel B. The direction of rotation can be determined by either the channel A signal leads or lag channel B, as shown in Figure 3.2.4. These encoders signal will be send to microcontroller to determine the distance travelled and angular speed of the wheel, as shown in Figure 3.2.7. The program flow chart is shown in Figure 3.2.6.

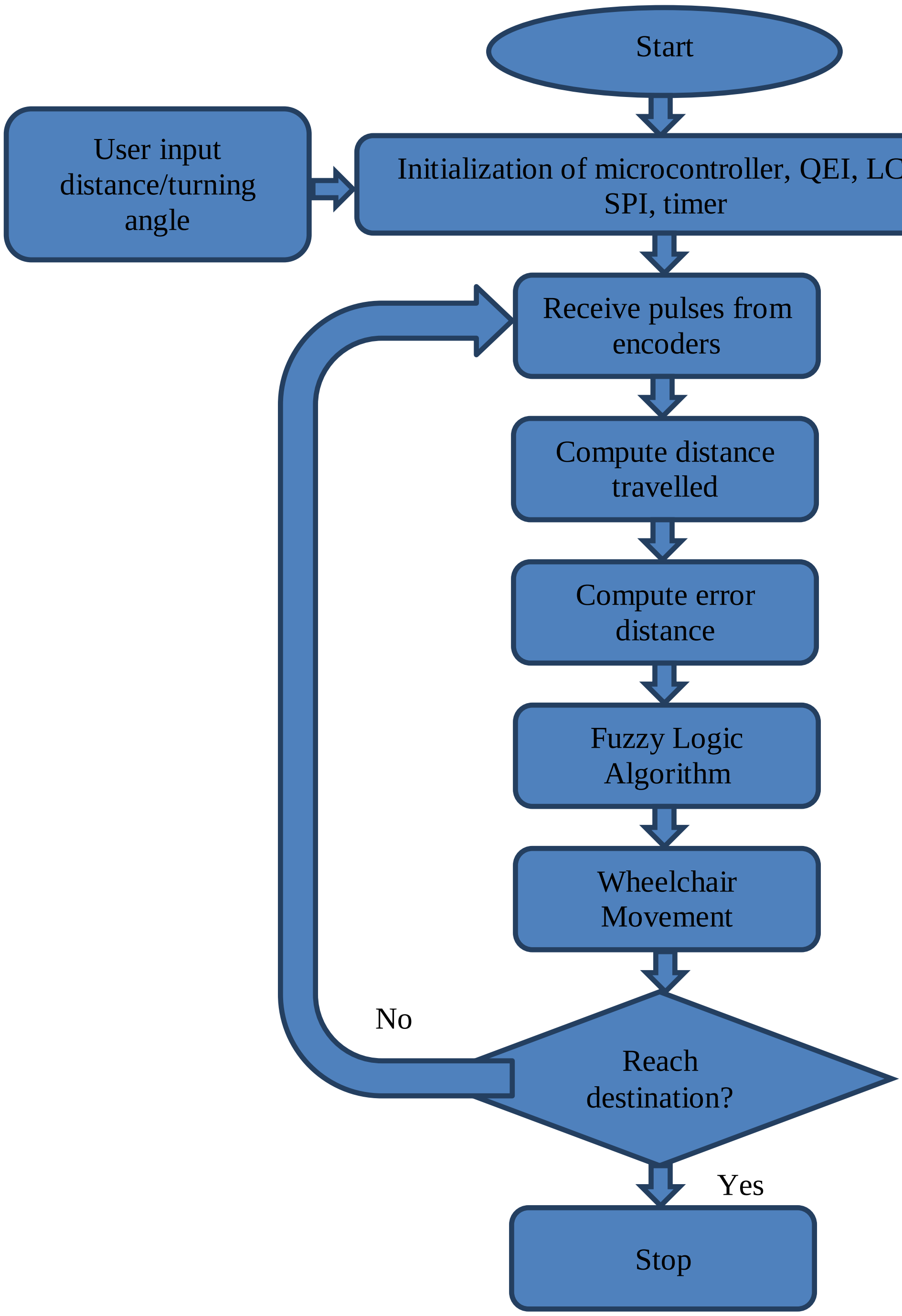

Figure 3.2.6: Program flow chart of microcontroller

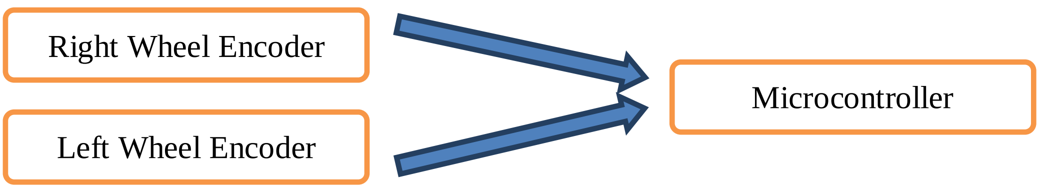

Figure 3.2.7: System flow chart of encoders

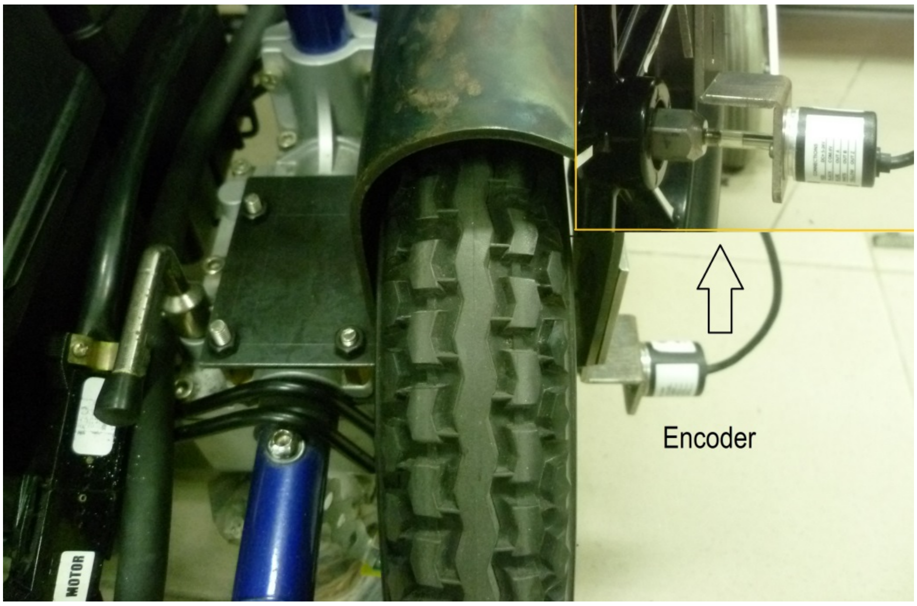

Figure 3.2.8: Encoder mounting

3.2.6 Liquid Crystal Display (LCD)

The LCD is used to display the data such as distance travelled, angular speed of both wheels, error indication, the mode of the fuzzy logic controller (move straight or turning) and so on. This LCD will display some important parameter to user so that user can know the current condition of the fuzzy logic controller without the needs of laptop to display the data, as shown in Figure 3.2.9.

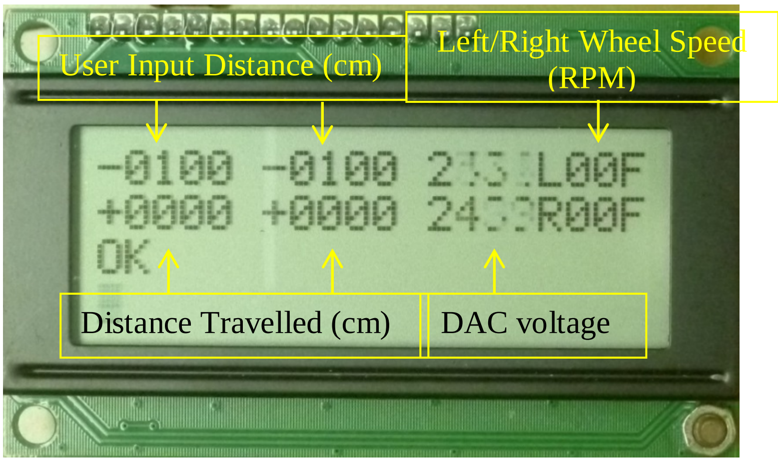

Figure 3.2.9: LCD Display

3.2.7 Serial Converter

The function of serial converter (Figure 3.2.10) is used to interface the UART to USB. In older days, many communication interfaces between devices is through computer serial port and nowadays all is using USB. Although the computer serial port has been phase out, but microcontroller communication still using UART. Thus, a tool such as serial converter is necessary for the communication between USB and UART. In this project, USB to serial converter is used as the communication between the microcontroller and computer, as shown in Figure 3.2.1. With this converter, the data from microcontroller can be sending to computer on real time basis.

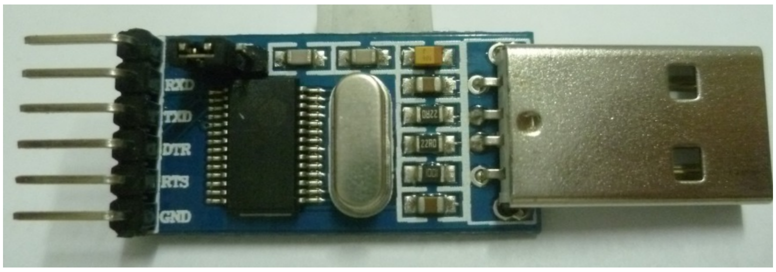

Figure 3.2.10: Serial converter

3.3 Fuzzy Logic Control

In this chapter, the Fuzzy Logic concepts will be discussed includes the fuzzy sets, membership functions, fuzzification, rules, inference, defuzzification and the design of fuzzy logic control.

3.3.1 Introduction

The main objective of fuzzy logic has been to make the system think like people. It can deal with the vagueness intrinsic to human thinking and natural language. With the fuzzy logic algorithms, the machines or system can understand and respond to vague human concepts such as slow, fast, hot, cold, small, and large and so on. Fuzzy logic also could provide a relatively simple approach to reach definite conclusions from imprecise information.

The advantage of using fuzzy logic in a system is it could greatly reduce the complexity of the control system, able to model the complex, nonlinear problem linguistically rather than mathematically. Thus it can help to increase productivity, and to reduce the cost and time-to-market.

3.3.2 Assumptions in a Fuzzy Control System Design

There are six basic assumptions that commonly made whenever a fuzzy rule-based control policy is selected:

a) The plant is observable and controllable. The state, input and output variable of the system are usually available for observation and measurement. In this fuzzy logic controller project, the input will be the distance value from the encoder. The rate of change of distance (speed) and the rate of change of speed (acceleration) will be computed in the microcontroller. The output from the microcontroller is the regulated voltage (DAC) which in turn controls the speed of the motor.

b) There exists a body of knowledge comprising a set of linguistic rules, engineering common sense, intuition, or a set of input-output measurements data from which rules are extracted. In other words, a linguistic model can be created based on the knowledge of expert.

c) A solution exits.

d) The solution is “good enough” for the system, not necessarily the optimum/best one.

e) The range of precision of the controller is within the acceptable range.

3.3.3 Fuzzy Logic Controller

A simple fuzzy logic control system block diagram isFigure 3.3.1. The knowledge base module contains the knowledge of all the input and output fuzzy partitions. In this FL speed controller, the input will be the distance from encoder and the output is the regulated voltage to motor. This module will include the term set and membership functions that define the input variables to the fuzzy rule base system and the output variables to the plant under control.

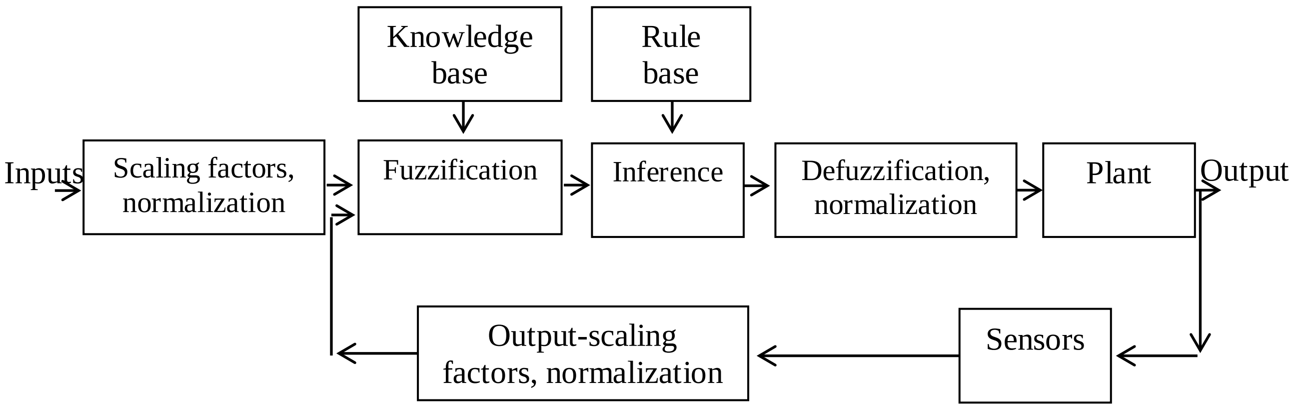

Figure 3.3.1: Fuzzy logic control system block diagram

The steps in designing the fuzzy control system are:

a) The inputs and outputs of the system will be identified.
b) The universe of discourse by each variable into a number of fuzzy subsets will be partitioned and assigning each a linguistic label.
c) The membership functions for each fuzzy subset will be determined.
d) The fuzzy relationship between the input fuzzy subsets and the outputs fuzzy subsets will be assigned to form the rule-base.

e) Appropriate scaling factors for input and output variables will be chosen to normalize the variables to the [0, 1].
f) The inputs will be fuzzified to the controller.
g) Fuzzy reasoning will be used to infer the output contributed from each rule.
h) The fuzzy outputs will be aggregated.
i) Defuzzification will be applied to form a crisp output.

3.3.4 Fuzzy Sets and Membership Function

A fuzzy set is a set where the degrees of membership between 1 and 0 are allowed. It allows partial membership. Thus, fuzzy set can better reflects the way intelligent people think. To perform fuzzy computation, the inputs and outputs must be converted from the crisp value into linguistic forms. Fuzzy membership function is a tool that converts the crisp value to linguistic terms. A fuzzy membership functions can contain several fuzzy subsets and each fuzzy subsets represent one linguistic term. In this project, the linguistic terms that used to represent the input and output values are defined by five fuzzy subsets/variables as shown inTable 3.3.1.The degree of membership is the number of indicating how much a crisp value can be a member in each subset. The crisp value can be converted partially in many subsets and the degree of membership in each subset may be different.

Table 3.3.1: Fuzzy Linguistic Terms

Term	Definition
VB	Very Behind
B	Behind
JR	Just right
F	Far
VF	Very Far

The control parameter that will be used in this project is the error of distance. The distance between current location and desired location is the error of distance. The distance will be measured from the encoder mounted on the wheel and update to microcontroller in real time. The speed will be computed in the microcontroller to monitor the maximum speed to reach the desired location with minimum overshoot. This computed distance error will be used as the input for the fuzzy logic controller. Based on the real time distance error, the fuzzy logic controller will determine how fast the wheelchair will move automatically.

There are many shapes can be used to represent the membership function such as triangular-shaped, trapezoidal-shaped, Gaussian curve, generalized bell shaped, pi-shaped and so on. The x-axis and y-axis represents the input variable and fuzzy values respectively. The triangular shaped membership function is shown inFigure 3.3.2 and Equation 3.3.1.

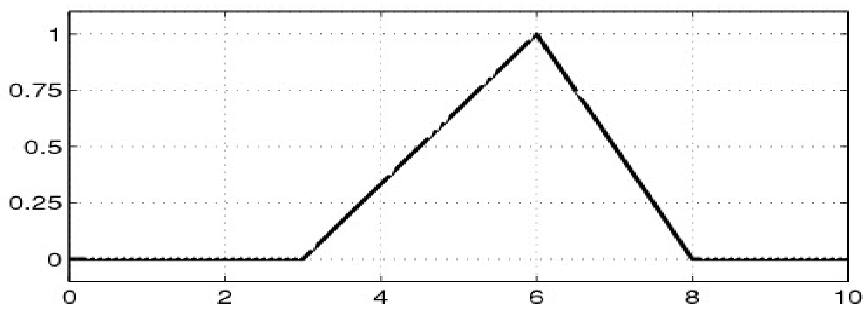

Figure 3.3.2: Triangular-shaped membership function

$$f(x;a,b,c) = \max\left(min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),0\right) \qquad 3.3.1$$

The trapezoidal shaped membership function is shown inFigure 3.3.3 and Equation3.3.2.

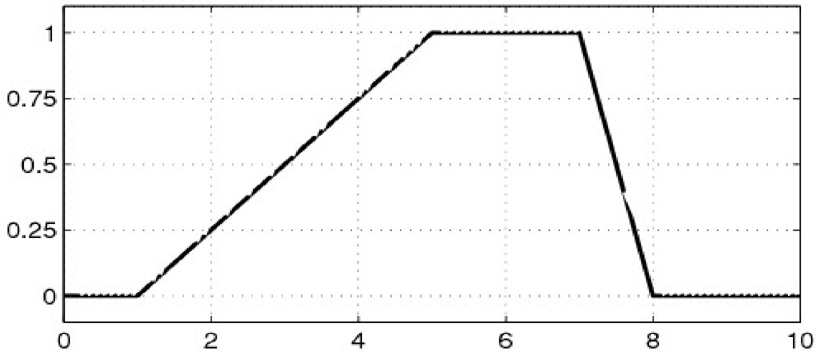

Figure 3.3.3: Trapezoidal-shaped membership function

$$f(x; a, b, c, d) = \max\left(min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \qquad 3.3.2$$

The Gaussian function is shown in Figure 3.3.4 and Equation 3.3.3.

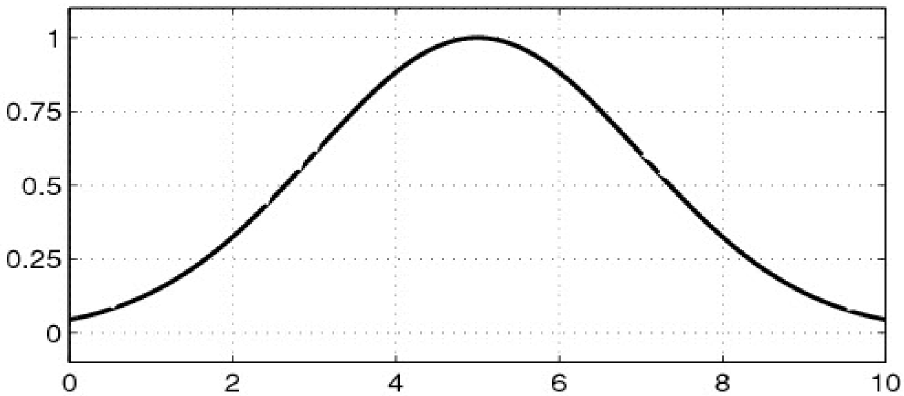

Figure 3.3.4: Gaussian membership function

$$f(x; \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \qquad 3.3.3$$

The generalized bell shaped membership function is shown in Figure 3.3.5 and Equation 3.3.4.

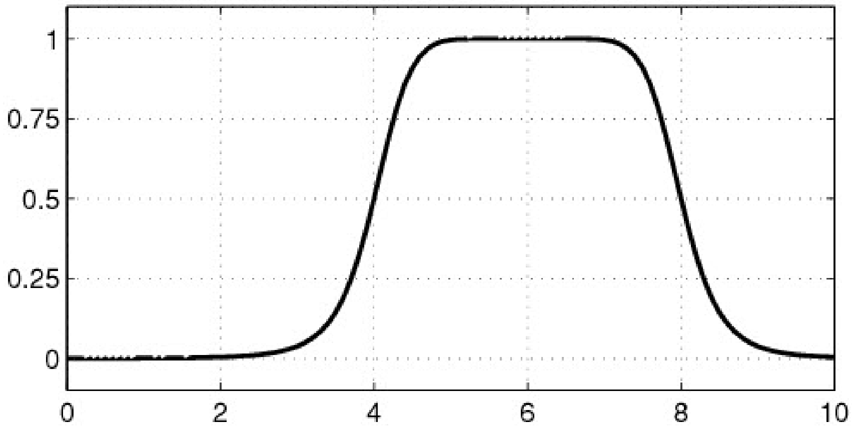

Figure 3.3.5: Generalized bell shaped membership function

$$f(x;a,b,c) = \frac{1}{1 + \left|\frac{x-c}{a}\right|^{2b}} \qquad 3.3.4$$

In this project, the triangular and trapezoidal membership function will be adopted for the sake of simplification and reduce computational demand on microcontroller.

3.3.5 Fuzzification

Fuzzification is to translate the input values to fuzzy set membership. The degree of membership function is range from 0 to 1 and the sample of fuzzification is show in Figure 3.3.6.

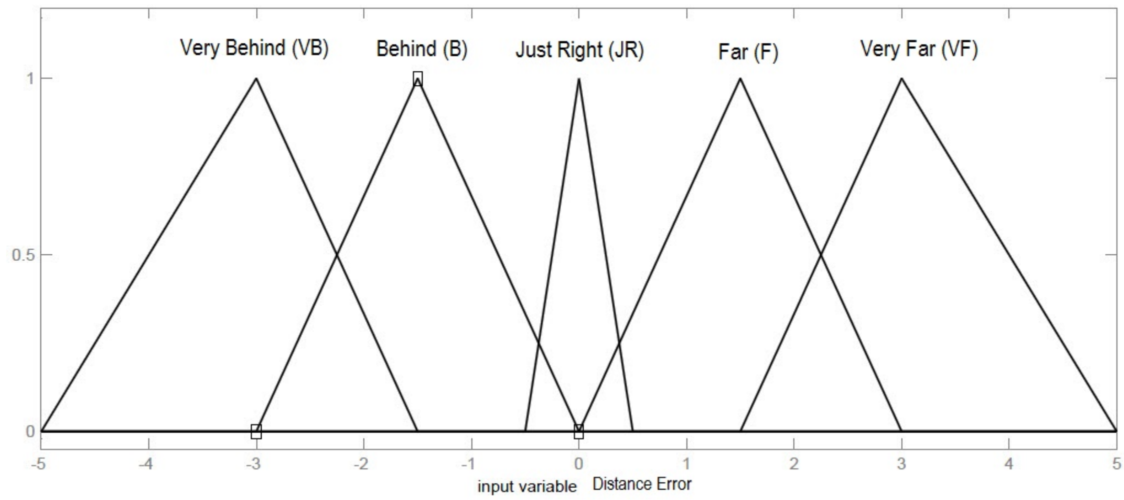

Figure 3.3.6: Fuzzification

When the value of error (distance) is -1.25, the degrees of membership function for slow and too slow are 0.5 respectively. This fuzzification result in more than one values of degree of membership functions when the membership functions are overlaps.

3.3.6 Inference \ Fuzzy Reasoning

Fuzzy reasoning is based on inference rules of the form

IF (antecedent 1) and (antecedent 2), THEN (consequent)

This form of expression is commonly known as IF-THEN rule based form. It expresses an inference such that a person knows a fact (antecedent), then the person can infer or derive another fact called consequent.

Graphical technique of inference will be discussed in the following. The first inference method is created by Mamdani and Assilian and the method is then named as Mamdani inference system. To illustrate this Mamdani system, a two-rule system where each comprises of two antecedents and one consequent. This is analogous to the speed controller that use dual input which is speed error and rate of speed error, and single output which is regulated voltage.

The inputs x_1 and x_2 are crisp values. Figure 3.3.7 illustrates the graphical analysis of two rules, where the symbol A_{11} and A_{12} represents the first and second fuzzy antecedents of first rule respectively whereas the symbol A_{21} and A_{22} represents the first and second antecedents of second rule respectively. The symbol B_1 and B_2 represents the consequences of the first and second rule respectively. The minimum function is arises because the antecedent pairs are connected by a logical “and” connective. The minimum membership function value for the antecedents propagates through to the consequent and truncates the membership function for the consequent of each rule. Next, the truncated membership functions of each rule are aggregated using either conjunction rule or disjunctive rules. In Figure 3.3.7, the rules are disjunctive, so the aggregated membership function comprising of the outer envelope of the individual truncated membership forms from each rule. In order to find a crisp value from this aggregated output, a process called defuzzification could be employed and a value such as y* would result.

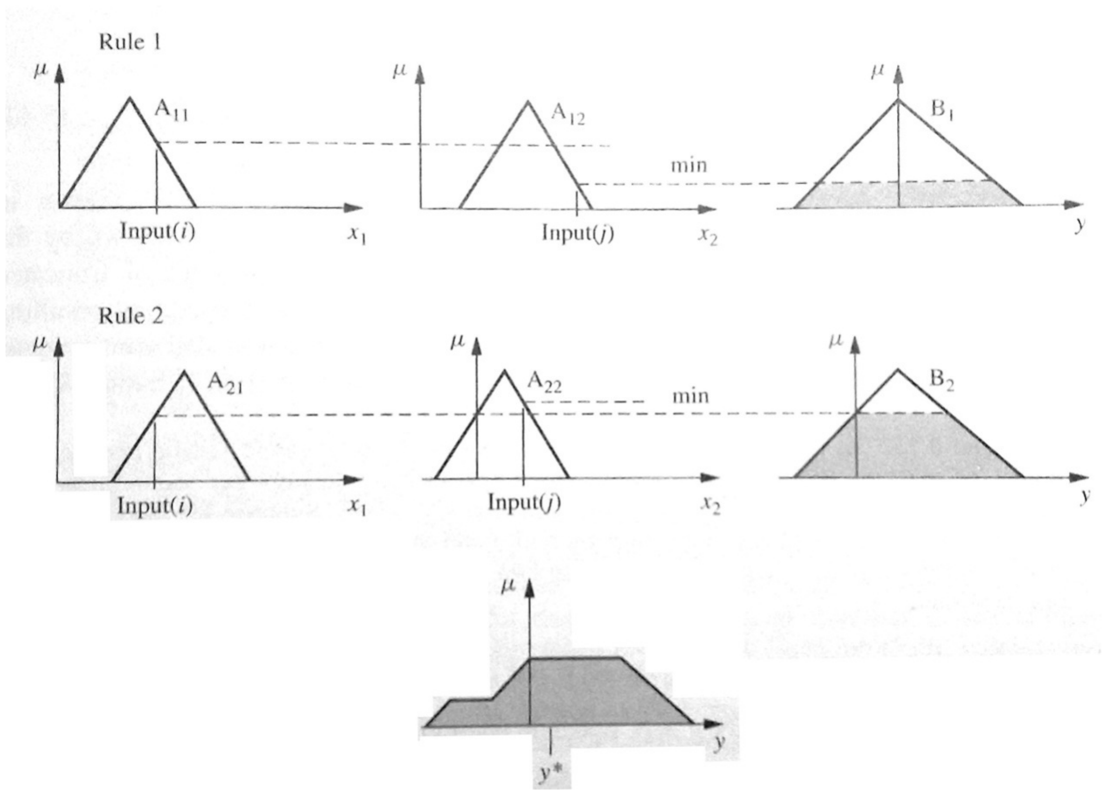

Figure 3.3.7: Graphical Mamdani (Max-Min) inference method with crisp inputs.

In the Sugeno fuzzy inference, Michio Sugeno suggested to use a single spike, a singleton, as the membership functions of the rule consequent. A singleton is a fuzzy set with a membership function that is unity at a single particular point on the universe of discourse and zero everywhere else. The Sugeno style aggregation is shown in Figure 3.3.8. The fuzzification process is exactly same as the Mandani system. The main difference between Mandani and Sugeno is that the Sugeno output membership functions are either linear or constant. A typical rule in Sugeno fuzzy model is

IF input 1 = x_1 AND input 2 = x_2, then output = $k_1x_1 + k_2x_2 + k_3$

wherek_1, k_2, and k_3 are constants (weightage).

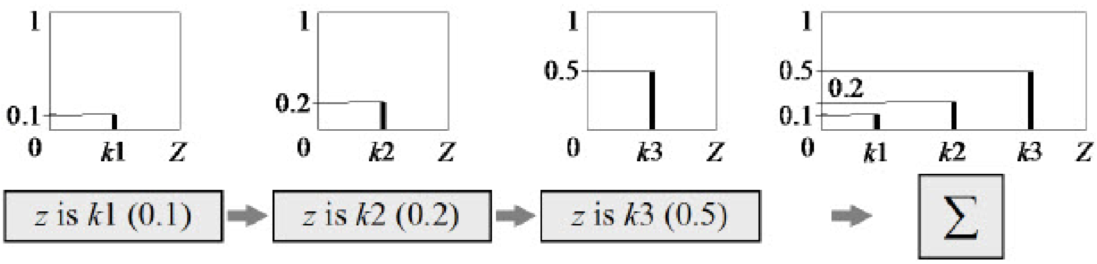

Figure 3.3.8: Sugeno-style aggregation

This Sugeno system uses weighted average (Equation 3.3.6) in the defuzzification process whereas the Mandani system normally uses the centroid method to defuzzied aggregated membership functions. The advantages of the Sugeno methods are

a) It is computationally efficient.
b) It works well with linear techniques
c) It works well with optimization and adaptive techniques.
d) It has guaranteed continuity of the output surface.
e) It is well suited to mathematical analysis.

The advantages of the Mamdani method are

a) It is intuitive.
b) It has widespread acceptance.
c) It is well suited to human input.

3.3.7 Defuzzification

Defuzzification is a process of translating the results of inference process into crisp value. In fact, this crisp values is the values that will used as the control action to the motor. Generally, there a few common defuzzification methods:

a) Centroid method

This method is also known as the center of mass or center of gravity method. The defuzzied output is defined by Equation 3.3.5.

$$y^* = \frac{\int \mu_F(x) x dx}{\int \mu_F(x) dx} \quad 3.3.5$$

b) Weighted average method (Sugeno-Defuzzification)

This method is the most frequently used in fuzzy applications (Equation 3.3.6) because it is one of the more computationally efficient methods. This method is also known as Sugeno-Defuzzification. The limitation of this method is restricted to symmetrical output membership functions.

$$y^* = \frac{k_1\mu_1(x) + k_2\mu_2(x) + k_3\mu_3(x)}{\mu_1(x) + \mu_2(x) + \mu_3(x)} \quad 3.3.6$$

c) Max membership principle

This method also known as height method and it is limited to peaked output functions. The smallest value of the domain with maximum membership is selected.

d) Mean max membership

This method known as middle of maxima is closely related to max membership principle, except that the locations of the maximum membership can be non-unique.

e) Center of sums

This method is not restricted symmetric membership functions. This process involves the algebraic sum of individual output fuzzy sets. The disadvantages of this method are that the interesting areas are added twice, and involve in finding the centroids of the individual membership functions.

f) Center of largest area

If the output fuzzy set has at least two convex subregions, then the center of gravity of the convex fuzzy subregion with the largest area is used to obtain the defuzzied value of the output.

g) First/last of maxima

This method uses the overall output/union of all individual output fuzzy sets to determine the smallest value of the domain with maximized membership degree.

From the above listed advantages in Section 3.3.6, the weighted average method (Sugeno-defuzzification) is selected as it greatly reduced the computational requirement. This is because the microcontroller's processing power is not high enough to process the others methods. Thus, by using Sugeno defuzzification can increases the system response and give better control as well as efficiency.

3.3.8 Design of Fuzzy Logic Control

In this microcontroller, three fuzzy logics systems were implemented for forward/backward movement, turn right movement and turn left movement. The fuzzy logics design structures for the three different movements are shown Figure 3.3.9.

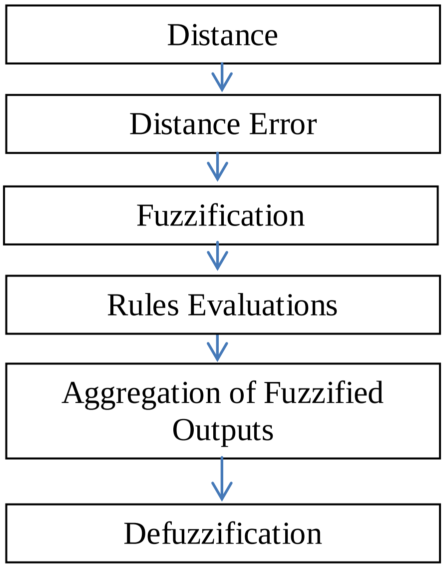

Figure 3.3.9: Fuzzy Logic design structure

3.3.8.1 Forward/Backward Fuzzy Logic

The input parameter for the microcontroller is the pulses from the encoder which mounted on the motor, as shown in Figure 3.2.8.This pulse will be used to compute equivalent distance travelled in the microcontroller. The desired distance/location will be set and send from the mapping module or by user. The difference between the current location and the desired location is the error of distance. This error of distance will be the input parameter for the fuzzy logic controller.

The fuzzification of the fuzzy logic for forward/backward movement is shown in Figure 3.3.10. This fuzzification mainly composes of triangular and trapezoidal membership function. There are two trapezoidal and five triangular membership functions.

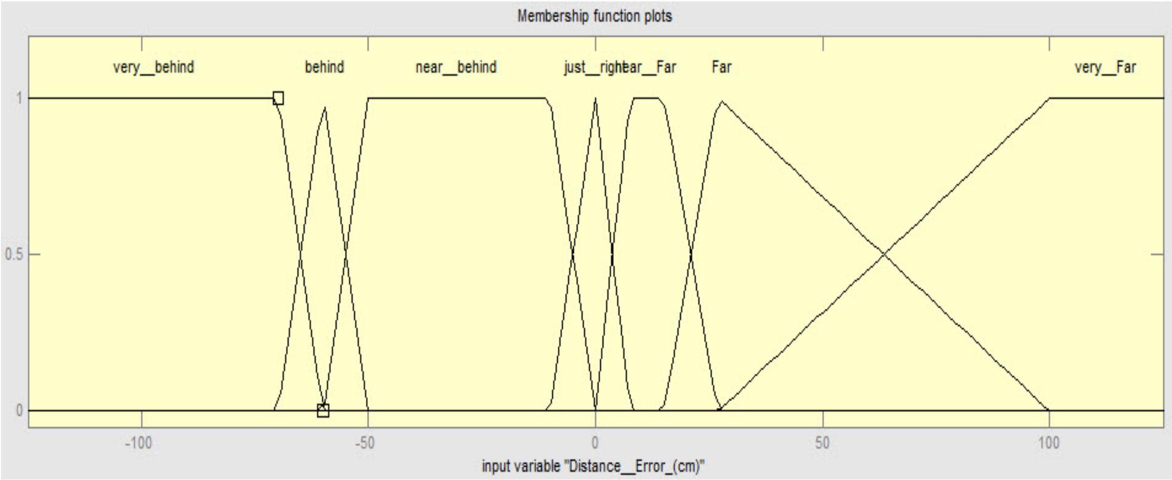

Figure 3.3.10: Fuzzification for forward/backward movement

The rule for this fuzzy logic controller is summarized in Table 3.3.2.These rules are implemented into the microcontroller and tested in the real environment. The rules will be modified if needed.

Table 3.3.2: Rule matrix in linguistic form

Distance Error	**Very Behind**	**Behind**	**Near Behind**	**Just Right**	**Near Far**	**Far**	**Very Far**
Control Action	Very Backward	Backward	Near Backward	Stop	Near Forward	Forward	Very Forward

Rules and aggregation for distance error

1) If Distance Error is Very Behind then Control action is Very Backward
2) If Distance Error is Behind then Control action is Backward
3) If Distance Error is Near Behind then Control action is Near Backward
4) If Distance Error is Just Right then Control action is Stop
5) If Distance Error is Near Far then Control action is Near Forward
6) If Distance Error is Far then Control action is Forward
7) If Distance Error is Very Far then Control action is Very Forward

The Figure 3.3.11shows the Defuzzification results for this fuzzy logic system. When the distance error is more than 100cm, the control action will set the wheelchair to maximum speed. When the distance error is getting lesser and lesser, the speed of the wheelchair is slowing down gradually.

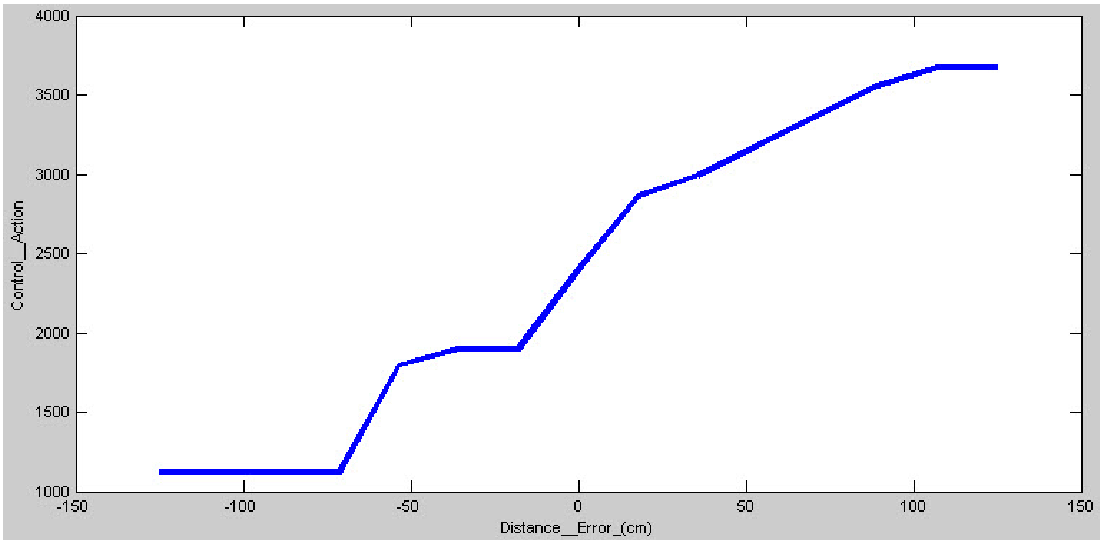

Figure 3.3.11: Surface plots for forward/backward movement

3.3.8.2 Turn Right Movement

The design structure of fuzzy logic is shown in Figure 3.3.9. The input parameter of fuzzy logic system is the degree of turning. The trajectory of each wheel travelled will be used to compute the amount of the wheelchair has turn/rotate, Figure 3.3.12. The assumptions of the wheel trajectory are:

a) The right and left wheel are connected rigidly.

b) No slip occurs when turning.

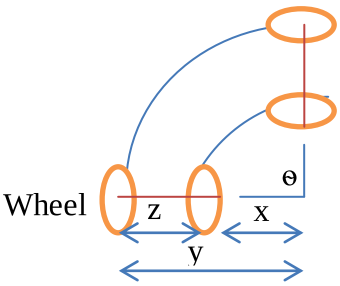

Figure 3.3.12: The trajectory of wheelchair turning movement

The derivation of the trajectory equation:

$$x_{circumference} = 2\pi x \frac{\theta}{360} \quad \text{Equation 3.3.7}$$

$$y_{circumference} = 2\pi y \frac{\theta}{360} \quad \text{Equation 3.3.8}$$

$$x = y - z; y = \frac{y_{circumference}}{2\pi} \frac{360}{\theta} \quad \text{Equation 3.3.9}$$

Subs Equation 3.3.9 into Equation 3.3.7:

$$x_{circumference} = 2\pi(y - z)\frac{\theta}{360}$$

$$x_{circumference} = \left[2\pi \frac{y_{circumference}}{2\pi} \frac{360}{\theta} - 2\pi z\right] \frac{\theta}{360}$$

$$y_{circumference} = x_{circumference} + 2\pi z \frac{\theta}{360} \quad \text{Equation 3.3.10}$$

The fuzzification of this fuzzy logic system for turn right movement is shown in Figure 3.3.13. This fuzzification composes of three triangular membership functions.

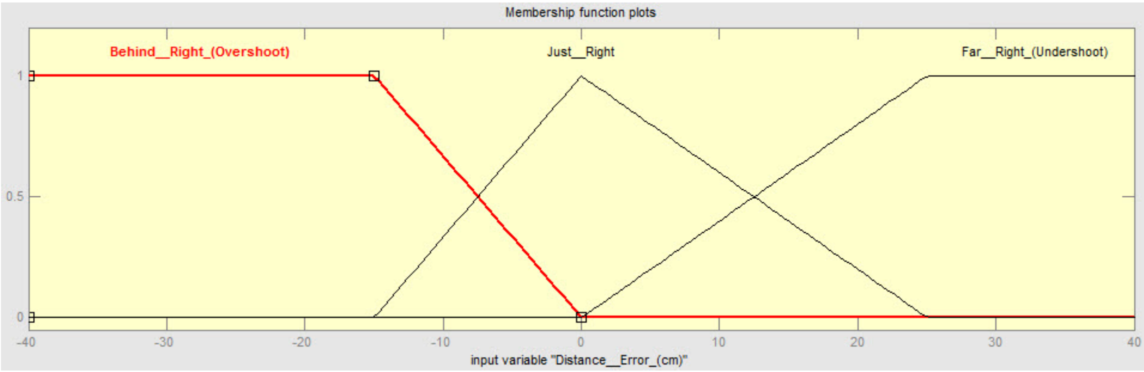

Figure 3.3.13: Fuzzification for turn right movement

Rules and aggregation for degree of turning

a) If Distance Error is Behind Right then Control action is Move Right CCW
b) If Distance Error is Just Right then Control action is Stop
c) If Distance Error is Far Right then Control action is Move Right CW

The defuzzification of turn right fuzzy system is shown in Figure 3.3.14.

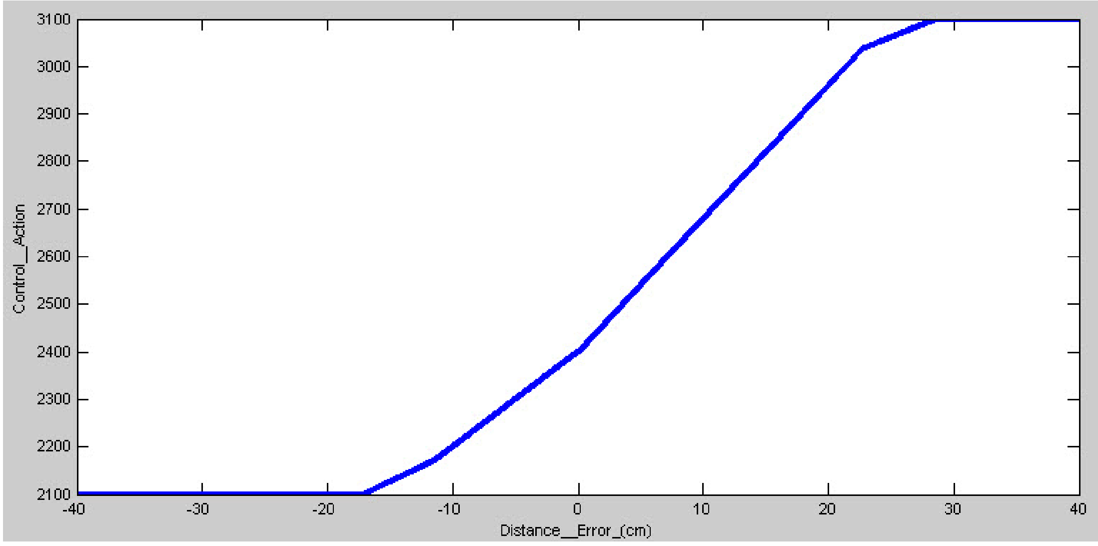

Figure 3.3.14: Surface plot for turn right movement

3.3.8.3 Turn Left Movement

The design structure of fuzzy logic is shown in Figure 3.3.9. The input parameter of fuzzy logic system is the degree of turning. The trajectory of each wheel travelled will be used to compute the amount of the wheelchair has turn/rotate. The fuzzification of this fuzzy logic system for turn right movement is shown in Figure 3.3.15. This fuzzification composes of three triangular membership functions.

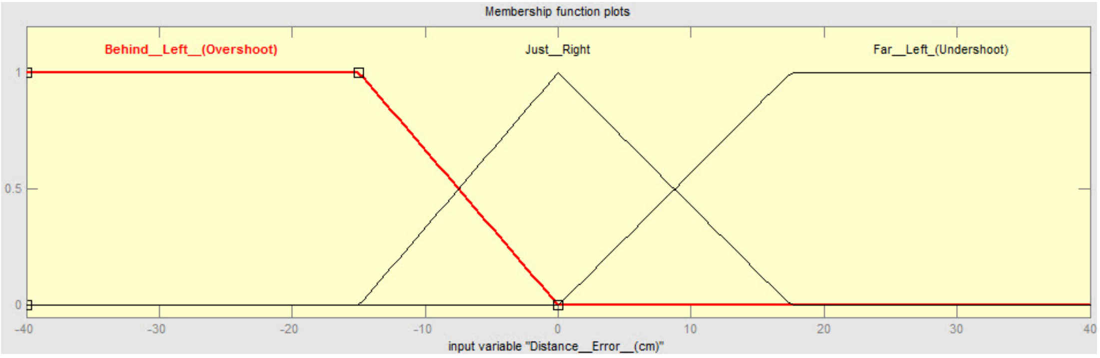

Figure 3.3.15: Fuzzification for turn left movement

Rules and aggregation for degree of turning

a) If Distance Error is Behind Left then Control action is Move Left CW
b) If Distance Error is Just Right then Control action is Stop

c) If Distance Error is Far Left then Control action is Move Left CCW

The defuzzification of turn right fuzzy system is shown in Figure 3.3.16.

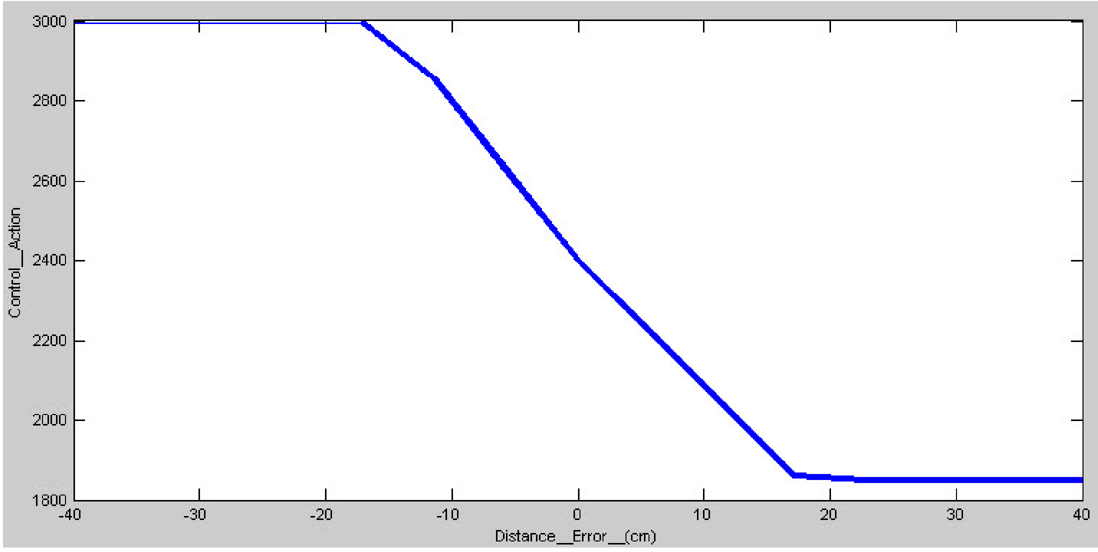

Figure 3.3.16: Surface plot for turn left movement

3.3.8.4 Center Rotate Right/Left Movement

The design structure of fuzzy logic is shown in Figure 3.3.9. The input parameter of fuzzy logic system is the degree of turning. In the trajectory of each wheel travelled will be used to compute the amount of the wheelchair has turn/rotate,Figure 3.3.17. In this centre rotate movement, the speed of both wheels may not always be the same. Therefore, it may cause one wheel is rotating faster than another which may result in the shifting of the center of rotation. In this program, the distance travelled on right and left wheel will be used to compute the angle of rotation. The fuzzy logic algorithm has been implemented in this centre rotate right/left movement.

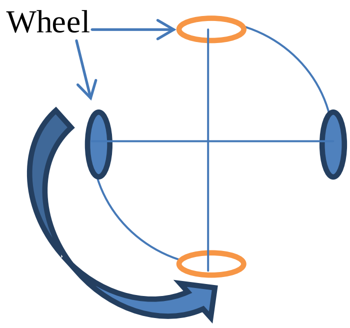

Figure 3.3.17: Centre rotate – right/left movement

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The objective of this fuzzy logic controller is to control the wheelchair to reach the destination in the shortest time and without overshoot/undershoot. Several experiments were conducted to test the Fuzzy logic control system for the wheelchair microcontroller. The experiments were as follows:

a) The speed responses of the wheelchair without load and with load for different input distance
b) The distance accuracy of the wheelchair without load and with load for different input distance
c) The turning angle of wheelchair without load and with load for different input angle

These experiments showed the overall integration of the wheelchair fuzzy logic microcontroller with input from the user. All the experimental data were recorded in the PC through the serial to USB converter on a real time basis. All the recorded data are attached to the Appendix (CD). With different inputs such as distance required to move from the current location of the wheelchair to the next location and the turning angle of the wheelchair, the test were carried out to observe the performance, consistency and accuracy of the wheelchair. All the graphs and table are shown and discussed below.

4.2 Speed Response of the Wheelchair for Different Input Distance

In this topic, the speed response of the wheelchair will be discussed for the wheelchair move forward and backward.

4.2.1 Forward

The graph of wheel forward angular speed versus time for 100cm, 300cm and 500cm are plotted and shown in Figure 4.2.1, Figure 4.2.2 and Figure 4.2.3. In each particular distance, the wheelchair angular speed is tested with load (80kg) and without load.

In Figure 4.2.1, the maximum speed of the wheelchair is about 25 RPM. The graph patterns with load and without load are quite similar. The only main difference between load and without load is that the response of wheelchair with load is slightly lagged 0.4 second behind the one without any load. This similar pattern is consistently appears for different distance, as shown in Figure 4.2.2 and Figure 4.2.3. This might due to the reason that inertia is higher when have load of 80kg, which will cause the motor to respond slower. The motor will require higher force to overcome the inertia.

Furthermore, there is small region of constant speed during deceleration in Figure 4.2.1. This because one of the fuzzy logic memberships functions is a trapezoidal shape, as shown inFigure 3.3.10. This trapezoidal shape causes the constant speed when the distance error is within the range of the membership function. This constant speed pattern does not appear in Figure 4.2.2 and Figure 4.2.3 because both cases have achieve the maximum achievable wheelchair speed (50RPM), therefore, this trapezoidal membership functions is designed to slow down the wheelchair speed without scarifying the accuracy of reaching the location. The test has been conducted without the trapezoidal membership function; the wheelchair tends to overshoot as much as 15cm.

The gradient of the graph represents the acceleration of the wheelchair. By observing the graph gradient for load and without load, the gradients are almost the same. Therefore, the difference of wheelchair acceleration with no load and load is almost negligible.

There are several main considerations when controlling the deceleration of the wheelchair. The deceleration should not cause any wheel slip as it will affect the accuracy of the distance travelled. Second, the deceleration should not be too high until the user feels uncomfortable. Next, the deceleration should not cause any damage to the gearbox and the motor of the wheelchair. The maximum deceleration of the wheelchair is tuned until there is no wheel slip and the movement does not cause any uncomfortable to the user.

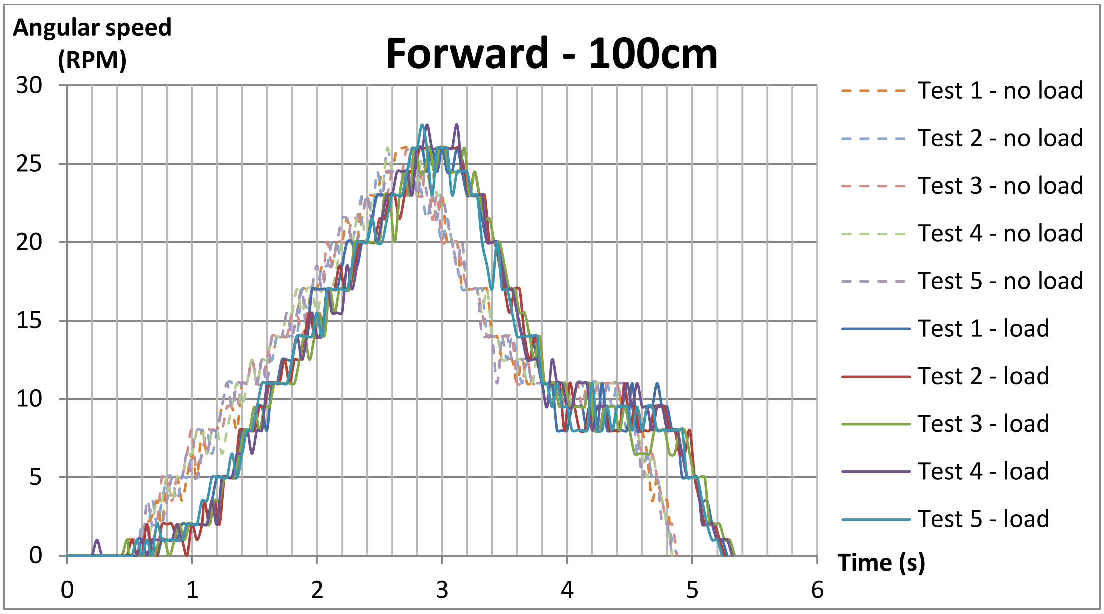

Figure 4.2.1: Graph of angular speed versus time for forward – 100cm

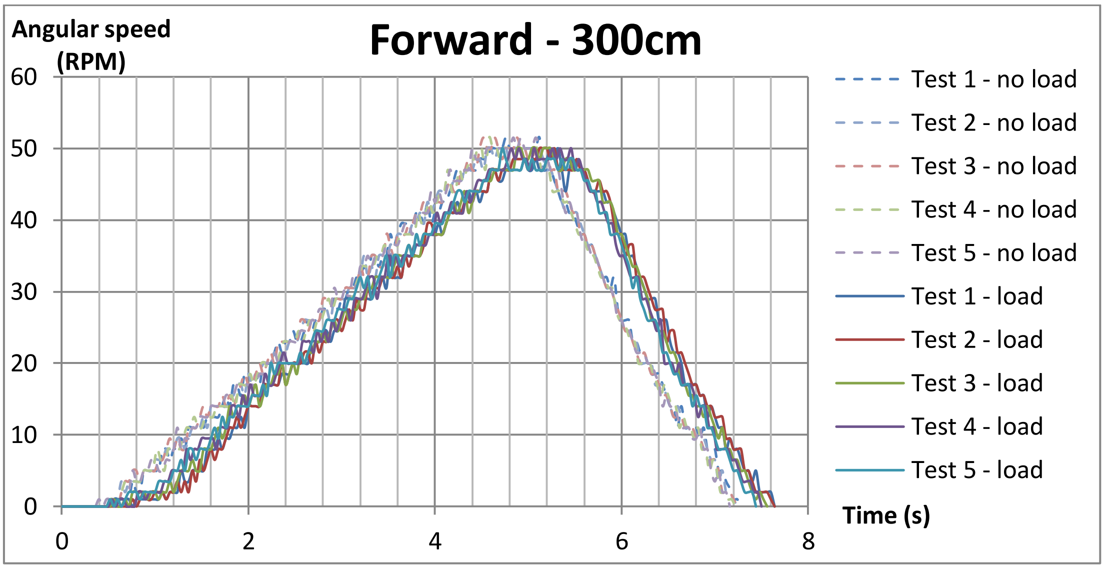

Figure 4.2.2: Graph of angular speed versus time for forward – 300cm

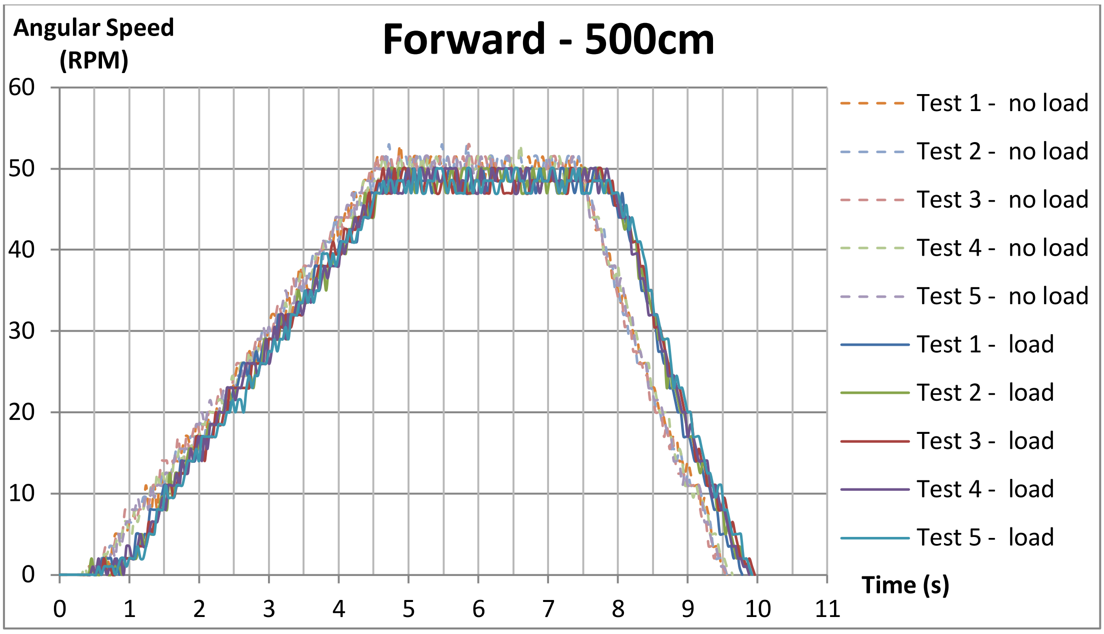

Figure 4.2.3: Graph of angular speed versus time for forward – 500cm

4.2.2 Backward

The graphs of backward wheel angular speed are plotted and shown in Figure 4.2.4 and Figure 4.2.5. The graph shows that the wheelchair motor is slight lagging behind when it has a load. The maximum achievable backward angular speed by this wheelchair is about 27 RPM.

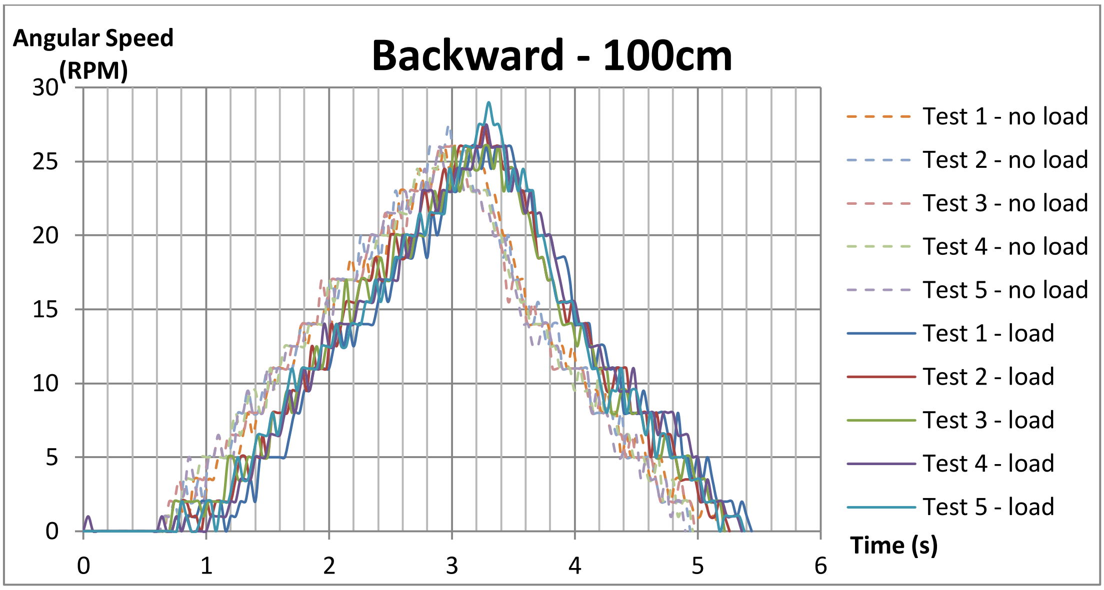

Figure 4.2.4:Graph of angular speed versus time for backward – 100cm

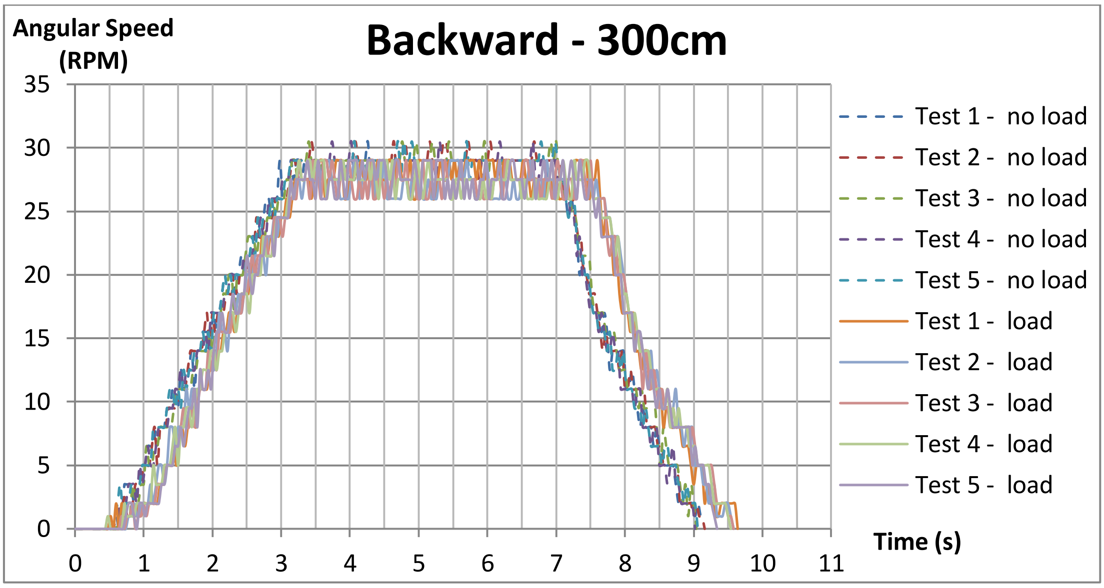

Figure 4.2.5:Graph of angular speed versus time for backward – 300cm

4.3 Distance Accuracy of the Wheelchair

The distance travelled of the wheel with load and without load for different input distance (forward and backward), were recorded and tabulated in Table 4.3.1 and Table 4.3.2. In Table 4.3.1, the result has shown that the error is within the range of -1cm to 2cm. This error is relatively small compare to the distance travelled. Therefore, it is an acceptable error. In Table 4.3.2, the error for wheelchair move backward is ranging from -4cm to 1cm. The result with no load (100cm) is slight undershoot. This might be due to too high a deceleration of the wheelchair.

Table 4.3.1: Distance accuracy of the wheelchair - forward

	Distance (cm)					
Input:	**100cm**		**300cm**		**500cm**	
	No load	Load	No load	Load	No load	Load
Test 1	100.0	101.5	300.5	301.0	500.5	502.0
Test 2	99.5	100.5	300.5	301.0	500.5	501.5
Test 3	99.5	100.5	300.0	301.5	501.0	501.5
Test 4	99.5	101.0	300.0	301.0	501.0	502.0
Test 5	99.5	100.5	300.5	302.0	500.5	502.0
Average	99.6	100.8	300.3	301.3	500.7	501.8

Table 4.3.2: Distance accuracy of the wheelchair - backward

	Distance (cm)			
Input:	**100cm**		**300cm**	
	No load	Load	No load	Load
Test 1	96.0	98.0	301.0	301.0
Test 2	96.0	99.5	301.0	301.0
Test 3	96.0	98.5	301.0	299.0
Test 4	96.0	99.0	300.5	300.5
Test 5	96.0	99.0	301.0	300.0
Average	96	98.8	300.9	300.3

4.4 Turning angle of the Wheelchair

The turning angles were calculated based on the wheel distance travelled and tabulated inTable 4.4.1 and Table 4.4.2. The accuracy of the turning angle for both right and left direction are quite accurate, the error is up to -2˚ to 2˚. The results also shown that there is a tendency of overshooting when there is no load on the wheelchair.

Table 4.4.1: Right turning for 90˚, 180˚, 270˚, 360˚

RightTurning (˚)								
Input:	**90˚**		**180˚**		**270˚**		**360˚**	
	No load	Load	No load	Load	No load	Load	No load	Load
test 1	92.3	91.2	181.3	179.1	273.7	271.5	362.7	359.4
test 2	93.5	90.1	182.5	181.3	273.7	270.3	362.7	359.4
test 3	92.3	91.2	182.5	181.3	271.5	270.3	362.7	358.2
test 4	93.5	92.3	181.3	182.5	271.5	271.5	361.6	358.2
test 5	94.6	90.1	182.5	181.3	273.7	272.6	361.6	359.4
Average	93.2	91.0	182.0	181.1	272.8	271.2	362.2	358.9

Table 4.4.2:Left turning for 90˚, 180˚, 270˚, 360˚

Left Turning(˚)								
Input:	**90˚**		**180˚**		**270˚**		**360˚**	
	No load	Load	No load	Load	No load	Load	No load	Load
test 1	89.0	93.5	179.1	182.5	269.2	272.6	357.1	361.6
test 2	90.1	93.5	179.1	181.3	269.2	272.6	357.1	361.6
test 3	89.0	93.5	178.0	182.5	268.1	271.5	359.4	360.5
test 4	90.1	93.5	178.0	182.5	268.1	272.6	361.6	360.5
test 5	90.1	93.5	179.1	182.5	268.1	272.6	361.6	360.5
Average	89.7	93.5	178.7	182.2	268.6	272.3	359.4	360.9

CHAPTER 5

Conclusion and Recommendations

5.1 Conclusion

A Fuzzy Logic Controller (FLC), with feedback from two encoders installed at the wheels, was developed to control the translational and rotational movements of a commercially available motorized wheelchair. The encoders are used to compute the distance travelled by the wheelchair and to update the FLC on a real time basis. The fuzzy logic algorithms were tuned manually. The FLC enabled the wheelchair to travel between 2 locations with the shortest possible time without overshooting or undershooting the targeted destination. In addition, the FLC enabled the wheelchair to turn right and left as well as rotate in both directions on the spot at a comfortable speed without causing dizziness to the rider. The capabilities of the wheelchair were tested successfully unloaded (without a rider) and loaded (with a rider).

5.2 Recommendation

Although the accuracy is within the expected range, it can be further improved by implement other sensors. For the turning movement, the accuracy can be improved with the use of a digital compass. With a digital compass as feedback in the system, the accuracy can be greatly increased. Besides, a graphical user interface (GUI) can be used to provide an interface for the user to control the fuzzy logic controller directly.

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CHAPTER 6

APPENDIX

6.1 Schematic of PCB for microcontroller

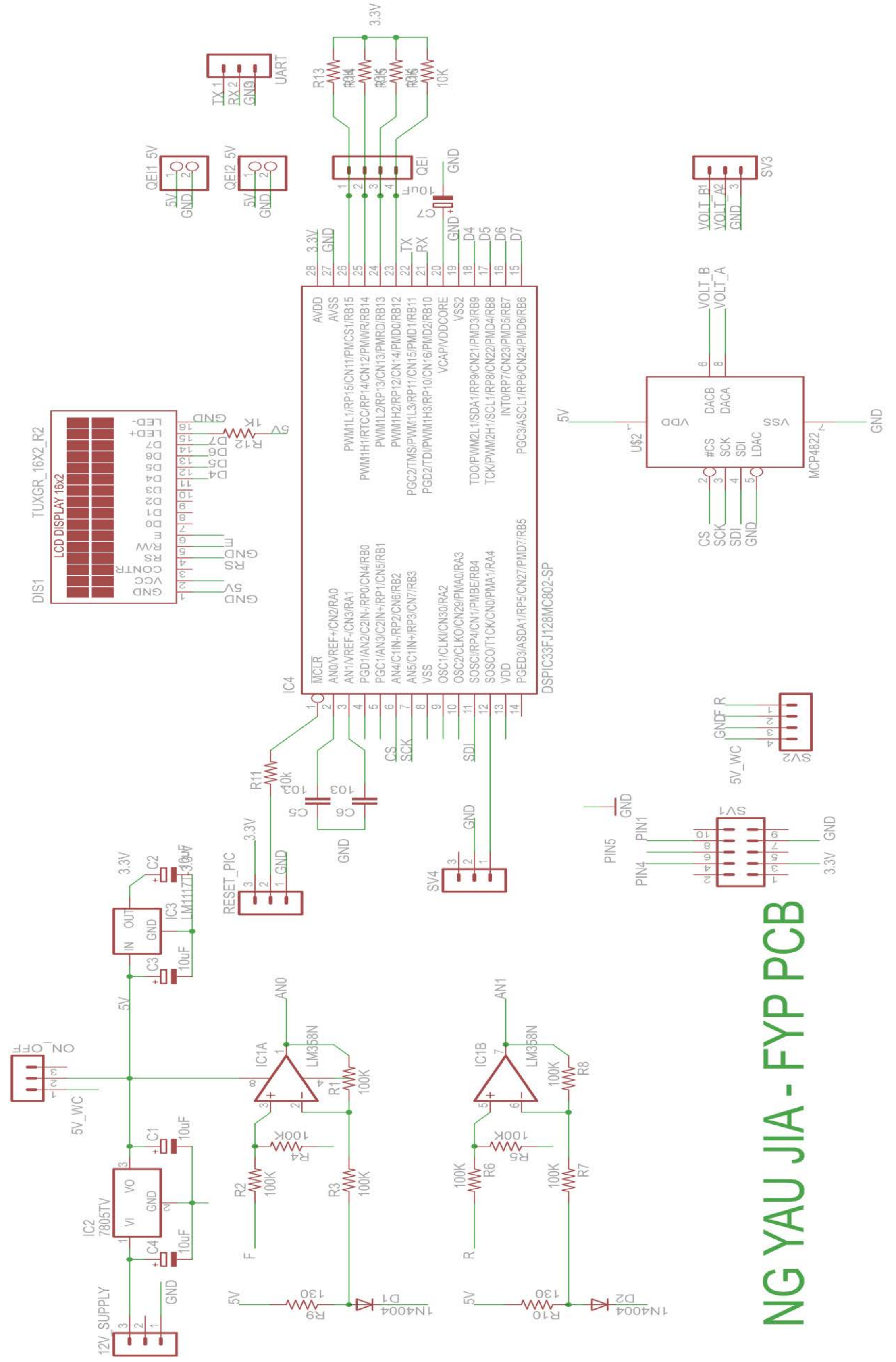

Figure 6.1.1: Schematic Diagram of PCB

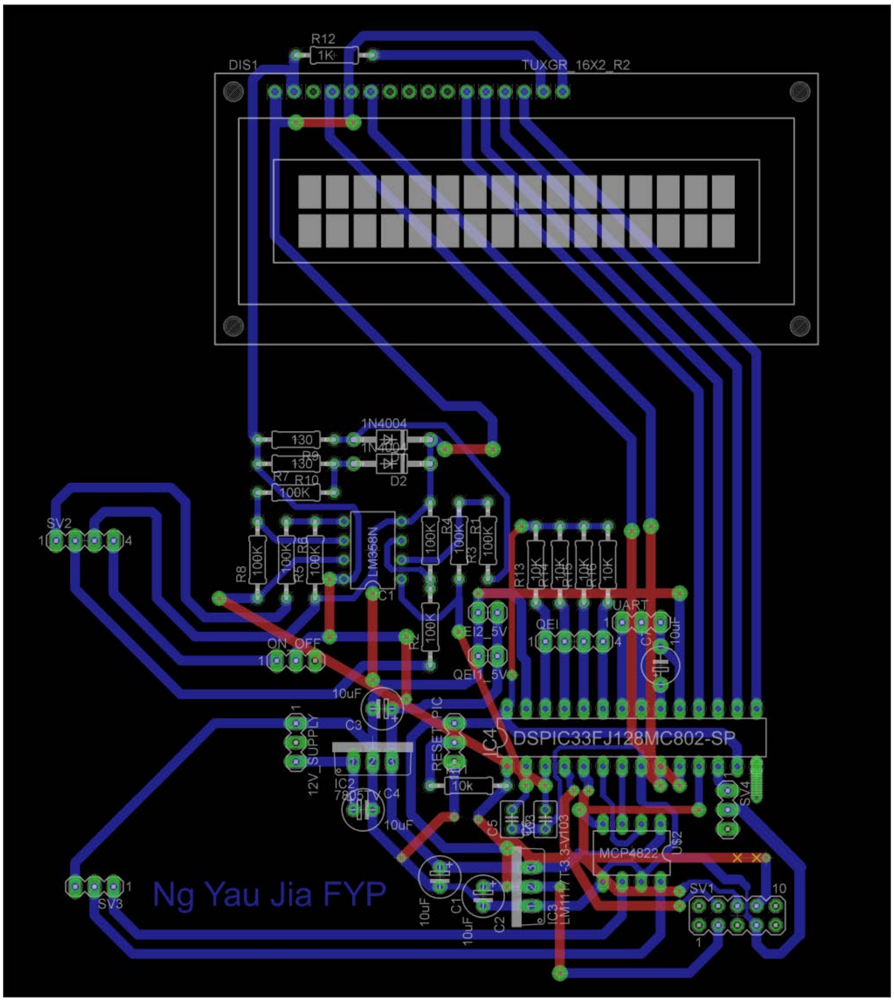

Figure 6.1.2: PCB

6.2 Schematic of PCB for Joystick Bypass

Figure 6.2.1: Schematic of Joystick Bypass PCB

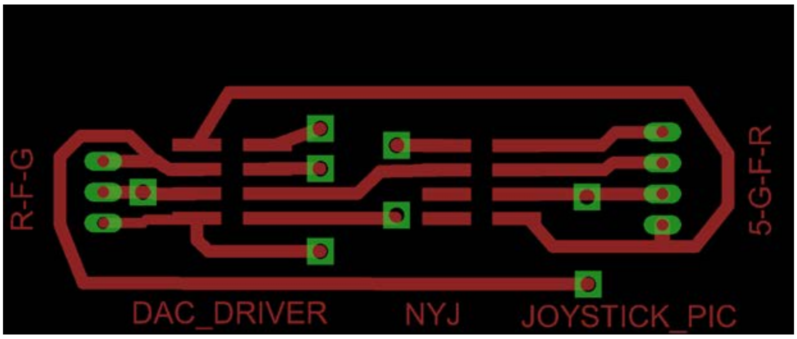

Figure 6.2.2: Joystick Bypass PCB

6.3 Encoder Mounting Mechanical Drawing

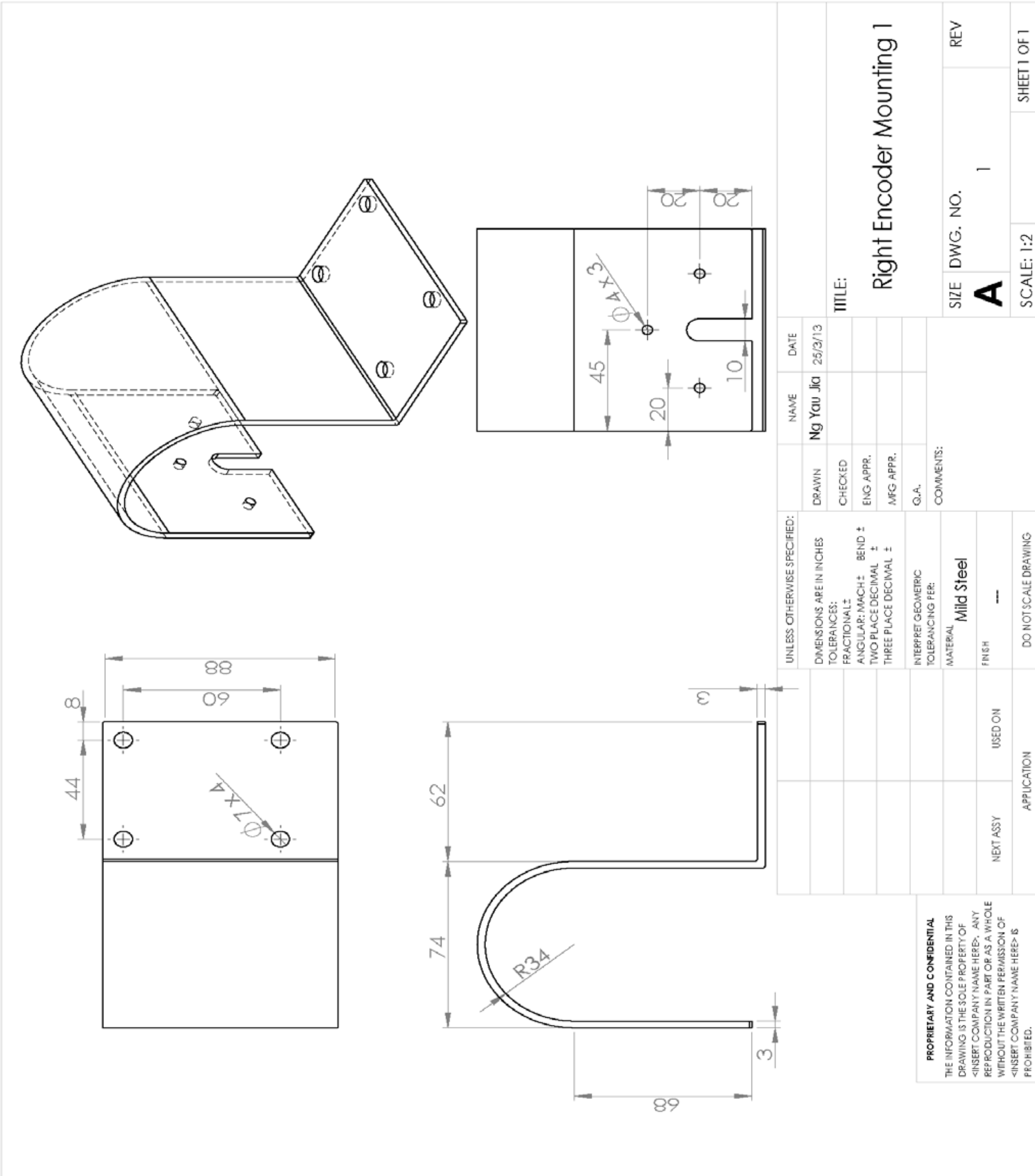

Figure 5.3.1: Encoder Mounting Drawing Part 1

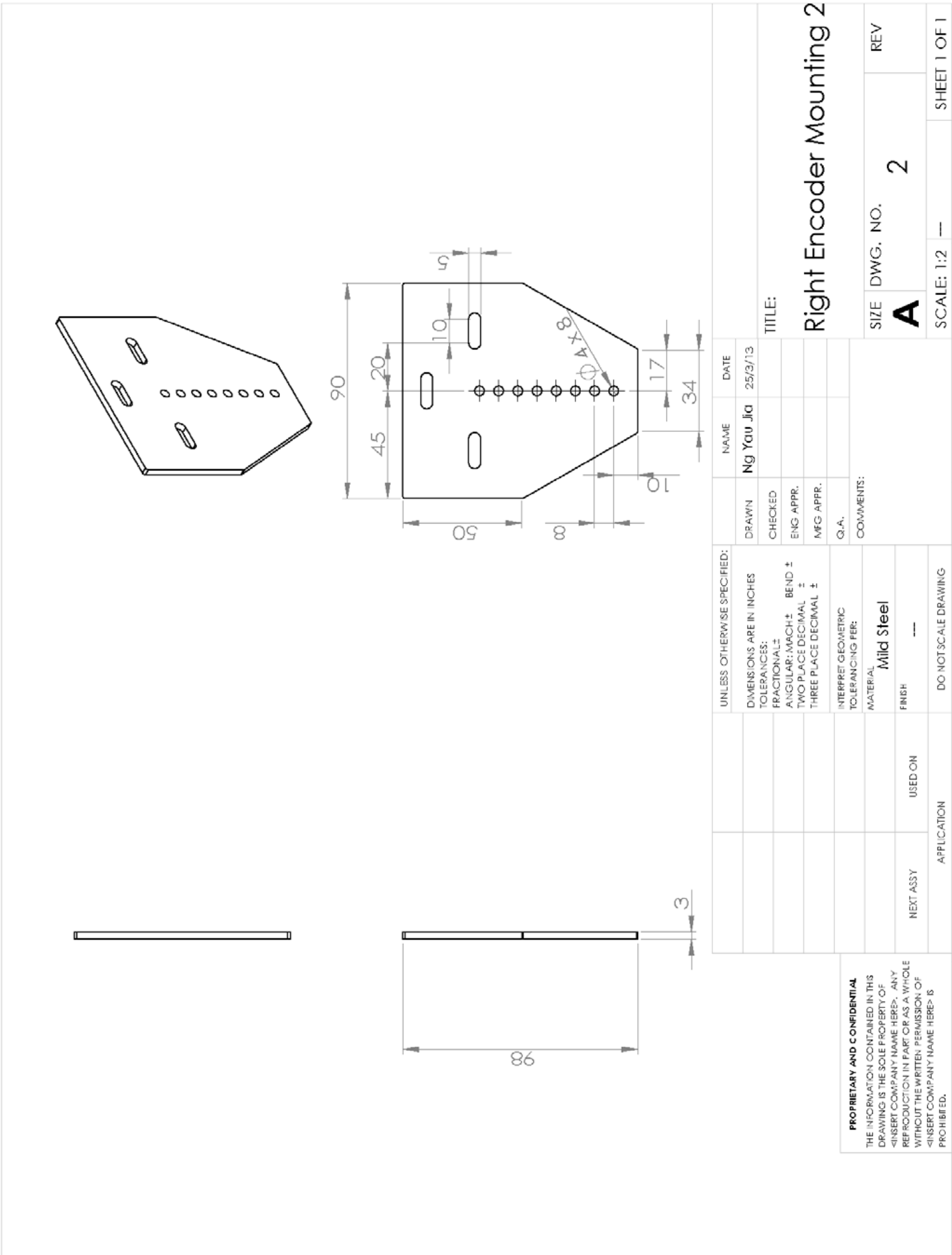

Figure 5.3.2: Encoder Mounting Drawing Part 2

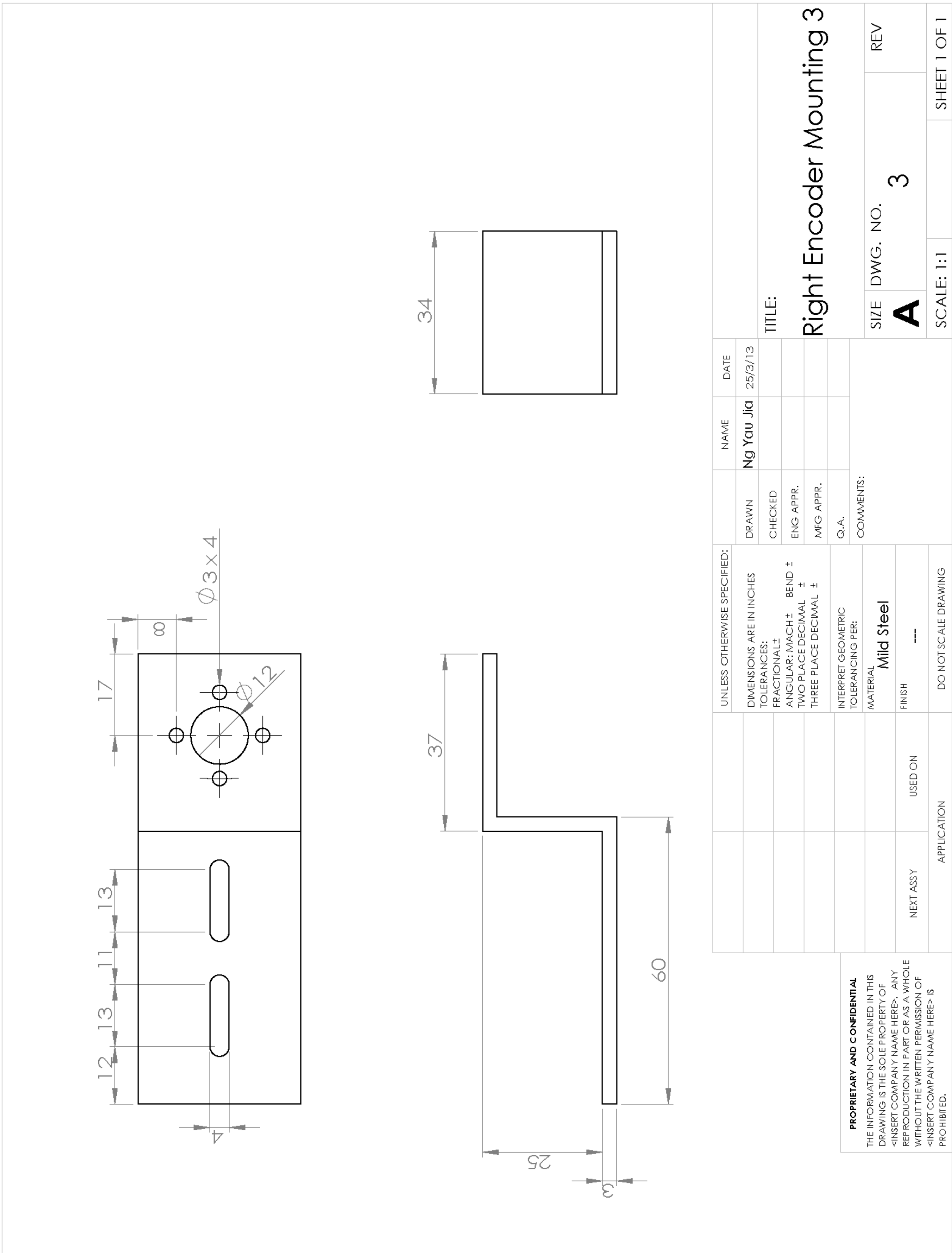

Figure 5.3.3: Encoder Mounting Drawing Part 3

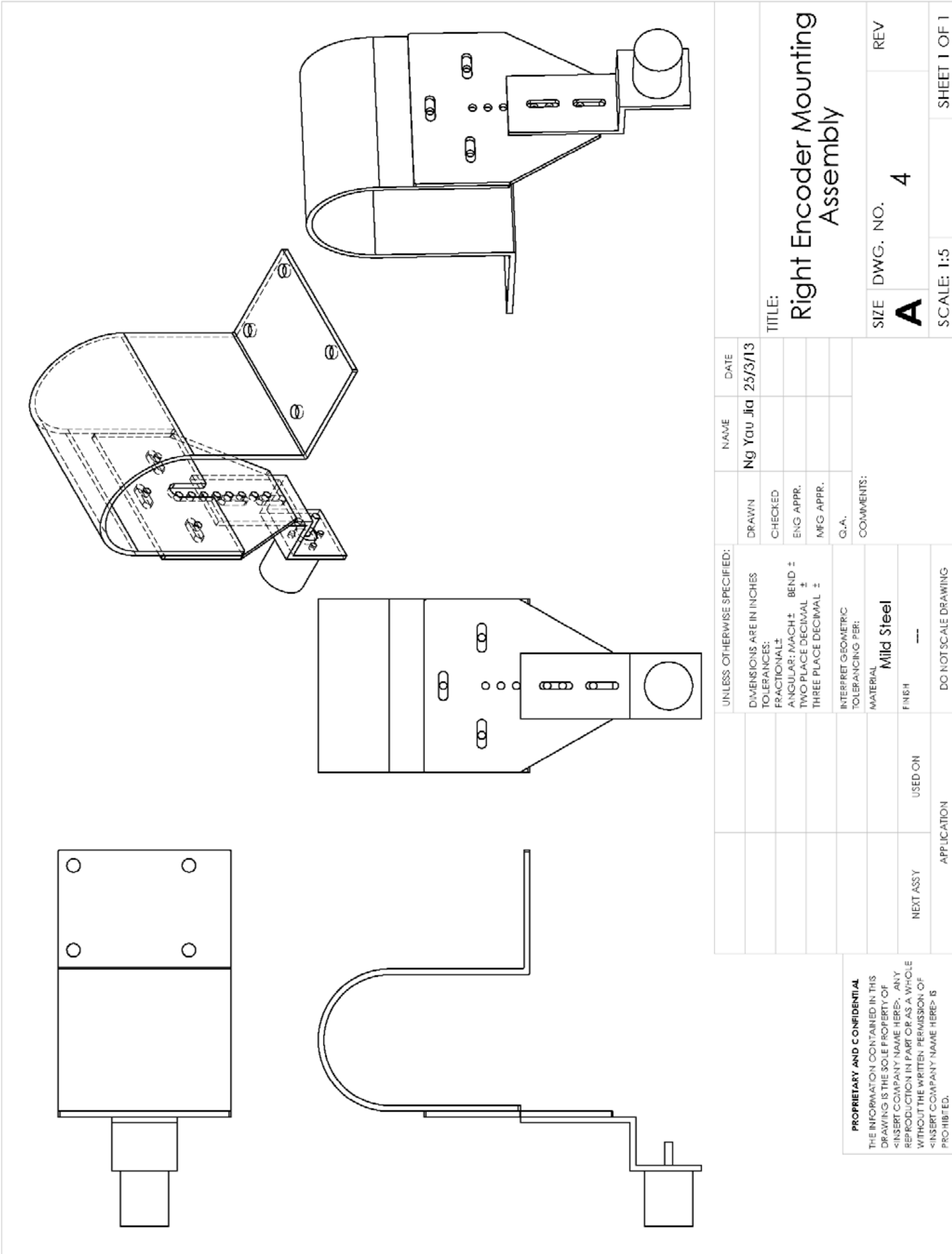

Figure 5.3.4: Encoder Mounting Assembly Drawing

6.4 Fuzzy logic program and data for forward/backward, turning right/left movement and video

Please refer to the attached CD.