AN INTELLIGENT DISTRIBUTED CONTROLLER FOR A WHEELCHAIR THAT IS OPERATED BY A BRAIN-COMPUTER INTERFACE

By

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ABSTRACT

AN INTELLIGENT DISTRIBUTED CONTROLLER FOR A WHEELCHAIR THAT IS OPERATED BY A BRAIN-COMPUTER INTERFACE

Vincent Ng Chet Shen

An Intelligent Distributed Controller for a wheelchair that is operated by a Brain-Computer Interface (BCI) was developed. The system is intended for subjects who had lost control of their muscles to sit on the wheelchair to use motor imagery to activate EEG signals to operate a binary switch in a BCI system to select one of the predefined locations. The result of the selection is communicated to the distributed controller which then navigates the motorized wheelchair to the destination. The wheelchair is equipped with sensors to enable it to negotiate past obstacles that might be in the way. A camera mounted on the wheelchair enables it to follow a track consisting of a black tape laid down on the floor. Radio-frequency identification (RFID) tags are embedded on the track to provide the coordinates of important locations. The main controller consists of an 8 bit microcontroller programmed to run on a Fuzzy Logic algorithm to control the wheelchair as it travels along the track. Seven normal subjects have been recruited to test the system. They are required to sit on the wheelchair and to use motor imagery to select a location and to allow the wheelchair to take them to the selected location. This had been repeated for 3 other locations. All seven subjects successfully completed the tasks but with varying completion times.

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APPROVAL SHEET

This dissertation/thesis entitled "**<u>AN INTELLIGENT DISTRIBUTED CONTROLLER FOR A WHEELCHAIR THAT IS OPERATED BY A BRAIN-COMPUTER INTERFACE</u>**" was prepared by VINCENT NG CHET SHEN and submitted as partial fulfillment of the requirements for the degree of Master of Engineering Science at Universiti Tunku Abdul Rahman.

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SUBMISSION OF THESIS

It is hereby certified that **VINCENT NG CHET SHEN** (ID No: **08UEM08106**) has completed this thesis/dissertation entitled "AN INTELLIGENT DISTRIBUTED CONTROLLER FOR A WHEELCHAIR THAT IS OPERATED BY A BRAIN-COMPUTER INTERFACE" under the supervision of Dato' Prof. Dr. Goh Sing Yau (Supervisor) from the Department of Mechanical and Material Engineering, Faculty of Engineering and Science.

I understand that University will upload softcopy of my thesis in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

Yours truly,

(*Vincent Ng Chet Shen*)

DECLARATION

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

Name ______________________________

Date _______________________________

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LIST OF ABBREVIATIONS

ADC	Analogue to Digital Converter
BCI	Brain-Computer Interface
CCD	Charge-Coupled Device
COG	Center of Gravity
DAC	Digital to Analogue Converter
DAQ	Data Acquisition System
DSP	Digital Signal Processing
EEG	Electroencephalography
EOG	Electrooculography
FLC	Fuzzy Logic Controller
FP	False Positive
GUI	Graphical User Interface
IR	Infrared
I2C	Inter-Integrated Circuit
LED	Light-Emitting Diode
MF	Membership Function

PID	Proportional–Integral–Derivative
PC	Personal Computer
PCB	Printed Circuit Board
RFID	Radio-Frequency Identification
RF	Radio Frequency
TTL	Transistor–Transistor Logic
TP	True Positive
UART	Universal Asynchronous Receiver/Transmitter

CHAPTER 1.0

INTRODUCTION

1.1 Objective

The objective of the work described in this thesis is to develop an Intelligent Distributed Controller for a wheelchair that is operated by a Brain-Computer Interface (BCI) system to navigate in an indoor environment. The wheelchair will enable subjects who have lost control of their muscles to move to selected locations.

1.2 Background and motivation

The BCI controlled motorized wheelchair system consists of two independent subsystems namely the BCI system and the Intelligent Powered Wheelchair [1].

The BCI system uses changes in electroencephalography (EEG) activity measured using electrodes placed on the scalp of a paralyzed subject as a result of imagined motor action to control a wheelchair or prosthetic hand [1,2]. A typical BCI system consists of an EEG amplifier, a Data Acquisition System (DAQ) and a computer laptop with Digital Signal Processing (DSP) software [1,2]. The BCI system studied provides a selection of 4 predefined locations and communicates the selected location to the Intelligent Powered Wheelchair system [1].

The Intelligent Powered Wheelchair system is designed to follow a black tape laid down on the floor in the room as a track leading to the destinations. The wheelchair will move along the track guided by camera sensors. The data acquisition board will acquire the signals from the camera sensors. The signals are used as feedback for the Fuzzy Logic Control (FLC) system to ensure that the wheelchair follows the track on the floor. In order for the controller system to navigate the wheelchair to the selected location, it has to be intelligent enough to know its current location, the path and the direction towards the selected location. The RFID tags and reader provide the coordinates of the current location of the wheelchair. The wheelchair system is also fitted with ultrasonic sensors to detect obstacles along the track and allow the system to avoid the obstacles.

A completely paralyzed subject or one who has lost control of his/her muscles has to rely on the assistance of other people to move around. This not only makes them a physical burden to other people, especially their loved ones, but also makes them feel helpless and useless. The Intelligent Distributed Controller for a wheelchair system will improve the quality of life of these paralyzed patients.

1.3 BCI System

The present BCI system is used to control a powered wheelchair. Changes in EEG signals as a result of motor imagery of right hand, left hand or foot movements from electrodes placed at 2.5 cm anterior and posterior to the electrode positions C3, Cz and C4 of the international 10/20 system are recorded and amplified in a bipolar amplifier. The EEG analog signals are digitized in a 16-bit analog to digital converter (ADC) at a sampling rate of 256 Hz for each channel. The data are then transmitted to a laptop computer via an RS232 interface.

The signals acquired by the computer are passed through a 5 - 40 Hz elliptic band pass filter to reduce noise. The autoregressive AR model order 8 are found for every 1 second of data with no overlap. The mathematical equation of an AR process is shown in the following equation.

$$y[n] = \sum_{k-1}^{p} a_k y[n-k] + w[n]$$

where $y[n]$:current output;
$w[n]$: white noise with mean zero,
variance s^2;
a_k : AR coefficients;
and p : AR model order

Linear Discriminant Analysis (LDA) is used as the classifier in the present study.

1.4 Contributions

The BCI system is not listed under my contribution as this has been developed by another student in our research group. The result of BCI selection is used as an input to the distributed controller.

My contributions in this project are as follows:

1) A Distributed Controller system for a powered wheelchair that is operated by the BCI system was developed.
2) All sensor modules were designed, built and tested.
3) Fuzzy Logic Control algorithm was implemented in the powered wheelchair.
4) Integration between the BCI system and the wheelchair system.

CHAPTER 2.0

LITERATURE REVIEW

2.1 Introduction

The implementation of a BCI system with a distributed controller for a wheelchair requires a multi-disciplinary approach. In this chapter, the literature reviews are separated into several sections to show clearly the different approaches and components used to build a “smart” wheelchair over the past few decades. The first section describes the history and development of the wheelchair and also the recent development of “smart” wheelchairs to fulfil the special needs for paralyzed subjects. The following sections will discuss the control methods for the powered wheelchair and particularly wheelchairs that are suitable for use with a BCI system.

2.2 History of the wheelchair and its development.

The first reported wheelchair was made for Phillip II, the King of Spain who lived from 1527 to 1598) [3]. The main features of the wheelchair include a raised platform for the King's legs and an adjustable back rest. It was not self-propelled so he had to rely on his servant to push it around. In 1655, a paraplegic watchmaker named Stephen Farfler who was disabled managed to build a self-propelled robust-looking chair on a three wheel chassis [4]. The first motorized wheelchair with spoked wheels was produced by a British engineer in 1916 [3], but the wheelchair was difficult to store in car due to its non-foldable design. In 1932, Harry Jennings, a Los Angeles engineer designed a foldable wheelchair and established a company to mass produce the new portable wheelchair and these were the forerunners of the commonly used wheelchair of today[4]. However, the development of the wheelchair did not stop here but extended to the "smart" wheelchair. A "smart" wheelchair typically consists of a standard powered wheelchair with a computer and a collection of sensors.

A "smart" wheelchair helps subjects with disabilities who find the standard powered wheelchair difficult to use. Several studies have shown that both adults and children benefit from powered wheelchairs and manual wheelchairs [5]. Independent mobility reduces dependence on a caretaker and family members and promotes self-reliance.

Many individuals with disabilities can be satisfied with traditional manual or powered wheelchairs but a segment of them finds it difficult or impossible to use wheelchairs independently. They include, but are not limited to, individuals with low vision, visual field reduction, spasticity, tremors, or cognitive deficits. These individuals often lack independent mobility and rely on a caretaker to push them around in a manual wheelchair.

"Smart" wheelchairs have been designed to provide navigational assistance to the user in a number of different ways, such as assuring collision-free travel, aiding the performance of specific tasks (e.g., passing through doorways), and autonomously transporting the user between locations. The following are among the more well known "smart" wheelchairs developed.

1. Tao Project (Applied AI Systems Inc.)

The Tao Project developed 2 robotic wheelchairs [6], Tao-1 and Tao-2. The aim of the project was to create an add-on system to a standard powered wheelchair to provide a higher level of autonomy. The Tao wheelchairs perform 5 functions as described below. Two CCD colour cameras and 10 to 12 infrared (IR) sensors are used to constantly detect the depth and size of free space ahead of the chair. The cameras are also used to identify landmarks in the environment so that the chair can travel from its present location to a given destination by tracking them. An on-board topological map is used to describe the system landmarks.

a) Basic collision avoidance

- When a wheelchair encounters an obstacle using IR sensors, it first reduces its speed and will react accordingly to the obstacle, either stopping or turning away from it to avoid hitting it. The figure below shows the output of the active IR sensors.

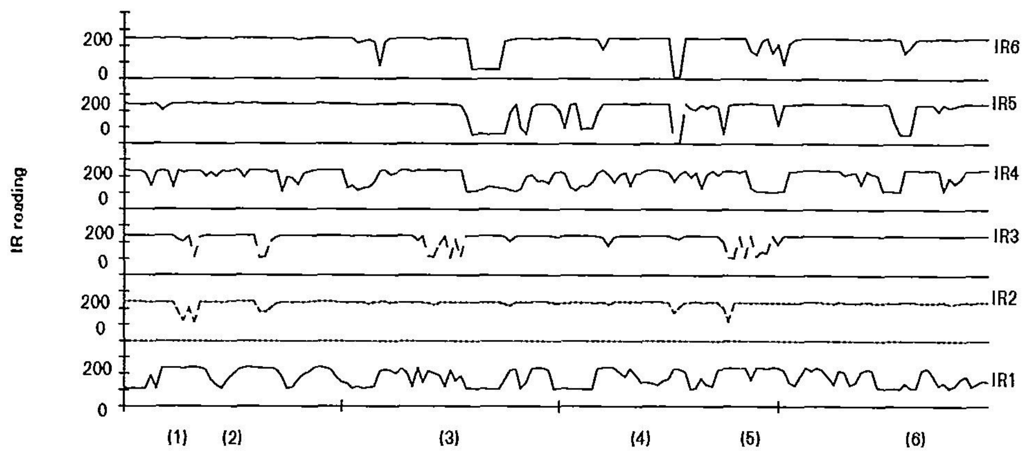

Figure 2.1: Output of active IR(infrared) sensors (adopted from [6]).

b) Passage through a narrow corridor.

- When surrounded by walls on each side of the path, as in a hallway, the chair travels autonomously from one end to the other parallel to the walls.

c) Entry through a narrow doorway.

- The wheelchair automatically reduces its speed and cautiously passes through a narrow doorway.

d) Ability to manoeuver in a tight corner.

- The autonomous chair should try to find a break in the surroundings and escape the confinement by itself unless instructed otherwise by the user.

e) Landmark based navigation.

- Topological map is used to describe the system of landmarks.

2. Wheelesley (MIT Artificial Intelligent Laboratory)

The goal of the Wheelesley project is to create a complete robotic wheelchair that can navigate both indoor and outdoor with automatic switching between modes [7]. In order for the system to be useful, it must be easily customized for the access methods required for each user. The system does not rely on maps for navigation, it relies on the user to give navigation commands. The Wheelesley wheelchair uses the powered wheelchair built by KISS Institute of Practical Robotic. 12 SUNX proximity sensors ensure collision free travel when the wheelchair passes through a narrow doorway. Six ultrasonic range sensors perform obstacles avoidance. A vision system with a Pentium based notebook computer is responsible for outdoor navigation while a Macintosh Powerbook provides the graphic user interface. The Wheelesley wheelchair offers users a few options to command the wheelchair depending on which option is best suited to the user. These include the standard joystick, a GUI from a Powerbook, an eye tracking system which uses EOG signals from the user and single switch scanning. The following figure shows the GUI of this wheelchair.

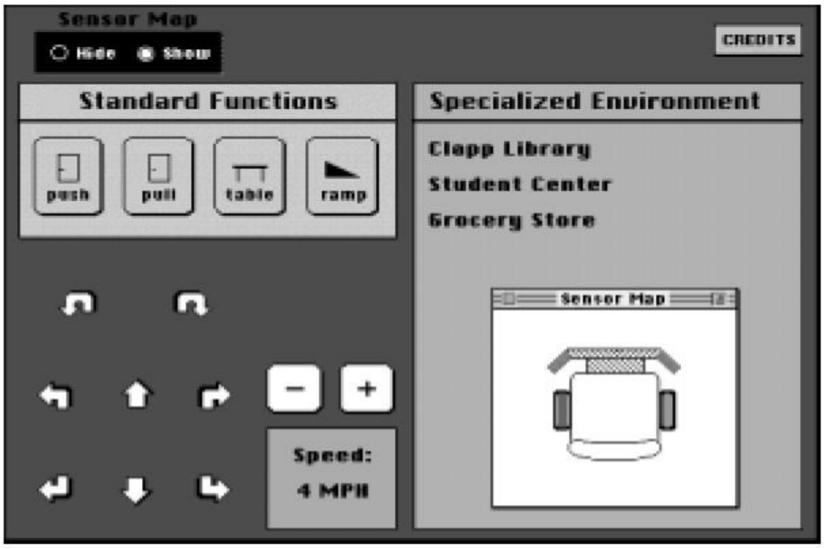

Figure 2.2: GUI screen (adopted from [7])

3. Deictically controlled wheelchair (NortheasternUniversity)

The objective of the project is to create a “gopher” wheelchair that can be given commands easily and accurately by the disabled [8]. The wheelchair will retrieve objects autonomously with commands from the user. The system is deictic, the user gives commands by selecting a target region on a video image of the world. The idea is that humans will perform object recognition, route planning and contingency planning while the wheelchair performs safety shutoff and motion control. The system does not need a model of either the environment or the object since the robot is not performing the path planning or the object recognition. The system needs only to form enough of a model of the object so that it can track the position of the object well enough to perform a visual motion.

In a shared robotic system, actuators need to physically perform tasks and sensors are required to provide feedback and an interface is required for the user to communicate with the wheelchair. In order for the "gopher" wheelchair to move around, reach out and grasp an object, position sensors are used to keep the target in view as the wheelchair moves. For navigation, the chair is converted to accept commands from an RS232 interface from a 386 PC-104 computer. Motion controller cards from Motion Engineering provide the interface to the motors' power amplifiers. Optical encoders will measure the motion of the belt that runs from the drive to the wheels. A Cognex vision system for the video and motion control software and a Directed Perceptions pan-tilt unit which moves a pair of stereo cameras have been used. The stereo cameras provide the main sensing of the system through a single digitizing board in the Cognex. A Quad Box combines the cameras' NTSC signals into a single video image which can be digitized as one. In this way, simultaneous acquisition of stereo images is achieved. The user can command the wheelchair by clicking on a landmark in the screen. Video tracking is achieved at the rate of 3 frames per second.

4. NavChair (University of Michigan)

The goal of NavChair is to provide mobility for people who are unable to efficiently drive a standard powered wheelchair [9]. NavChair is designed to function in an indoor environment with several modes including general obstacles avoidance, door passage and automatic wall following. These different modes will switch automatically to ensure smoothness in navigation.

NavChair uses a standard powered wheelchair from Everest & Jennings. To ensure NavChair will perform well in all modes, an array of 12 Polaroid ultrasonic transducers are mounted on the front of a standard wheelchair lap tray. An IBM-compatible 33MHz 80486-based computer interfaces with all sensors and performs necessary calculations. Individual sonar readings are often erroneous but with Error Eliminating Rapid Ultrasonic Firing method, errors are reduced and it creates a sonar map of the chair's surroundings. The accuracy of the map is further enhanced by keeping track of the wheelchair's motion via the wheel rotation sensors built into the wheel motors. The result is a sonar map that is surprisingly accurate given the constraints of individual sonar sensors.

MIT researchers are currently developing a robotic wheelchair that is capable of learning and adapting to the user and also responds to verbal commands. The aim is to have each wheelchair personalized for its user and the user environment. Instead of manually capturing a detailed map of a building, this system does it automatically with important places identified along the way. The wheelchair uses WiFi signals, wide-field cameras and laser rangefinders, coupled with computer systems that can construct and localize within an internal map of the environment as it moves around. The wheelchair prototype relies on a WiFi system to make its maps and then navigate through them. In future, the wheelchair will have add-on collision-avoidance system using detectors to prevent bumping into another wheelchair, walls or other obstacles. In addition, a mechanical arm will be added on to the chair to aid the patients further by picking up a cup and bringing it to the person's lips. The research has been funded by Nokia and Microsoft.

2.3 Basic components of a "smart" wheelchair.

From the above literature review, the basic components of a typical "smart" wheelchair are identified and listed as follows:

1) Input command (source of the command)

Any "smart" wheelchair will have to receive commands from the user. The commands are usually from user's voice (voice control), eyes movement (eyes control), hand or head movement (head control) or brain control (EEG control). This part involves signal processing and provides a set point or control action for the next level of control. In this project, the BCI system using EEG control will be the input command for the controller.

2) Input of sensor signals

Generally, a "smart" wheelchair employs quite a lot of sensors. It includes but is not limited to Infrared sensors (IR), sonar sensors, laser range finder, wheel encoder sensors, proximity sensors, accelerometer sensors etc. All sensors are used to sense the environment and to feedback the signals to the system controller. Sensor fusion is needed in order to simultaneously acquire sensor data for the controller.

3) Coordination of local controllers

This involves communication and task planning for wheelchair movements.

4) Local control

Local control of the wheelchair to move around is achieved by using one of the following controllers (P, PI, PID, Fuzzy Logic or advance control like Neuro Fuzzy etc).

5) Actuations

Since all powered wheelchairs come with their own motor drivers, in the study the researcher will reuse the built-in wheelchair driver by emulating the signal to the driver controller.

Hardware considerations

From the literature review, the following hardware parts are typically employed:

1) Microcontroller/Microprocessors/computer laptop.
2) Sensor modules including ultrasonic module, IR module, laser, wheel encoder module etc.

3) Actuator driver (joystick emulator/emulate signals to the original driver)
4) ADC and DAC for signal conversion.
5) Feedback circuits (signal conversion).

There are many approaches of implementing the “smart” wheelchair, each of them has its pros and cons. The selection of sensors and sensor fusion and the architecture of the system will contribute a lot to the performance of the “smart” wheelchair. There is no clear comparison on which system is better than the other, each system will have its uniqueness and suitability for use in a different environment and some are even custom made for a specific user. There is no single “smart” wheelchair that can work in any environment under any circumstances without any constraint. Each of the “smart” wheelchairs will work under certain constraints and is targeted to a specific environment for better performance.

2.4 Local Control Methods

From the previous section, we have an overview of the development of the “smart” wheelchair. They have similar sensors like sonar sensors, IR sensors, wheel encoder sensors and vision sensors but they are arranged with different setups leading to different results. All these sensors are used to monitor the surrounding and feedback the signals to the wheelchair controller in order to make decisions on where to move or how to move to the desired location as requested by user. In this section, the review will be focused on the controller.

There are many control strategies available like PI, P, PID, hybrid control Fuzzy Logic [10- 15], Neuro Fuzzy, and Fuzzy Logic [16- 20]. Each of the control methods has its advantages and disadvantages. Even advanced control methods like Neuro Fuzzy and Adaptive control will still have some weaknesses when dealing with uncertainties of the system behavior. To achieve good performance control, a detailed study of the system and its characteristics is needed. The control parameters and the aims of the implementation will play a big role in developing the controller.

Conventional control systems like P, PI, PID require an exact system model for better control. Besides that, conventional control cannot handle indefinite and inconsistent system behaviour. Fuzzy logic can solve the problem which conventional control cannot handle. It offers simplicity and works well without an exact system model. There are some misconceptions about Fuzzy logic. Fuzzy Logic is not fuzzy but it is a precise logic of imprecision and approximate reasoning [21]. Fuzzy Logic is able to converse, reason and make rational decisions in the environment of uncertainty, incompleteness of information, conflicting information and partiality of true and partiality of possibility [21].

CHAPTER 3.0

METHODOLOGY

3.1 Overview

The following steps were followed in the design for the Intelligent Distributed Controller. A review of the current State of Art of “Smart wheelchairs” was carried out. Five sensors were carefully chosen and their PCB boards were fabricated. The Fuzzy Logic (FL) algorithm was implemented to control the wheelchair. The Fuzzy Logic Controller was built and tuned. The system was integrated with the BCI system. Finally, tests were conducted to verify the functionality and performance of the system.

3.2 Sensors Module

3.2.1 Wheels Encoder

A simple and reliable optical encoder as shown in Figure C.1(Appendix C) was developed. Its main usage was to provide feedback of the speed of the wheelchair to the FLC. Two sets of optical encoders were used, one for each of the left and right wheels. They were mounted facing the spokes of the wheels (Figure C.2). The transmitted Infrared waves hit the spokes of the wheel and are bounced back to the receiver generating pulses. A controller module, as shown in Figure C.3, was developed to acquire the pulses and to calculate the speed of the wheelchair. The system flow chart and the program flow chart of the wheel encoder module are given in Figure C.4 and Figure C.5 respectively. The schematic diagram is provided in Appendix B and the source code is provided in Appendix A.

3.2.2 Digital Compass

A digital compass (Figure C.6) was used in this project to provide the heading direction of the wheelchair at any given time. The heading direction was used when computing the correct path for the wheelchair to the chosen destination. The Honeywell HMC6352 was chosen as it can be used in strong magnetic field environments and has proven high resolution (0.5 degree) and accuracy (2.5 degRMS). The HMC6352 operates in a low voltage range (2.7V to 5.2V) and is easy to integrate with the microcontroller. The digital compass controller was designed and built (Figure C.3). It shares the same controller as the wheel encoder. The schematic diagram is provided in Appendix B and source code is provided in Appendix A.

3.2.3 Ultrasonic Sensor

Ultrasonic sensors were used for obstacle avoidance. Ultrasonic sensors use through beams to detect objects. Ultrasonic waves move in a straight line in a uniform medium and are reflected and transmitted back after hitting an object. The time taken for the emitted wave to come back can be used to determine the object distance.

In this project, LV-MaxSonar-EZ1 was used (Figure C.7). The MaxSonar was chosen, in preference to others, because of its ultra-low power consumption and its ability to detect an object within a range 0.15 m to 6.47 m. The schematic diagram is given in Appendix B. Six ultrasonic sensors were required for obstacle detection and avoidance and they were installed around the wheelchair as shown in Figure C.8. A controller is built to control the six ultrasonic sensors (Figure C.9).

The microcontroller (PIC16F877A) is used to communicate with the ultrasonic sensors via UART communication. The PIC16F877A sends a request signal to the ultrasonic sensors and sensors will respond by sending the distance data. A multiplexer (SN74LS151) from Motorola is used to switch between the six sensors to acquire data one set at a time. An inverter (SN7414) from Texas Instruments is used to invert the signals because the MaxSonar is originally made to communicate to a PC. The truth table and logic diagram of the multiplexer is shown in Figure C.10 and Figure C.11 and the logic diagram for SN7414 is shown in Figure C.12. The system flow diagram is shown in Figure C.13 and the program flow diagram is shown in Figure C.14.

3.2.4 Radio-Frequency Identification (RFID)

The RFID is an automatic identification method. It consists of a reader (Figure C.15) and tags (Figure C.16). There are basically two major types of RFID tags in the market, active and passive. For the passive tags, the RFID reader transmits a radio frequency when powered ON. Whenever the RFID tags are located near to the RFID reader, the tag will receive the radio frequency waves via the antenna inside the tag. The RF will then be converted to electrical power that is enough for the tag to transmit the data inside the tag to the RFID reader.

Passive RFID tags are used in this project. Each RFID tag represents a location. Four RFID tags are used to represent four locations, namely, locations A, B, C and D. Location A can be the kitchen in a house whereas location B can be the living room, etc. RFID tags are placed on the track and the RFID reader is placed under the wheelchair (Figure C.17) so that the reader can identify the tags when the wheelchair navigates along the track.

A 13.56 MHz RFID reader and tags are used in the project. A controller module (Figure C.18) incorporating a Microchip was built to control the RFID reader. Microcontroller (PIC16F876A) communicates with the RFID reader via UART protocol and runs at 19200 baud rate. The PIC16F876A needs to send a signal to turn on the RF signal of the reader followed by a data request. If a tag is detected, the data will be sent to PIC16F876A and displayed on the LCD of the controller module. The system flow chart is given in Figure C.19 and the program flow chart is given in Figure C.20. The schematic diagram of the controller module is provided in Appendix B and the source code is provided in Appendix A.

3.2.5 Camera Sensor

A camera sensor (CMUcam3) as shown in Figure C.21 was used. It is an embedded camera. It is installed in front of the wheelchair (Figure C.22). A bracket was fabricated to mount the camera on the wheelchair. The bracket enables the CMUcam3 to be tilted 180 degrees and its vertical position raised or lowered.

The main purpose of CMUcam3 is to provide feedback of the position of the wheelchair with respect to the track. The range is from zero to hundred. Zero means the wheelchair is positioned towards the extreme left, fifty means it is positioned at the centre and one hundred means it is positioned towards the extreme right of the track. The image processing is done within the camera itself but a controller module is needed to control the CMUcam3. Thus, a controller module (Figure C.23) was developed.

A microcontroller (PIC16F876A) is used. It communicates with the CMUcam3 at 115200 baud rate. To enable it to follow the black tape track on the floor, colour tracking was implemented. A series of instructions and steps were sent by the PIC16F876A to the camera to follow the track. The system flow and program flow charts are shown in Figure C.24 and Figure C.25 respectively. The schematic diagram is provided in Appendix B and the source code is given in the Appendix A.

3.2.6 BCI Controller Interface Module

The BCI controller interface module was built as shown in Figure C.26. It communicates between the FLC and the BCI system. The subject selects the desired location using the BCI system and the data is sent to the

BCI controller interface module using Bluetooth communication. A microcontroller PIC16F876A is used in the BCI controller interface module.

The Bluetooth device is connected to the DB9 connector. The MAX232 is used to convert the signal data from TTL to RS-232 serial port protocol before the data is sent using Bluetooth. It is necessary since microcontroller uses the TTL protocol. The connection diagram is shown in Figure C.27. The system flow and program flow chart is shown in Figure C.28 and Figure C.29 respectively.

Data coming from the BCI system will be ignored by the BCI controller interface module if a selection is made when the wheelchair is in navigation mode. This is to avoid unintended selection by the subject during wheelchair navigation. The subject is only allowed to make a new selection after the wheelchair has reached the previously selected location.

3.2.7 DAC Converter Module

The powered wheelchair that is used in this project comes with its own wheelchair driver. The wheelchair is controlled by the joystick. A DAC module was built to receive instructions from the FLC and to bypass the joystick control. The DAC module receives and converts the digital signals from FLC to analogue voltages that are used to drive the wheel chair.

The DAC converter module uses a microcontroller (PIC16F877A). It receives instructions from FLC and outputs a series of data to DAC8032. The DAC8032 (8 bits) together with LM384 op-amp are used to convert the digital signals to analogue voltages to drive the wheelchair. The pin connection diagram is given in Figure C.31. A 5V voltage reference (REF02) from Burr-Brown is used to ensure precision conversion. The pin configuration is given in Figure C.32 and an LCD provides status update of the module.

Table 3.1 shows the data that is required to be sent by the PIC16F877A after receiving instructions from the FLC.

Direction	**Channel 1 (decimal)**	**Channel 2(decimal)**
	138	184(slow) to 208(fast)
	135(right) to 163(extreme right)	184(slow) to 208(fast)
	110(left) to 133(extreme left)	184(slow) to 208(fast)

Table 3.1 Navigation data

To move forward, two analogue voltages need to be generated. It is 138 for channel 1 and 184-208 for channel 2. The number 138 is in decimal format. It is equivalent to the binary number 10001010. PIC16F877A sends the number 10001010 for DAC8032 to generate an appropriate voltage for channel 1 and at the same time sends the number 10111000 to another DAC8032 to generate a voltage for channel 2. A different binary number is used to make the wheelchair move in a different direction.

Figure C.33 shows the system flow chart. The schematic diagram is provided in Appendix B and the source code is provided in Appendix A.

3.2.8 FLC (Main Controller)

An FLC (main controller) was built as shown in Figure C.34. All together six modules are connected and they communicate with the FLC using Inter-Integrated Circuit (I2C) protocol. The six modules are the wheel encoder and the digital compass module, the camera module, the ultrasonic module, the RFID module, the BCI controller interface module and the DAC converter module. The system overview diagram is given in Figure C.35.

I2C is a communication protocol that was invented by Philips. It is a multi-master serial single-ended computer bus. It uses 2 bidirectional open-drain lines, Serial Clock (SCL) and Serial Data Line (SDA). The voltage used is 5V. The I2C bus speed is 100kbit/s for standard mode and 400kbit/s for fast mode. The address uses 7 bits for typical usage or up to 10 bits for other features.

In this project, FLC (main controller) is the master and the other modules are slaves. The master initializes the transmit mode by sending a start bit followed by a slave address that it wishes to communicate with (7-bits), followed by another single bit which will determine either to write or read from the slave (write = 0, read =1). The slave will then respond by sending back an ACK bit (acknowledged) if such an address exists. Once the ACK bit is received by the master, then it will continue to either send or receive data based on the previous bit that it sent.

All the microcontrollers that are used in the project are equipped with I2C capability. The typical connection between the master and the slaves is given in Figure C.36. Rp is required from the master side and the typical value is ($4K\Omega$).

There are a total of four locations available for the subject to choose in this project. They are locations A, B, C, and D as shown in Figure C.37. An RFID tag was installed in each location. The program starts by initializing the input and output ports and the I2C address of the microcontroller (PIC16F876A). The first module that is called by the program is the RFID module followed by digital compass. This is to update the current location of the wheelchair and its heading direction. A pre-record of the digital compass data over all the locations are needed.

Next, the BCI controller interface module is called by the program. It is to identify which location has been selected by the subject via BCI system. The camera module is called by the program to get the position of the wheelchair with respect to the track followed by the fuzzy logic sub-routine. After the Fuzzy Logic is calculated, the result is sent to the DAC converter module to generate the respective analogue voltages and the wheelchair starts to follow the track to the selected destination.

The output of the Fuzzy Logic is a finite number. In order to have the right data sent to the power module channel 1 and 2, four equations are needed to convert the Fuzzy Logic result to a power module form. The four linear equations are as shown below. Note that x is the Fuzzy logic result and y is the decimal number that is to be sent to the power module. Equations 3.1 is for the angle and equations 3.2 is for the speed.

$y = -1.1428x + 134.8$…………………Eq 3.1

$y = 10x + 150$………………………… Eq 3.2

By knowing the wheelchair's current location, the heading direction and the subject's selected location, the program refers to a pre-programmed table (Figure C.38) which tells the wheelchair to turn left or turn right during the next junction. During the junction turn, the wheelchair moves out from the track by turning left or right until the track is detected (perpendicular).

The RFID module is constantly called by the program to update the location of the wheelchair. The Program issues a stop signal when the selected location is reached and subject is free to select a new desired location again. The track finding sub-routine is called if the wheelchair accidentally goes out from the track. The Program checks the last position of the wheelchair with respect to the track and turns back to the track.

The Ultrasonic module is constantly called by the program to ensure that there is no obstacle blocking the way. If there is any, an obstacle avoidance sub-routine is called. As described in the previously chapter, the ultrasonic sensors are installed around the wheelchair as given in Figure C.8. The Obstacle avoidance sub-routine is called when the ultrasonic sensor 1 and sensor 2 encounter obstacles on the track. The Main controller checks Sensors 3 and 4 to determine the available path either from the left or right. Figures C.39 and C.40 illustrate how the wheelchair passes an obstacle from the left and from the right. The wheelchair stops when there is no available path to pass the obstacle.

3.3 Fuzzy Logic Control

3.3.1 Introduction

In this chapter, the basic concepts of Fuzzy Logic are discussed. This includes Fuzzy Sets or Membership function, Fuzzification, Fuzzy reasoning (Rules Evaluation & Aggregation), Deffuzzification, control structure. Techniques and components involved are also described.

3.3.2 Overview of Fuzzy Logic

The Fuzzy Logic Controller (FLC) is used in the present system to overcome the uncertainty or changing of the system model. FLC has been applied in many fields including consumer products [22- 23], industry process control [24], information system [25] and also medical instrumentation [26-27]. One feature of Fuzzy Logic is to make computers think like people [28-30]. By using Fuzzy Logic algorithms, computers can understand and respond to human concepts such as slow, fast, moderately slow and moderately fast. Fuzzy Logic has the advantage of modelling nonlinear and complex problem linguistically rather than mathematically [30- 32]. By using natural language processing and embedded system technology, almost every application can gain some benefits from Fuzzy Logic. Fuzzy Logic incorporated in embedded system can enhance performance, increase simplicity and productivity, and reduce cost and design time [33].

To use Fuzzy Logic, the knowledge of a human expert is needed to develop the algorithm that mimics the expert thinking and to study the stability of the Fuzzy system. The Fuzzy Logic concept was initially proposed by LoftiZadeh and the earliest implementation was on the steam engine by EbrahimH.Mamdani [34]. Fuzzy Logic has become the popular approach used by researchers in solving nonlinear and inconsistent problems [35- 38].

3.3.3 Fuzzy Logic Controller

The typical basic structure of Fuzzy Logic Controller is shown in Figure 3.1. It is actually very similar to the basic conventional control system as shown in figure 3.2.

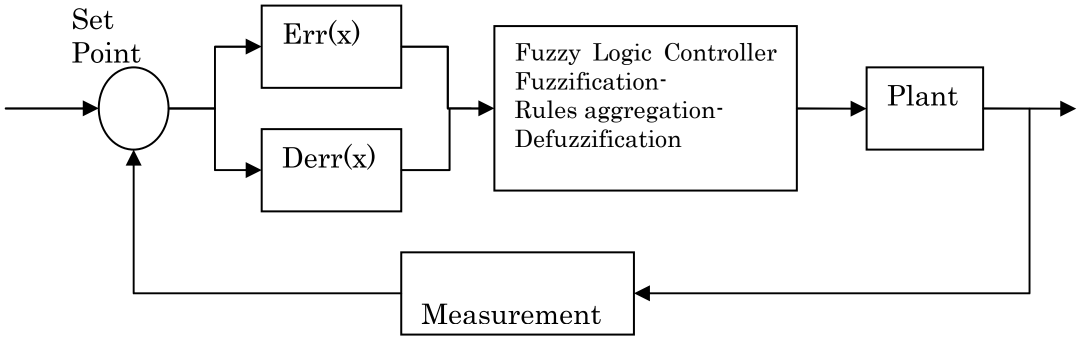

Figure 3.1 Fuzzy Logic Control System

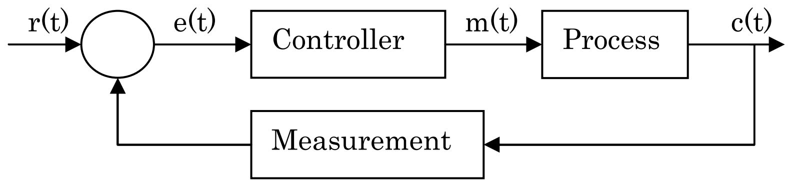

Figure 3.2 A typical block diagram of a conventional control system

The FLC block consists of a few subsystems. These are called Fuzzification, Rules evaluation & aggregation and Defuzzification. Fuzzification comprises the process of translating crisp values into grades of membership for linguistic terms of fuzzy set. The Rule and Aggregation will determine the output of Fuzzy Logic by referring to the fuzzfied inputs and the rules that are made. Defuzzification is the process of converting inferred fuzzy control actions into a crisp control action.

3.3.4 Composing Fuzzy Sets/Membership Function (MF)

Fuzzy sets or Membership Function is the mapping that associates each element in a set with its degree of membership. It is defined over the whole possible range of the variables, Universe of Discourse. Membership Function will represent all the input and output variables using linguistic terms like cool, hot, small, large, etc, which a control decision by word can be carried out. There are two control parameters in this project, displacement angle (N2, N1, Z, P1, P2) and the speed of the wheelchair (slow, medium, fast) measured from the sensors. The data from sensors will then become the input of FLC and it is translated into Error and Rate of Error where Error is the difference between set positions (your desired position) to the current position.

$Z[n] = SetP[n] - Pos[n]$……………..Eq 3.3

where,

$Z[n]$ = Error,

$SetP[n]$ = Set point (the desired position for wheelchair)

$Pos[n]$ = Current position of wheelchair

Rate of Error is the difference between previous error and current error.

$Z'[n] = Z[n] - Z[n-1]$…………………Eq 3.4

where,

$Z'[n]$ = Rate of Error,

$[n]$ = positive integer

A membership function can be represented in many shapes, the common membership function includes triangular function, trapezoidal function, Gaussian function, trim function [1], etc. The horizontal axis represents input variable, it can be say 0 to 100 or 0.1 to 1 depending on the personal preference. The vertical axis represents the fuzzy value. It must be from 0 to 1, when 0 represents strongly disagreed and 1 represents strongly agreed. The triangular membership function is given in Figure C.41, the trapezoidal function is given in Figure C.42 and the Gaussian function is given in Figure C.43.

The triangular and the trapezoidal Membership Functions are used in the project. Both of the Membership Functions are relatively easy and suitable to use with embedded system. The MF that is used in the project is given in Figure C.44.

3.3.5 Fuzzification

Fuzzification is the process of transforming crisp values into Fuzzy values. A Fuzzy value is the degree of truth ranging from 0 to 1 that serves as the value assigned to a variable. The Fuzzification process is given in Figure 3.3.

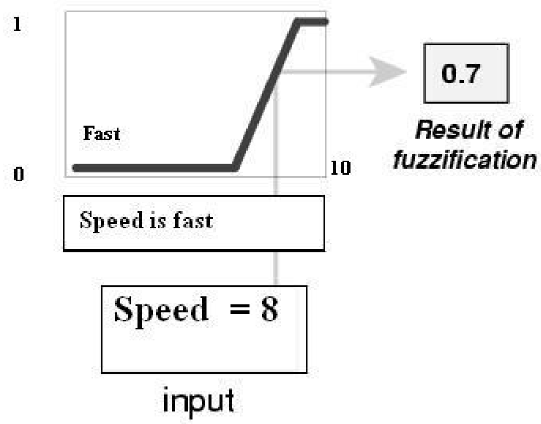

Figure 3.3 Fuzzification process

A trapezoidal membership function called Fast with an input range from 0 to 10 and the fuzzy value between 0 and 1 is used. In this example, the input is 8. Hence the fuzzification result is 0.7. Fuzzification can result in more than one output if it overlaps within the range of one more MF regions as shown in Figure 3.4.

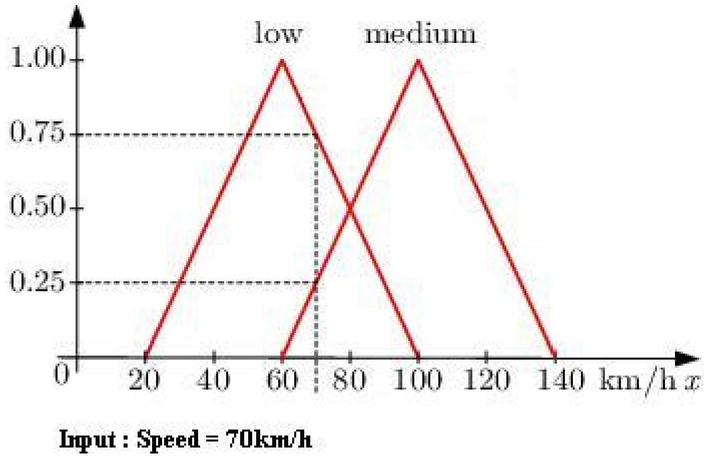

Figure 3.4 Two fuzzy values with one input

The Speed of 70 km/h falls between 2 membership functions, Low and Medium, resulting in 2 fuzzy values, 0.75 for Low membership function and 0.25 for Medium membership function. The technique that is used to process Fuzzification in this project is shown in Figure 3.5.

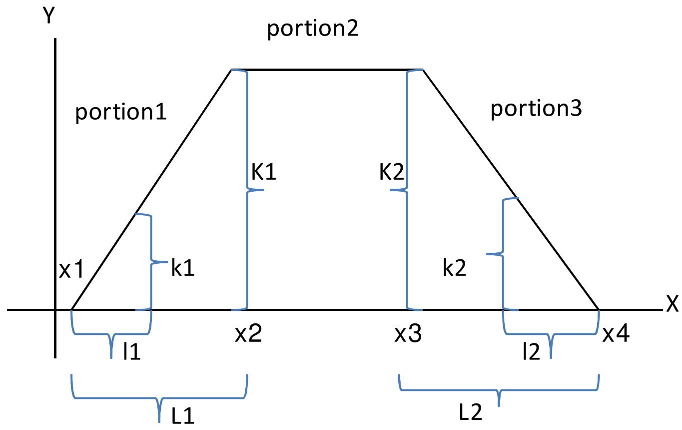

Figure 3.5 Membership function

The relationship of L1, L2, K1, K2 for portion 1 are show below.

$$\frac{k_1}{K_1} = \frac{l_1}{L_1}$$

Where, $K_1 = 1$; $l_1 = x - x_1$; $L_1 = x_2 - x_1$; x is input

By rearranging,

$$k_1 = \frac{x - x_1}{x_2 - x_1}\text{; so,}$$

$$y_1 = \frac{x - x_1}{x_2 - x_1};$$

Applying the same procedure for portion 2 we get:

$$y_2 = 1;$$

Applying the same procedure for portion 3 we get:

$$y_3 = \frac{x_4 - x}{x_4 - x_3};$$

The Fuzzified value for all input membership functions can be represented below:

$$y = \begin{cases} \dfrac{x - x_1}{x_2 - x_1} \text{............}; \; x_1 \le x \prec x_2 \\ 1 \text{.................}; \quad x_2 \le x \le x_3 \\ \dfrac{x_4 - x}{x_4 - x_3} \text{.........}; \; x_3 \prec x \le x_4 \end{cases}$$

3.3.6 Fuzzy Reasoning

Fuzzy Reasoning makes use of Fuzzfied result to determine a control action based on the rules that have been made. This process produces another set of linguistic terms. Figure C.45 and Figure C.46 shows the set of rules created to control angle and speed respectively.

Since the fuzzy set defines linguistic variables, and Fuzzy inference rules can model a system linguistically. For example:

If x is A, THEN y is B, where A and B are fuzzy sets.

An inference rule could have more than one proposition. If a rule of inference has two propositions, the form will be:

If x is A and/or/not y is B, THEN z is C

where, A,B and C are fuzzy subsets of x,y and z.

In this case, Boolean Logic operators are needed. Since all computers and embedded systems use electronic switching devices such as transistors which assume one of two conditions, either “On” or “Off” thus the universe of discourse can be represented by (0,1). “0” is referred to as a singleton, which represents “Off” whereas, “1” represents “On”. Table 3.2 shows the corresponding basic binary operations.

Operation	**Symbol**	**Set Operation**
NEGATION	¬	COMPLEMENT
OR	+, $\vee$	INTERSECTION
AND	· , $\wedge$	UNION

Table 3.2 Basic binary operations

3.3.7 Defuzzification

Defuzzification is the process to convert the Fuzzy values obtained from the previous aggregation process into a crisp number. It is a must process since the next step in the process control can only accept a finite number. There are a few methods of Defuzzification.

1) Centroid method - also known as center of mass or center of gravity (COG). This is probably the most commonly used Defuzzification method.
2) Center of largest area - this method is good when the output consists of at least two convex fuzzy subsets which do not overlap.
3) First maxima – this method is applicable when the output is peaked, the smallest value of the domain with maximum membership is selected.
4) Weighted average method- also known as Sugeno-Defuzzification, this method is valid for symmetrical output membership functions. Each membership is weighted by its maximum membership value.

Sugeno-Defuzzification method is found to be the most suitable for an 8-bit microprocessor implementation since this method offers simple computation while still maintaining a result comparable to COG.

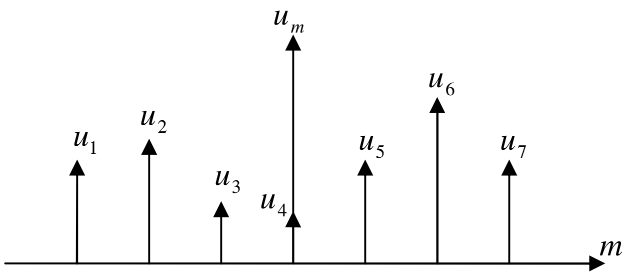

Figure 3.6 Output MF for Sugeno-Deffuzzification

$$U = \left(\frac{(Y_1 \times u_1 + Y_2 \times u_2 + \dots + Y_n \times u_n)}{(Y_1 + Y_2 + \dots + Y_n)}\right) \text{.............Eq 3.7}$$

$$U = \left(\frac{\sum_{n=1}^{n=M} (Y_n . u_n)}{\sum_{n=1}^{n=M} (Y_n)}\right) \text{..............................Eq 3.8}$$

Where,

u_n = Output MFs

Y_n = Fuzzy value from Fuzzy reasoning.

U = A crisp value representing FLC output.

3.3.8 Design of Fuzzy Logic controller

The input parameters for FLC are angle and speed. To control the wheelchair angle position, the controller needs to get data from camera sensors. The range is from 0 to 100 where 50 is the desired point. The wheelchair will be at the center of the track if the reading from camera sensors is 50. Membership N2 means the wheelchair is located at the extreme right and P2 is the extreme left. If N2 is detected, the wheelchair needs to flow towards the left to correct the error. If Z is zero, which means no error, the wheelchair is located at the middle of the track. If P2 is detected, it needs to correct back to Z by moving towards right. Figure C.47 shows the design structure for angle control.

Rules play a very important role in Fuzzy Logic design. It determines the control action of the wheelchair. To achieve smooth navigation, the number of rules associated cannot be too many since this will overload the microcontroller and slow down the whole process. The rules that are formed for angle control are shown below.

Rules and aggregation for angle

1) If Error is N2 then Correction is P3
2) If Error is N1 and Derror is Z then Correction is P2
3) If Error is N1 and Derror is P then Correction is P1
4) If Error is Z then Correction is Z
5) If Error is P1 and Derror is N then Correction is N1
6) If Error is P1 and Derror is Z then Correction is N2
7) If Error is P1 and Derror is P then Correction is N3
8) If Error is P2 then Correction is N3

Figure C.48 shows Defuzzification results. It ranges from 1 to 7 (from N3 to P3), a constant number. If the result shows number 4(Z), then no correction is needed as the wheelchair is at the middle of the track. If the result shows smaller than 4 (from P3 to P1) it means that the wheelchair needs to correct itself by moving to the right. So, the smaller the number, the more correction is needed.

To control the speed of the wheelchair, the controller needs to get data from both the encoder sensor and camera sensor. The output of the range of the encoder will be from 0 m/s to more than 1.2 m/s and the range of the camera will be from 0 to 100 where 50 is the centre point. Figure C.50 shows the input design structure for speed control.

There are 3 inputs, encoder, CMU position and its differential error. To control the wheelchair so that it stays on the track, the speed of wheelchair needs to be known. The speed is influenced by the weight of the user. The controller is designed to be used with the weight between “no load” to 100kg load.

Rules and aggregation for speed

1) If Cmu_position is N2 then Correction is Slow
2) If Cmu_position is P2 then Correction is Slow
3) If Cmu_position is N1 then Correction is Medium
4) If Cmu_position is P1 then Correction is Medium
5) If Cmu_position is Z then Correction is Fast
6) If Encoder is Slow then Correction is Medium
7) If Derror is N then Correction is Slow
8) If Derror is P then Correction is Slow
9) If Derror is Z then Correction is Fast
10) If Encoder is Fast then Correction is Medium

If camera detects N2 or P2, controller reduces the speed of the wheelchair to allow for major correction. This is to reduce the amplitude of oscillation and prevent the wheelchair from moving out from the track. As the wheelchair moves away from the middle of the track, the speed will change from fast to medium and from medium to slow. This explains rule 1 to 5. Rules number 6 and 10 are for trying to maintain the speed within a range of 60cm/s

As the weight of the subject is different varying from 40kg up to 100kg, the controller needs to ensure that the power is enough to drive a

100kg subject smoothly and reduce the power when the subject is lighter. Rules number 7 to 9 deal with Derror. From the same principle, if the deferential error is N or P, the wheelchair will tend to be slower to correct itself back to the middle. As shown in Figure C.49, the Defuzzification results is from 1 to 3(from slow, medium to fast), a constant number.

CHAPTER 4.0

RESULTS AND DISCUSSION

4.1 Introduction

Tests were conducted to validate the whole system. Section 4.2 describes the test on the FLC for the wheelchair. It is a test to evaluate the FLC performance. The test is carried out to show that the wheelchair can navigate from location to location including turning at the junctions and avoiding obstacles that appear on the track.

Section 4.3 describes tests on seven subjects using the BCI system to select destinations and allow the wheelchair to take them to the 4 selected locations. Section 4.4 describes a test by one subject to select a more randomized sequence of location selections including back tracking. The results are tabulated and discussed.

4.2 Testing the FLC

The FLC was tuned by amending the rules and testing to evaluate its performance. The experimental setup is given in Figure 4.1. The wheelchair was made to travel repeatedly from location A to location B for up to 10 times with and without a 90 kg load. The test is repeated from location B to C, C to D and D to A. All the travelled times are recorded and tabulated in Table D.1 to Table D.8 in Appendix D. The mean value of the travel time is calculated as shown in Table 4.1.

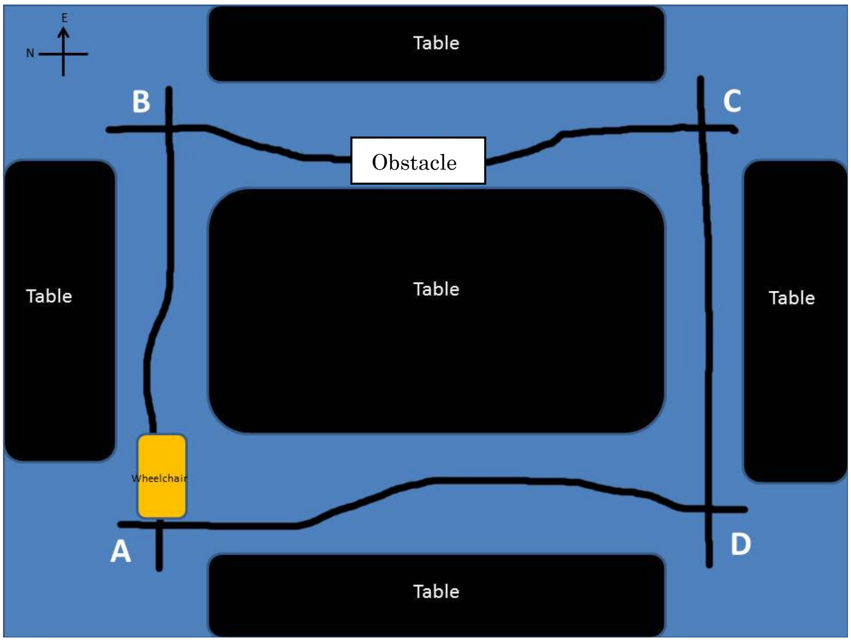

Figure 4.1 Experimental setup

	A to B	B to C	C to D	D to A
	seconds	seconds	seconds	seconds
Mean value (0kg) load	19.0	18.1	9.7	19.1
Mean value (90kg) load	18.9	19.8	10.0	20.0
Difference	0.1	1.7	0.3	0.9

Table 4.1 Mean value of travelled time (with and without load)

Table 4.1 shows that the differences of time taken to travel between 2 locations with and without 90 kg load are small. This shows the FLC was tuned correctly. Note that the time recorded is just the travelled time without junction turning.

Another test was conducted where the wheelchair was instructed to travel to a few locations. The total time to travel to all locations was recorded.

The wheelchair travelled from its initial position at location “A” heading east to location “C” passing through location “B”, negotiating past an obstacle to reach “C”. From “C”, the wheelchair turned right to reach location “D” facing west. From “D”, the wheelchair was required to reach location “B” by passing through location “A”, and the final location is “A” where the wheelchair was required to make a 180 degree turn at location “B”.

A similar test was conducted but with changes to the order of selection of locations. Again, the wheelchair would start from the initial location “A” heading east. The wheelchair was required to make a right turn to reach location “D”. From “D”, the wheelchair would make a left turn to reach “C” first and would make another left turn to reach “B” by passing through an obstacle. From location “B” heading north, the wheelchair turned 180 degrees, passed the obstacle and went back to location “C” heading south. The last location was location “A” where the wheelchair would turn right from location “C” passing through location “D” reaching location “A” facing north. Table D.9 and D.10 show the recorded completion times.

These tests show that the wheelchair is capable of going to any selected location. It manages to go from location A to C without stopping at location B. It also shows that the wheelchair can navigate past an obstacle from left and right. The test shows the wheelchair can make a 90 degree turn or a 180 degree turn at the junction.

4.3 BCI Tests on Subjects

Seven normal subjects were recruited to test the FLC with the BCI system. Each subject was required to sit on the wheelchair and to use motor imagery to select a destination and to allow the wheelchair to take him/her to the selected location. This is repeated for 3 other locations. The experimental setup is given in Figure 4.1.

Each subject was required to complete the following sequence of selections. The initial starting position of the wheelchair was location “A” heading north. The subject was asked to select location “B”. If the subject had chosen a wrong location, the BCI system would ask the subject to choose again until the correct location was selected. The wheelchair would move from location “A” to “B”.

At location “B”, the subject would be asked to select location “C”. The wheelchair would turn right and pass the obstacle to reach location “C”. From location “C”, the subject was required to select location “D”. The wheelchair would turn right, heading south to location “D”. The subject was required to choose the location “A” to go back to the starting point.

All seven normal subjects were required to sit on the wheelchair and use motor imagery to complete the sequence of selections. The selection time and wheelchair travelled time were recorded. Table 4.2 shows the results of the test carried out on the seven subjects.

Sub	TP%	FP%	A to B selection time(sec)	B to C selection time(sec)	C to D selection time(sec)	D to A selection time(sec)	A to B (Navigation)	B to C (Navigation)	C to D (Navigation)	D to A (Navigation)	Total time(sec)
1	54.5	56.09	10	150	75	90	20 sec	35 sec	21 sec	33 sec	434
2	57.14	39.43	10	190	80	85	23 sec	33 sec	20 sec	32 sec	473
3	73.68	0	10	40	20	50	16 sec	33 sec	20 sec	28 sec	217
4	35.78	24.52	65	220	285	80	16 sec	35 sec	21 sec	27 sec	749
5	93.33	67.85	10	45	25	35	16 sec	36 sec	20 sec	28 sec	215
6	79.16	53.84	10	80	55	65	16 sec	36 sec	20 sec	38 sec	320
7	3.72	5.60	1025	375	565	300	17 sec	35 sec	23 sec	30 sec	2370

Table 4.2 Completion time for seven subjects

Columns 2 and 3 of Table 4.2 show the True Positive (TP) and False Positive (FP) made by each subject during the experiment. Columns 3 to 6 show the time taken to make the correct selection for each location. Columns 7 to 10 show the time taken by the wheelchair to travel between locations. The last column shows the total time taken (location selection and wheelchair's navigation time) by each subject to complete the experiment using motor imagery to travel to all 4 locations.

There are 2 outstanding subjects, subject 3 and subject 5. Their total completion time is 217 seconds and 215 seconds respectively. The BCI performance is evaluated by finding the difference between True Positive (TP%) and False Positive (FP%). Subject 3 has the best BCI performance where his BCI performance is 73.68%. Subject 7 appears to be the weakest subject where he took 2370 seconds to complete the experiment.

For the wheelchair navigation, the times taken for all the seven subjects are about the same. Note that the time recorded includes the junction turn. The minor time variation between each subject is caused by the initial position of the wheelchair. Wheelchair arrives to the destination at different angles, sometimes slightly to the left and sometimes more to the right.

Under certain conditions, the wheelchair camera might fail to identify the black tape. This may be caused by the reflection of the ceiling lamp as shown in Figure 4.2. When the wheelchair encounters such a problem, the controller instructs the wheelchair to turn left or right on the same spot to look for the track. This causes some delay in the arrival time. This occurred when subject 6 performed his experiment. The time taken for him to reach “A” from “B” was 38 seconds instead of 28 seconds.

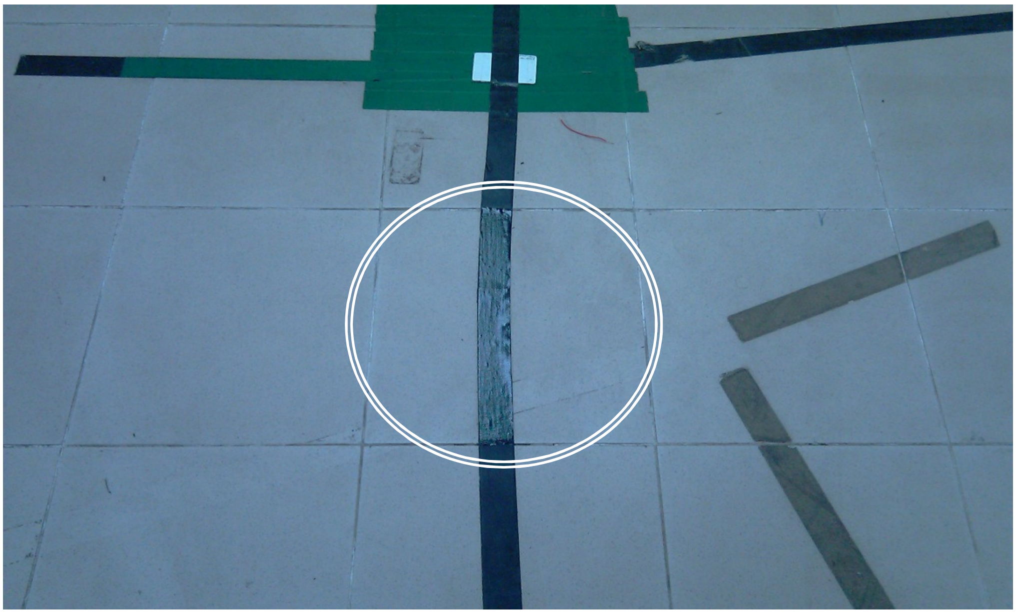

Figure 4.2 Reflective track

4.4 BCI Tests on Randomized Location Selection by One Good Performer

To demonstrate the capability of the BCI wheelchair further, a more complex randomized location selection sequence including back tracking was tested with one subject. The subject with the best performance in the previous test was chosen to carry out this test. The figure below shows the map for the test environment. The experimental setup is given in Figure 4.1

The subject would start at location “A” heading east. He would be required to select location “D” (facing south). The wheelchair would need to make a right turn and to reach location “D”. The next required location would be “B” (facing north). The wheelchair would need to make a left turn and to proceed to location “C”. Without stopping at “C”, the wheelchair would be required to turn left and to head North to location “B”. The wheelchair would need to pass the obstacle before reaching location “B”.

After arrival at “B”, the subject would be required to select location “C”. In this case, the wheelchair facing north would be required to make a 180 degree right turn to pass the obstacle again to reach location “C” heading southwards. The last location required by the test would be location “A”. The wheelchair would turn right heading westwards to pass through location “D” to reach location “A” heading northwards. Table 4.3 shows the result of this subject.

Subject	TP%	FP%	A to d selection time(sec)	D to B selection time(sec)	B to C selection time(sec)	C to A selection time(sec)	A to D (Navigation)	D to B (Navigation)	B to C (Navigation)	C to A (Navigation)	Total time(sec)
Peter	85.71	16.68	30	15	10	15	30	56	34	60	250

Table 4.3 Completion time by 1 subject

The BCI performance for this subject is 69.03% in this test. The average selection time for all four locations is 17.5 seconds. The subject completed the test in 250 seconds.

CHAPTER 5.0

CONCLUSION

An Intelligent Distributed Controller system with Fuzzy Logic Controller (FLC) for a wheelchair that was operated by a Brain-Computer Interface (BCI) was developed. All sensor modules including the wheel encoder and digital compass modules, the ultrasonic sensor module, the RFID module, the CMUcam2 camera module, the DAC converter module, the BCI controller interface module and FLC were designed, built and tested. The sensor modules communicated with the FLC using I2C communication protocol. The wheelchair system was integrated to the BCI system via Bluetooth communication. The FLC was manually tuned for optimum performance of the system.

Seven normal subjects were recruited. Each subject was required to sit on the wheelchair, used motor imagery to select a destination and to allow the wheelchair to take the subject to the destination. This was repeated for three other destinations. All seven subjects successfully completed the tasks although with varying completion times ranging from ten minutes to twenty minutes. To demonstrate the flexibility of the system, one other subject was required to select the four destinations in a more random manner with back tracking between certain locations. The minimum possible time for this sequence was fifteen minutes. The subject completed all the tasks in twenty minutes.

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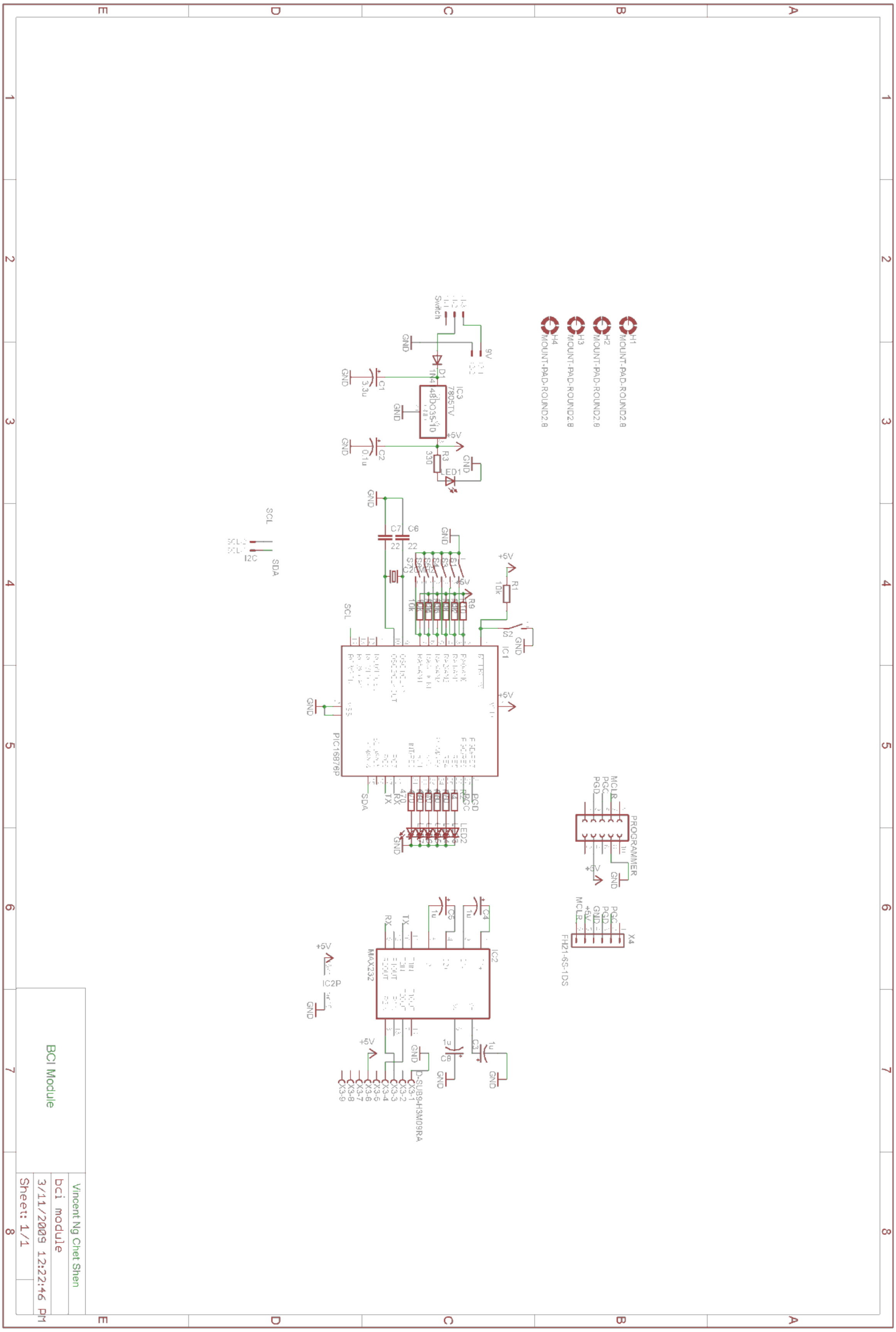
Appendix A

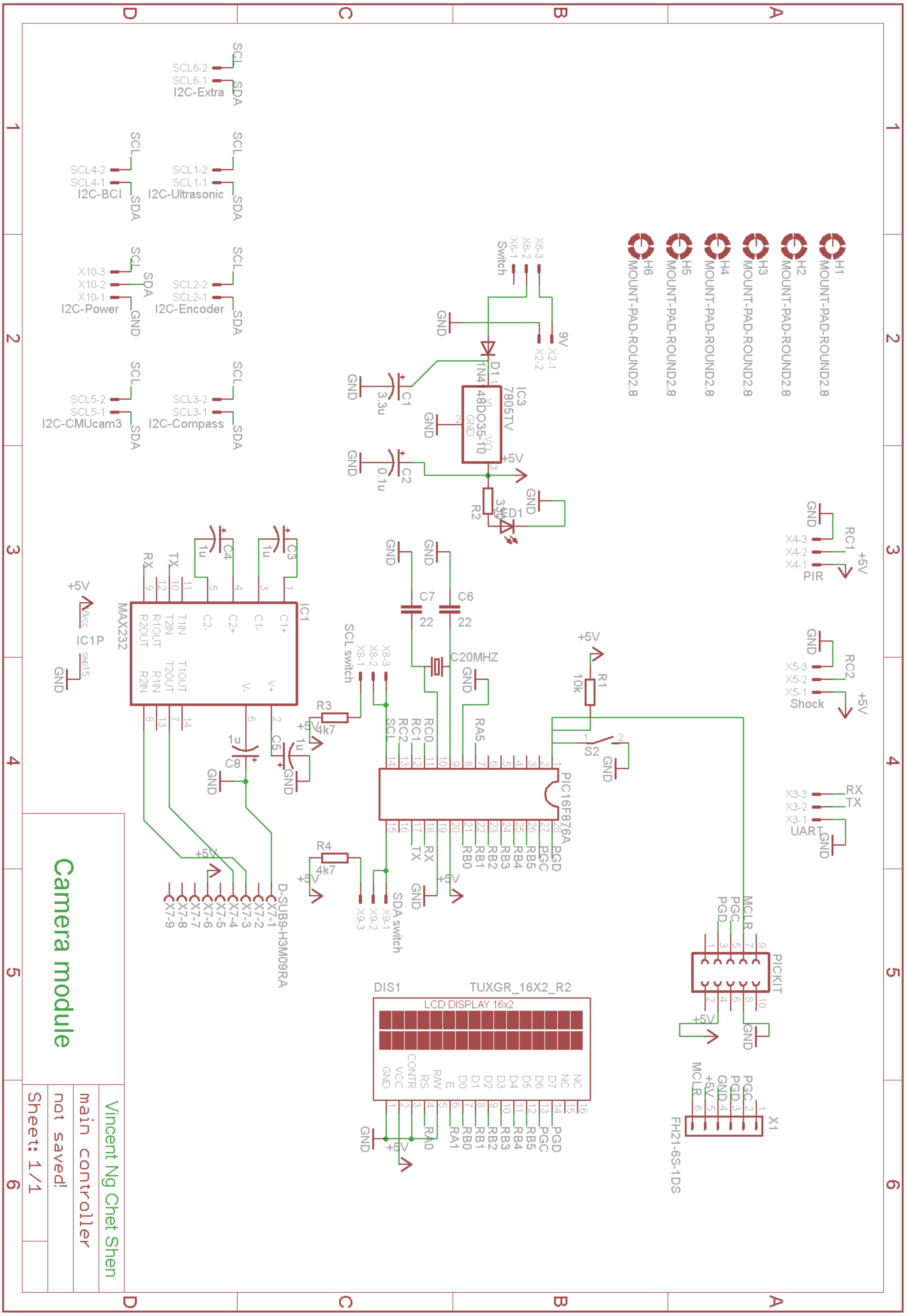
Please refer to the CD attached for the program source code.

Appendix B

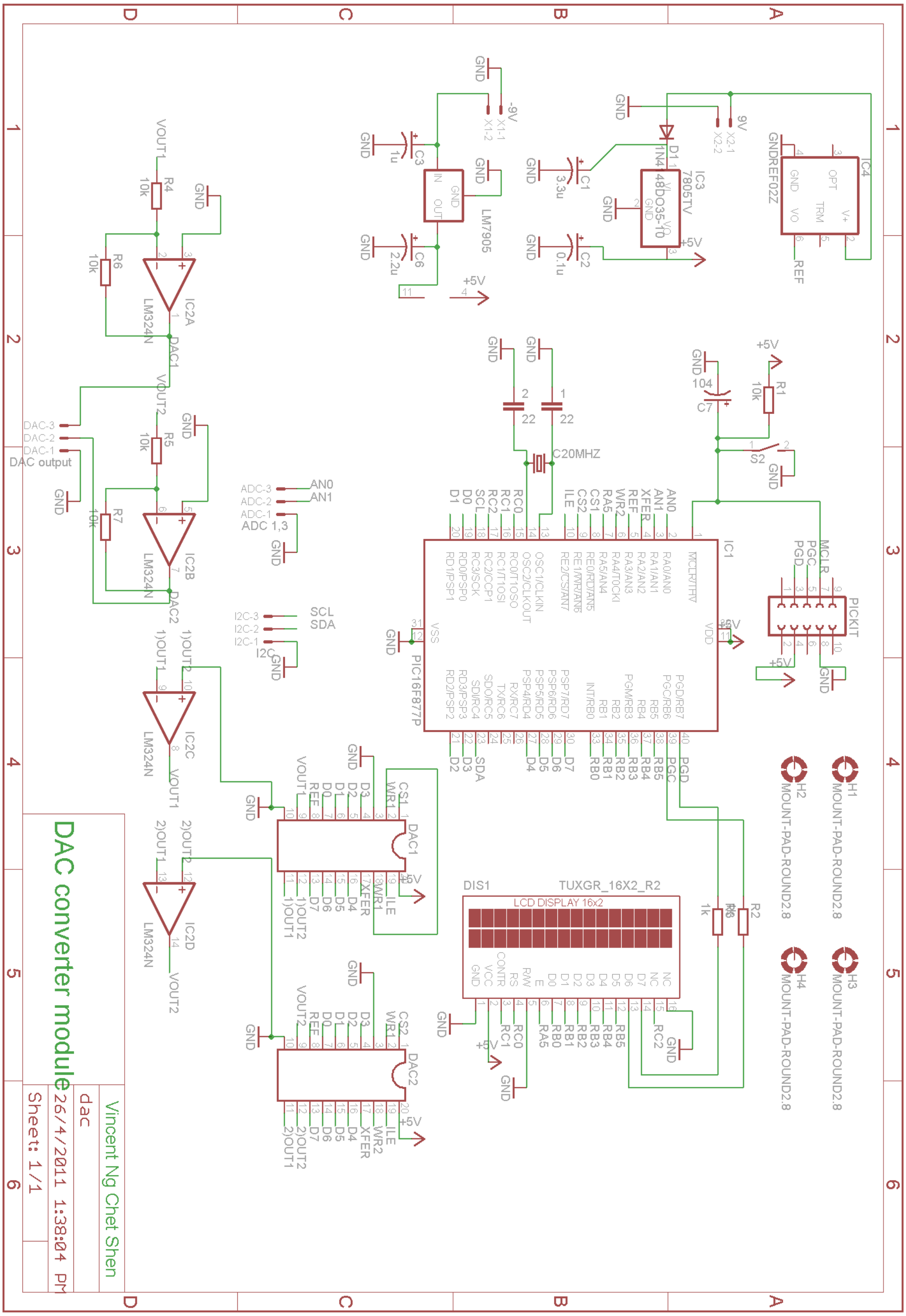
Schematic diagram : BCI Controller Interface



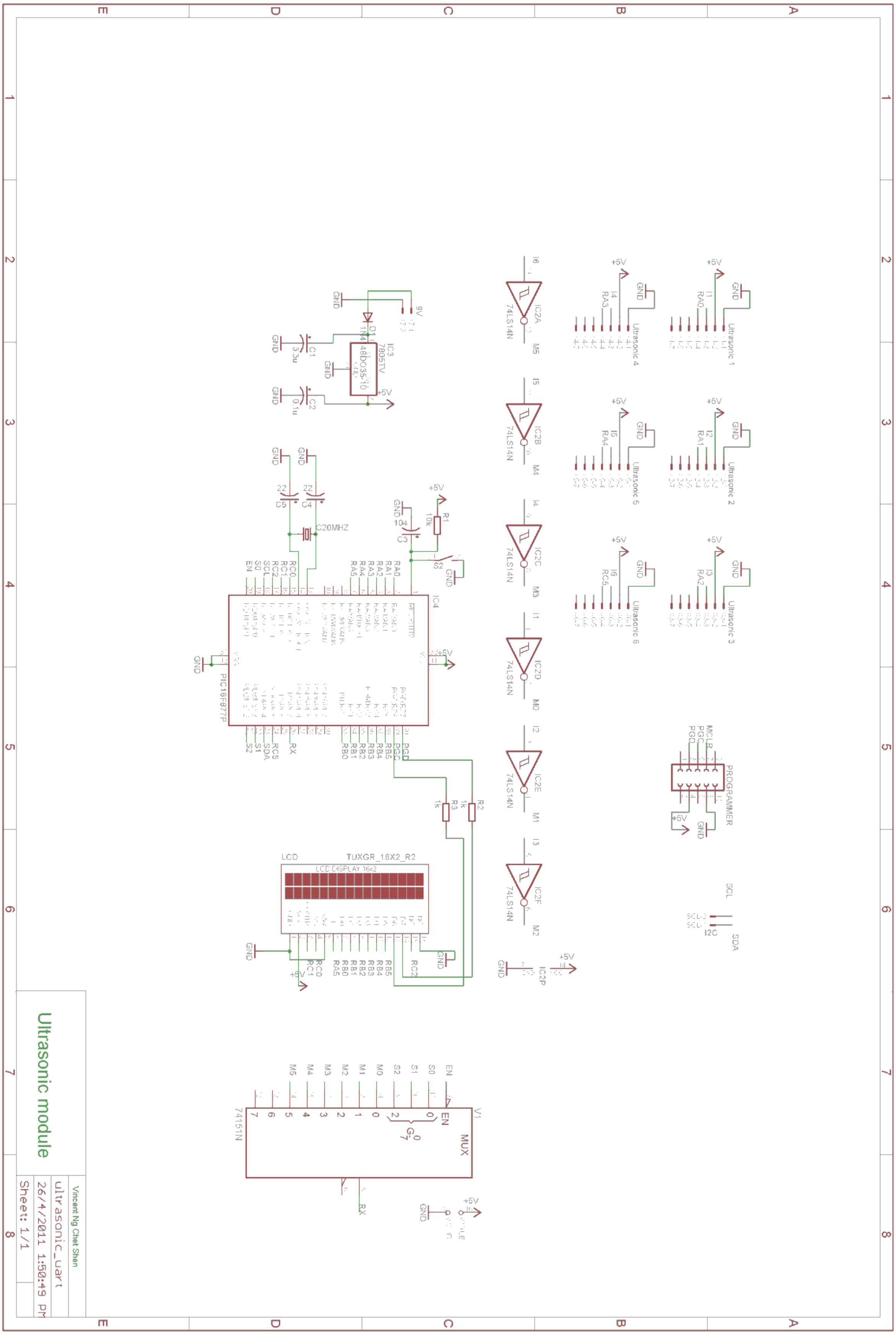
Schematic Diagram : Camera Module



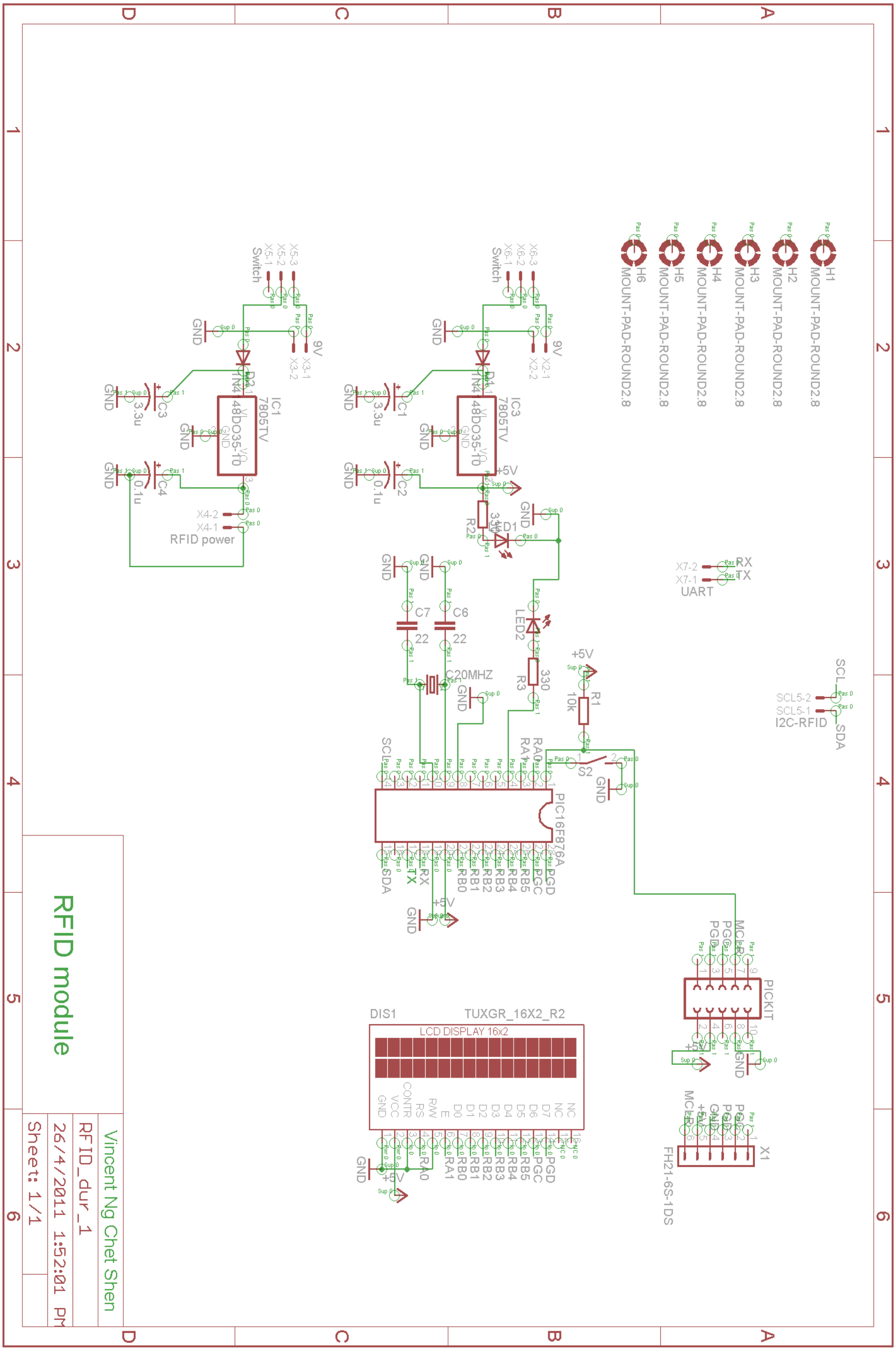
Schematic Diagram: DAC Converter Module



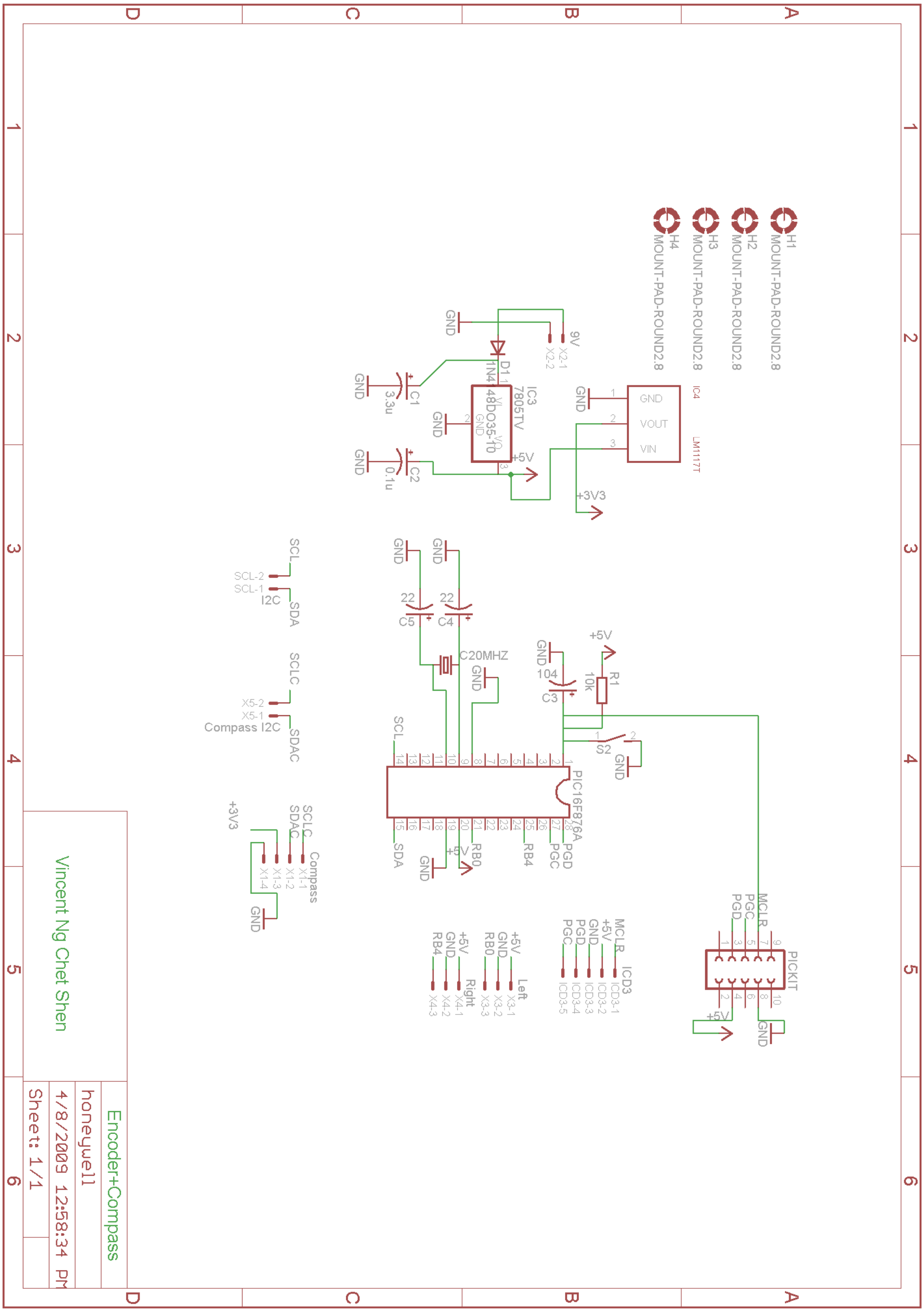
Schematic Diagram : Ultrasonic Module



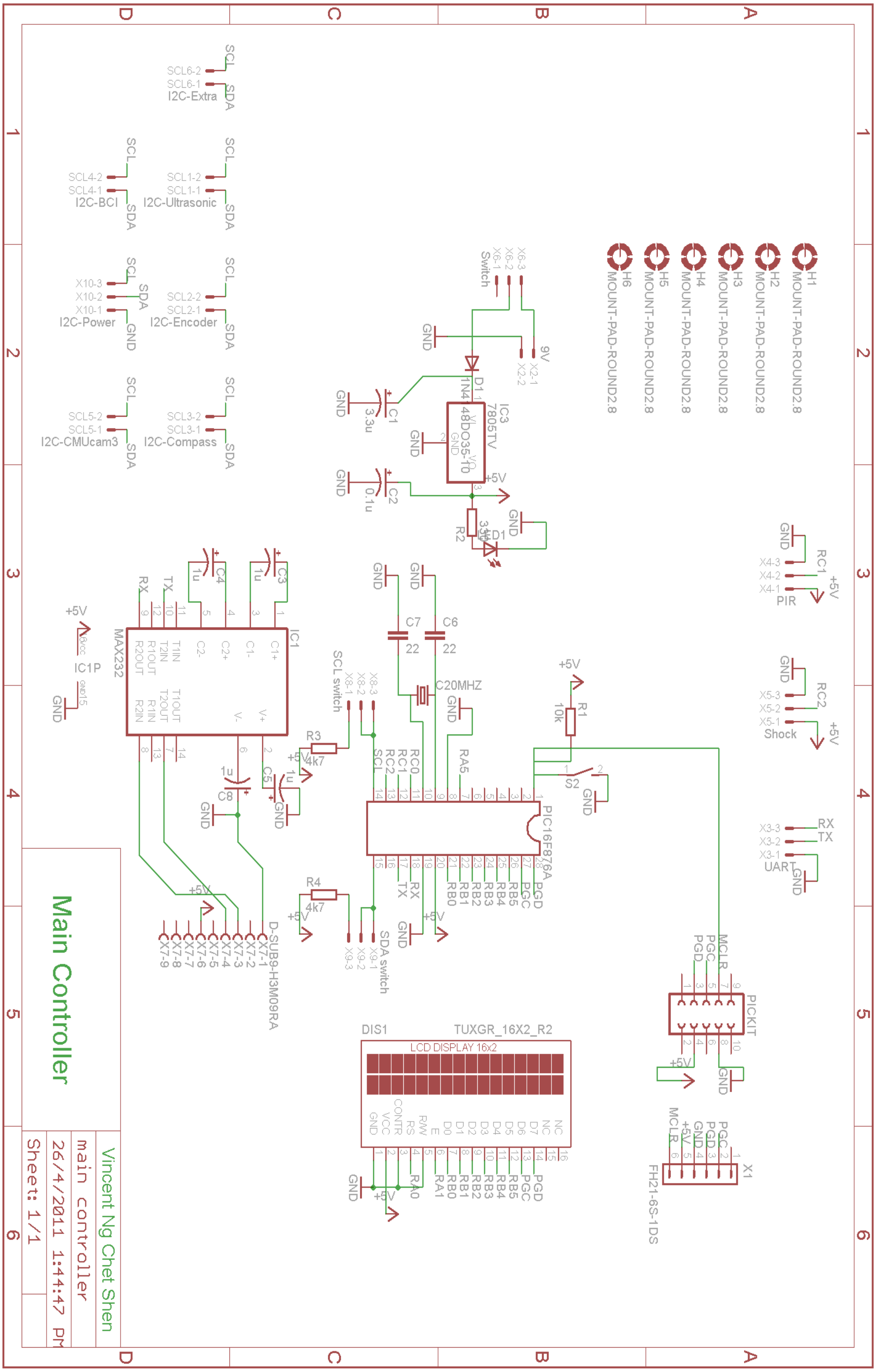
Schematic Diagram : RFID Module



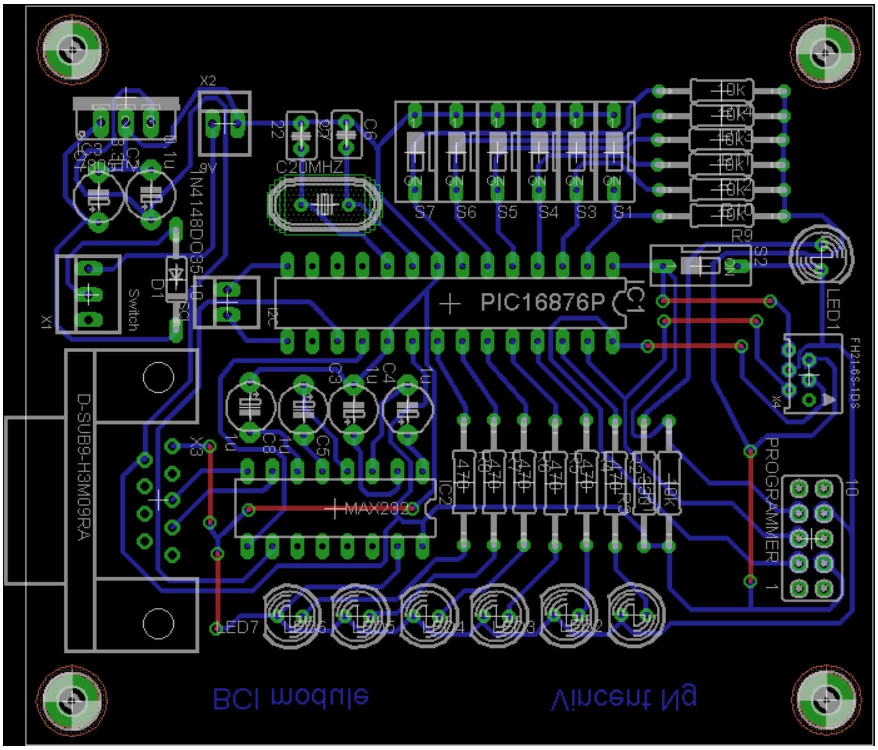
Schematic Diagram : Wheelchair Encoder and Compass Module



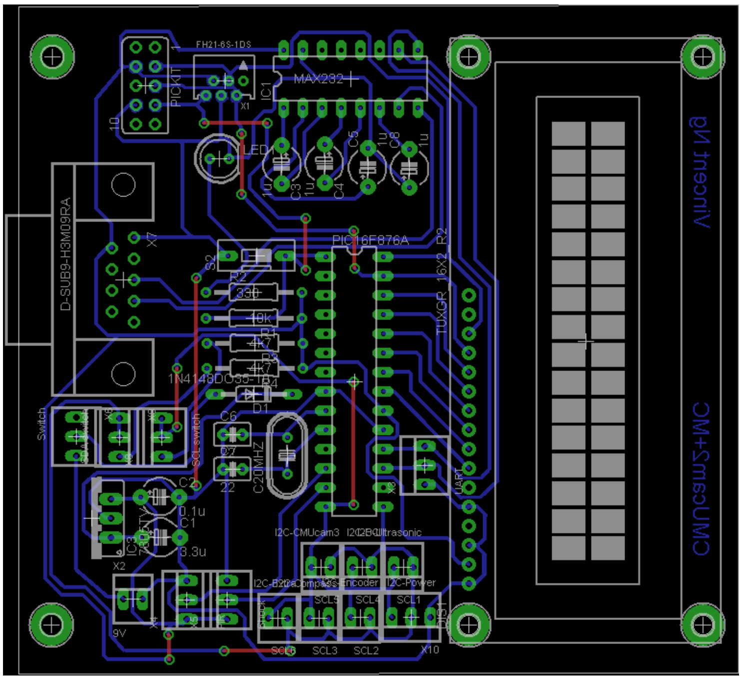
Schematic Diagram: Main Controller (Fuzzy Logic)



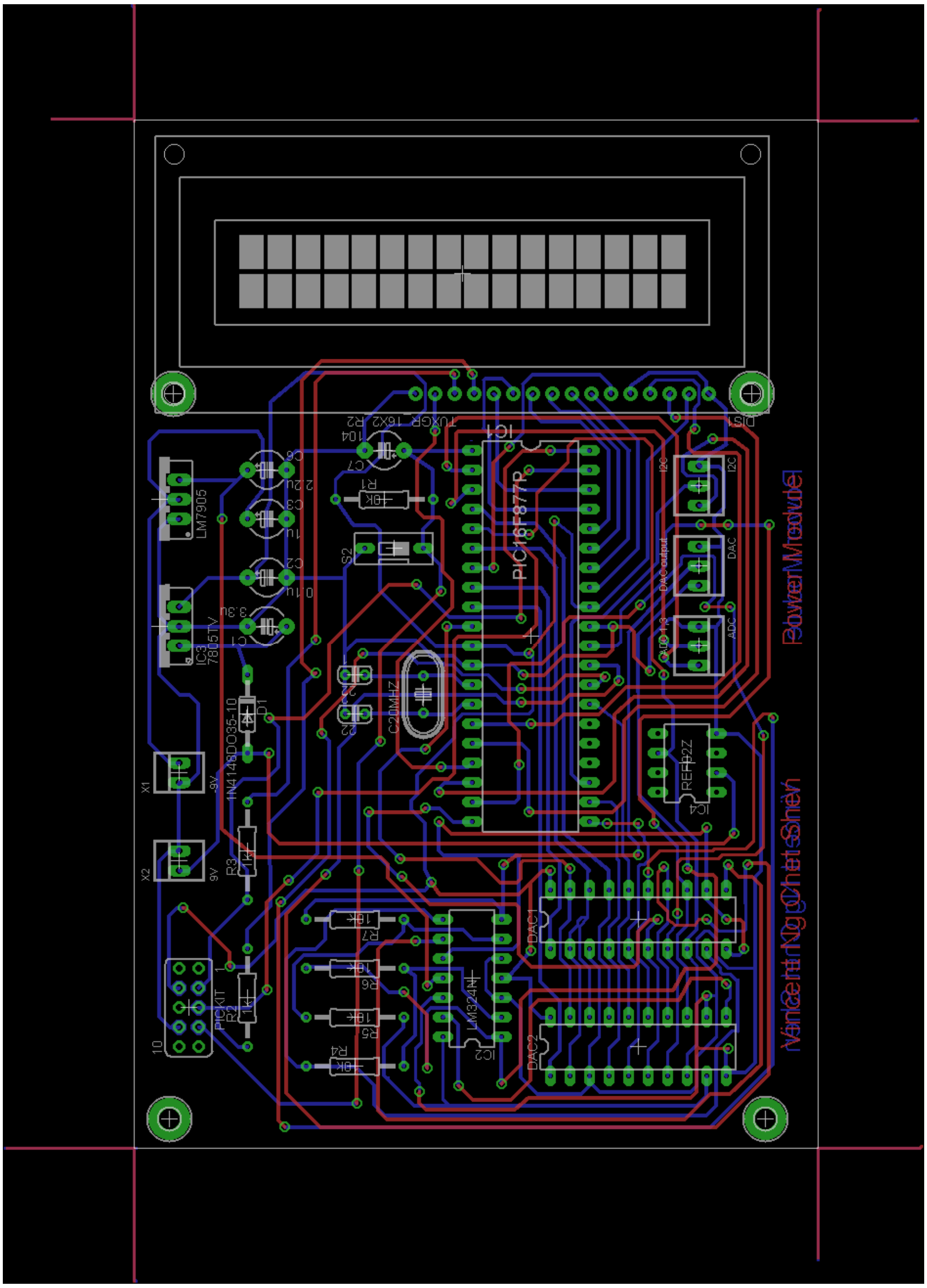
BCI Controller Interface Board



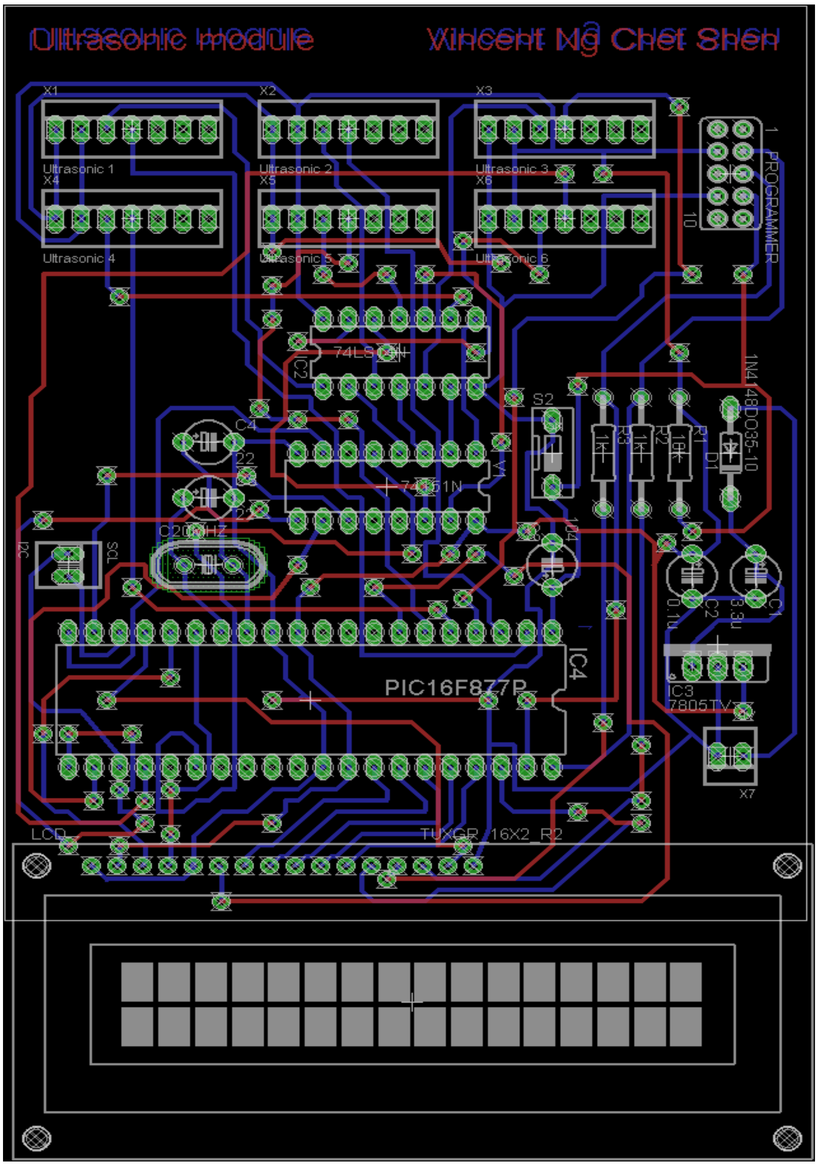
Camera Module Board



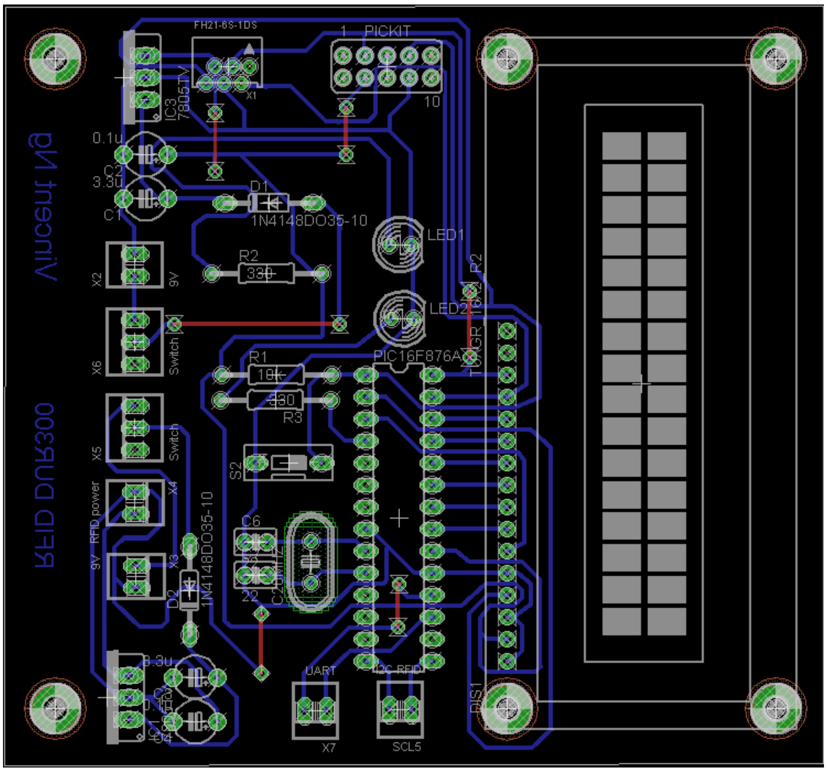
DAC Converter Module Board



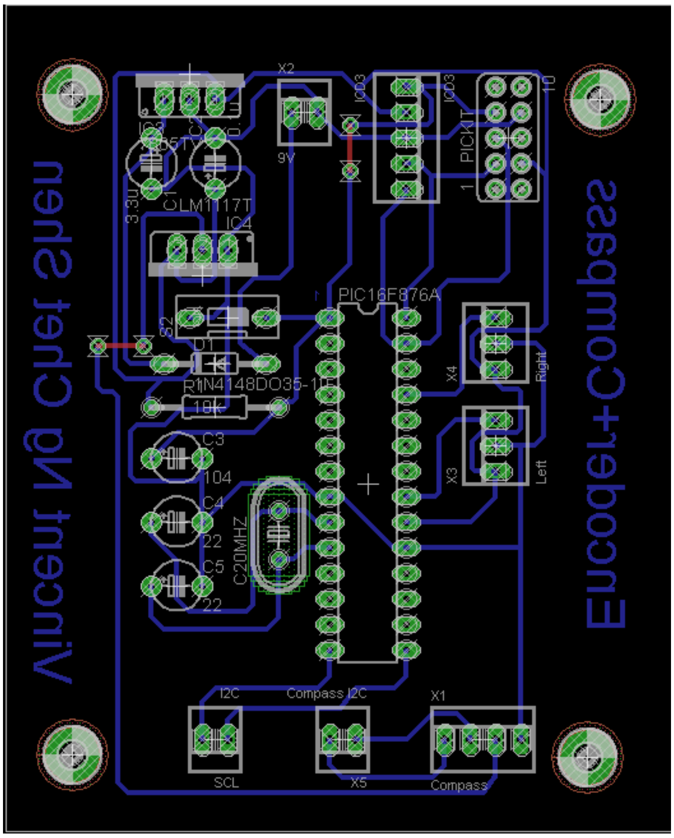
Ultrasonic Module Board



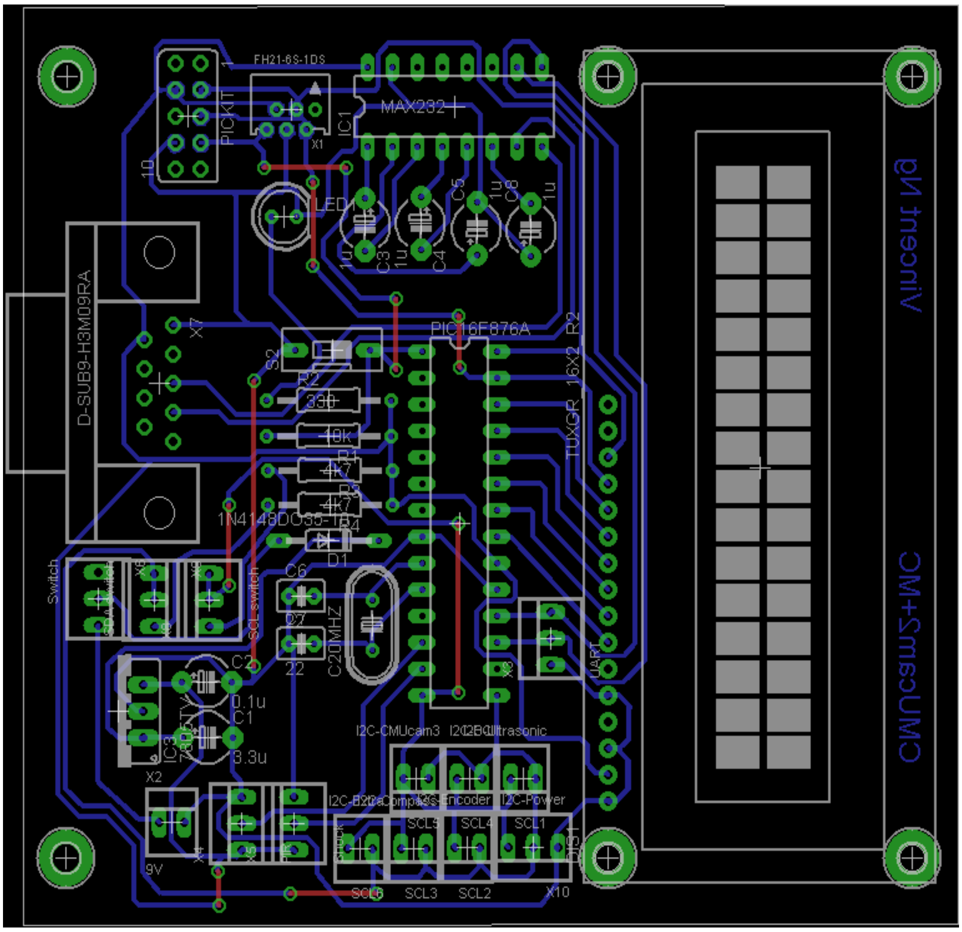
RFID Module Board



Wheelchair Encoder and Compass Module



Main Controller (Fuzzy Logic) Board



Appendix C

Figure :

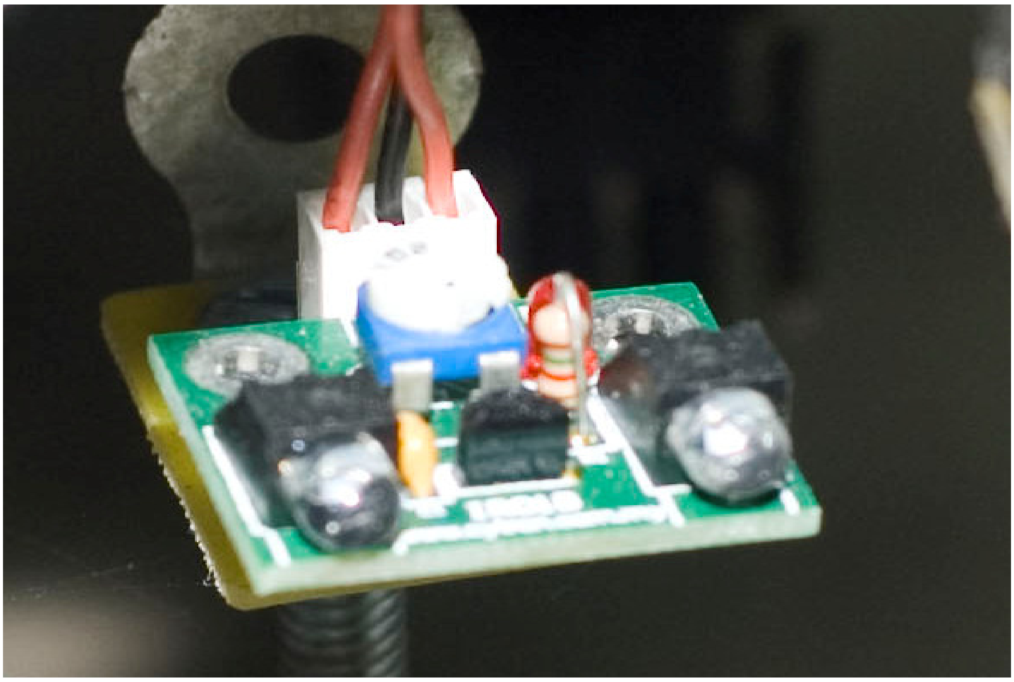


Figure C.1 Optical Encoder

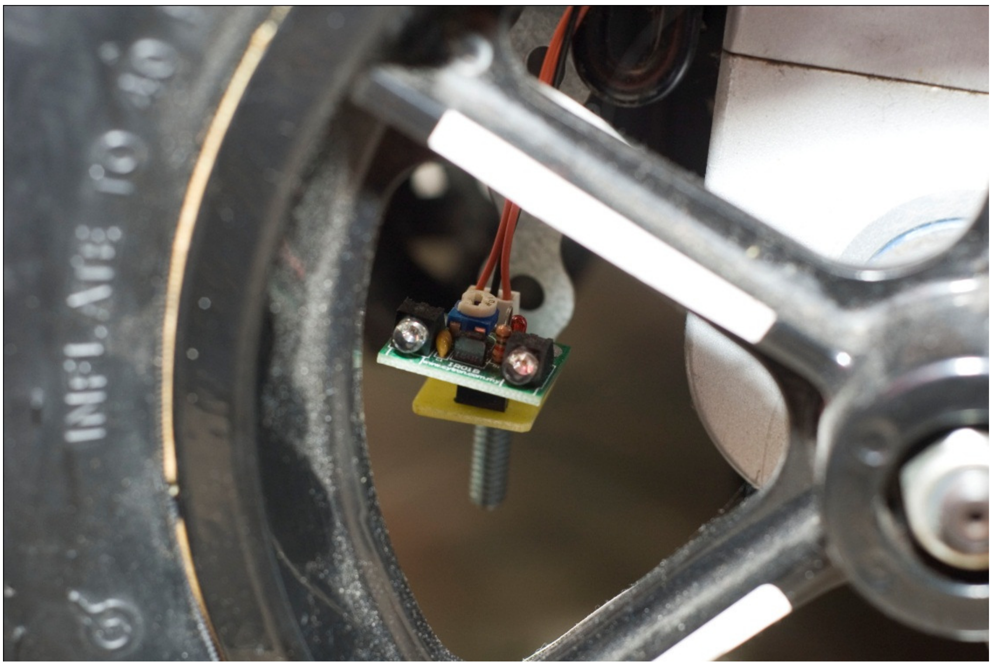


Figure C.2 Encoder mounted beside wheel

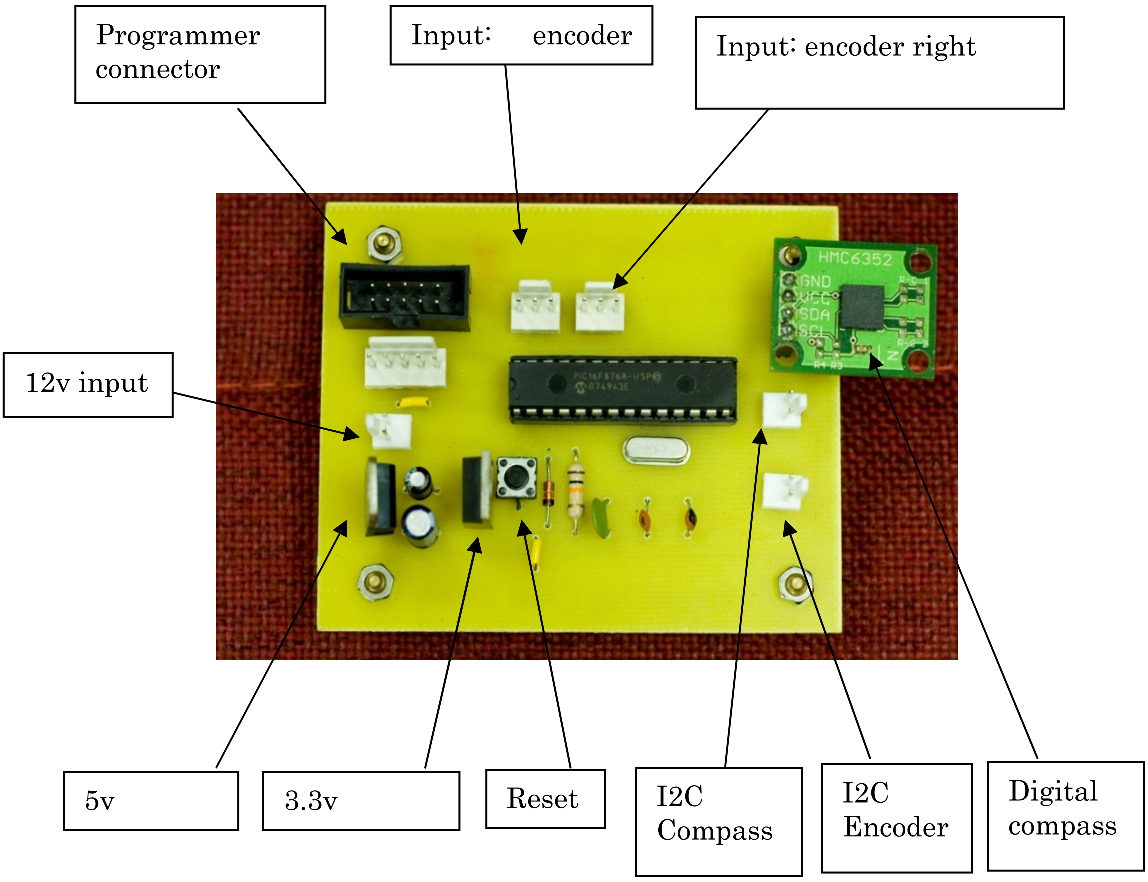


Figure C.3 Wheel encoder and compass module

Figure C.4 System flow chart of wheel encoder module

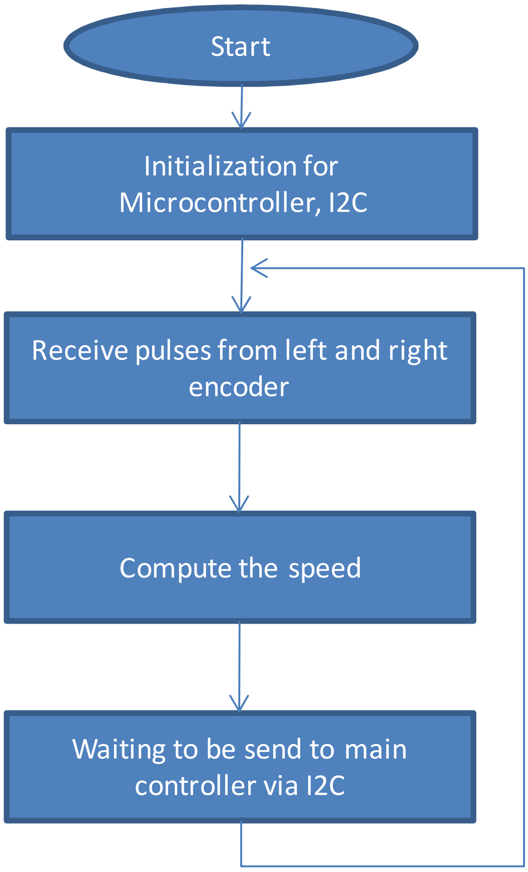


Figure C.5 Program flow chart for wheel encoder module

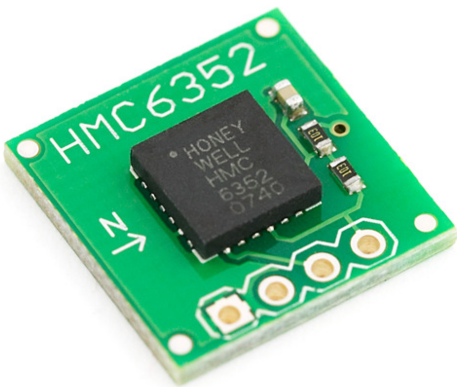


Figure C.6 Honeywell HMC6352

Figure C.7 LV-MaxSonar-EZ1 Ultrasonic Range Finder

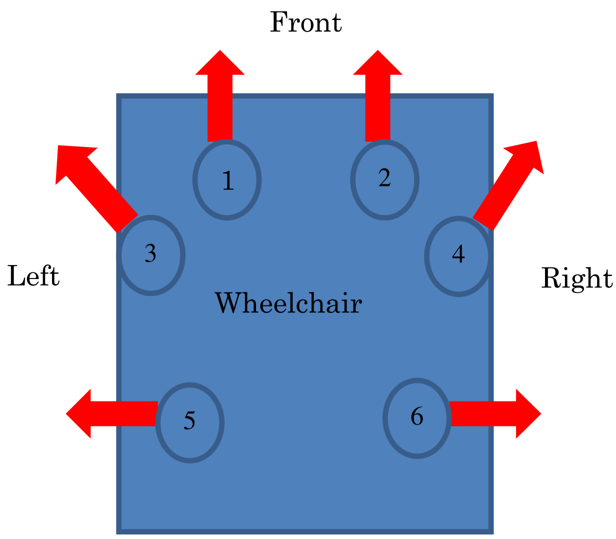


Figure C.8 Ultrasonics on the wheelchair

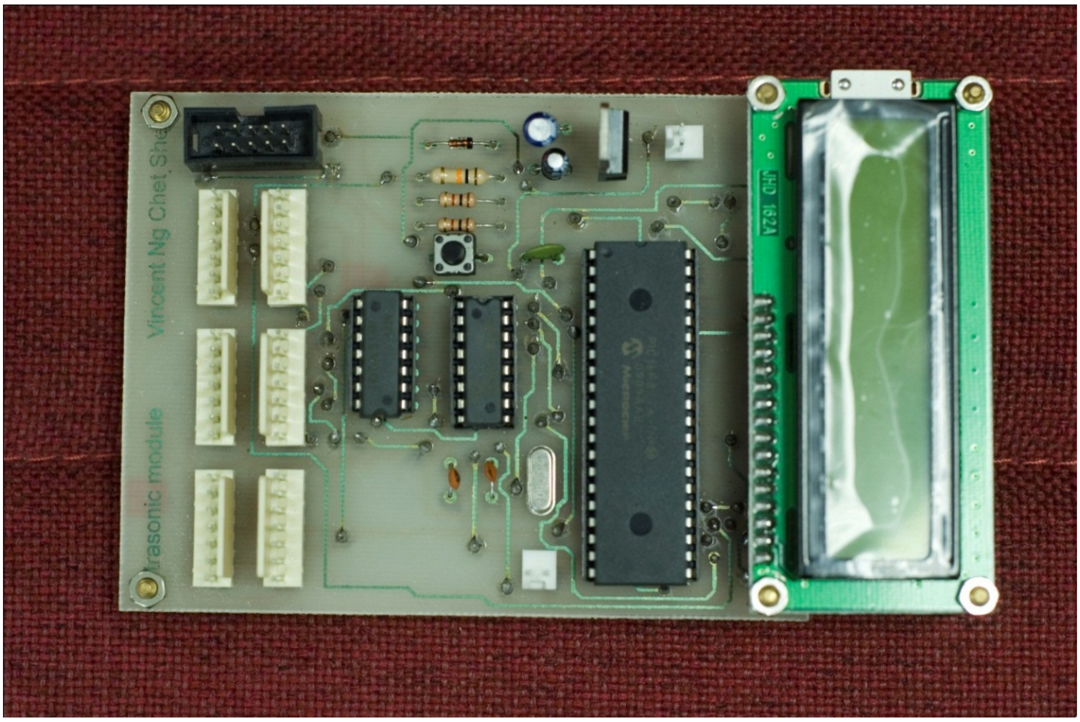


Figure C.9 Ultrasonic Module

TRUTH TABLE

$\overline{E}$	S_2	S_1	S_0	I_0	I_1	I_2	I_3	I_4	I_5	I_6	I_7	$\overline{Z}$	Z
H	X	X	X	X	X	X	X	X	X	X	X	H	L
L	L	L	L	L	X	X	X	X	X	X	X	H	L
L	L	L	L	H	X	X	X	X	X	X	X	L	H
L	L	L	H	X	L	X	X	X	X	X	X	H	L
L	L	L	H	X	H	X	X	X	X	X	X	L	H
L	L	H	L	X	X	L	X	X	X	X	X	H	L
L	L	H	L	X	X	H	X	X	X	X	X	L	H
L	L	H	H	X	X	X	L	X	X	X	X	H	L
L	L	H	H	X	X	X	H	X	X	X	X	L	H
L	H	L	L	X	X	X	X	L	X	X	X	H	L
L	H	L	L	X	X	X	X	H	X	X	X	L	H
L	H	L	H	X	X	X	X	X	L	X	X	H	L
L	H	L	H	X	X	X	X	X	H	X	X	L	H
L	H	H	L	X	X	X	X	X	X	L	X	H	L
L	H	H	L	X	X	X	X	X	X	H	X	L	H
L	H	H	H	X	X	X	X	X	X	X	L	H	L
L	H	H	H	X	X	X	X	X	X	X	H	L	H

H = HIGH Voltage Level
L = LOW Voltage Level
X = Don't Care

Figure C.10 Truth Table for SN74LS151 from Motorola

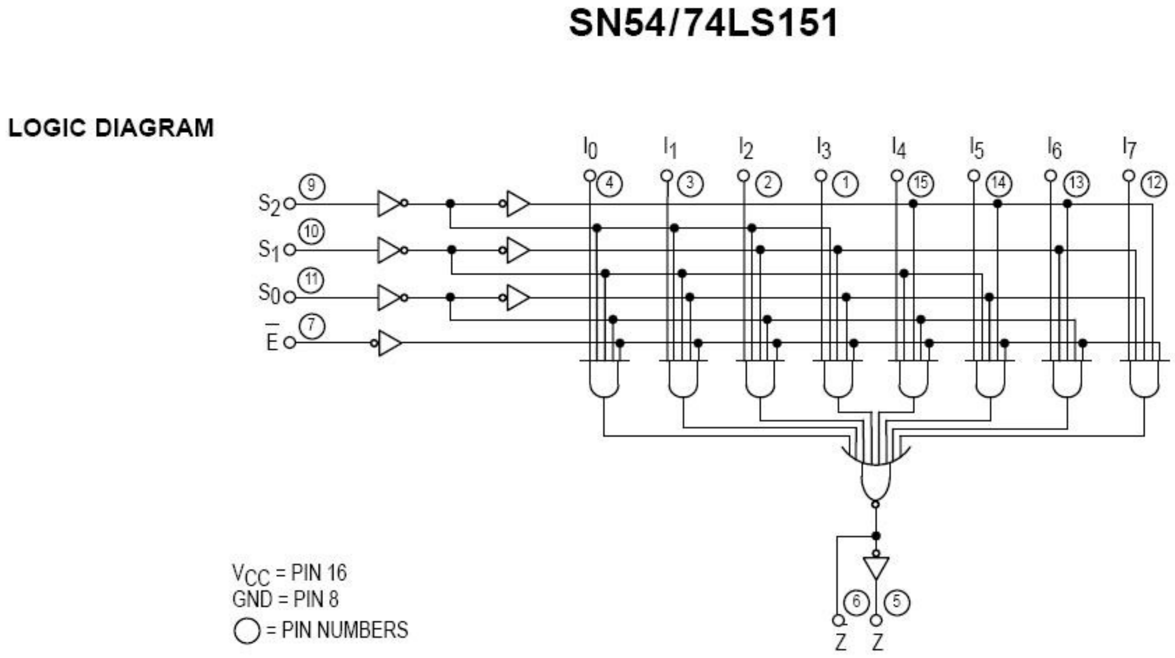


Figure C.11 Logic diagram of Motorola SN74LS151

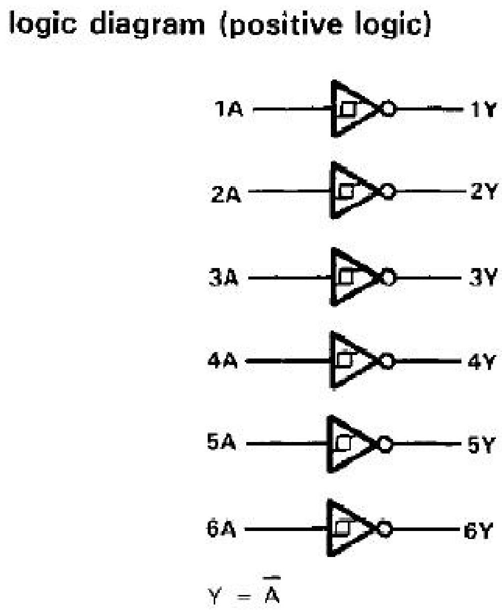


Figure C.12 Logic diagram of SN7414 from Texas Instruments

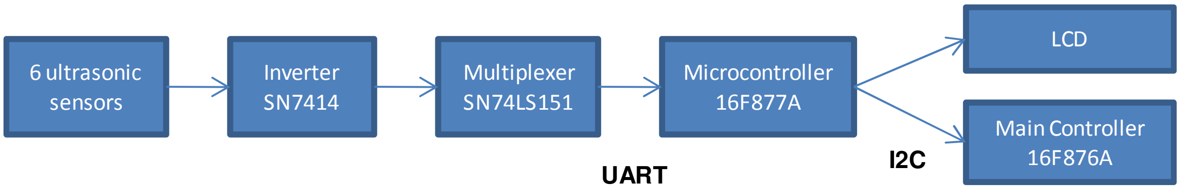


Figure C.13 System flow chart (ultrasonic)

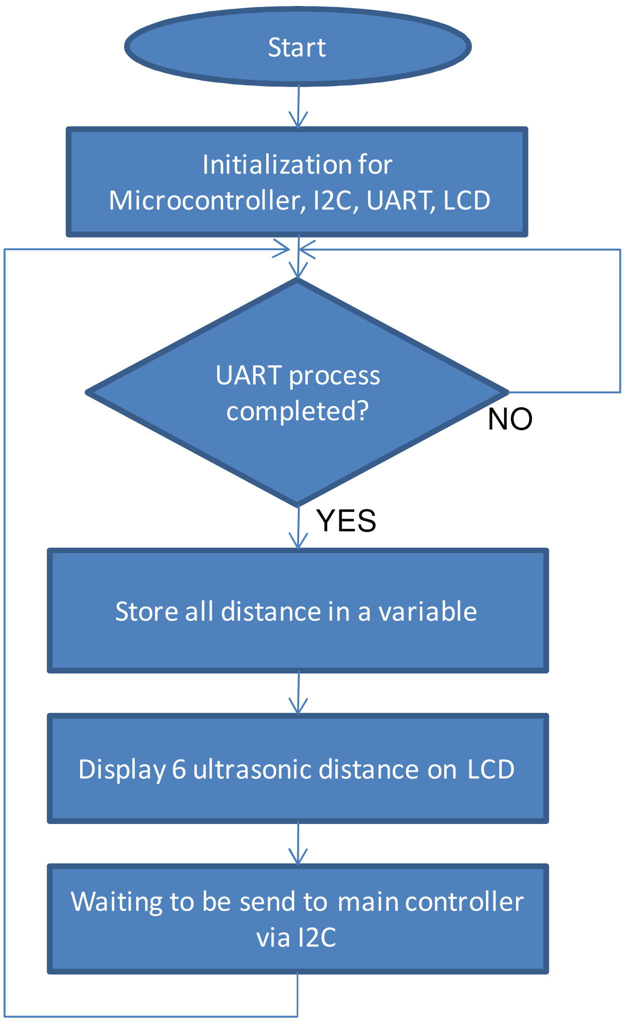


Figure C.14 Program flow chart (ultrasonic)

Figure C.15 RFID reader

Figure C.16 RFID tag

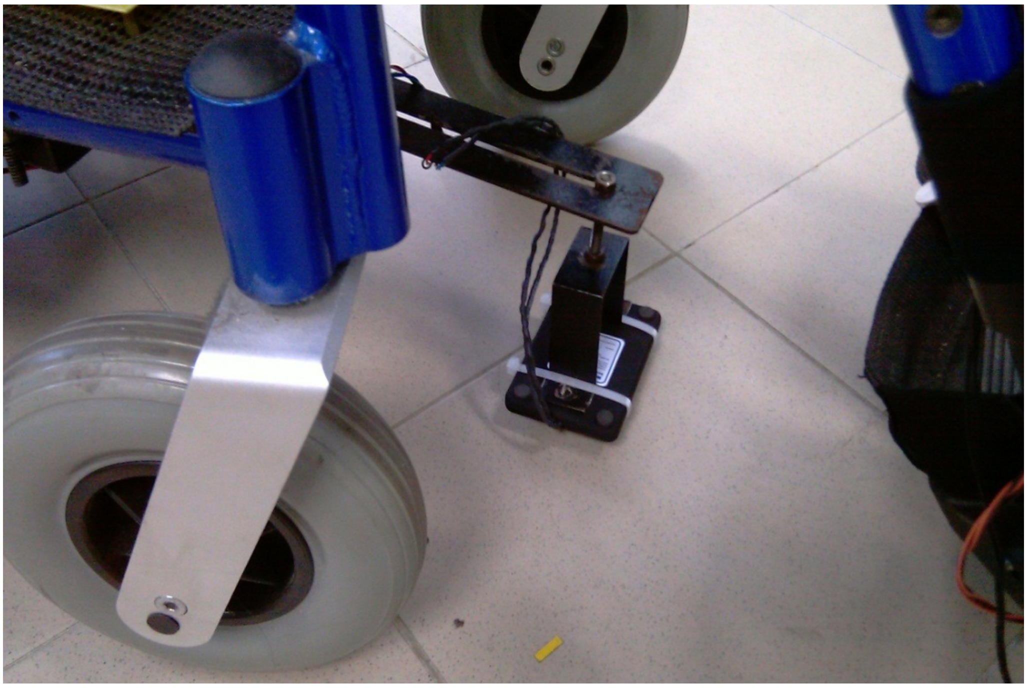


Figure C.17 RFID reader installed under the wheelchair

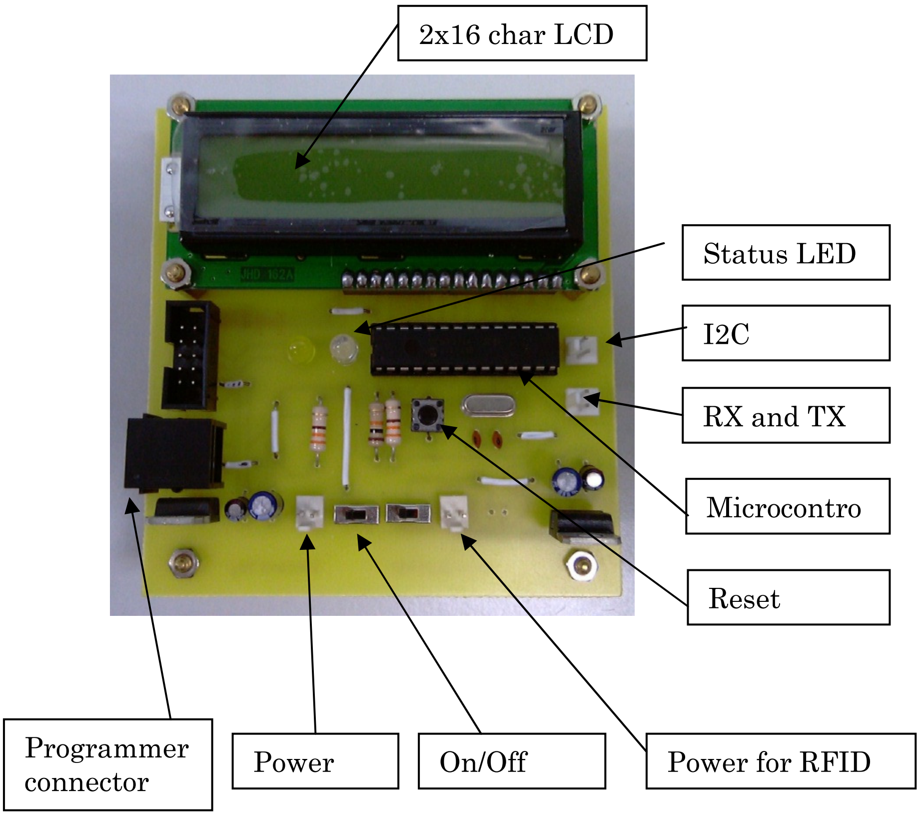


Figure C.18 RFID module

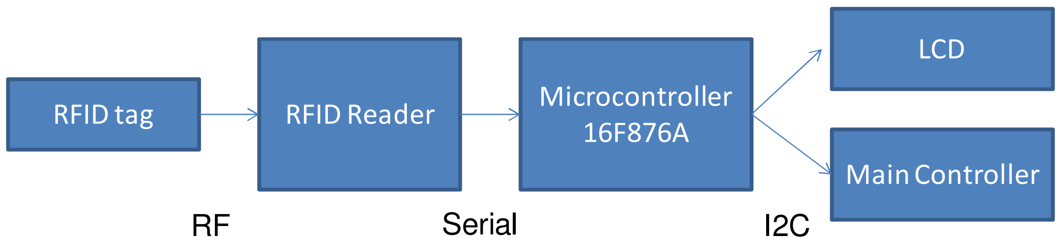


Figure C.19 System flow chart (RFID)

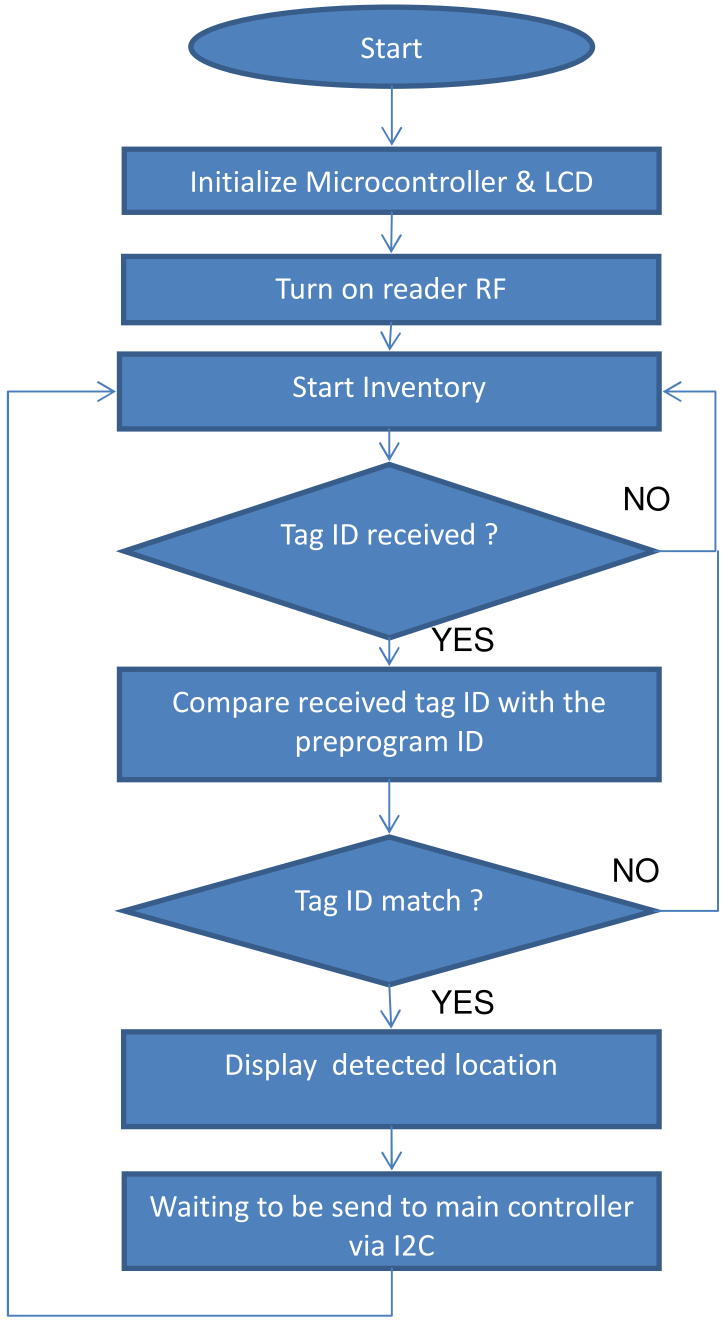


Figure C.20 Program flow chart (RFID)

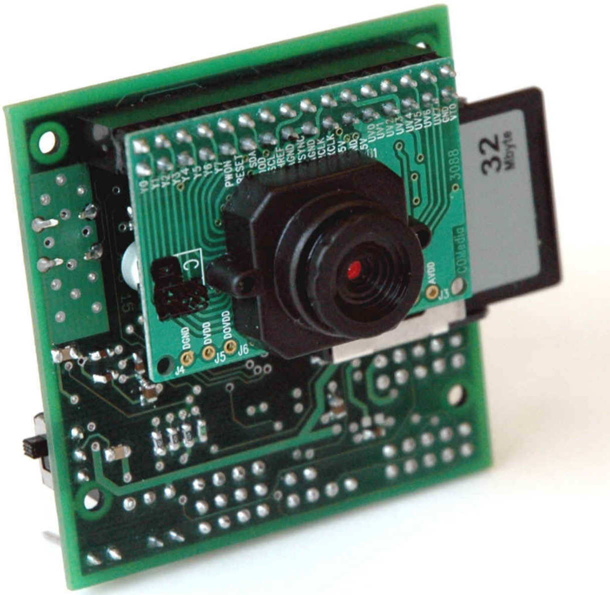


Figure C.21 CMUcam3 camera sensor

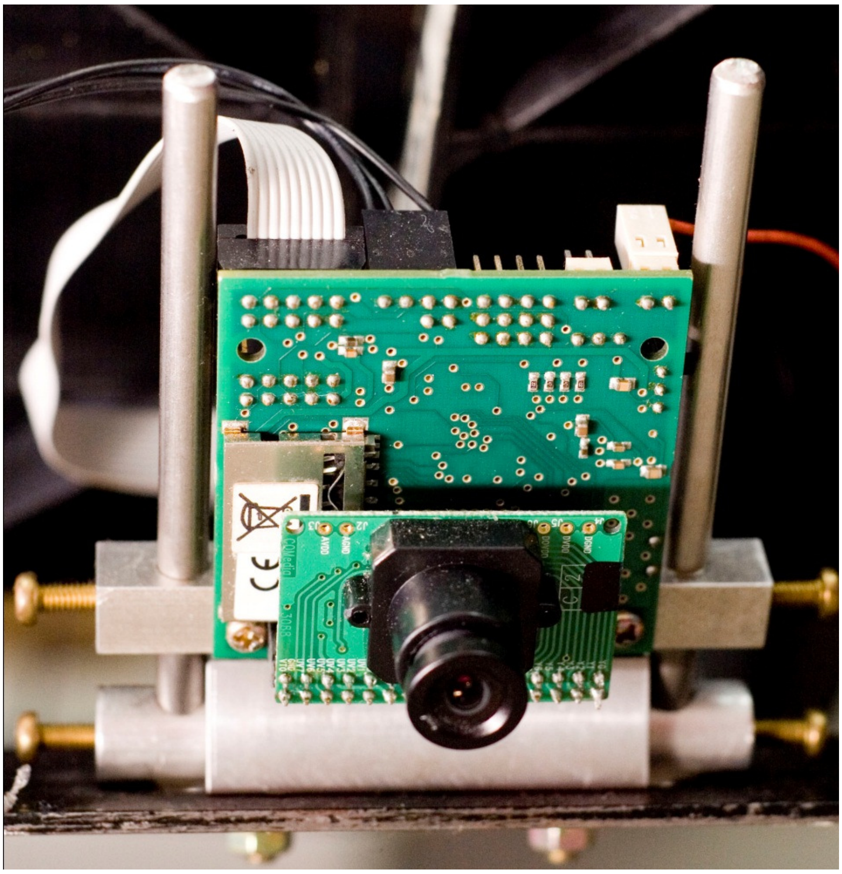


Figure C.22 CMUcam3 mounted in front of wheelchair

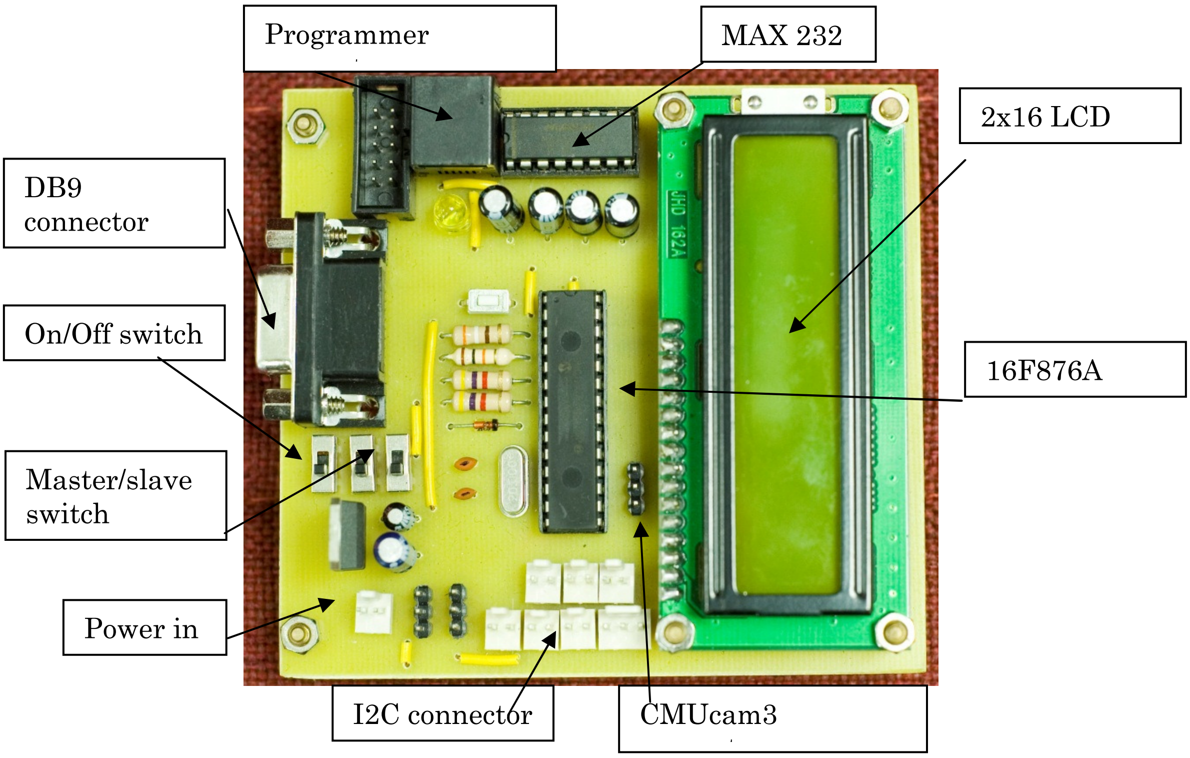


Figure C.23 Camera module

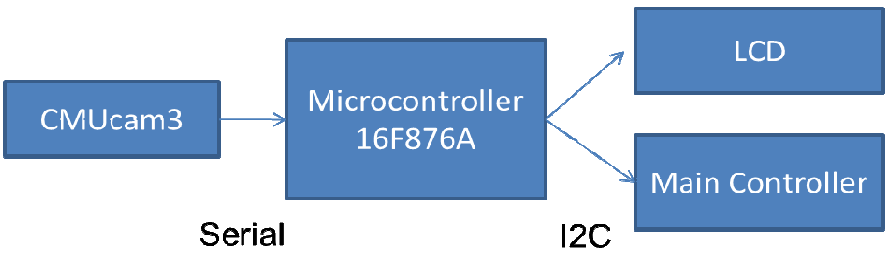


Figure C.24 System flow chart (Camera module)

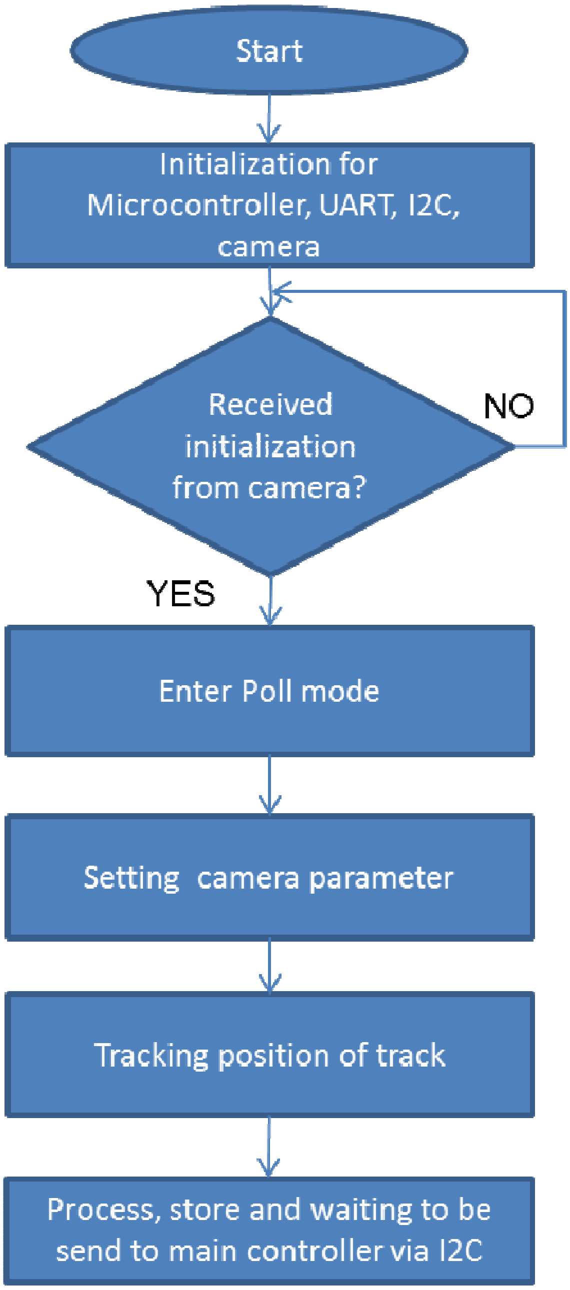


Figure C.25 Program flow chart (Camera module)

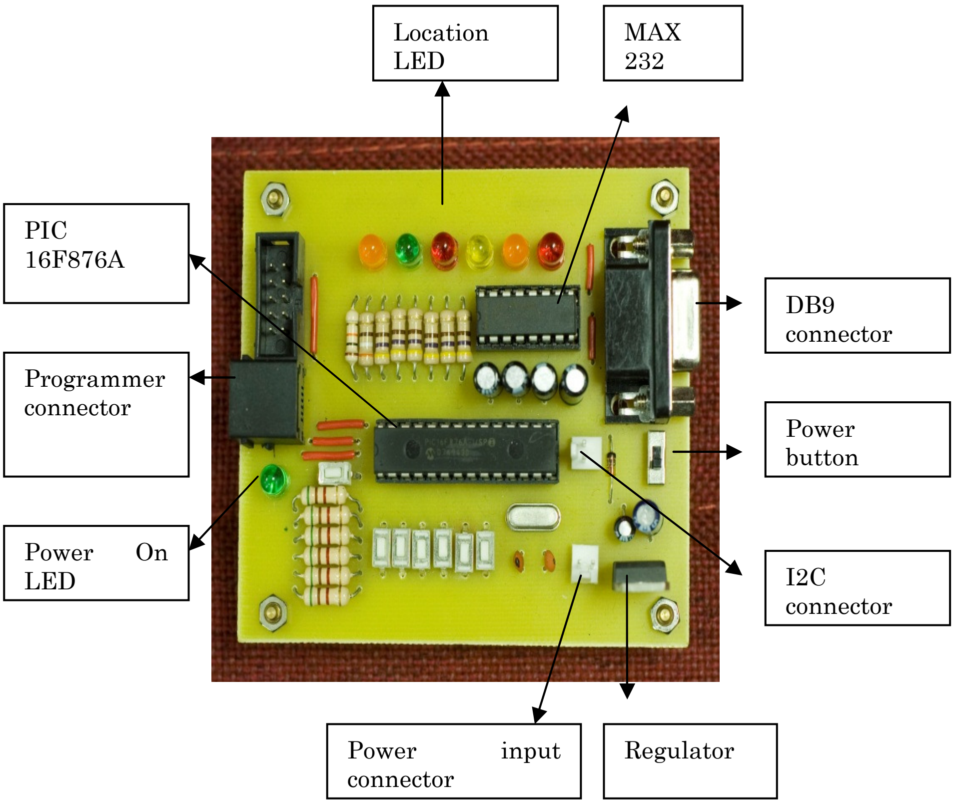


Figure C.26 BCI controller interface module

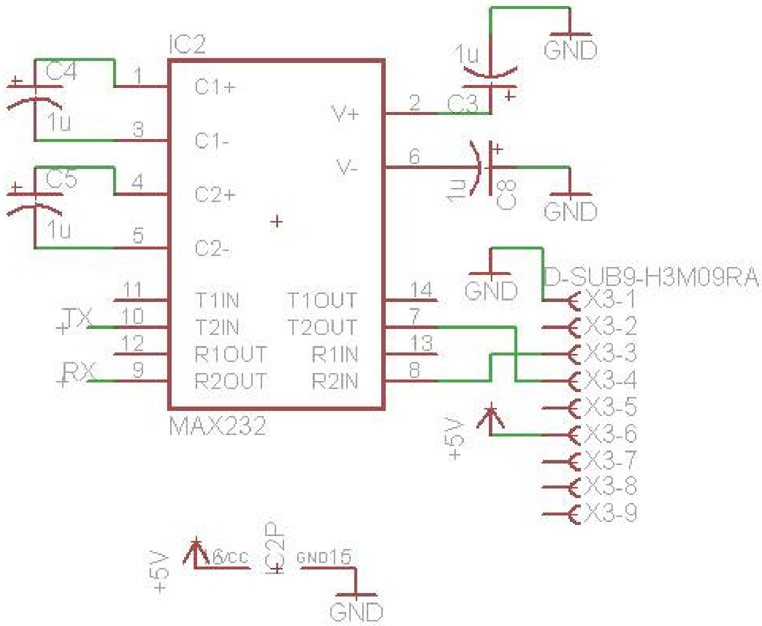


Figure C.27 Connection between MAX232 and DB9

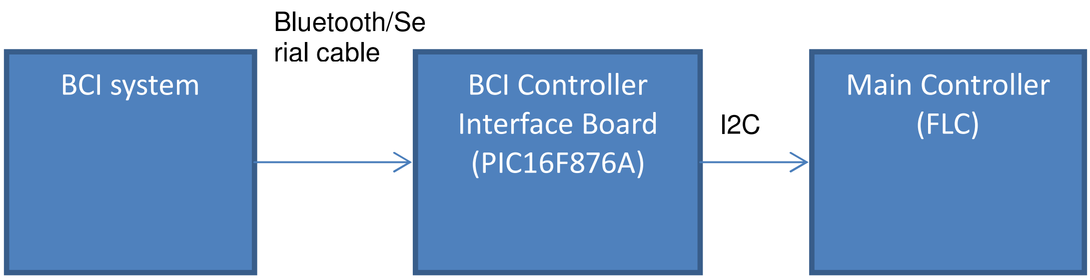


Figure C.28 System flow chart (BCI controller interface)

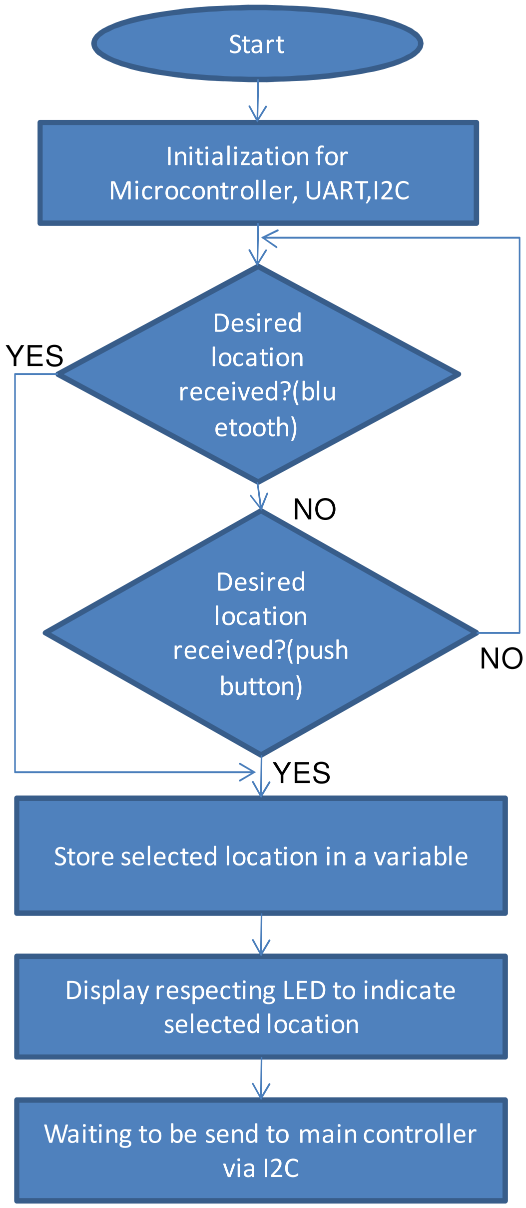
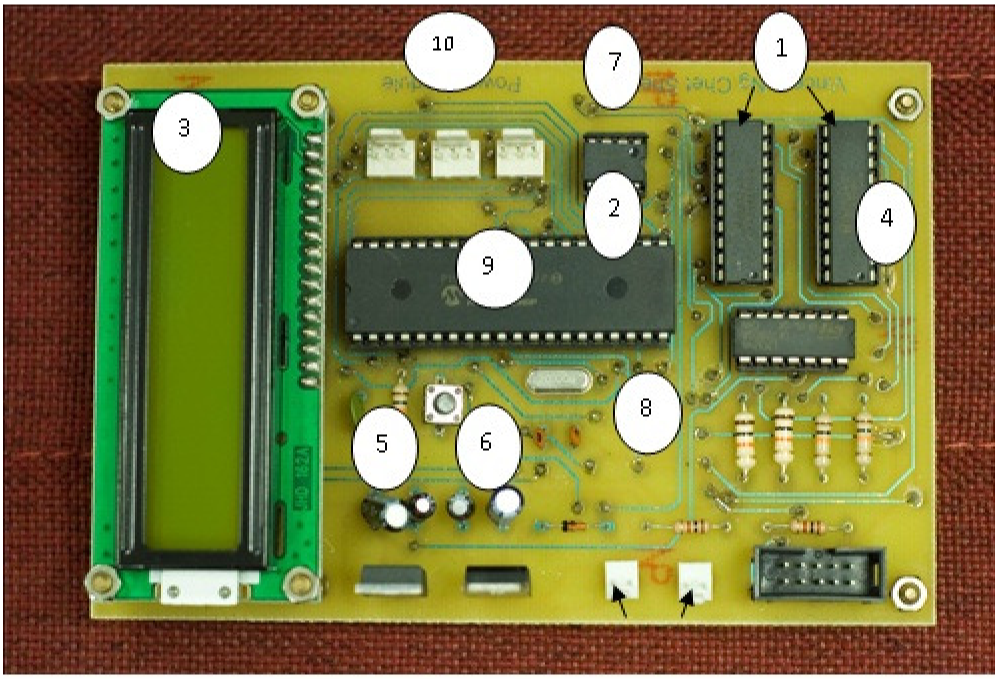


Figure C.29 Program flow chart (BCI controller interface)



1) DAC8032
2) PIC16F877A
3) 16X2 LCD
4) LM324 Op-amp
5) LM 7805 +5V voltage regulator
6) LM 7905 -5V voltage regulator
7) REF02 +5V voltage reference
8) Power input socket
9) Reset button
10) Output of ADC, DAC and I2C

Figure C.30 DAC converter module

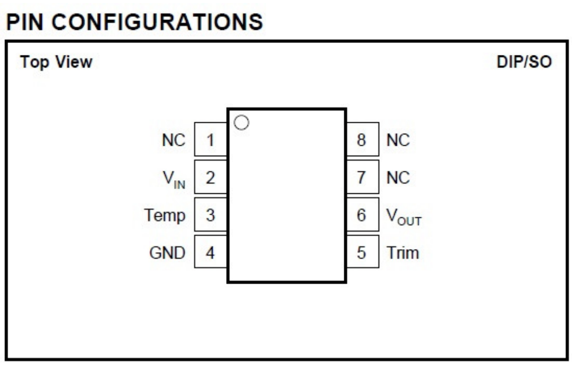


Figure C.32 Pin configuration of REF02

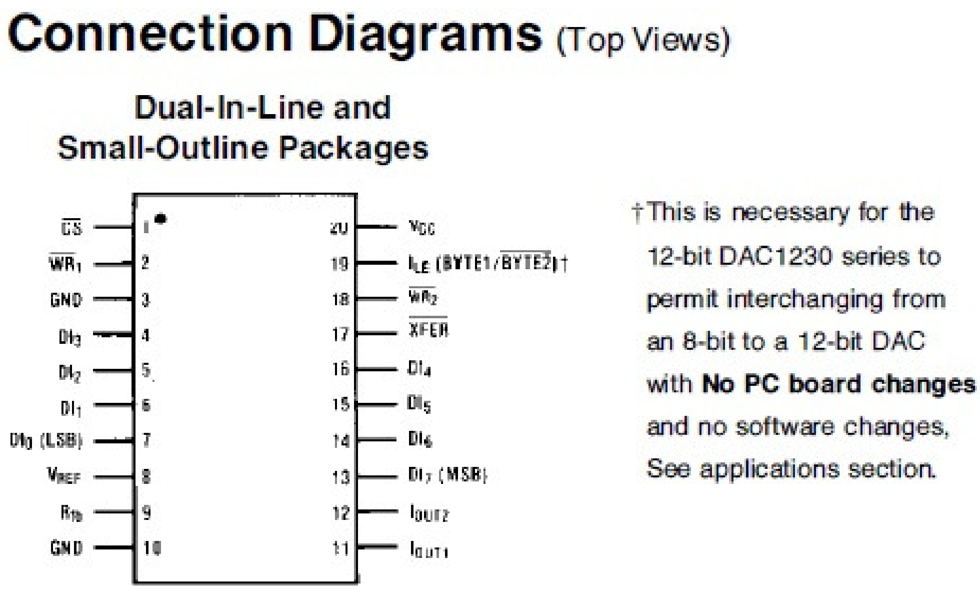


Figure C.31 Connection diagram of DAC 8032

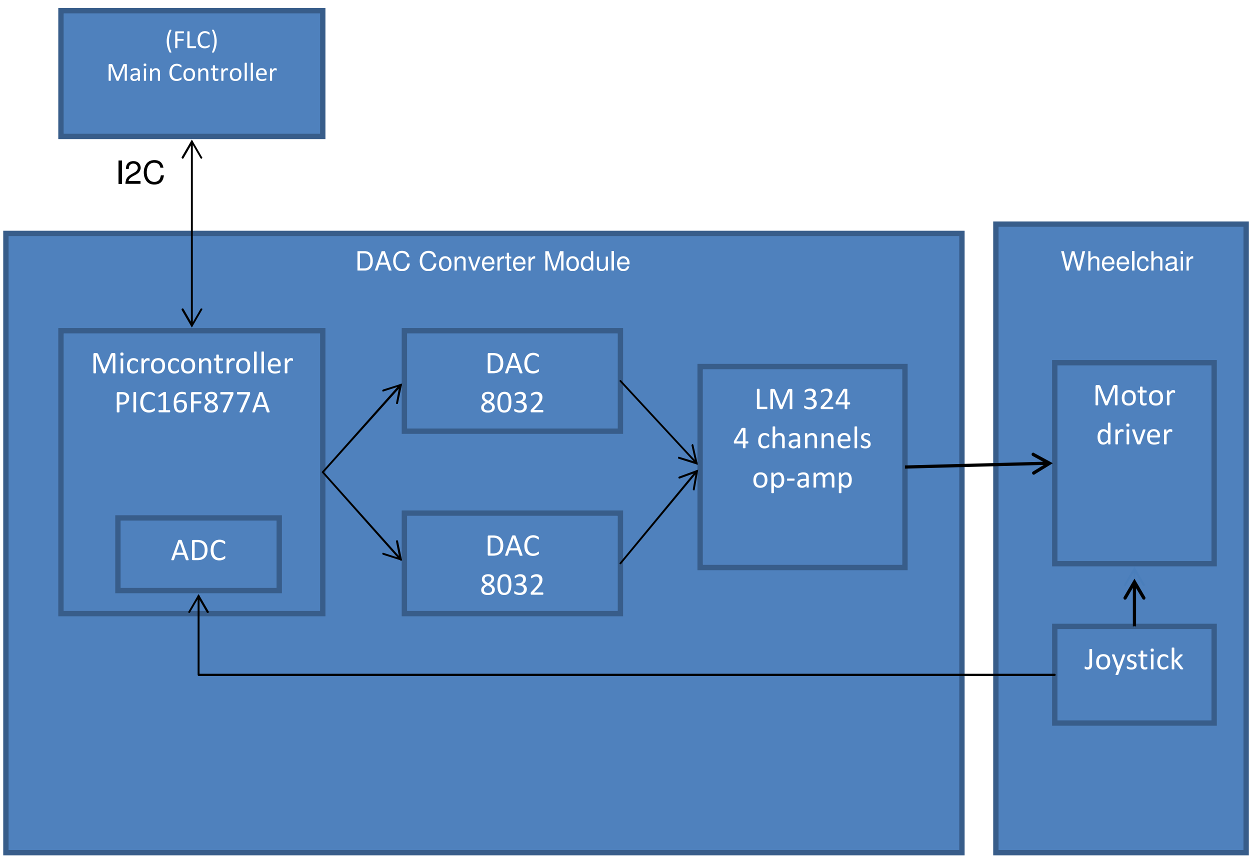
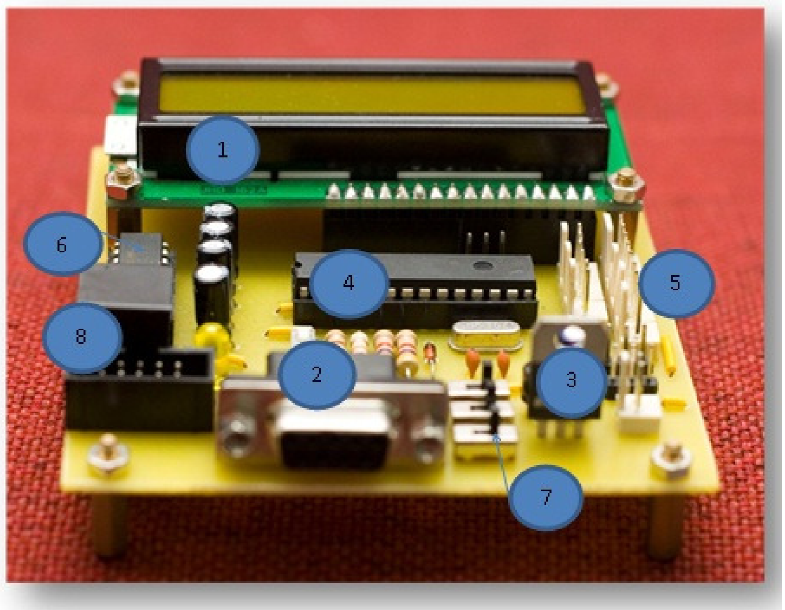


Figure C.33 System flow chart (DAC converter)



1) LCD display
2) DB9 connector
3) LM7805 voltage regulator
4) PIC16F876A
5) I2C connectors
6) MAX 232
7) On/Off Switch and Master/Slave switch
8) Programmer connectors

Figure C.34 FLC (Main controller)

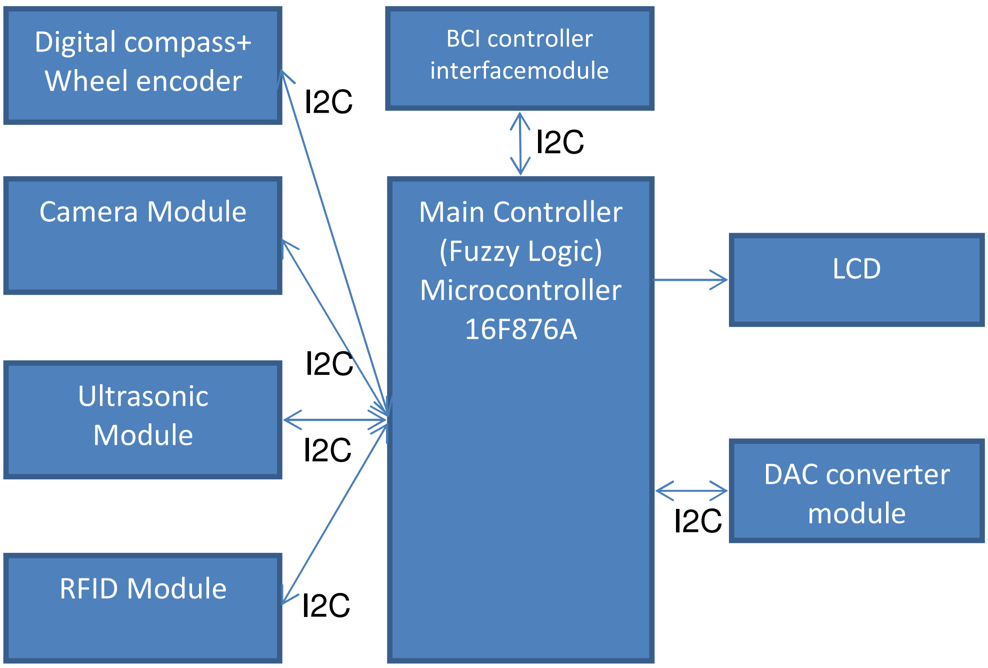


Figure C.35 System overview diagram (FLC)

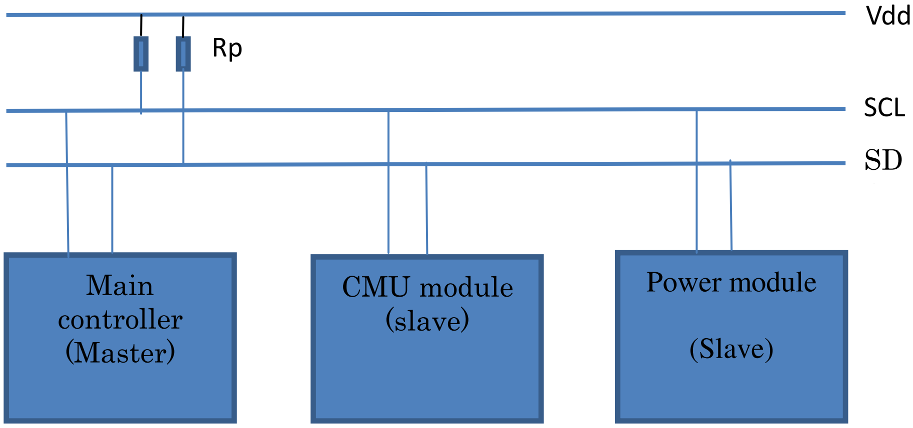


Figure C.36 I2C connection diagram

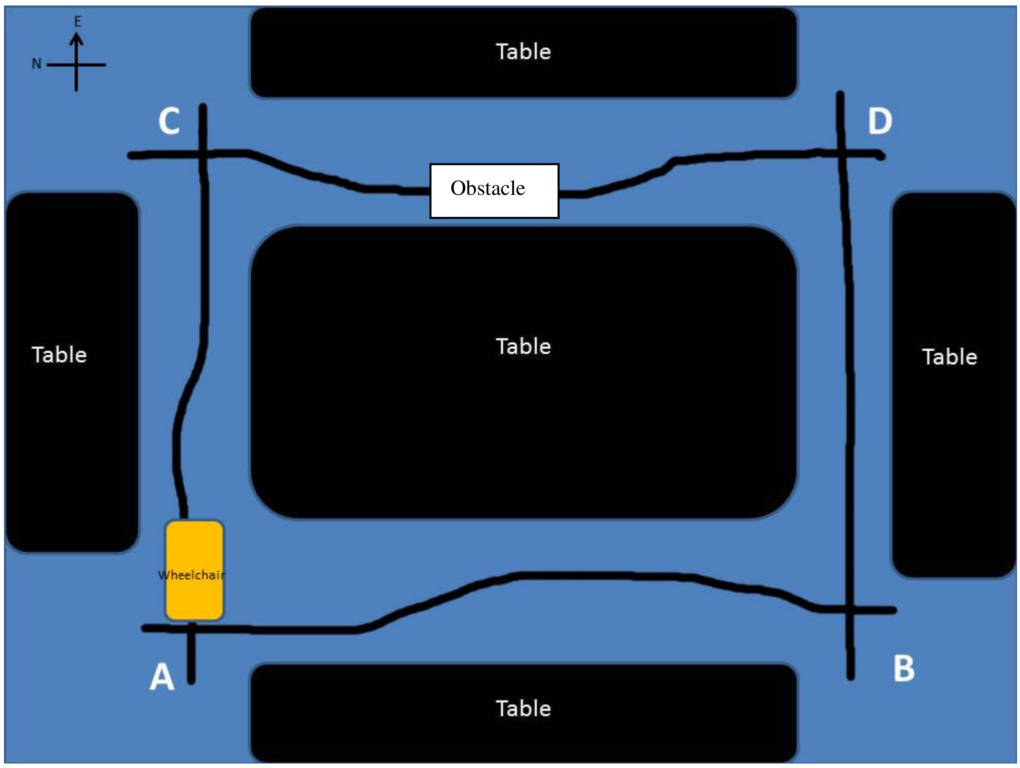


Figure C.37 Location A, B, C, D

RFID Location = A				
Subject selected location	North	South	East	West
B	R	L	S	R
C	R	L	S	L
D	R	S	R	L

RFID Location = B				
Subject selected location	North	South	East	West
A	L	R	R	S
D	L	R	R	S
C	R	S	R	L

RFID Location = C				
Subject selected location	North	South	East	West
D	L	R	L	S
A	L	R	L	S
B	S	L	L	R

RFID Location = D				
Subject selected location	North	South	East	West
B	S	R	L	R
C	R	L	S	R
A	S	R	L	R

* S = Straight
R = Right
L = Left

Figure C.38 Turn direction table

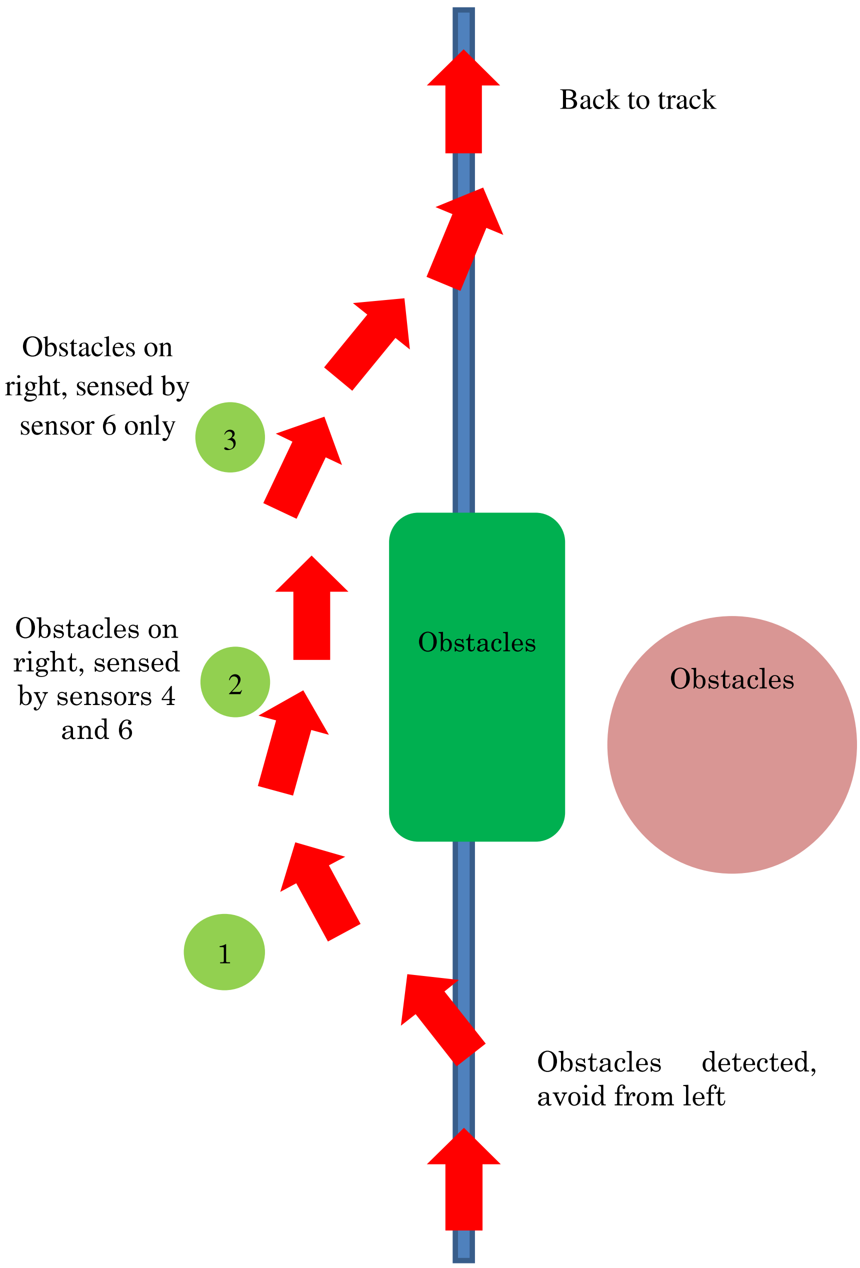


Figure C.39 Obstacles avoidance path (left)

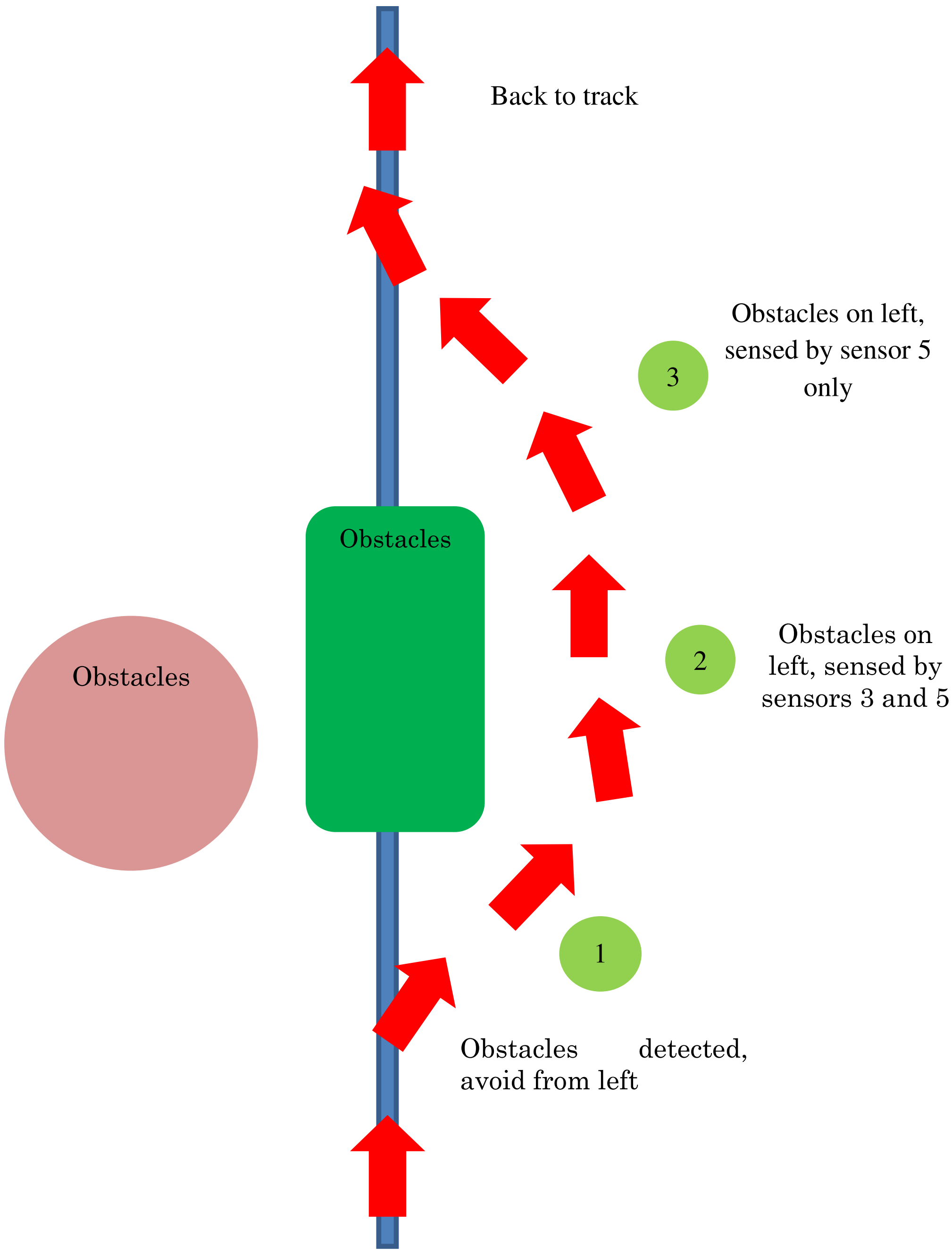


Figure C.40 Obstacles avoidance path (right)

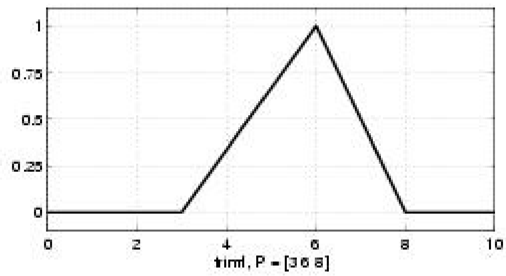


Figure C.41 Triangular membership function

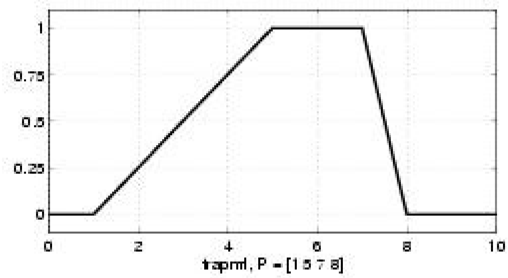


Figure C.42 Trapezoidal membership function

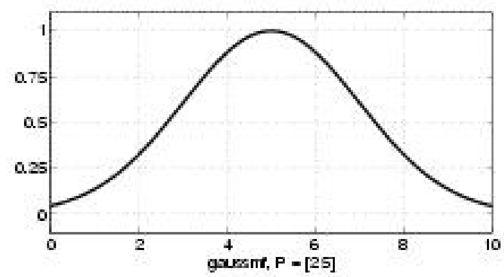
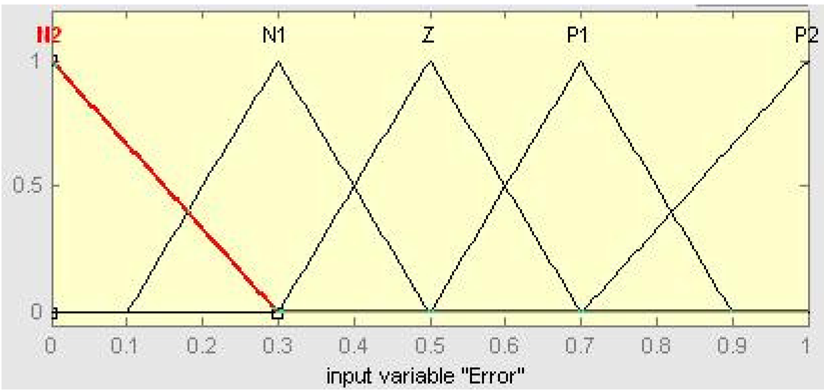
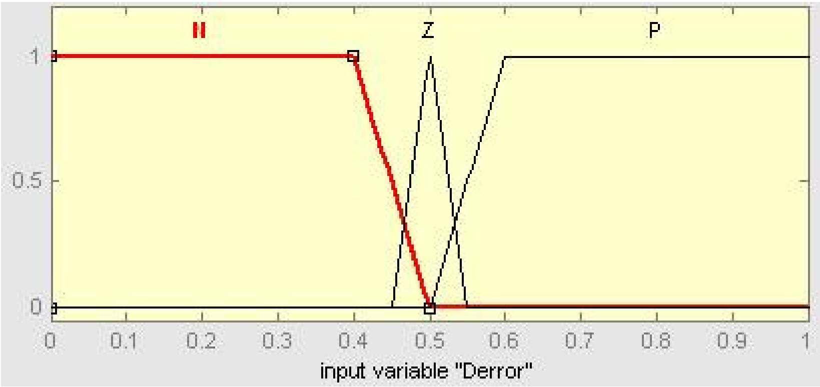


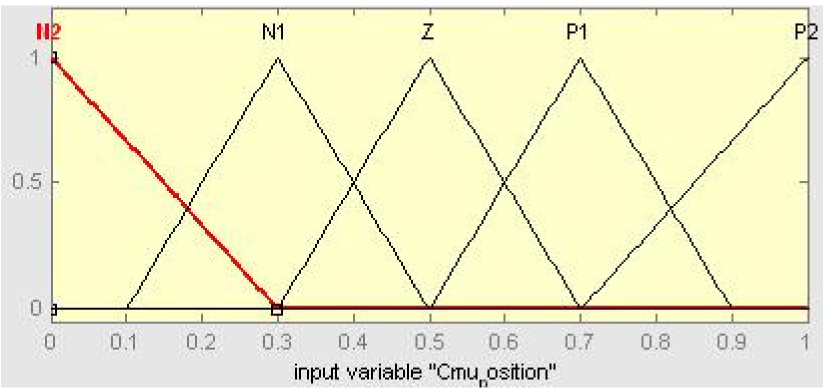
Figure C.43 Gaussian membership function



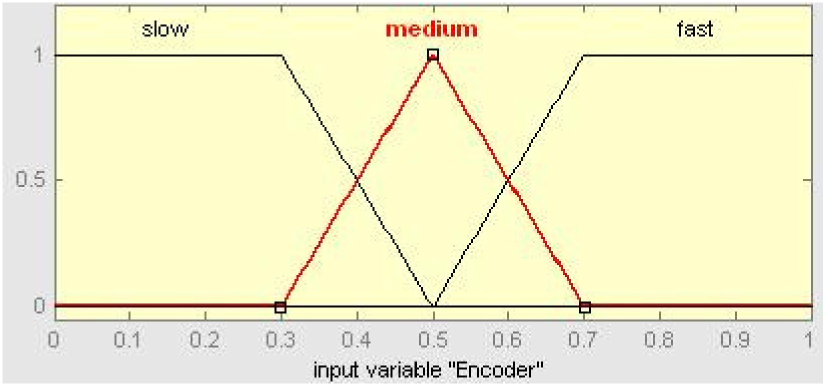
Z[n] (Error)



Z'[n](Rate of Error)



Camera's MF



Encoder's MF

Figure C.44 The proposed Membership Functions

1. If (Error is N2) and (Derror is N) then (correction is P3) (1)
2. If (Error is N2) and (Derror is Z) then (correction is P3) (1)
3. If (Error is N2) and (Derror is P) then (correction is P3) (1)
4. If (Error is N1) and (Derror is N) then (correction is P3) (1)
5. If (Error is N1) and (Derror is Z) then (correction is P2) (1)
6. If (Error is N1) and (Derror is P) then (correction is P1) (1)
7. If (Error is Z) and (Derror is N) then (correction is Z) (1)
8. If (Error is Z) and (Derror is Z) then (correction is Z) (1)
9. If (Error is Z) and (Derror is P) then (correction is Z) (1)
10. If (Error is P1) and (Derror is N) then (correction is N1) (1)
11. If (Error is P1) and (Derror is Z) then (correction is N2) (1)
12. If (Error is P1) and (Derror is P) then (correction is N3) (1)
13. If (Error is P2) and (Derror is N) then (correction is N3) (1)
14. If (Error is P2) and (Derror is Z) then (correction is N3) (1)
15. If (Error is P2) and (Derror is P) then (correction is N3) (1)

Figure C.45 Rules to control angle

1. If (Cmu_position is N2) then (correction is slow) (1)
2. If (Cmu_position is P2) then (correction is slow) (1)
3. If (Cmu_position is N1) then (correction is medium) (1)
4. If (Cmu_position is P1) then (correction is medium) (1)
5. If (Cmu_position is Z) then (correction is fast) (1)
6. If (Encoder is slow) then (correction is medium) (1)
7. If (Derror is N) then (correction is slow) (1)
8. If (Derror is P) then (correction is slow) (1)
9. If (Derror is Z) then (correction is fast) (1)
10. If (Encoder is fast) then (correction is medium) (1)

Figure C.46 Rules to control speed

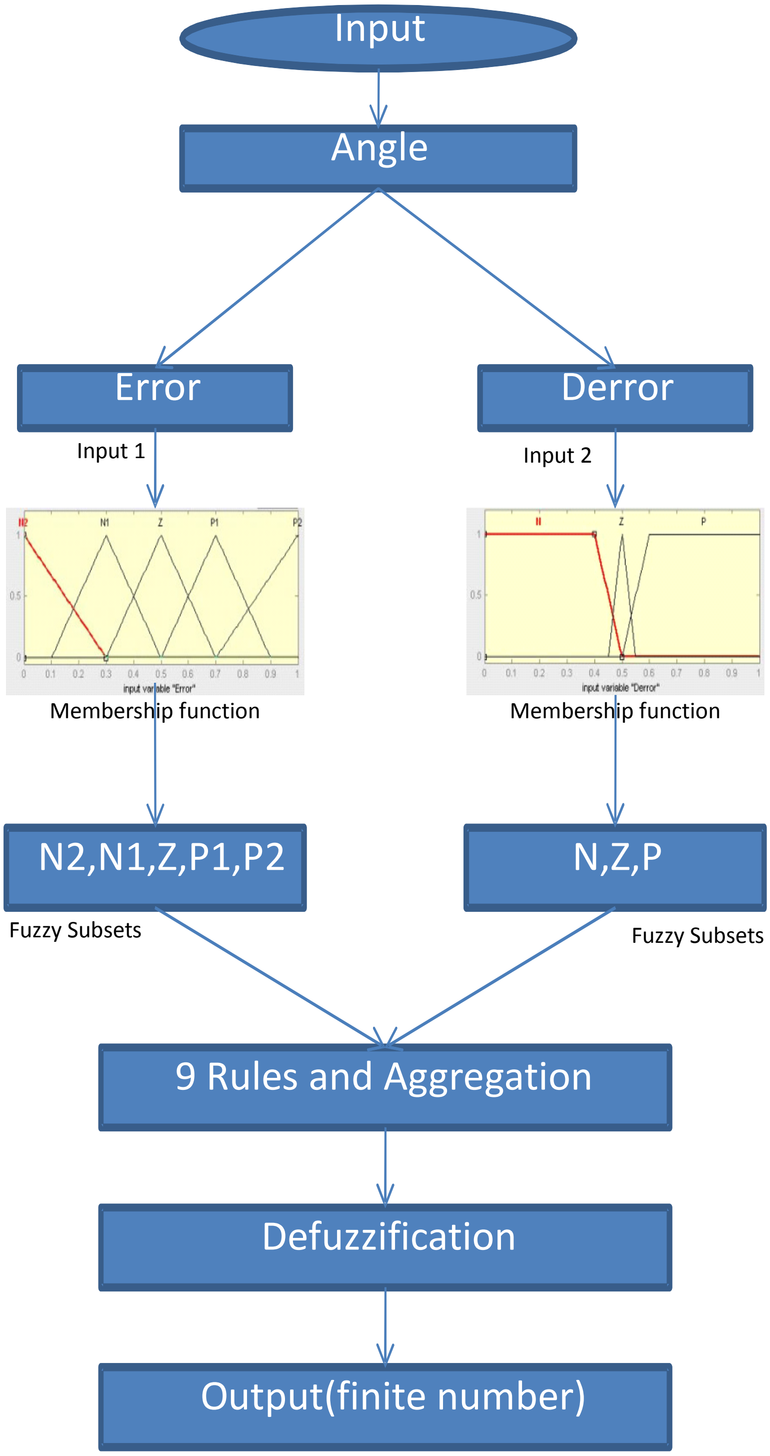


Figure C.47 Design structures (angle)

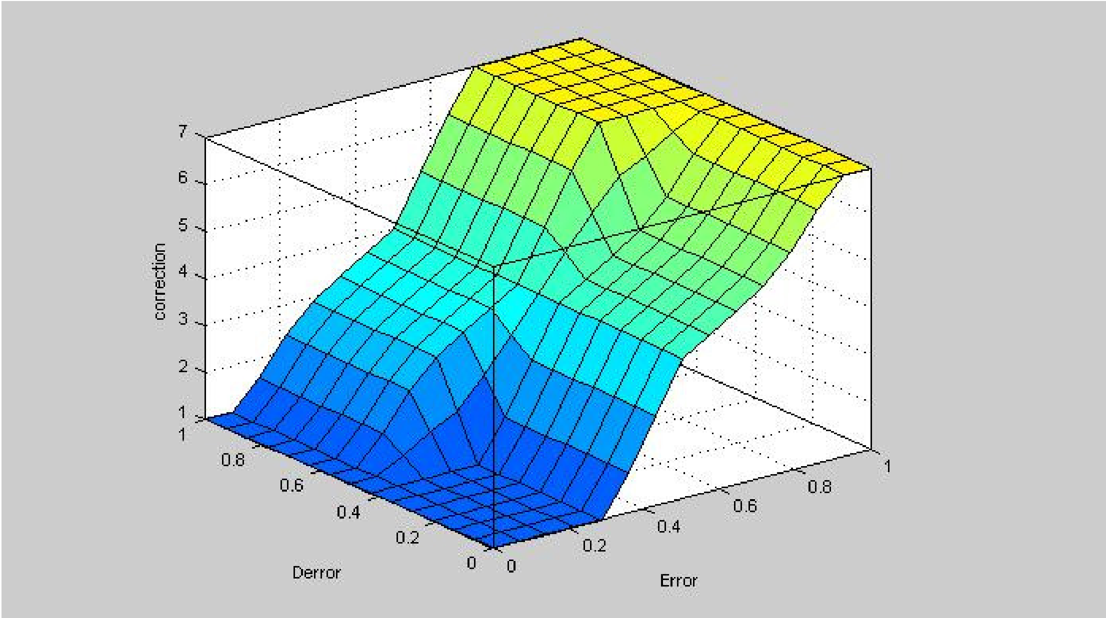


Figure C.48 Surface plots for angle

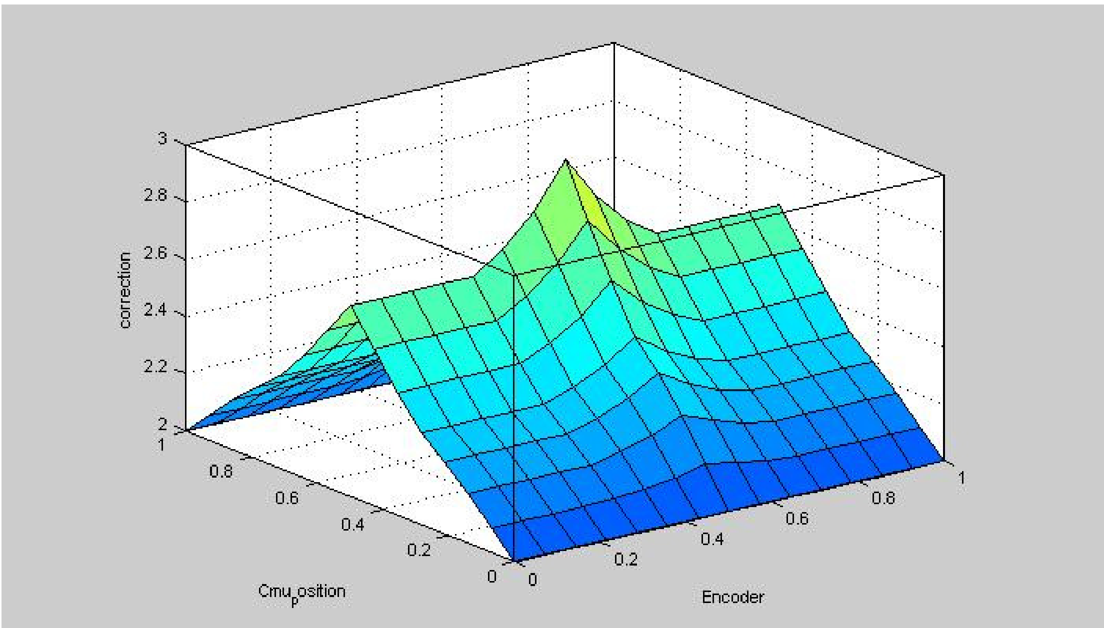


Figure C.49 Surface plots for speed

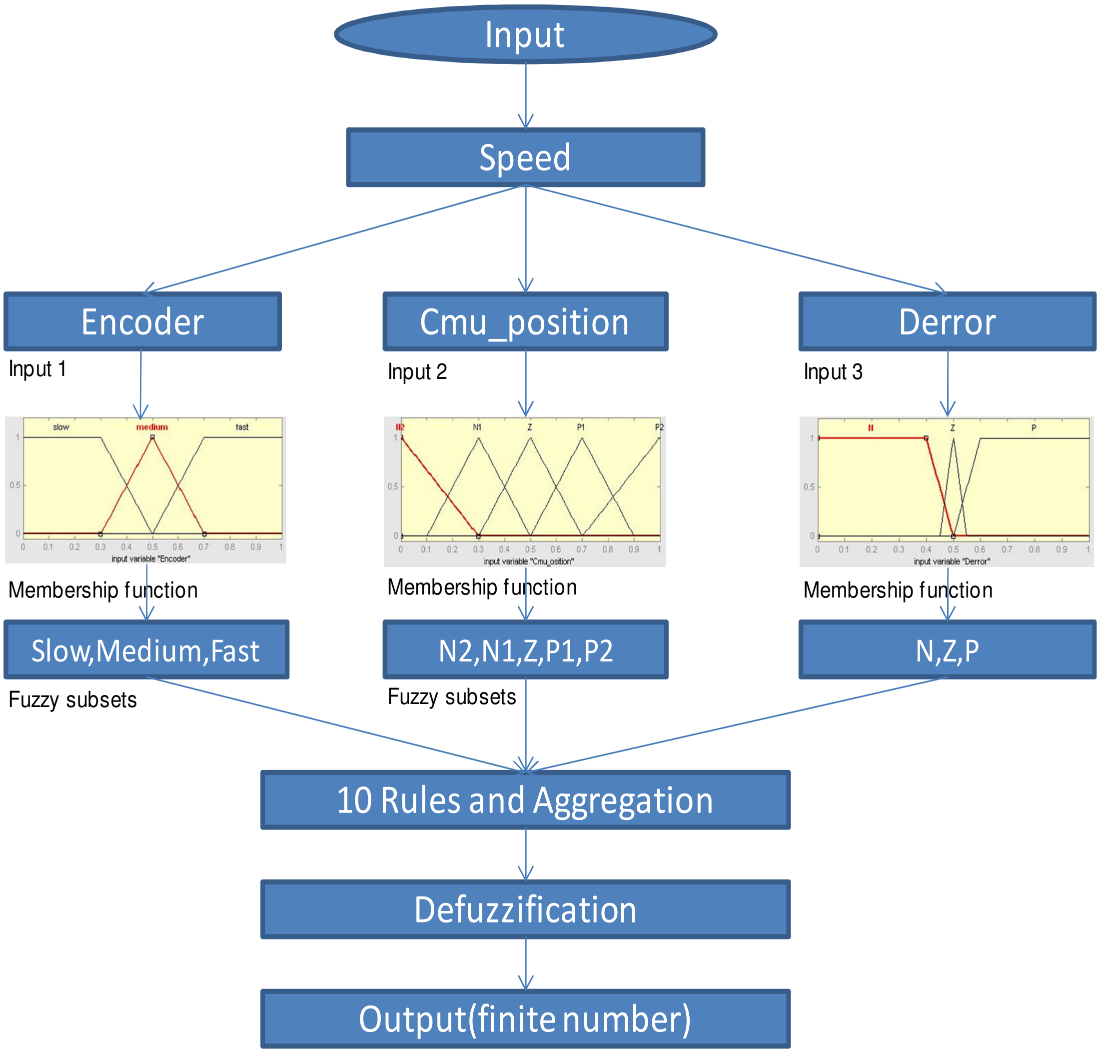


Figure C.50 Design structures (speed)

Appendix D

" A" to "B"	Time (no load)
Test 1	18 s
Test 2	18 s
Test 3	20 s
Test 4	19 s
Test 5	20 s
Test 6	20 s
Test 7	19 s
Test 8	19 s
Test 9	19 s
Test 10	18 s
Mean	19 s

Table D.1 Location A to B without load

" A" to "B"	Time (90kg load)
Test 1	18 s
Test 2	19 s
Test 3	20 s
Test 4	19 s
Test 5	19 s
Test 6	19 s
Test 7	18 s
Test 8	19 s
Test 9	19 s
Test 10	19 s
Mean	18.9 s

Table D.2 Location A to B with load

“ B” to “C”	Time (no load)
Test 1	19 s
Test 2	18 s
Test 3	19 s
Test 4	18 s
Test 5	17 s
Test 6	18 s
Test 7	19 s
Test 8	16 s
Test 9	20 s
Test 10	17 s
Mean	18.1 s

Table D.3 Location B to C without load

“ B” to “C”	Time (90kg load)
Test 1	18 s
Test 2	20 s
Test 3	20 s
Test 4	20 s
Test 5	19 s
Test 6	20 s
Test 7	22 s
Test 8	20 s
Test 9	19 s
Test 10	20 s
Mean	19.8 s

Table D.4 Location B to C with load

“C” to “D”	Time (no load)
Test 1	8 s
Test 2	10 s
Test 3	8 s
Test 4	10 s
Test 5	8 s
Test 6	10 s
Test 7	12 s
Test 8	12 s
Test 9	9 s
Test 10	10 s
Mean	9.7 s

Table D.5 Location C to D without load

“C” to “D”	Time (90kg load)
Test 1	10 s
Test 2	10 s
Test 3	11 s
Test 4	12 s
Test 5	10 s
Test 6	9 s
Test 7	9 s
Test 8	10 s
Test 9	9 s
Test 10	10 s
Mean	10 s

Table D.6 Location C to D with load

“D” to “A”	Time (no load)
Test 1	21 s
Test 2	20 s
Test 3	19 s
Test 4	19 s
Test 5	18 s
Test 6	18 s
Test 7	18 s
Test 8	20 s
Test 9	18 s
Test 10	19 s
Mean	19 s

Table D.7 Location D to A without load

“D” to “A”	Time (90kg load)
Test 1	20 s
Test 2	19 s
Test 3	20 s
Test 4	20 s
Test 5	20 s
Test 6	20 s
Test 7	24 s
Test 8	18 s
Test 9	20 s
Test 10	19 s
Mean	20 s

Table D.8 Location D to A with load

Location	Time
A to C	56 s
C to D	20 s
D to B	64 s
B to A	23 s

Table D.9 Wheelchair travelled time for test I

Location	Time
A to D	33 s
D to B	60 s
B to C	34 s
C to A	51 s

Table D10 Wheelchair travelled time for test II