INTELLIGENCE SEMI-AUTOMATED WHEELCHAIR (OBSTACLE DETECTION SYSTEM)

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

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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 **"INTELLIGENCE SEMI-AUTOMATED WHEELCHAIR (OBSTACLES DETECTION SYSTEM)"** was prepared by **LIEW YEE CHANG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering at Universiti Tunku Abdul Rahman.

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Supervisor : Dr. LEONG WAI YIE

Date : ____________________________

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INTELLIGENCE SEMI-AUTOMATED WHEELCHAIR (OBSTALES DETECTION SYSTEM)

ABSTRACT

An obstacle detection system that applies on an intelligence semi-automated wheelchair was build. The system was specially built for patients who were slow in response like patience with unsound mind or Parkinson. It was build to assist patients in transportation so that they were more independent. The main purpose of this system was to help the patient in preventing collision during travelling with wheelchair. Therefore, this system will improve the safety factor. This project focused in indoor use as it was design for the wheelchair used in hospital. Therefore, situations in a hospital were more concern during the design process. Several methods had been introduced for this type of system especially in smart mobile robot. Method uses may affect by the sensor as there are several types of vision sensor with different characteristics available in the market. Other similar projects were studied to have a better understanding on the system before the system was design. MaxSonar-EZ1 ultrasonic sensor from Cytron Technologies and PIC18F4520 from MicroChip Technology were the hardware used in this project to build the obstacle detection system. The surrounding information from the sensors were feed into the microcontroller that having special algorithm for processing. Edge detection and wall following concepts were used in the algorithm. After that, the microcontroller provided the specific output to the driving system to react accordingly. Two modes, semi-automated and automated were designed in the project for two control types. Different tests were carried out for the system and the results were satisfied. The system behaviour and reliability were discussed with the result. Finally, the system was concluded that it was reliable to certain degree as it did behave according to objectives. A recommendation section was included as the system was still able to improve. Further study was needed to make the system perfect.

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LIST OF SYMBOLS / ABBREVIATIONS

v	speed of wheelchair, m/s
r	radius of tachometer wheel, m
rpm	number of revolution per minute, rpm
V_{ref}	voltage reference, V
T_{AD}	A/D conversion clock, s
F_{osc}	oscillator clock frequency, Hz
T_{ACQ}	acquisition time, s
s	distance, m
u	initial velocity, m/s = 0m/s
t	time taken, s
a	acceleration, m/s^2

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CHAPTER 1

INTRODUCTION

1.1 Background

Due to the advance in technology, autonomous had become a popular research topic nowadays. Intelligent mobile robot like Honda ASIMO no longer odd to people and more and more mobile robot with different application had been introduced. Under medical field, wheelchair had been transform from a traditional wheelchair into an autonomous wheelchair as well.

Wheelchair was first introduced in 1595 where the Spanish King, Philip II of Spain who sat on a chair with small wheels mounted at the end of each leg. However, the chair cannot be self-propelled and need a servant to push it. In 1881, larger wheels are used and rim was added on each wheel for self-propelled purpose. Furthermore, due to the need of man power, wheelchair again transformed into motorized wheelchair in 1916 where user are able to control the movement with only a controller like joystick. This kind of wheelchair is quite widely use nowadays, but it is still insufficient when it came to patients who cannot control the wheelchair properly with the joystick.

Patients with slow in response, unsound mind, Parkinson's and so on is having difficulty in controlling the motorized wheelchair with the controller. Therefore, another advanced transformation is needed on the motorized wheelchair to form an autonomous wheelchair. An autonomous wheelchair shall include extra features like navigation system, obstacles detection system, auto-adjustable seat with pre-set program, automatic speed control and so on. This wheelchair shall have the ability to assist the patient or automatically transport the patient from a destination to another destination safely.

Lots of study and research had to be gone through in order to come out with an autonomous wheelchair. Some researches in intelligent mobile robot can be used as a reference because it also has the similar features such as the obstacle detection. Intelligent mobile robot with navigation system is usually come with an obstacle detection feature to form a complete system. It is a huge study in obstacle detection system as there are a lot of phenomena to be concerned. Therefore, this paper is focusing and discuss on the obstacle detection system for the Intelligence Semi-Automated Wheelchair.

Research on the obstacle detection system is not a new topic especially in mobile robot. With obstacle detection system, a mobile robot is assumed to be intelligent to a certain degree as it can transport without hitting an obstacle (Yi et al, 2009). With the development of sensor technologies, different types of obstacle detection system had been introduced. Since human being is using vision to detect an obstacle, vision sensor like ultrasonic sensor, camera, infrared sensor, or laser sensor is used to build an obstacle detection system. Besides hardware, software also plays an important role that work as the brain in the system. For example, neuron network to allow the system to learn with samples and fuzzy logic control to control the output (wheel) with a series of fuzzy control rule based on the input (sensor) given.

1.2 Aim and Objectives

The aim of this paper is to study on the obstacle detection system in term of the hardware as well as the software. This system is going to combine with other features like driving system and navigation system to form the Intelligence Semi-Automated Wheelchair. The main purpose of this obstacle detection system is to detect obstacle, identify the location of obstacle, and provide the right outputs to the driving system to response accordingly. It must help the patient who is slow in response to detect obstacle and prevent collision from happen. Safety of the user is the main concern in this study as obstacle detection system provides the safety feature to the wheelchair design. These abilities help the Intelligence Semi-Automated Wheelchair deal with the unknown environment especially under the indoor environment which is full with unexpected activities and limited space.

As mention previously, this system is going to combine with the driving system and navigation system. The Intelligence Semi-Automated Wheelchair is designed especially for hospital use where there will be a special track build for the navigation system. During the automatic mode where the autonomous wheelchair is running by itself, it will follow the track to travel from a destination to another destination. Therefore, the main obstacle to be concerned by the obstacle detection system is the obstacle that lies on the track. For examples, in a hospital, water bottle, medicine box and trolley might be accidently left on the walkway and blocking the wheelchair path. Besides static obstacles, moving object like human and moving trolley might also happen to be blocking the wheelchair path in a short period. Therefore, the obstacle detection system not just to obey the obstacle detection feature but also has to be respond in time to overcome the emergency situation with the moving obstacles.

Besides automated, the obstacle detection system also include semi-automated mode. This mode is activated when the user is controlling the wheelchair motion. The motion is decided by the user and the obstacle detection system works as the supporter. The system limits the particular motion when it detects an obstacle blocking the way. For example, it limits the forward motion from the user when there are obstacles in front of the wheelchair. Therefore, the main objective of this mode is to help the user in detecting the obstacles and preventing the user from controlling the wheelchair move toward the obstacles.

As a conclusion, the objectives of the obstacle detection system in this project are:

- detect static obstacles like transparent water bottle, medicine box, chair and table and then preventing collision
- detect moving obstacle detection like kids and moving trolley and then respond in time to avoid collision
- detect obstacles that blocking the wheelchair path and then avoid it to continue the movement (automated mode)
- detect obstacles that present at the wheelchair surrounding and then limit particular motion from user control (semi-automated mode)
- communicate well with driving system to have an efficient and reliable system
- the algorithm shall provide a smooth travelling to maintain the user comfortable

1.3 Flow of Content

The content of this paper is following the flow which starts with literature review where other related researches were studied base on this paper. Research methodology, the concepts or methods used in this paper, follow with the results and discussions that present the outcome of this study and the analysis of the outcome. Final part will be the conclusion and recommendations where a final conclusion base on the whole research is presented and further improvement for the research is stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section is going to discuss about the study of other research articles or reports that related to this paper. It is divided into few subsections to discuss separately, so that the paper is more organized and easy to be read. A final subsection is included in each group of hardware to have a comparison between the components. The comparison is done among the hardware instead of software because the choice of software used is most likely depending on the hardware used. For example, MPLAB was designed especially for supporting PIC microcontroller. The comparison is done in table form which provides a better view for the author to choose the best and most suitable component in this project. Besides that, concepts and algorithms used by the researches were also being studied and discussed.

2.2 Hardware

2.2.1 Introduction

Hardware used in obstacles detection system is one of the important aspects that should be paid more attention. Obstacles detection system is strongly rely on the vision sensor used to get the information from the surrounding environment as the input data for the system. There are many types of sensor available nowadays where each of it is having their own characteristics that suits different conditions. The mainly used sensors to avoid obstacles are ultrasonic sensors, vision sensors, infrared sensors, laser sensors and proximity sensors (Yang et al, 2010). Some of the sensors were studied and discussed based on their characteristics. There are a few companies in Malaysia which producing electronics components. Therefore, the characteristics of the sensors are taken from the datasheet provided to do the comparison.

Sensor itself is not enough to produce an intelligence system; a “brain” is needed to process the input from the sensor and provides the intelligence decision. The “brain” mentioned here will be the processor or commonly known as the microprocessor in mobile robot field. Unfortunately, a microprocessor may not be powerful enough to support a heavy processing. A computer processor is another choice when come into handling a heavy processing task. This situation is common when come to image processing. Due to the limited input ports of a computer, a data transmitting body is needed to link between the sensors and computer for communication purpose. The data transmitting body usually called as data acquisition system (DAS or DAQ). Instead of microprocessor, microcontroller will be a better choice because microcontroller is a microprocessor with extra features like PWM. Besides that, it is also not rare to use a programmable logic device like field-programmable gate array (FPGA) for fast signal processing (Gojić et al, 2011). Therefore, PIC microcontroller, FPGA and NI DAQ board were studied and discussed in this section.

2.2.2 Sensors

2.2.2.1 Ultrasonic Sensor

Figure 2.1: Ultrasonic Sensors (MaxBotix, 2012)

Figure 2.1 shows the examples of ultrasonic sensor. It is very clear that ultrasonic sensor uses ultrasound to detect an obstacle. This kind of sensor is very common in obstacles detection system as it is low in cost with mature technology and generates simple range data. The location of the obstacle can be detected by the ultrasonic distance that using the time difference. This can be explained through the working principle of an ultrasonic sensor.

Ultrasonic sensor consists of a transmitter and a receiver. First, ultrasonic transmitter launches ultrasonic wave in a direction which then spreads in the air. At the same time of the wave launches, the sensor begins timing. When the ultrasonic wave encounter an obstacle that blocking it from transmitting further, the wave will immediately reflect back to the sensor and receive by the sensor receiver. The timing will stop if the receiver receives a signal. In this way, it can calculate the distance of obstacles from the launcher according to the velocity of the ultrasonic wave and the time interval recorded by the sensor timer (Yi et al, 2009).

The disadvantage of ultrasonic sensor will be the poor direction and limited angle ranging which caused single channel of ultrasonic ranging system insufficient to meet the requirement of an obstacle detection system. Blind spots tend to occur due to this disadvantage. In order to overcome this problem, a lot of researches include multiple sensors in their design and compensated the readings to produce a better and more accurate outcome. Usually, they combined a number of ultrasonic sensors in a ring-shape distribution to form a module and then mounted a few sets of the module around the wheelchair. Figure 2.2 below shows the block diagram of the ultrasonic system by Mazo 2001. In the figure, eight ultrasonic transducers were combined to form a module and then four modules were mounted at each corner of the wheelchair. It was clearly shows how the propagation of the ultrasonic wave had covered the surrounding of the wheelchair. This was then overcome the blind spot problem.

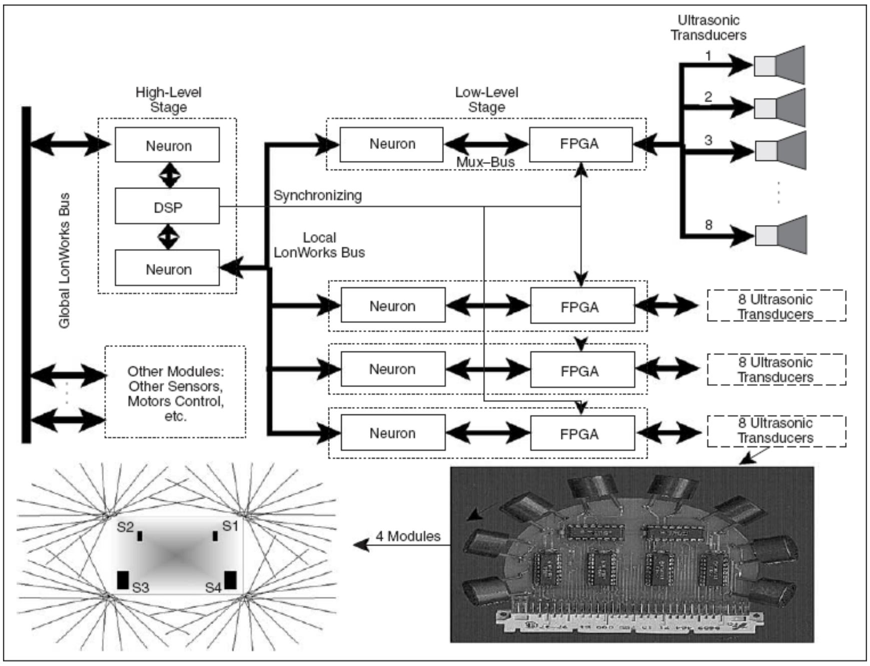

Figure 2.2: Block diagram of the ultrasonic system (Mazo, 2001)

There are two types of ultrasonic sensors produce by Cytron Technologies Sdn Bhd that suited to be used in the obstacle detection system. Both of the sensors can be refered to Figure 2.1 where the sensor on the left is MaxSonar-EZ1, and on the right is a new model, HRLV-MaxSonar-EZ. The characteristic of both sensors are taken from the datasheets provided by Cytron and presented in Table 2.1. Next, the beam characteristics for both HRLV-MaxSonar-EZ and MaxSonar-EZ1 were also studied and shown in Figure 2.3 and Figure 2.4 respectively.

Table 2.1: Characteristics of MaxSonar-EZ1 and HRLV-MaxSonar-EZ

Characteristic	Ultrasonic Sensor	
	MaxSonar-EZ1	**HRLV-MaxSonar-EZ**
Range	Detect Object: 0 – 254 in (6.45 m) Sonar range: 6 – 254 in (0.15 – 6.45 m)	Detect Object: 1 mm – 5 m Sonar range: 30 cm – 1 m
Supply Voltage and Current Draw	5V supply with 2mA typical current draw	2.5V to 5.5V supply with nominal current draw of 2.5mA to 3.1mA
Resolution	1 in (25.4 mm)	1 mm
Reading Rate	20 Hz (0.05 s)	10 Hz (0.1 s)
Outputs	• Serial (RS232) • Analog (10 mV/inch) (0.39 mV/mm) • Pulse width (147 uS/inch) (5.74 uS/mm)	• Serial (RS232 or TTL) • Analog (0.92 mV/mm) • Pulse width (1 uS/mm)
Cost	RM 138.00	RM 159.00

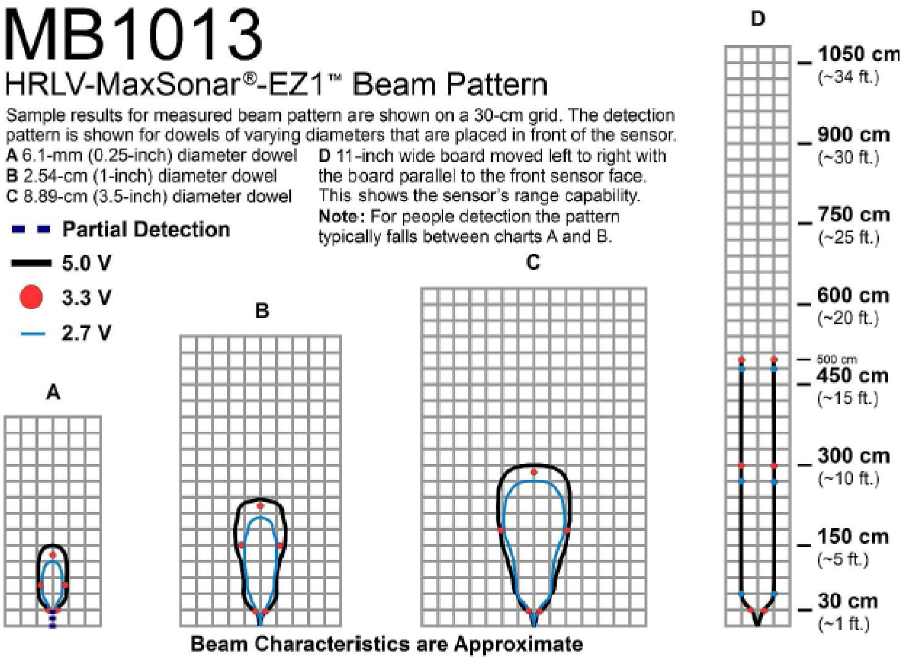

Figure 2.3: Beam Characteristics of HRLV-MaxSonar-EZ1 (MaxBotix, 2012)

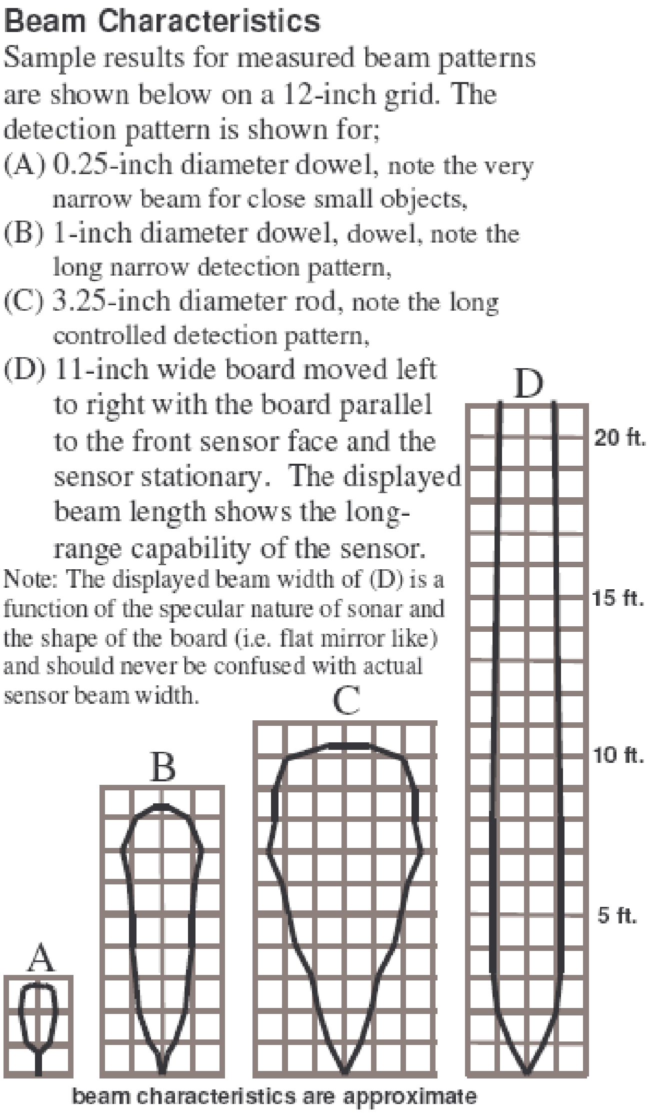

Figure 2.4: Beam Characteristics of MaxSonar-EZ1 (Maxbotix, 2006)

2.2.2.2 Laser Sensor

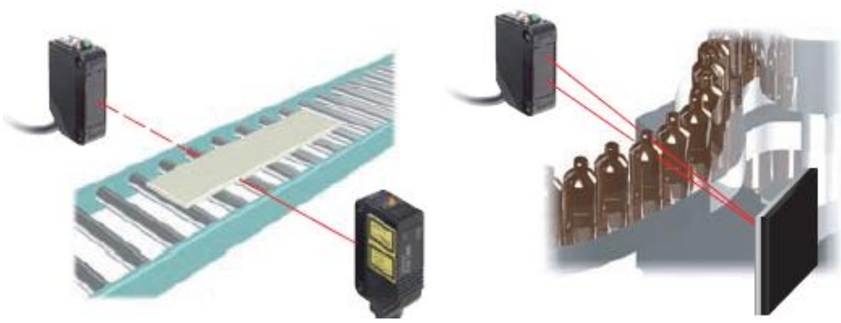

Figure 2.5: Laser Sensors (OMRON, n.d.)

According to Fu et al, 2012, laser sensor could be categorized into time-of-flight (TOF) and triangulation as shown in Figure 2.5 where TOF laser sensor emits a straight line beam while triangulation laser sensor emits a triangular shape beam. The TOF laser scanner has the advantages of a wide measuring range and high relative accuracy at a long distance. In general application it can be considered as the ideal straight line sensor to get the exact position of obstacle. Although TOF laser scanner is having very high accuracy among the others, but it is very expensive and high power consumption, so it is not practical to apply on an autonomous wheelchair that makes the product unaffordable. Besides, the power source of a wheelchair is only from the battery, so it is impossible to support a TOF laser sensor. On the other hand, laser beam is harmful to human eyes. This is one of the factor causing laser scanner is not widely used in mobile robot as it is moving around and may accidently emits the laser beam on a human eye.

Comparing with TOF, triangulation laser sensor had a better advantage for obstacle detection system. TOF emits only one narrow straight beam which only detecting one point, while triangulation laser sensor had the ability to scan multiple points simultaneously. This ability increases the scanning speed and yet improves the system response. Besides that, triangulation laser sensor also lower in cost as well as lower in power consumption as compare to TOF laser sensor. Due to these features, triangulation laser sensor is more common used in mobile robot in detecting obstacles as compare to TOF laser sensor. Laser sensor is used commonly to extract the feature (obstacle) in 3D instead of 2D to have better information for advance usage such as path selection.

Refer to research by Mazo 2001, it used laser emitter and CCD camera to detect obstacles in 3-D position of multiple points and space limits of the environment. The laser beam was used to provide the position of the obstacles before an image was captured by CCD camera. This made the segmentation process easier and faster as the position of obstacle was determine clearly with red beam line in the image as shown in Figure 2.6. After image processing, the result is shown in the bottom image of Figure 2.6 where the whole image left only the beam lines for further calculation.

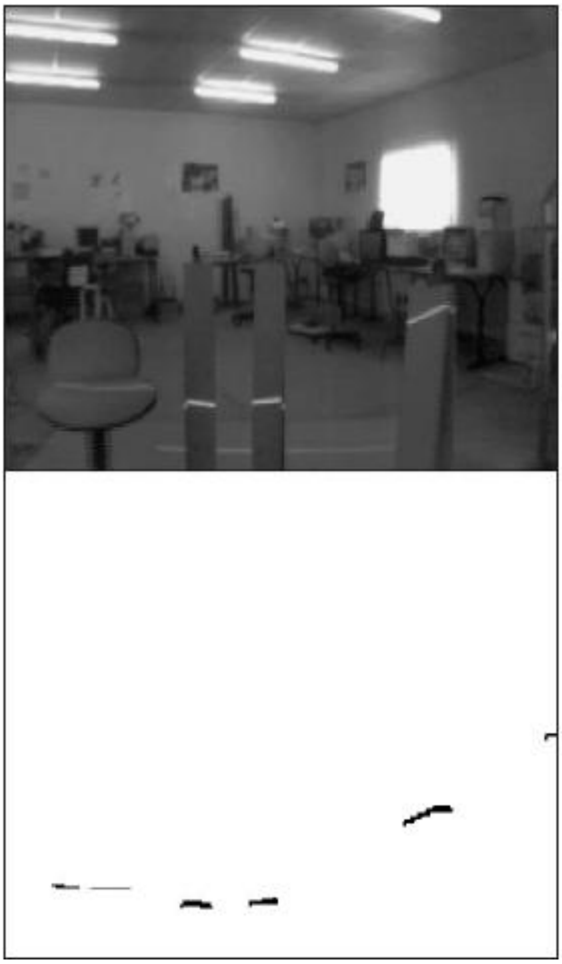

Figure 2.6: Object location: lightened scene (top) and segmentation (bottom) (Mazo, 2001)

Besides, research by Fu et al, 2012 also is using the 3D triangulation laser scanner with camera to detect obstacle. In the research, both sensors were actually mounted on a moveable body to achieve two degrees of freedom (DOF) where one is a rotational/roll DOF on the lateral and the another is a bending/pitch DOF on the front. The diagram in Figure 2.7 shows the set of the mechanism. The mechanism is needed to obtain the height information of the detected obstacle. For obstacle avoidance operation in the research, the experiment result is shown in Figure 2.8 where the robot is able to find a path to escape from the obstacles.

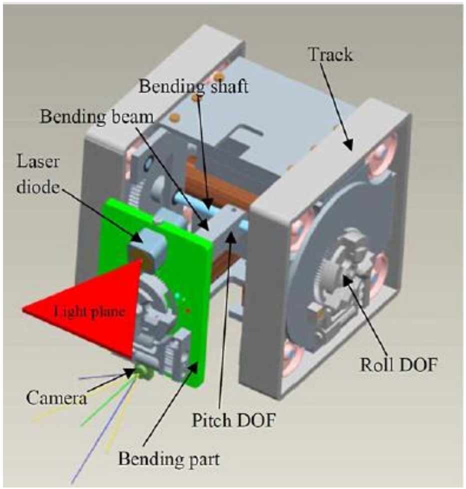

Figure 2.7: CAD drawing of active 3D triangulation laser scanner integrated on the movable part of Replicator robot (Fu et al, 2012)

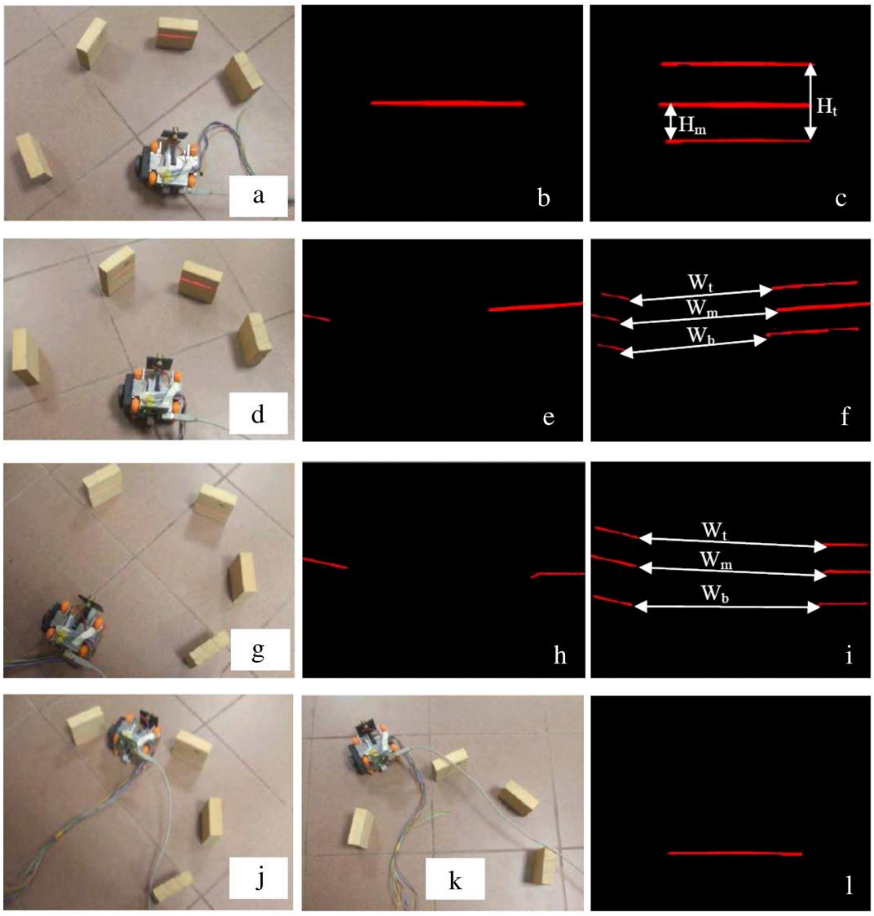

Figure 2.8: Experiment result (Fu et al, 2012)

Again, the characteristic of laser sensor is obtained by referring to the existing product in the market. Two examples of laser sensor were taken from

OMRON Industrial Automation, E3ZM-CT81 and E3Z LT86. The characteristics of both products were extracted from the datasheet and presented in Table 2.2 below.

Table 2.2: Characteristics of E3ZM-CT81 and E3Z LT86

Characteristic	Laser Sensor	
	E3ZM-CT81	E3Z LT86
Range	15 m	60 m
Standard Sensing Object	Opaque: 12 mm dia. min.	Opaque: 12 mm dia. Min.
Minimum Detectable Object (Typical)	6 mm dia. Opaque object at 3 m	-
Supply Voltage	10 – 24 VDC	10 – 30 VDC
Current Consumption	40 mA	35 mA
Response Time	Operate or Reset: 1 ms max.	Operate or Reset: 1 ms max.

2.2.2.3 Vision Sensor

Figure 2.9: Vision Sensor (OMRON, n.d.)

A vision sensor shows in Figure 2.9 actually is a camera that can be used as an obstacle detection device. Vision sensor is the sensor which is having the most similar vision as human being eye, stereo vision. The main advantage of vision sensor on obstacles detection is the wide range detection ability which it can capture an image and detect the whole obstacle or even multiple obstacles instead of just detecting only one point on the obstacle. With this ability, it is able collect more information such as the shape of an object and the speed of a moving object. With multiple cameras or image sequences of a camera, the distance of the obstacle detected from the sensor could be determined and the speed detection has also become one of the ability of vision sensor.

Refer to the report from Kinsky et al, 2011, webcam which also consider as one of the vision sensors was used in their project. Two webcams were mounted on top of the obstacle avoidance robot to form the stereo vision as shown in Figure 2.10.

Figure 2.10: Obstacle Avoidance Robot (Kinsky et al, 2011)

With two sensors mounted, there will always be two images of the same scene taken from different perspectives as shown in the example given in Figure 2.11. Therefore, few processes had to pass through to form a single image before it could proceed with the obstacle detection process. From the article, the experimental results on real time are shown in Figure 2.11 where obstacles are present in white boxes.

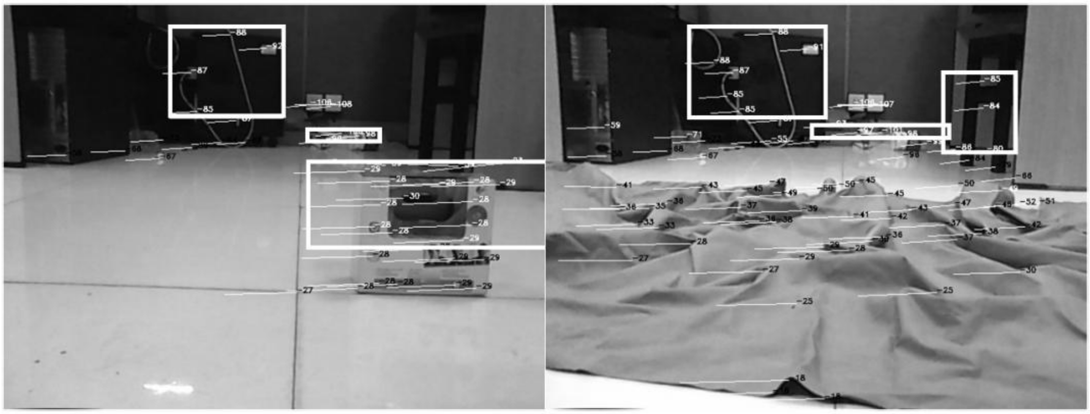

Figure 2.11: Experimental Result on Obstacles and Non-obstacles (Kinsky et al, 2011)

Since vision sensor grab image that consists of much information, image processing is needed to handle all the information. This is the disadvantage of vision sensor where time is needed to process the image before the system is able to determine an obstacle. Lots of image processing like image smoothing, noise filtering, edge enhancement and feature extraction needed a large calculation which is also need much demanding on the central processor. This sensor considered bad in real time situation as it is not able to provide fast response as needed in obstacle detection system. Besides, this kind of sensor is highly affected by light intensity of the surrounding, so it is not a very stable system when it comes to a different lighting level environment. Next, it is also unable to detect obstacles that are transparent like glass which may occurred in an unknown environment especially in hospital.

There are many types of vision sensor available in the market where commercial type can be found in our daily life like webcam, while some of them are from industrial sector. Therefore, two examples are taken from each fields and the characteristic is presented in Table 2.3. The webcam example is from Logitech, Webcam C110, while vision sensor from industrial field is FQ-MS120-M vision sensor from OMRON.

Table 2.3: Characteristics of Webcam C110 and FQ-MS120-M

Characteristic	Vision Sensor	
	Webcam C110	FQ-MS120-M
Optical Resolution	True 640x480, Interpolated 1.3MP	-
Frame Rate	30 fps	60 fps (16.7 ms)
Focal Length	2.3 mm	-
Supply Voltage	-	21.6 – 26.4 VDC
Current Consumption	-	•450mA max. (With FL-series Strobe controller and lighting) •250mA max. (Without external lighting)
Response Time	Operate or Reset: 1 ms max.	Operate or Reset: 1 ms max.

2.2.2.4 Comparison between Sensor Hardware

Table 2.4 shows the comparison between the sensors hardware discussed previously. The sensors compared are ultrasonic sensor, laser sensor and vision sensor. Some of the features like range are important in obstacle detection system. The way of comparison is base on the research where the suitability of the sensor on obstacle detection system is the main concern here. The comparing method was simple with numbering from “1” to “3” due to three number of sensors were compared. “1” represents the best sensor among the three in the particular feature; follow by “2” and then “3” which is the worst compared among the sensor.

Table 2.4: Sensors Comparison

Features	Ultrasonic	Laser	Vision
Wide Range	3	2	1
Long Range	3	1	2
Processing Time	2	1	3
Cost	1	3	2
Availability	1	3	2
Power Consumption	1	3	2

The comparison shows that ultrasonic sensor is the best in term of non-technical feature, while laser sensor is the best in term of technical feature. Vision sensor is in the middle range among all three, but it is having a big problem with the processing time. The time taken for processing is not suitable for real time application like obstacle detection system where immediate response is needed as the wheelchair is moving.

2.2.3 Microprocessor and DAQ

2.2.3.1 PIC Microcontroller

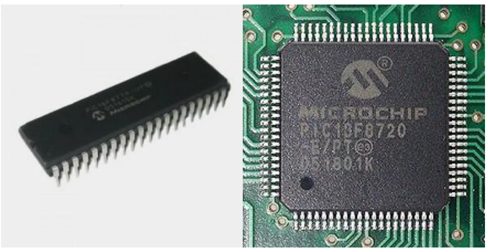

Figure 2.12: Examples of PIC Microcontroller (Microchip Technology Inc)

Figure 2.12 shows two example of PIC Microcontroller taken from MICROCHIP. Due to the characteristics of PIC Microcontroller where low cost, low power consumption, large user base, easy to use and easy to obtain, PIC Microcontrollers are very popular among robot field. A PIC Microcontroller can be interpreted as a mini computer where it has build in memory and RAM. In more details, PIC Microcontroller has a central processing unit (CPU) to run the programs, random-access memory (RAM) to hold variables, read-only memory (ROM) and input-output line (I/O ports). As stated previously, PIC Microcontroller also includes extra built-in peripheral like PWM, A/D and D/A converter (Premadi et al, 2009). PIC Microcontroller can be programmed according to different application with all this features. Unfortunately, the little PIC Microcontroller is unable to support huge amount of programs like computer. It is useful in running a program and repeating the program which is suitable to be used in robot field. Besides, it is less power consumption that can support with only battery as carry by mobile robot.

PIC Microcontroller consider as the simplest processor where it consists low number of instruction from about 35 instructions for the low-end PIC Microcontroller to over 80 instructions for the high-end PIC Microcontroller. PIC Microcontroller is using modified Harvard architecture (Figure 2.13) which instructions and data come from separate sources. The architecture had simplified the timing and microcircuit design greatly, which then improve the clock speed, reduce the price and power consumption.

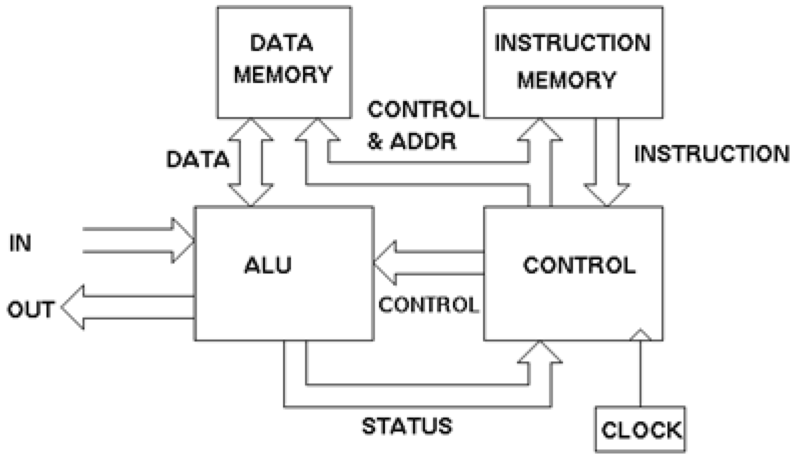

Figure 2.13: Harvard Architecture (Microchip Technology Inc)

MICROCHIP does provide some software like MPLAB, emulator and compiler that support the PIC Microcontroller. With all this support tools, we can write a program in some programming language like C language, compile the language and burn into the PIC Microcontroller with the help of computer and programmer device. The software also can be used in debugging mode to debug the program before it is programmed into the microcontroller.

2.2.3.2 Field-Programmable Gate Array (FPGA)

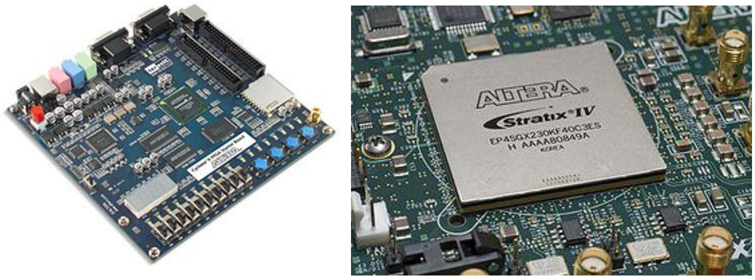

Figure 2.14: Examples of FPGA (Altera, 2006)

As shown in Figure 2.14, FPGA is not just a single chip like PIC microcontroller but it is actually an electronic board that consists of a lot of components. FPGA stands for field-programmable gate array which is an integrated circuit designed with the ability to be configured again by user after. This is why FPGA says to be "field-programmable" that make it different from an application-specific integrated circuit (ASIC). ASIC is customized for a particular use, while FPGA is manufactured for general-purpose use. The FPGA configuration is generally specified using a hardware description language (HDL).

FPGA contain many programmable logic components that call as logic cell. Figure 2.15 shows the logic cell schematic that consists of a lookup table (LUT), a D-flip flop and a 2-to-1 multiplexer. A logic cell can implement into any type of logic function like AND or OR. All the logic cells in the FGPA can connect together with the interconnect resources which are wires or multiplexes that placed around the logic-cells. With this interconnect resources, different types of logic function can be combined to create a complex logic function that useful in their corresponding application. Therefore, FPGA is a good device to design digital logic application.

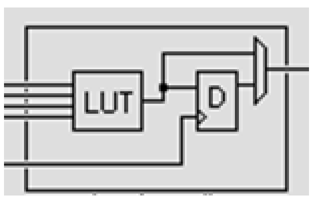

Figure 2.15: Logic Cell in FPGA (Nicolle, J. P., 2006)

Besides logic cell, FPGA also contains I/O cells where interconnect wires will connect the cells to the boundary of FGPA. The function of this I/O cells is similar to the I/O ports in PIC microcontroller that used to communicate with other external element like sensor. FPGA is famous to be used in application where fast speed process is needed. It is different from PIC microprocessor as it can run the instructions in parallel. Multiple set of instruction can be run simultaneously with FPGA as the cells can be separated and grouped accordingly.

As stated previously, hardware description language (HDL) is used in FPGA. On other hand, a simple program structure can use schematic design to configure the FPGA as it provides a clear visualization on the design. A common HDL uses nowadays will be Verilog. Similar to microcontroller, FGPA companies also provide their own software that supports their products. The software can be used to complete the task like design entry, simulation, synthesis and place-and-route and programming through special cable (JTAG). There are two main companies which are Xilinx and Altera that controlling the FPGA market. Xilinx provides software called ISE WebPack, while Altera provides Quartus II Web Edition. The software will be further discussed in Software section.

2.2.3.3 DAQ Device

Figure 2.16: NI DAQmx 9.0.2 (National Instrument, 2012)

It is common that physical phenomenons around us like temperature, light and sound provide us continuous signal which is called as analog signal. Unfortunately, analog signal is not understandable by computer that use in processing the data. This is why a data acquisition system is needed to sample the analog signals with a time of period and convert the resulting samples into digital numeric values. Figure 2.16 shows an example of DAQ device produced by National Instruments (NI). Data acquisition system consists of three parts which are sensor, DAQ hardware and computer. DAQ hardware will be the focus in this section.

DAQ hardware acts as the interface between a computer and signals from the sensor that obtain from the measurement on the physical phenomenon on outside world. It digitizes the analog signals into digital signals so that a computer can interpret the data and use in processing. The three main components of DAQ hardware are the signal conditioning circuitry, analog-to-digital converter (ADC), and computer bus.

Signal conditioning circuitry is needed because the signal direct from sensor may not powerful enough to be read or too powerful that may cause damage to the electronic component. The signal from sensor has to be manipulated in order to suit the requirement of the ADC component. This signal conditioning circuitry may include amplification, attenuation, filtering, and isolation. Next, the analog signal after signal conditioning stage will feed into ADC to be converted into digital signal. Since analog signal vary continuously, it is impossible to sample the signal all the time. ADC will sample an analog signal at a specific time and represent it in digital form. One sample will take in every each time interval and from a digital signal as shown in Figure 2.17.

From Figure 2.17, graph a) is the analog signal; follow by b) where each signal value at each time interval is taken. Then, graph c) shows how to connect to all reading to from a digital signal. Finally, graph d) shows the original signal is reconstructed back from the digital signal by software. The digital signal will then input into a computer with a computer bus. The computer bus serves as the communication interface between the DAQ device and computer for passing instructions and measured data. The examples of computer bus are USB, PCI, PCI

Express, Ethernet or even Wi-Fi. It is important when choosing the computer bus because different type of bus suit different application condition.

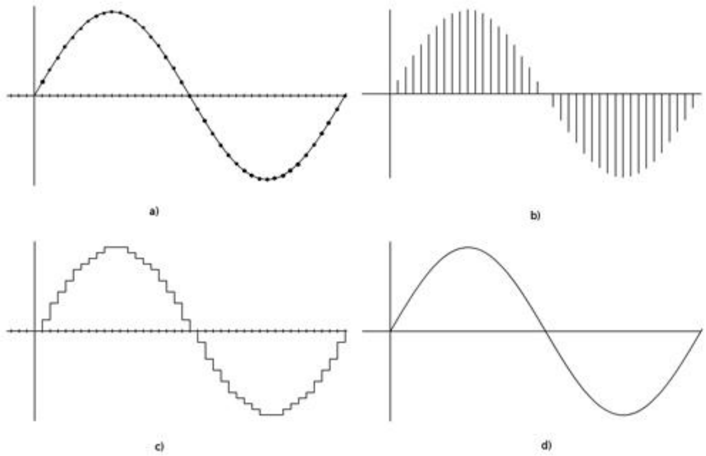

Figure 2.17: Data Sampling in ADC (National Instrument, 2012)

Other than that, functions like digital-to-analog converter (DAC) to output analog signals, digital I/O lines to input and output digital signals, and counter/timers to count and generate digital pulses are also include in most of the DAQ hardware nowadays. National Instruments is quiet popular with its DAQ device, so the characteristic of NI DAQ device is study and shown in Table 2.5.

Table 2.5: Characteristics of NI DAQ Devices

Features	**Single Device**	
	Portable DAQ	**Desktop DAQ**
Bus	USB, Wi-Fi, Ethernet	PCI, PCI Express
Portability	Best	Good
Number of I/O Channels	1 – 100	1 – 100
I/O Configuration	Fixed	Fixed
Max Sample Rate	2 MS/s	10 MS/s
Built-In Signal Conditioning	Available	No
Synchronization/Triggering	Good	Better
Programming Languages	LabVIEW, C, C++, VB .NET, C# .NET	

2.2.3.4 Comparison between Microcontroller and DAQ

Similar to the sensor comparison, Table 2.6 showed the comparison between the Microcontroller and DAQ. The hardware compared is PIC Microcontroller, FPGA and NI DAQ device. Again, the way of comparison is base on the suitability of the hardware on obstacle detection system. The comparing method is by numbering from “1” to “3” due to three number of hardware are compared. “1” represents the best among the three in the particular feature; follow by “2” and then “3” which is the worst among the sensors.

Table 2.6: Microcontroller and DAQ Comparison

Features	PIC Microcontroller	FPGA	NI DAQ
Processing Speed	2	1	3
Familiarity (Author)	1	2	3
Popularity	1	2	3
Availability	1	2	3
Cost	1	3	2

From the comparison, it is clear that PIC Microcontroller is the best choice among the other hardware. FPGA is good in handling processing as it can run different instructions simultaneously that speed up the processing time. NI DAQ is needed when come to a large and long processing like image processing by using vision sensor.

2.3 Software

2.3.1 Introduction

Software always come in pair with the hardware where without software, the hardware is meaningless. In this section, some useful software like MPLAB and LabView are discussed.

2.3.2 MPLAB IDE

MPLAB IDE is a software produced by MICROCHIP to support their products. Embedded system application can develop through this software with computer and build into the microcontroller to function accordingly. IDE stands for Integrated Development Environment that a single integrated environment to develop the program or code for embedded microcontrollers. MPLAB provide components that allow user to write, edit, debug and program the code.

First of all, the designer has to create or design the source code with either assembly language or other natural programming language like C language. In this stage, it is all depend to the designer to complete the task according to his own style of writing the program. Next, the program will go through the compiler or assembler or linker that uses to make sure the code created is understandable by machine. The language tool will convert the program code into machine code that contain only "ones and zeros". This machine code will then become the firmware to be programmed into the microcontroller. Before the firmware is programmed into the hardware, MAPLAB actually provide a debugger to run on the program to check if there is any error occurred. This is a very useful tool especially for complex program coding. In debugger mode, the user can observe the result change according to the program code. Through this code analyzing, the error can be easily detected and edit again by the user repeating the development cycle.

MPLAB IDE provides the advantage to prevent any unwanted result on the hardware itself as this may cause damage to the hardware. Program code with "bug" may cause the hardware to behave wrongly or even crazily. This situation wills not just damaging the microcontroller but it may also cause damage on other component that connected with the microcontroller. Besides, it also saves time and cost in developing stage. User just deal with the software at the design stage without wasting time to program into the hardware for testing purpose. On the other hand, it may difficult to detect the actual "bug" by only observing the hardware behaviour. Therefore, MPLAB IDE produces by MICROCHIP give a big hand in embedded system design when deal with the PIC microcontroller.

2.3.3 LabVIEW

LabVIEW is produced by National Instruments that using a graphically-based programming language instead of word representation like C language and BASIC language. It is common that graphical representation give a better and clearer view to the user. Therefore, LabVIEW is popular for applications like test and measurement (T&M), instrument control, data acquisition, and data analysis.

Virtual Instrument (VI) is a LabVIEW programming element that consists of a front panel, block diagram, and an icon that represents the program. The front panel displays all the interfaces for the user to control like knob and ON/OFF switch or observe the output from indicators like LED. The front panel actually handles the function of the inputs and outputs. Next, the blocks contained in the block diagram in LABVIEW actually equivalent to the program code like in C language. Each of the block diagrams represents different coding function where user just has to drag and drop on the window and combine the blocks accordingly to form a complete program code. On the other hand, the icon is a visual representation of the VI that has specific connectors for program inputs and outputs. For complex program, multiple VIs can be used and combined to form a large scale application.

Similar to MPLAB IDE, LabVIEW also provide feature for programming and debugging. It has the flexibility of a programming language combined with built-in tools designed specifically for test, measurement, and control. As mention previously, NI has a product, DAQ device that use to acquire data from sensor measuring the outside world physical phenomenon. The data required can use as the input of a program and process accordingly to provide the output. LabVIEW will be the best software to be use in this situation. For the obstacle detection system, the reading from the ultrasonic sensors for example can acquire by using DAQ device and then transmit into the computer to use in LabVIEW. The program will build in LabVIEW to process the input and then produce the relevance output to control the driving motors of the wheelchair.

2.4 Global and Local Planning

First of all, there are two levels of obstacle avoidance planning, global planning and local planning. The concept of global obstacle avoidance planning is that the system examines the “whole world” of the environment and store in the system. The planning is base on the whole environment. On the other hand, local obstacle avoidance planning is a reactive planning; it examine the area surrounding the system and react accordingly. For example, if there is an unknown obstacle happened to block the path that the system is taking, global planning system tends to take another path to reach the destination as it knew all the paths of the environment. But, system with local planning, it tries to find a way to avoid and swerve around the unknown obstacle and then continue taking the same path to the destination.

A combination of both global and local planning made a system better, but not all design is able to apply both planning. A small microcontroller is impossible to examine the whole environment and store all the data in the system. Besides that, it is hard for an indoor use system to fully identify the whole environment, not like outdoor use system where GPS technology can be used together with the satellite available globally.

2.5 Concept and Algorithm

2.5.1 Introduction

Concept and algorithm plays an important role in this obstacle detection system design. Concept and algorithm can be explained as a solution for a problem. Concept determines how the problem is being solved while algorithm is the procedures or steps to go through in order to reach the output wanted. Algorithm can be considered as the content of a concept and it uses to proof that the concept is workable. In computer science or robotic field, algorithm usually represent in equation form and mostly in a flow chart. Algorithm shows step by step procedure usually with more than one equation for calculation, data processing and automated reasoning. It may also divide into different stages to process with the same data input for comparison before come out with the final output. By studying a system algorithm, the working sequence or the concept of the whole system can be roughly understand.

Project with similar title "Obstacle Detection System" may use different concept and algorithm. Although the similar hardware and software use, different people may have different method to achieve the same objectives. Some of the concepts and algorithm use in the studied projects will be discussed in this section.

2.5.2 Fuzzy Logic

Traditionally, logic theory is based on the binary set that include only two-valued logic, "1" and "0". In real case, it is common to present as true or false. But there are many situations where true and false is not sufficient enough. For example, height of people where short represents as "0", tall represents as "1"; there will be no representations that use to define quite tall in logic theory. Therefore, fuzzy logic is introduced to modify the logic theory that consists of degree of truth. It is a form of many-valued logic that can deals with approximate value rather than fixed value. Fuzzy logic will have the range values from the value "0" to "1" which has the ability to handle concept of partial truth.

In some situation, fuzzy logic may have few sets of range between the two logic values which the degree of truth can actually being divided and managed into some specific functions. Fuzzy logic is usually constructed by using the IF-THEN rules with the form as shown in statement below. The number of statement is depends to the number of set of range according to the degree of truth.

$$\text{IF variable IS property THEN action} \tag{2.1}$$

In the research of Yi et al, 2009, fuzzy logic is used in designing the controlling system. The operation includes fuzzification, knowledge base, fuzzy reasoning and defuzzification. Fuzzification converts the input variables into fuzzy variables and being process in knowledge base that store relevant data and fuzzy control rules. The fuzzy reasoning will then generate a resultant output with respect to the fuzzy rules and finally the defuzzification will converts the fuzzy variables back into output variables. The composition diagram of fuzzy-controller is shown in Figure 2.20.

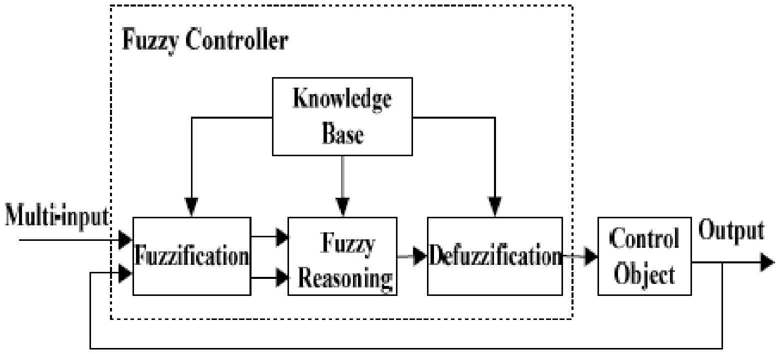

Figure 2.20: Composition Diagram of Fuzzy-Controller (Yi et al, 2009)

In the research, the readings from the nine ultrasonic sensors are used and being classified according to their position in term of angle and distance. The inputs to the fuzzy reasoning are the obstacle orientation angle relative to the robot heading (θ) and the distances measured from obstacle to the orientation of left-front (*dl*), right-front (*dr*) and front (*df*) side of the robot. The output is the robot rotation angle (Φ) (Yi et al, 2009). With all this fuzzy variables, the research authors come out with three-membership function as shown in Figure 2.21. Graph (a) shows the quantitated distance including *dl, dr* and *df,* while Graph (b) shows the orientation angle, θ. The final graph (c) shows domain of robot turning angle, Φ where *LB* indicates “left big”, *LM* indicates “left middle”, *LS* indicates “left small”, *Z* in token of “zero”, *RS* indicates “right small”, *RM* indicates “right middle” and *RB* indicates “right big”.

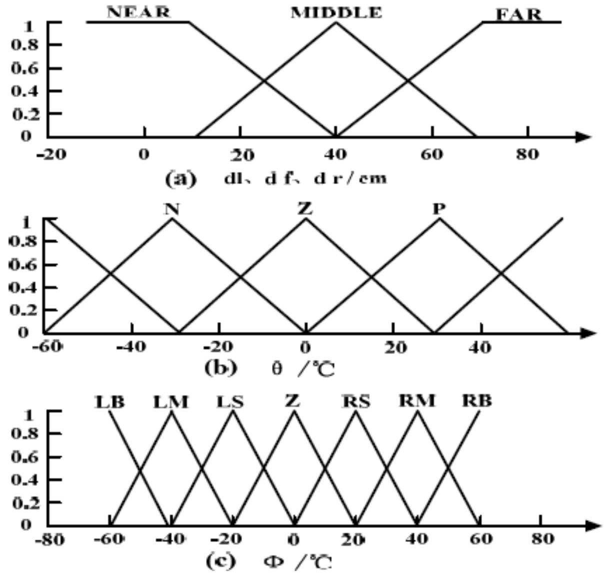

Figure 2.21: The Membership Functions of Variables (Yi et al, 2009)

IF-THEN rule is being applied in the research, but statements are not included in the article. It provides an example where if the *dl* is "NEAR", *df* is "FAR", *dr* is "FAR" and the θ orientation is "P", then Φ will be *RS*. This is one of the statements in the research that conclude, if the robot encounters such a situation, it will turn toward right side slightly.

Fuzzy logic will be the simplest algorithm to be applied into obstacle detection system as it is using the IF-THEN statement. With logical thinking, the IF-THEN statements can be easily constructed base on the situation that may happen. Unfortunately, this algorithm will be hard to apply when complex design obstacle detection system occurred when more sensors are using. Large number of statement may need for complex design which will consume more space on the processor and yet need more time in processing in each reading.

2.5.3 Edge Detection

Edge detection is one of the famous concept uses in obstacle avoidance system. The key of this concept is detecting the edge of the obstacle. System with edge detection algorithm will always try to determine the position of the vertical edges and believe that the space between two vertical edges will be an obstacle. The two vertical edges will be the obstacle boundaries. Therefore, the system will always steer the robot to go around the obstacle by turning left off the left vertical edge or turning right off the right vertical edge.

This concept is simple and quite reliable to a certain degree. Unfortunately, the main disadvantage of this concept will be the robot need to stop at the front of the obstacle. This is because the system need time to detect the two vertical edges and get a more accurate measurement about the obstacle. Besides that, the performance of the system with this concept is highly depends to the sensitivity of the sensor accuracy use. Depends to different sensor use for the system, different algorithm is created to achieve this concept. In Borenstein & Koren 1988 research, ultrasonic sensors are used with edge detection concept. Their system is having two distinct modes of operation: scanning mode and measuring mode. As the robot is moving, scanning mode is activated to scan is there any obstacle happen to present on the way. The algorithm in this mode will keep checking the following statement:

$$\text{IF } R_i(j) < \text{TD AND } R_i(j) \leq R_i(j-1) \text{ THEN ALARM} \quad (2.2)$$

where

TD = *threshold*

$R_i(j)$= *range reading of transceiver i*

$R_i(j-1)$= *previous range reading of transceiver i*

Once the statement is TRUE, it means there is an obstacle detected and the robot will come to a stop in front of the obstacle. After that, the system will go into measuring mode. In measuring mode, the robot will rotate the manipulator with the ultrasonic transducer to a certain degree left and then right to scan the obstacle. The two vertical edges are defined when the range reading is having a large change during the rotation. Figure 2.22 shows that the position of the left vertical edge is determined at point 9 to point 10 while the sensor, S1 is rotate. When there is a close-to-far transition between subsequent range readings, it indicates that there is a vertical edge.

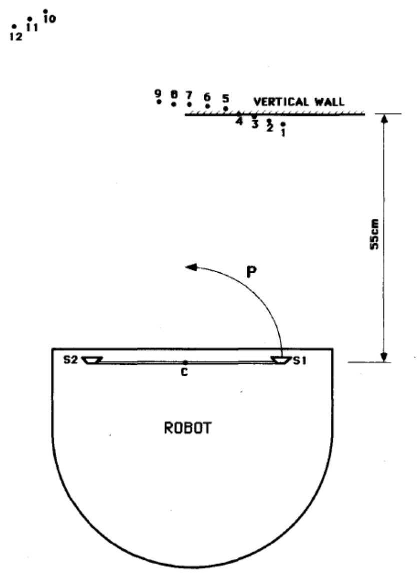

Figure 2.22: Typical Scan of Vertical Obstacle (Borenstein & Koren, 1988)

2.5.4 Wall-Following

Wall following concept use only two basic modes of motion. First mode, directly move toward the target. A straight line path is form from the origin position of the system toward the target position set. If there is no obstacle present on the path, the robot will directly move on the straight line path toward the target. Second mode will be obstacle boundary following. Once the robot encounter an obstacle on the path, the algorithm will move to this mode, and the robot will take the obstacle boundary as the guide and travel along the boundary. Algorithm will then decide when the robot has break away from the obstacle and then continue with the straight path toward the target. The second mode will reactivate whenever an obstacle in detected on the path. Since this concept uses only two modes which is focus only on the robot's surrounding, it is categorized under local decision.

A study on this wall following concept is done by Kamon & Rivlin 1995. An algorithm with the name DistBug is introduced in this research. This algorithm guaranteed the reach the target under an unknown environment or it will report if the target is unreachable. As mention previously, DistBug consists of two basic modes of motion. The two algorithm description is shown as below (Kamon & Rivlin, 1995):

1. Go directly to the target, until one of the following occurs:
   a) The target is reached. Stop.
   b) An obstacle is reached. Go to step 2.
2. Choose the boundary following direction. Follow the obstacle boundary untll one of the following occurs:
   a) The target is reached. Stop.
   b) The free range in the direction to the target guarantees that the next hit point will be closer to the target than the last hit point. Go to step 1.
   c) The robot completed a loop around the obstacle The target is unreachable. Stop.

From the algorihtm, the range data from the sensor is used to decide the steering direction. The hit point mention mean the point where the robot meet an obstacle, so the steering direction shall guarantee that the robot is keep approaching near the target, not the otherwise. Figure 2.23 shows an example of how the wall following is worked.

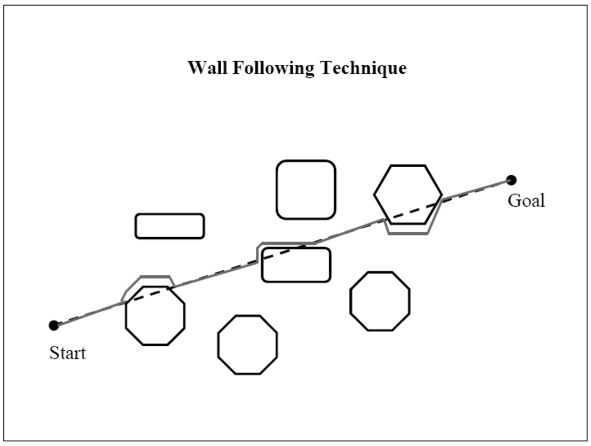

Figure 2.23: Example of Wall Following Technique (Kamon & Rivlin, 1995)

2.5.5 Black Hole

Previous concepts are deal more to one obstacle in one time, while black hole technique is a way that examines all the obstacles in front of the robot. This is because system with black hole technique attempts to identify all the empty holes between the obstacles. From all the holes available, it will search for the largest hole to pass through the obstacles area. Due to this concept, the shape and the size of the robot shall well know by the system, so that the hole detect is big enough.

A research example regarding to this concept is by Bischoff 1999. The robot design in this research will wander around with obstacle avoidance system to recognize its environment. The robot is using camera as the visual sensor, so it has the ability to detect multiple obstacles in once. After segmented the image taken, the robot will move to the obstacle free region that having the largest space. Next, it will go through algorithm to check the size of the hole and then come out with specific steering angle to pass through the obstacles.

2.5.6 Potential Field

Potential Field method is about virtual forces form between the robot with the obstacles and the goal. A final force is compute from all the virtual forces and then an action of the robot is generated according to the final force. A repulsive force is form between the robot and an obstacle, so that the force will repulses the robot away from the obstacle. The number of repulsive force is depend to the number of obstacle detect by the robot. On the other hand, there is always an attractive force between the robot and goal, so that the robot is being attracted toward the goal. A resultant force is calculated with the algorithm from all the virtual forces available. The resultant force is then use to decide the desired heading and velocity of the robot. All the virtual forces are representing in vector form in order to carry out the calculation. System with this concept is having a major benefit where the robot does not have to stop in front of the robot for further processing. Therefore, this concept allows the robot to avoid the obstacles smoothly.

A study is done from Seki et al, 2008 based on this concept. A laser range sensor is use in this study where it has a circular detection area that enable the system to detect all the obstacles avaliable surrounding the robot. There is a special feature in this study where there are two repulsive forces form from an obstacle. This difference is mainly cause by the sensor used. In common project, multiple sensors like ultrasonic sensor are use to surround the robot's body, so different obstacle may detect by different sensor. Therefore, the repulsive force is created between the obstacle and the particular sensor that is detected the obstacle. In the project of Seki et al, 2008, one point at the front, r_f and one point at the rear, r_r as shown in Figure 2.24 are taken as the reference point to determine the repulsive forces. The process of the obstacle avoidance system by Seki et al, 2008 is followed the algorithm as shown in Figure 2.25.

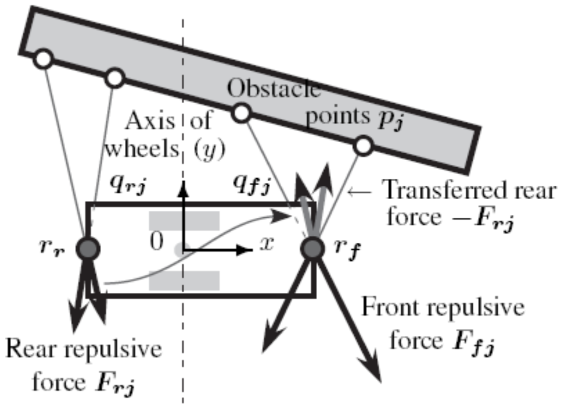

Figure 2.24: Reference Points on Robot (Seki et al, 2008)

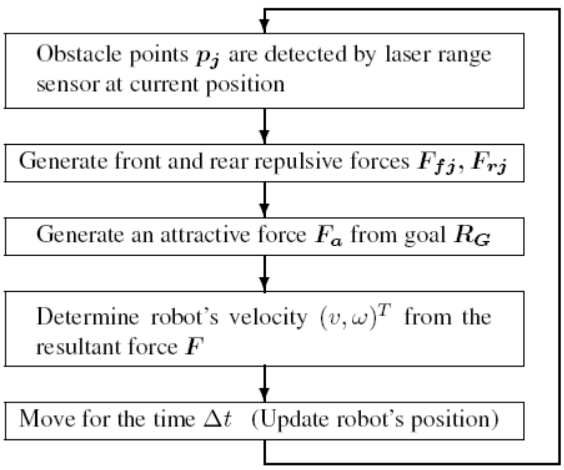

Figure 2.25: Flowchart of proposed algorithm (Seki et al, 2008)

2.5.7 Personal Concept

In this section, the concept used by one of the studied research is presented. The project is about Obstacle Avoidance Robot by Kinsky et al, 2011 that build a robot with two webcam as the sensors. Due to two sensors included, there will always be two images of the same scene taken from different perspectives. The images first go through a module call Get Stereo Calibration to pair up both left and right images with similar scene as the position of the webcams may change. After make sure that both images are from the same scene, the images will then go through stereo rectification to correct the intrinsic distortion of the cameras and align the images.

Next, sparse stereo module will finds out all the feature points in the left image and then match with the right image. Feature points are areas that are visually distinctive. By using the X and Y position of the points and their disparity between the images, the points can be put into three-dimensional space as shown in Figure 2.26. Once sparse stereo module is done, it is important to determine the flat plane which is the floor. It is common and logic that floor will be the most bottom region detected by a mobile robot. It is clearly shows in Figure 2.26 where the bottom 10 points highlighted in black is the floor.

Next stage will be the determination of the obstacle points. In this report, the authors assume the points above the ground plane that exceed the preset distance as the obstacle points. Figure 2.26 shows that points out of the black shaded box are the obstacle points. Once the obstacle points have clearly defined, the next module will combine the points which are close to each other into a cluster that represent as one obstacle. Blue boundaries are used to frame the obstacle points as shown in Figure 2.26 where there will be two obstacles in the example.

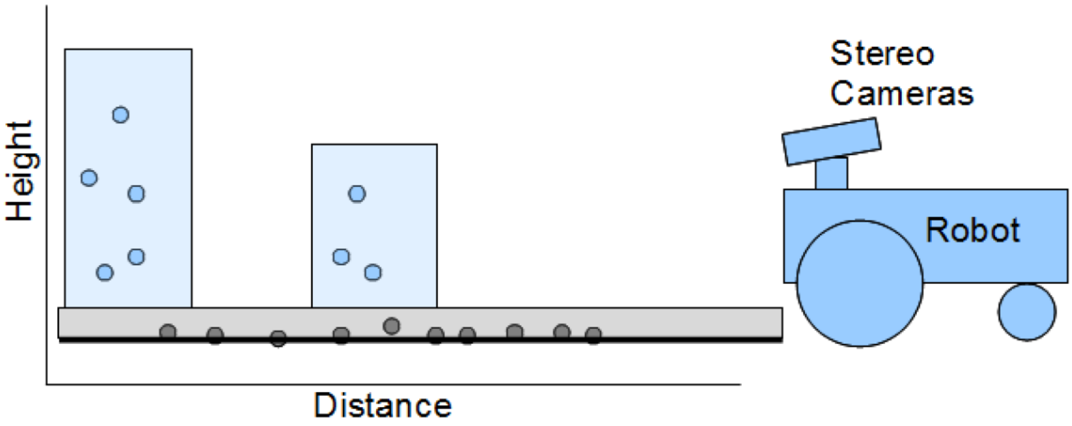

Figure 2.26: Result from Modules (Kinsky et al, 2011)

The result is then further interpreted where the distance and position of the obstacles are identified and command will be sent to move the robot. The interpreted data is shown in Figure 2.27 to provide a clearer view. The concept used in this project is good to a certain degree of assumption like the most bottom area of the image obtain is always assumed to be the floor. This may provide an error if an obstacle is very near to the sensor which has covered the bottom part of the image acquire. Further research is still needed to improve the system.

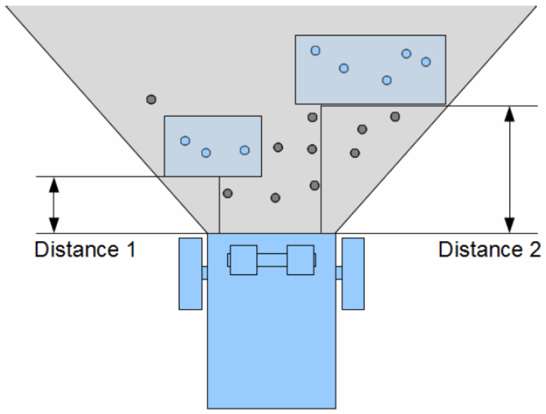

Figure 2.27: Result after Last Module (Kinsky et al, 2011)

CHAPTER 3

METHODOLOGY

3.1 Introduction

Obstacle detection system consists of two hardware, sensor and microcontroller that provide the intelligence of “see and observe” to the intelligence semi-automated wheelchair. After the study of other existed research projects, vision sensor like human eye plays the initial role where the situation of environment surround is being identified. Ultrasonic sensor was the choice for this project for the intelligence semi-automated wheelchair. Besides that, PIC Microcontroller was considered as the programming hardware for this project. It is common that MPLAB is use to program as this software is coupled with PIC Microcontroller. After that, the process of mechanical and electronic developments was presented in the following section. Finally, the concept and algorithm was discussed as the last section.

3.2 Ultrasonic Sensor

Ultrasonic sensor was the choice in this project due to its characteristics that suit this project. The detect range from ultrasonic sensor was consider sufficient for obstacle detection system. Sensor with far range like laser may assume to be overdesign for this project. Besides, a wide spread detection area in short distance provided the advantage to the robot to “observe” more about its front area. Moreover, ultrasonic sensor provided simple data which can be process with a small microcontroller only.

Camera with computer as the processor will make the wheel chair become bulky and heavy. Lastly, ultrasonic sensor was the most economical among all those vision sensors discussed previously. This will then made the wheelchair design more affordable to everyone.

After a study about the movement of the design wheel chair, six MaxSonar-EZ1 ultrasonic sensors were decided to use in this project. The six sensors were distributed into front, left, right and back. Two sensors were located at the front; one sensor was located at each left and right; while back included two sensors as well. Figure 3.1 showed the draft of the position of the six ultrasonic sensors on the base of the wheelchair. Two sensors were included at the front and the back to cover the whole area that the sensors facing. For left and right, only one sensor was needed for each side because the base was using differential drive. During turning, only the head of the base was turning while the back side was somehow fixing in position. Therefore, a sensor was needed at the front of each side to prevent any collision happen during turning.

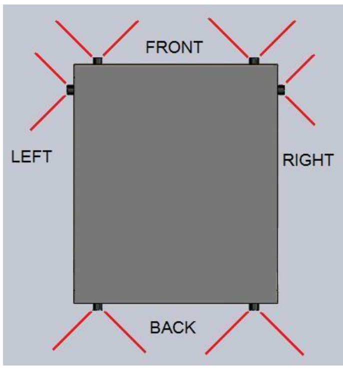

Figure 3.1: Position of Six MaxSonar-EZ1 Ultrasonic Sensors

3.3 PIC Microcontroller

As mention previously, ultrasonic sensor provided simple data, so a small PIC microcontroller was sufficient to be use as the “brain” in this obstacle detection system. There were lots of families under PIC microcontroller where PIC16F and PIC18F microcontroller were commonly use and were sufficient for most of the robotic application. PIC24 and 33 may make the design of this project overdesign. Therefore, PIC18F4520 was chosen for this project due to its characteristic.

First of all, ultrasonic sensor provided analog data, so the microcontroller chosen had to include an analog-to-digital converter module (ADC). PIC18F4520 had this module and yet it was having a special feature on this module where there was a 10-bit analog-to-digital converter module. With extra two bits compared to others, PIC18F4520 had a more precise converter scale up to 1024 instead of only 256. Besides that, PIC18F4520 had up to twelve ADC channels which were more than enough to support six ultrasonic sensors. The twelve channels were represented in AN0-AN12 as shown in Figure 3.2 with the red circles. With extra channels, the author could still add more ultrasonic sensor on the design whenever was needed. Next, PIC18F4520 was a 40-pin PDIP that having extra one set of I/O ports (RD0-RD7 in Figure 3.2 with blue circles) for the author to communicate with other systems. The voltage value needed to power up this microchip was similar to the MaxSonar-EZ1 ultrasonic sensor used, which was 5V. Due to this similarity, author just had to design and prepared a 5V power supply for the obstacle detection system.

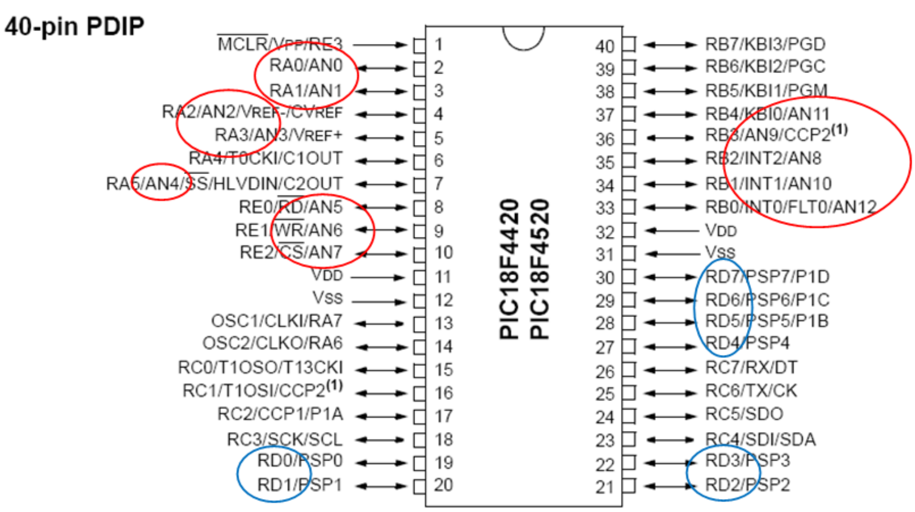

Figure 3.2: PIC18F4520 Pin Diagram (Microchip Technology Inc, 2004)

3.4 Mechanical Development

Since this project was focusing on designing the systems for autonomous wheelchair, a prototype of a wheelchair was enough to reduce the research cost. SolidWorks is 3D CAD design software that planned to use by the author to create the mechanical design. It was very user friendly where author who was not specialty in mechanical design field was still able to learn and pick up with the software.

Before any mechanical design was started, the author looked into the design of motorized wheelchair that available at the market. From the study, the author found out that most of the designs somehow separated the wheelchair into two parts, the base and the chair. The base contained most of the components of the motorized wheelchair like motor, wheels, battery and the control unit. On the other hand, the chair part included the chair itself and the user interface like joystick. Obstacle detection system was more to automated system and did not need any user interface to control the system. Therefore, the design for this project was focusing on the base only but not the chair design. Fabrication of the prototype will be carried out by the author together with the members who were in charge in other systems of the intelligence semi-automated wheelchair.

3.5 Electronics Development

As mention previously, PIC18F4520 microcontroller was chosen as the core controller of the obstacle detection system. Six ultrasonic sensors were used in the system to detect the obstacle. Next, this system was going to combine with the driving system and navigation system of the wheelchair, so communication between the systems was needed. Besides, an indicator to show the specific sensor that detects an obstacle was planned to include for the ease of research study.

Similar to mechanical development, Eagle PCB software was used to design the PCB circuit board. Schematic can be draw with this software to complete the circuit of the system. Most of the electronics components were included in the software with the correct dimension to ease the process. If the component was not in the library, user could create the library with the software and included it in the schematic. After that, the schematic can be converted into the PCB board layout. All the components included in the schematic will display on the PCB board layout and the user just dragged and placed to arrange the PCB board design.

3.6 Concept and Algorithm

This section was going to talk about the concepts and algorithms that going to apply on this project for the obstacle detection system. In this project, concept used and algorithm design shall obey the requirements shown in the list below in order to achieve the objectives stated previously:

- detect obstacle and send specific signal to the driving system to avoid the obstacle
- the algorithm clear about the size and shape of the system structure so that the it will not collide with the obstacle when travelling
- the algorithm always clear with the situation of the system surrounding
- the algorithm shall provide a smooth travelling to maintain the user comfortable
- the algorithm shall make the system stop if there is obstacle that too near to the system
- the algorithm shall able to handle both static and moving obstacle

After study on other concepts and algorithms used by other similar project, edge detection concept was suitable in this project circumstance. As discussed previously, edge detection concept allows the system to determine where the edge of the obstacle is. Then, the system will steer around the obstacle by turning left off the left vertical edge or turning right off the right vertical edge. The choice of this concept was highly base on the travelling method of the wheelchair. There were two travelling modes design for the semi-automated wheelchair in this project.

First mode will be automatic mode where the wheelchair was travelling by line following as designed in the navigation system. There will be a special path provided for the wheelchair to travel around the building. The obstacle detection system played the role in detecting obstacle that blocking the wheelchair path and then send signal to the driving system to avoid the obstacle. The flow chart in Figure 3.3 was showing the working principle of this mode. Initially, the wheelchair was moving with navigation system that following the track provided that aligned with the left wall. This was set based on the traffic in Malaysia where car was always taking the left lane when travelling. Once an obstacle was detected blocking the path line, the obstacle detection system will take over the wheelchair control. As shown in the flow chart, the wheelchair would slow down and then the lean right signal was sent to the driving system to detect the obstacle edge. At this stage, edge detection concept was used and identified the position of the edge. After that, the same signal was continuous sent to the driving system for a short period so that the whole wheelchair was having enough space to pass the edge without collision.

Once the edge had passed by, a forward signal was sent to the driving system to move the wheelchair. At this stage, the left sensor was activated to detect another edge of the obstacle which was considered as the end edge. After that, lean left signal was sent and the wheelchair started to lean left. Toward the end, the wheelchair will definitely avoid the obstacle and then back to the track prepared by the navigation system. The navigation system will then take over the wheelchair control.

The algorithm used in this system can be explained as sensory based algorithm where the system was directly used the information from the sensor to response accordingly (Kamon & Rivlin, 1995). It also called as local planning algorithm. The algorithm for the automatic mode will be as shown below:

1. Detect obstacle bloking the front path.
2. Slow down the speed and start to lean to the right.
    a. Front sensor detect obstacle edge. Go to step 3.
    b. If not. Repeat with step 2.
3. Steer another short period to the right.
4. Move forward with slightly to the left steer.

   a. Front sensor detect obstacle. Go to step 3.
   b. If no. Go to step 5.
5. Move forward with another short period.
6. Move forward with slightly left steering.
   a. Detect line path (navigation system). Go to step 7.
   b. If no. Repeat step 6.
7. Navigation system takes over the control.

The second mode was semi-automatic mode where the wheelchair was controlled by the user to travel around, while the obstacle detection system worked as the safety support element. Once an obstacle was detected, the obstacle detection system cut off the user control and the wheelchair will then come to a stop. At this stage, the user control was limited from the direction to the obstacle. For example, if the obstacle was detected to be at the front of the wheelchair, the user was only able to control left or right turning without any forward motion. Once the obstacle was no longer blocking the way, the normal user control will reactivate back. The process was clearly shown in the flow chart in Figure 3.4.

The algorithm used for semi automatic mode was presented as shown below:

1. Detect obstacle bloking the travel direction.
2. Slow down and stop the wheelchair.
3. Limit the user control from the direction of the obstacle present.
   a. If obstacle still present in the sensor range. Repeat step 3.
   b. If no. Go to step 4.
4. Normal user control is resume

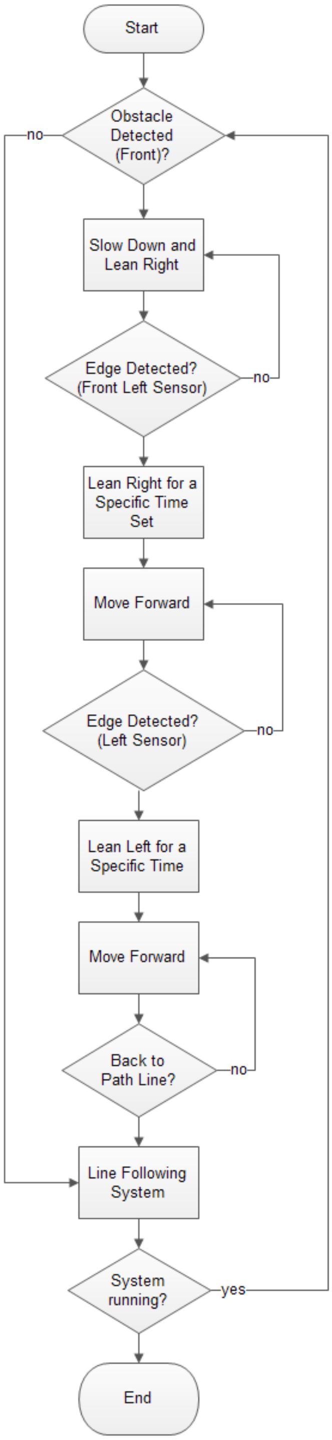

Figure 3.3: Automated Mode

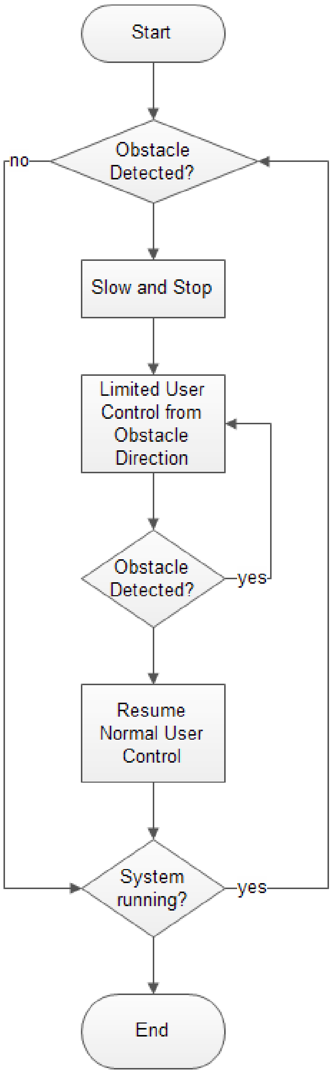

Figure 3.4: Semi-Automated Mode

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Mechanical Development

Initially, the position of the wheels was very important to have a stable base. In the first concept design, two differential wheels and two caster wheels were used in this project. Differential drive was used due to its simplicity of driving control. Therefore, each differential wheel was mounted with one DC motor. Caster wheel was chosen as the front wheel so that the front part was free to move in any direction depending to the driving wheel. Besides wheels and motors, battery was needed as the power supply to the whole system. Since the two batteries had to remove from the base to be charge from time to time, it was design to place above the motor. The batteries were chosen to place together with the motor in order to create more space for the control unit boards. A battery box was also design to hold both batteries, so that it was easier to remove the batteries in one from the base. Figure 4.1 below showed the first conceptual design in this project.

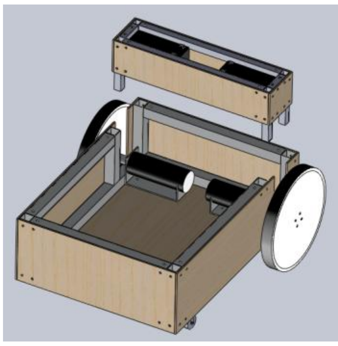

Figure 4.1: Mechanical Design Version 1

Next, the author found out that the first design was having weight distribution problem, where the back part of the base was fill with the two main components of the system that were heavy. The front base may lifted up when the base was having acceleration. Therefore, the batteries were shift to the front to counter weight the motors. At the same time, it was still obey the condition where the batteries were ease to remove. Besides that, the mounting of the battery holder was complicated, so the author did not included it in the second design. A special space was created to place the battery with L-shape plate, so that the battery was stay in position when the base was moving. Since the chair was above the base, it made the design complicated if the batteries had to remove from above. Therefore, instead of placing the front plywood permanently, the author designs the front plywood to be flexible so that it could be open as shown in Figure 4.2. The middle space between the motor and battery was reserved for the control unit boards.

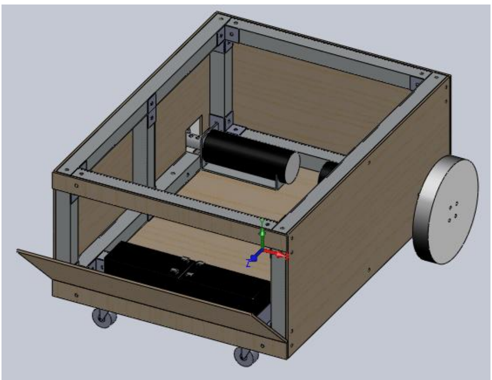

Figure 4.2: Mechanical Design Version 2

The design was carried on with the ultrasonic sensor mounting for the obstacle detection system. As mention previously, there were six ultrasonic sensors in total to be mounted on the base with the distribution, two at the front, one at each of the left and right and another two at the back. In order to have a simple design, the ultrasonic sensors were design to mount on the plywood. Hole would be drill on the plywood so that the ultrasonic sensor could directly mount on it as shown in Figure 4.3. This design was constructed out as shown in Figure 4.4.

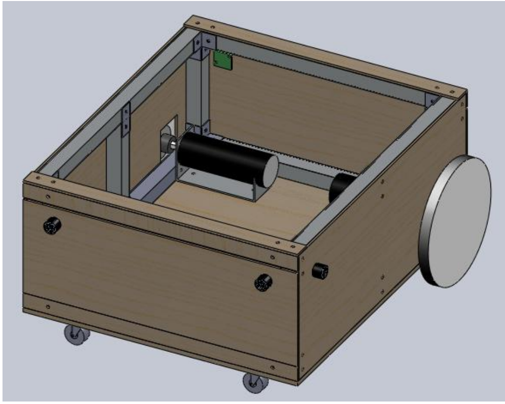

Figure 4.3: Mechanical Design Version 3 with SolidWorks

Figure 4.4: Constructed Mechanical Design Version 3

Once the design version 3 was constructed, few tests were done on the design. First of all, the most important component, ultrasonic sensor was tested. Unfortunately, the reading from the ultrasonic sensor did not achieve the expectation. Although there was no obstacle in front of the ultrasonic sensor, the sensor provided a reading of 240.2 mV. This showed that it was only able to detect an obstacle that was lower than 0.6 m away from the base. This distance was considers near and the base would had not enough time to response to avoid the obstacle. The factor on this problem was the height of the sensor on the base which was only 16.5 cm. In order to overcome this problem, the height of the sensor mounting had to be increased, but this would then cause the design became not practical. Therefore, the author decided to mount the sensor on top of the base with a small tilt on the sensor holder as shown in Figure 4.5 and Figure 4.6. This increased the distance that the base able to measure, at the same time, it did not influence the base size. With an approximate 10 degree angle tilt and the height of 21 cm, the sensor was able to read a maximum reading of 0.993 V, which was approximate 2.5 m.

This may be difference when it came into the real wheelchair size. For a standard motorized wheelchair, the base was approximate 40 cm in height. By using trigonometry with the previous readings, the distance that could be measure with the sensor height of approximately 35 cm will be 1.3 m. The wheelchair would have enough time to response if it detected the obstacle at the distance of 1.3 m. Therefore, the ultrasonic sensor was still can mount on the base body in the real motorized wheelchair that follow the previous design. This was important because if the sensor was mounted on top of the real wheelchair base, it may be blocked by the user's leg. The system would treat the user's leg as an obstacle and stopped the wheelchair although there was no obstacle.

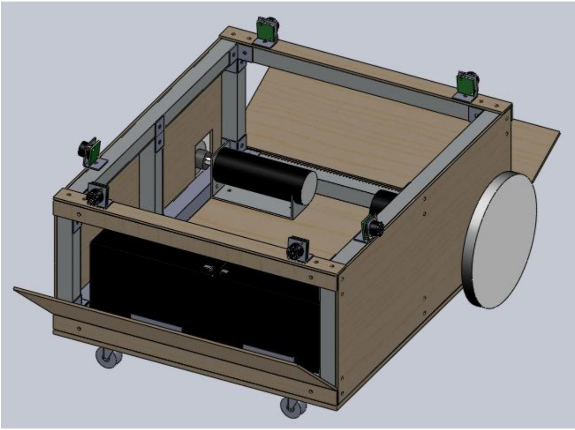

Figure 4.5: Ultrasonic Sensor on Wheelchair

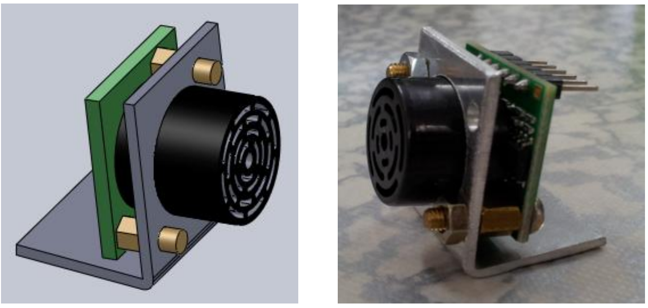

Figure 4.6: Ultrasonic Sensor Set

4.2 Study of Design’s Behaviour

After the fabrication of the base, the behaviour of the wheelchair base design was studied by carry out some experiments. The behaviour of the six MaxSonar-EZ1 Ultrasonic Sensors on the base was studied and the coverage area by the sensor was also determined. The shape of the ultrasonic wave emitted was also determined and then a suitable threshold for the distance could be set to detect the obstacle.

First of all, the distance measure by the sensor from the base was tested. A rectangular shoe box with the dimension 32 cm (L) x 12 cm (W) x 19 cm (H) was used as the obstacle. A SANWA digital multimeter was used to determine the distance measure with the reading obtained from the ultrasonic sensor. On the other hand, the actual distance was measured by using a measuring tape. Since the sensor was using inch as the unit, the whole test was carried out by using inch and the result was shown in Table 4.1. The setting for the test was as shown in Figure 4.7. First, the obstacle was shift to a specific distance by using the measuring tape, and then the measuring tape was removed to prevent any confusion by the sensor. After that, the reading from the sensor was obtained from the multimeter. The percentage errors were calculated where all were below 5 % which were relatively small. The difference and the percentage error of result were plot into the graph as shown in Figure 4.8 and Figure 4.9. As a conclusion, the result showed that the design was accepted.

Figure 4.7: Distance Measuring Test Setting

Table 4.1: Distance Measuring Test Result

No	Actual Distance, d_a (in)	Sensor Reading (mV)	Calculated Distance, d_c (in)	Difference (in)	Error (%)
1	12.0	124.0	12.4	0.4	3.33
2	18.0	182.0	18.2	0.2	1.11
3	24.0	229.8	23.0	1.0	4.25
4	30.0	288.5	28.9	1.2	3.83
5	36.0	346.6	34.7	1.3	3.72
6	42.0	405.0	40.5	1.5	3.57
7	48.0	463.0	46.3	1.7	3.54
8	54.0	520.0	52.0	2.0	3.70
9	60.0	584.0	58.4	1.6	2.67
10	66.0	637.0	63.7	2.3	3.48
11	72.0	696.0	69.6	2.4	3.33
12	78.0	765.0	76.5	1.5	1.92

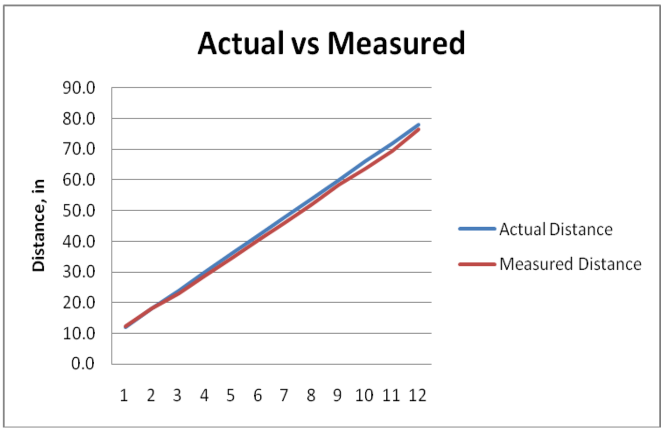

Figure 4.8: Graph of Actual Distance vs Measured Distance

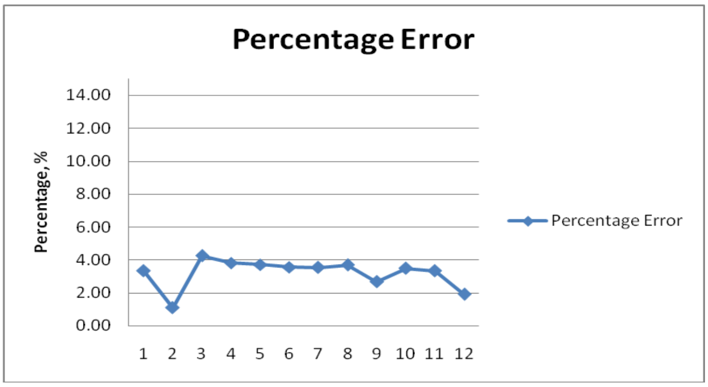

Figure 4.9: Graph of Percentage Error for Distance Measuring Test

Second test was about the wave propagation and the coverage area of the sensor. From the datasheet, the propagation angles of B and C were considered. By using trigonometry equation, the angle of propagation of B was approximate 31.9˚, while C was approximate 39.3˚. By drawing the propagation areas on a mah-jong paper, the test was carried out as shown in Figure 4.10. Beside the specific angles, angles from 0˚-180˚ with the resolution 15˚ were also included. The similar obstacle was use in this test and it was place according to the angle set. In each angle, the obstacle was place in four different distances to obtain the distance measured by the sensor. Table 4.2 showed the result of the experiment.

The rows with yellow shaded represented the angle for the C propagation angle as stated in the sensor's datasheet. While, blue shaded rows were the B propagation angle. Supposedly, according to the information from the datasheet, the sensor would not detect any obstacle that was placed beyond the purple line as shown in Figure 4.11. The shaded area in the Figure 4.11 and the thicker bolder in Table 4.2 showed the detected area according to the sensor datasheet. Surprisingly, after the experiment, the author found out that when the obstacle was placed at the angle of 60˚ and 120˚, it was still able to detect the obstacle as shown in Table 4.2. This make the system more reliable as the sensor coverage was wider compared to the datasheet, which mean that it was able to obtain more information from the surrounding. Percentage errors were calculated by using the difference between the actual distance and measured distance for the detected area (60˚-120˚). Table 4.3 showed the result of the percentage error and a graph was prepared as shown in Figure 4.12 to show the results in one. The result showed that the maximum percentage error was 5% which was still considered as relatively low. In conclusion, the result showed that the design was satisfied.

Figure 4.10: Sensor Coverage Test Setting

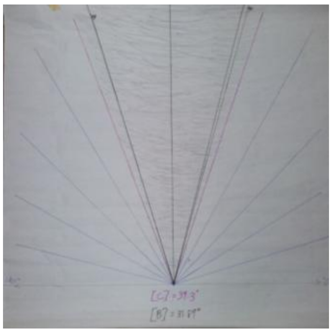

Figure 4.11: Mahjong Paper with Angles Setting

Table 4.2: Sensor Coverage Test Result

		Distance (in)			
		15	**30**	**45**	**60**
Angle (°)	**0**	No	No	No	No
	15	No	No	No	No
	30	No	No	No	No
	45	No	No	No	No
	60	14.30	28.70	43.30	57.90
	70.35 (C)	14.42	28.75	43.50	56.90
	74.06 (B)	14.27	28.77	43.40	57.00
	75	14.28	28.80	43.30	56.90
	90	14.30	28.80	43.50	57.00
	105	14.32	28.77	43.40	57.00
	105.90 (B)	14.32	28.75	43.40	57.00
	109.65 (C)	14.28	28.75	43.40	57.00
	120	15.20	29.80	43.40	58.80
	135	No	No	No	No
	150	No	No	No	No
	165	No	No	No	No
	180	No	No	No	No

Table 4.3: Percentage Error for Sensor Coverage Test Result

Angle (°)	Actual Distance (15 in)		
	Measured Distance	Difference (in)	Error (%)
60	14.30	0.7	4.67
70.35 (C)	14.42	0.6	3.87
74.06 (B)	14.27	0.7	4.87
75	14.28	0.7	4.80
90	14.30	0.7	4.67
105	14.32	0.7	4.53
105.90 (B)	14.32	0.7	4.53
109.65 (C)	14.28	0.7	4.80
120	15.20	0.2	1.33

Angle (°)	Actual Distance (30 in)		
	Measured Distance	Difference (in)	Error (%)
60	28.70	1.3	4.33
70.35 (C)	28.75	1.3	4.17
74.06 (B)	28.77	1.2	4.10
75	28.80	1.2	4.00
90	28.80	1.2	4.00
105	28.77	1.2	4.10
105.90 (B)	28.75	1.3	4.17
109.65 (C)	28.75	1.3	4.17
120	29.80	0.2	0.67

Angle (°)	Actual Distance (45 in)		
	Measured Distance	Difference (in)	Error (%)
60	43.30	1.7	3.78
70.35 (C)	43.50	1.5	3.33
74.06 (B)	43.40	1.6	3.56
75	43.30	1.7	3.78
90	43.50	1.5	3.33
105	43.40	1.6	3.56
105.90 (B)	43.40	1.6	3.56
109.65 (C)	43.40	1.6	3.56
120	43.40	1.6	3.56

Angle (°)	Actual Distance (60 in)		
	Measured Distance	**Difference (in)**	**Error (%)**
60	57.90	2.1	3.50
70.35 (C)	56.90	3.1	5.17
74.06 (B)	57.00	3.0	5.00
75	56.90	3.1	5.17
90	57.00	3.0	5.00
105	57.00	3.0	5.00
105.90 (B)	57.00	3.0	5.00
109.65 (C)	57.00	3.0	5.00
120	58.80	1.2	2.00

Figure 4.12: Graph of Percentage Error for Sensor Coverage Test

4.3 Electronics Development

As mention previously, six ultrasonic sensors were used in the system, so six ADC pins of the microcontroller were needed as the input of the system. In order to have communication with other system, ten I/O ports were included with the pin headers for connection purpose. On the other hand, six I/O ports were set as output to be used as the indicator. Besides that, CCP1 and CCP2 pins under PWM module were included with pin headers as well so that the author was able to control and test with the driving motors before combining with the driving system. Another two I/O ports, RD0 and RD1 were included to control the direction of the driving motor. Lastly, the author included a 10 ways box header in the circuit design to ease the programming process.

In designing the obstacle detection system board, all of the components were included in the Eagle library except the microcontroller. PIC18F4455 was taken to replace PIC18F4520 because both were having the similar set of pins. The schematic design and the board design for the obstacle detection system were as shown in Figure 4.13. The board was fabricated out by the author and the product was as shown in Figure 4.14.

Besides that, a power board circuit for the whole wheelchair system was also designed by author. A readymade 5V/3.3V power stick from Cytron Technologies was used to convert the power source 12V from the battery to the specific voltages. The outputs from the power stick were duplicated out into few molex connectors to supply power. At the same time, 24V from the battery was duplicated out into two connectors for the driving motors and 12V for DC motors. Figure 4.15 showed the schematic and PCB board design for the power board design. Since the power stick was readymade, it did not included in the software library, so the author created the library according to the dimension. Similar to the connector for the 12V and 24V, the author created the library according to the dimension. Once the PCB design was done, the board was fabricated out by the author and the product was as shown in Figure 4.16.

Next, the author came out with a simple design circuit with six LEDs and six 4.7kΩ resistors to work as the indicator for the six ultrasonic sensors. Figure 4.17 showed the simple design where the LEDs were arranged according to the sensors position. The top two LEDs in Figure 4.17 represented the front sensors. Follow on, the left and right LED that represented the left and right of the sensors respectively. Next, the final bottom two sensors represented the back sensors of the wheelchair. With this indicator, the author was able to determine which sensor was detecting an obstacle and which was not. This eased the study of the system behaviour.

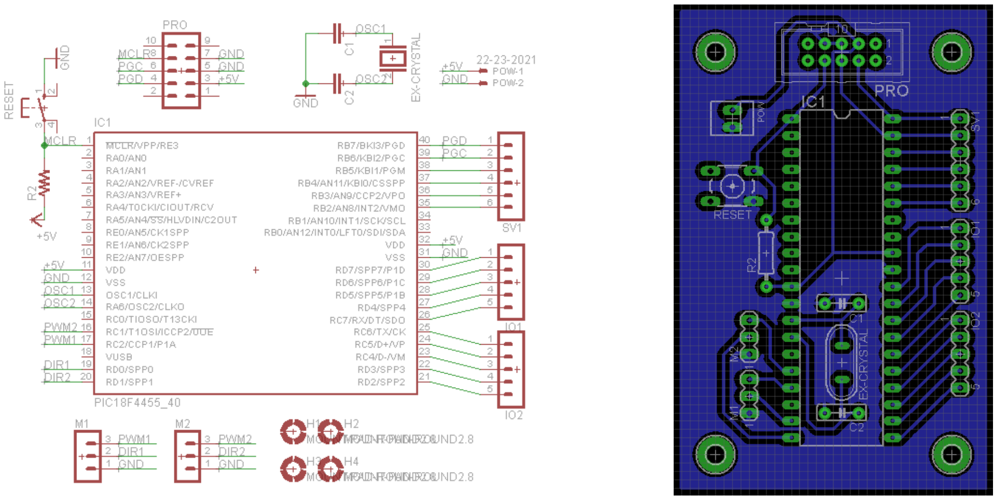

Figure 4.13: Schematic and PCB Board of Obstacle Detection System

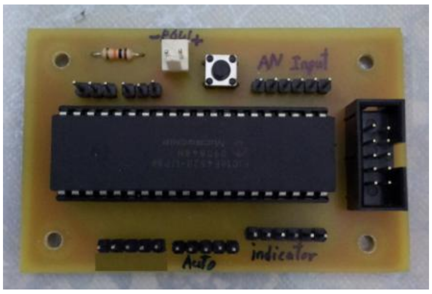

Figure 4.14: Obstacle Detection System Board

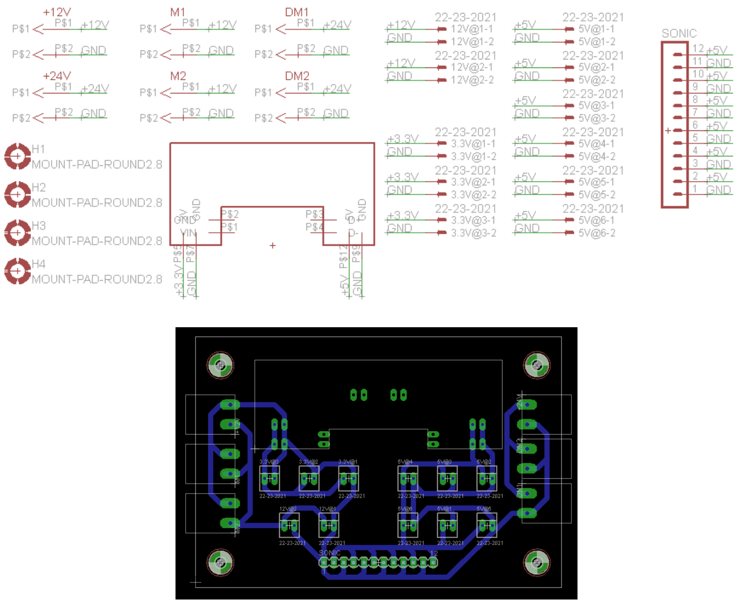

Figure 4.15: Schematic and PCB Board of Power Board

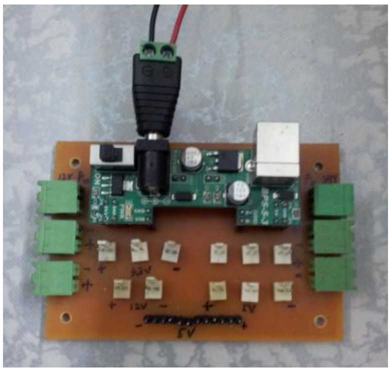

Figure 4.16: Power Board

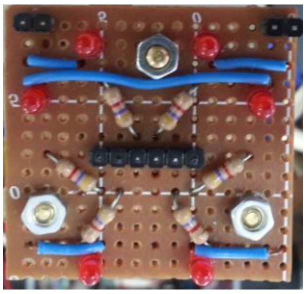

Figure 4.17: Ultrasonic Sensor Indicator

4.4 System Development

After electronics and mechanical developments, the author started with the system development by combining the mechanical and electronic parts. Wiring was done between them as shown in Figure 4.18. Table 4.4 showed the connections of all the header pins of the PIC18F4520. Each row of the header pins were categorized into few groups like sensor input, motor control (PWM) and indicator.

Programming or system coding was developed according to the coding flowcharts shown in Figure 3.3 and Figure 3.4. Since ultrasonic sensor provided analog reading, ADC module was the main function used to obtain the reading from the sensor. The ADC setting for the system was set with a code function ADCInit(). By referring to PIC18F4520 datasheet, two registers, ADCON1 and ADCON2 were included in the function. As mention previously, AN0 to AN5 were set as analog pins. Next, the voltage reference, 5 V was set with V_{dd} and V_{ss} of the microcontroller to simplify the circuit. Since the microcontroller provided a 10 bits ADC module, the author calculated the resolution with the equation as shown below and the result was 1 bit represented 4.88mV.

$$resolution = \frac{V_{ref}}{2^{10}} \tag{4.1}$$

where
V_{ref} = voltage reference, V

According to the sensor datasheet, the sensor provided a voltage output with a range from 0V to 2.55V. Since the maximum output voltage was only 2.55V, it did not use up all the 1024 bits (2^{10}) of the ADC module. By dividing the maximum voltage with the resolution obtained previously, it gives a result of 522.54 which was round off to 522 bits. This showed that the microcontroller would read the sensor reading in bit form from 0 bit to 522 bit that represented the distance detected. According to the datasheet, the sensor was having a resolution of 10mV/in. This means that every changes of the sensor reading (1 in) would make an approximate 2 bits change in the microcontroller. As a conclusion, the resolution of microcontroller's bits per inch was approximate 2bits/in. This resolution was determined to ease the author in developing the coding especially in setting the distance threshold to detect obstacle.

Next, the acquisition time in ADC module was a very important factor. The acquisition time represented the time taken for the microcontroller to take a reading. There were some requirements to obey when setting this factor like the minimum and maximum of A/D conversion clock, T_{AD} which were 0.7µs and 25µs respectively. Since there were six sensors to be read in one time, the author set the acquisition time as fast as possible. With the minimum requirement of T_{AD}, the A/D conversion clock was set to $F_{OSC}/32$. By using the equation as shown below, T_{AD} was calculated to be 1.6µs with 20MHz as the oscillator clock frequency. The result obeyed the requirement where 1.6µs was higher than 0.7 µs.

$$T_{AD} = \frac{1}{\frac{F_{osc}}{32}} \tag{4.2}$$

where

T_{AD} = A/D conversion clock, s

F_{osc} = oscillator clock frequency, Hz

Again, PIC18F4520 datasheet stated that the minimum time acquisition shall be 2.4 µs. Therefore, the following equation was chosen to obey the requirement where the acquisition time was 3.2 µs. As a result, every time the system took the sensor readings, it spent 19.2 µs. After ADC module initialization was done, the coding was constructed according to the two modes presented in the flowcharts

$$T_{ACQ} = 2T_{AD} \tag{4.3}$$

where

T_{ACQ} = acquisition time, s

T_{AD} = A/D conversion clock, s

After the ADC initialization, a function, ADCRead(x) was prepared in the coding. It eased the sensor reading process as there were six ultrasonic sensors included in the system. In the function, the correct channel of the ADC must first determined before the ADC was ON and started. For example, when the front left sensor reading was needed, the variable x value was set to two with the statement ADCRead(2). This was because the sensor was connected with the pin, AN2. Once the channel was set, the ADC was ON and started by the coding. Once the reading was taken, the GO_DONE bits in the register ADCON0 became zero state which indicated the reading process was done. The ADC was then set OFF and then returned the reading value to the variable set in the coding for further usage.

Lastly, a delay function, msdelay(y) was included in the coding to ease the programming process when a delay was needed. The delay function was having an approximately 10ms delay which mean it was having a delay with the resolution

10ms. The variable, y value represented the multiplier value of the delay. For example, in order to achieve a 50ms delay, the value x was set to be five with the statement msdelay(5).

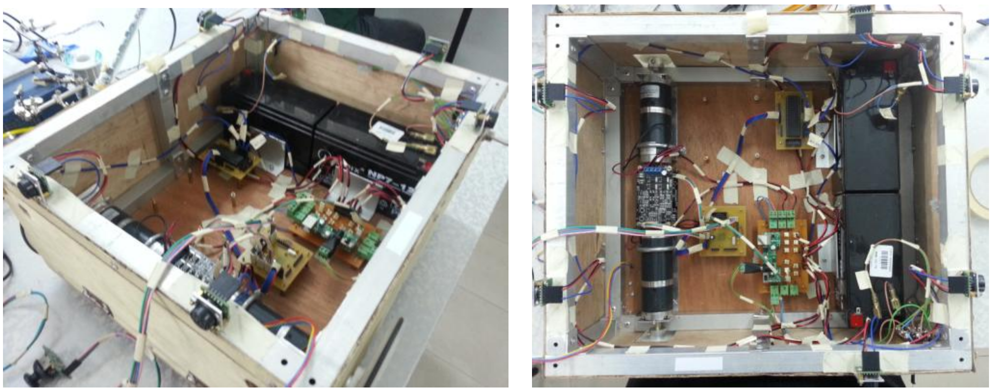

Figure 4.18: Combination between Electronics and Mechanical

Table 4.4: Microcontroller Pin Assignment

Ultrasonic Sensor Input		**Sensor ON/OFF Control**	
Pin	**Position**	**Pin**	**Position**
AN0	Front Right (FR)	RC6	Back Right (BR)
AN1	Right (R)	RC5	Back Left (BL)
AN2	Front Left (FL)	RC4	Front Left (FL)
AN3	Left (L)	RD3	Front Right (FR)
AN4	Back Left (BL)	RD2	Off Automated Mode (Input from driving system)
AN5	Back Right (BR)		

Indicator		**Motor Control**		**Driving System**	
Pin	**Position**	**Pin**	**Motor**	**Pin**	**Driving Signal**
RB7	Left (L)	CCP1	Motor Speed 1	RD7	Forward
RB6	Back Left (BL)	CCP2	Motor Speed 2	RD6	Left
RB5	Front Left (FL)	RD0	Motor Direction 1	RD5	Right
RB4	Front Right (FR)	RD1	Motor Direction 2	RD4	Reverse
RB3	Back Right (BR)			RC7	Mode Input
RB2	Right (R)				

4.5 System Testing

4.5.1 Introduction

Since there were two modes, automated and semi-automated in this system, the system was going to test accordingly and presented separately. Before any combination with other system, the author tested the system by using LEDs to show the output of the microcontroller. A breadboard was used in this testing to construct the LEDs and button as shown in Figure 4.19. Green LEDs indicated the signals output from the microcontroller to the driving system, while the single yellow LED indicated the input from the driving system to the microcontroller to change between the two modes. Since there was no connection with the driving system yet, a button was used to change the signal to choose the mode of the system. The breadboard was temporally attached on the wheelchair as shown in Figure 4.20 for better viewing during the testing process.

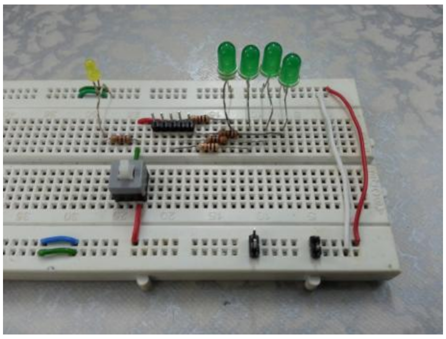

Figure 4.19: Testing Circuit on Breadboard

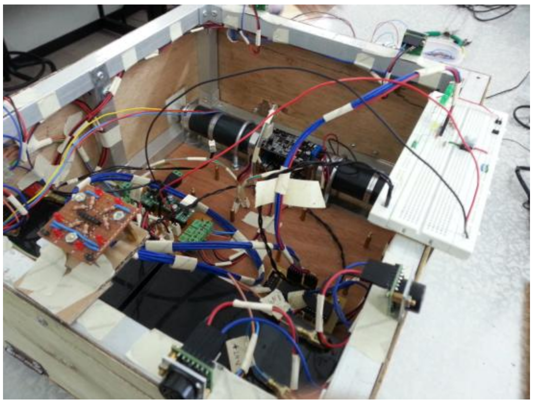

Figure 4.20: Testing Circuit Breadboard on Wheelchair

4.5.2 Semi-Automated Mode

The system under semi-automated mode responded to its algorithm and flow chart as shown in Figure 3.4. According to the coding constructed, I/O pins from RD4 to RD7 were chosen to send the output signals according to the directions. On the other hand, RC7 was the input pin for the choice of the system mode. The most right green LED as shown in Figure 4.19 represented the forward motion signal where the driving system limited the wheelchair from moving forward. In this situation, the user was unable to move the wheelchair to forward with the joystick. The second right green LED represented left turning and followed with the third and forth that represented the right turning and reverse. For this mode, the input to the microcontroller had to be in LOW state where the yellow LED on the testing circuit breadboard must not light up.

4.5.2.1 Result

The semi-automated test was presented in this section. Few situations were prepared and the results were observed. Figures from Figure 4.21 to Figure 4.24 represented the output when one of the sensor coverage areas of the wheelchair was being blocked. Lastly, Figure 4.25 represented the outcome when multiple sensors detected obstacles.

As shown in Figure 4.21 where the front sensor was tested, the top two LEDs of the indicator were lighted up and the microcontroller outputted the forward signal which was represented by the most right green LED. The test was continued with the left sensor where the left sensor of the indicator was lighted up and the second most right of the green LED was lighted up that represented left turning signal. Similar test was run for right sensor and back sensors and the results were satisfied as it followed the expected outcome according to the coding. Next, the author also carried out a test on a situation where multiple obstacles were blocking the wheelchair. Obstacles were put at the front right sensor, left sensor and right sensor. The result of the test was shown in Figure 4.25 where the LEDs of the indicator were lighted up accordingly to the sensors and the microcontroller outputted the signals to limit the motion of forward, left and right. As a conclusion, the semi-automated system was working and the results were satisfied.

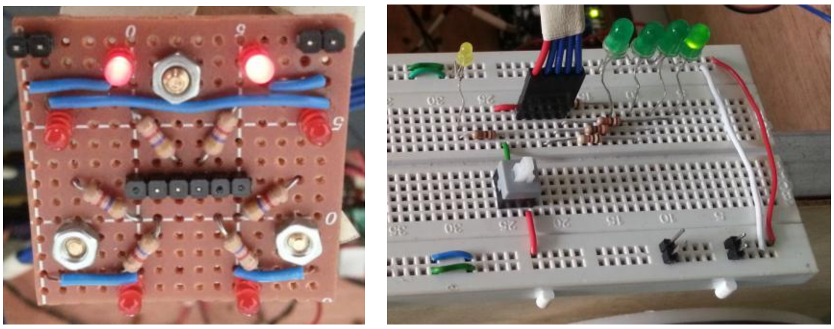

Figure 4.21: Front Sensor Test

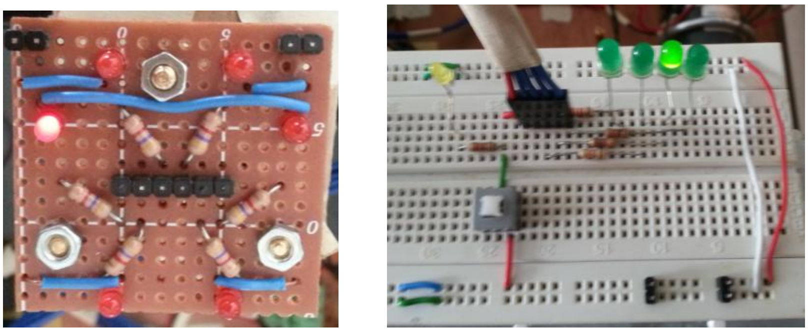

Figure 4.22: Left Sensor Test

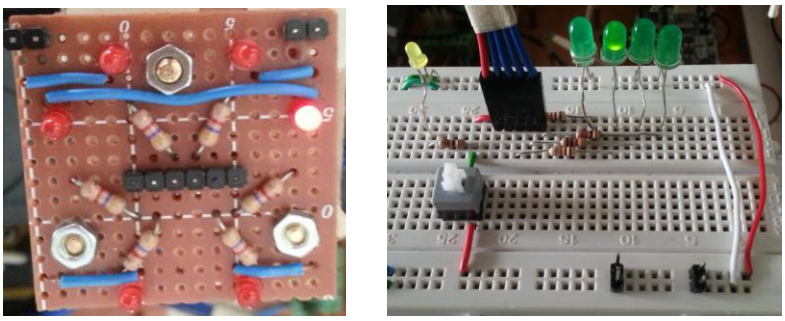

Figure 4.23: Right Sensor Test

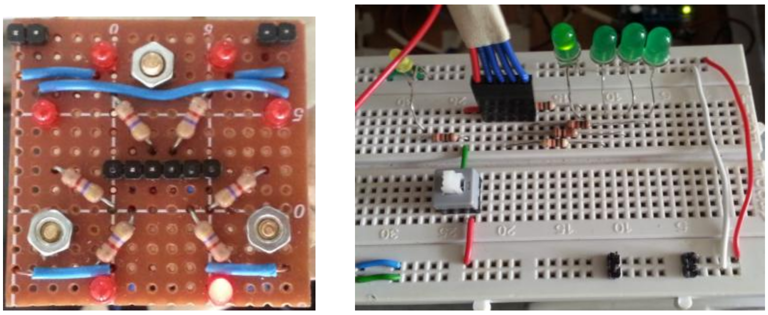

Figure 4.24: Back Sensor Test

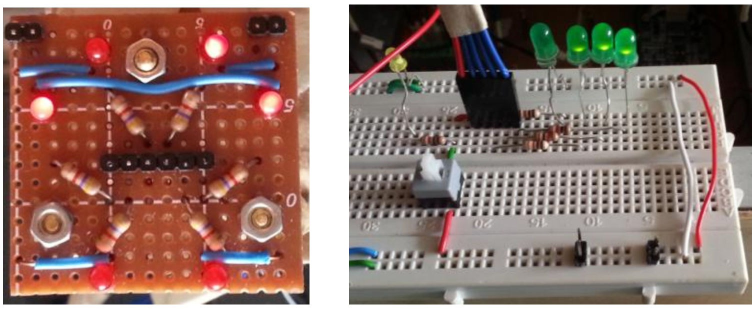

Figure 4.25: Multiple Sensors Test

4.5.3 Automated Mode

After the testing on the semi-automated mode, this section presented the automated mode test. Similar to semi-automated mode, the indicator and the testing circuit breadboard were used. In this mode, the indicator instead of only showing the specific position sensor detected an obstacle or not, it also used to show the stage of the automated system. Since both automated and semi-automated would never work at the same time, the same I/O ports from semi-automated mode were used. The similar signals were sent by the microcontroller to control the wheelchair motion. The only different was semi-automated mode limit the specific motion, but automated mode wants the driving system to response according to the signal provided. For example, if forward signal was sent by the obstacle detection system, the driving system must run the wheelchair in a forward motion straight to the front. As opposite from semi-automated mode, the input of the microcontroller must set to

HIGH state in order run the system in automated mode. The yellow LED on the testing circuit must light up as shown in Figure 4.26.

4.5.3.1 Result

The result for automated test was presented in this section where the concept as shown in the flow chart in Figure 3.3 was showed. Different from the semi-automated mode, automated mode was a process in avoiding an obstacle that blocking the front path during navigation. Therefore, instead of showing different situations, the system was tested with the whole process and the results were shown from Figure 4.26 to Figure 4.29.

The whole process was started when the front sensor detected an obstacle. This activated the system to overwrite the navigation system to control the wheelchair motion. The obstacle detection system was communicated with the driving system. The two front LEDs of the indicator will lighted up as shown in Figure 4.26 once it detected an obstacle at the front. As stated in the automated mode algorithm, the wheelchair would slow down and then leaned right until the front left sensor detected the obstacle's edge. During the lean right motion (second left green LED), the front right LED went off first followed by the front left LED as shown in third photo of Figure 4.26. Once the front left detected the obstacle's edge, the wheelchair remained lean right motion for another two seconds to make sure that it would not collide with the obstacle during the next motion. Then, the wheelchair was commanded to move forward until the left sensor detected the obstacle's edge. This was why the left LED was lighted up in this stage and the most right green LED represented the forward signal as shown in 4.27.

The process was carried on until the left sensor detected another obstacle's edge that indicated the wheelchair had come to the end of the obstacle. Forward signal (most right green LED) was sent for four seconds so that the wheelchair was totally passed the obstacle's edge. Finally, the wheelchair was instructed to lean left (second most right green LED) for two seconds followed by forward signal (most right green LED) until the wheelchair was back to the navigation path. All the LEDs result was showed in Figure 4.28. After that, the navigation system took back the wheelchair motion control.

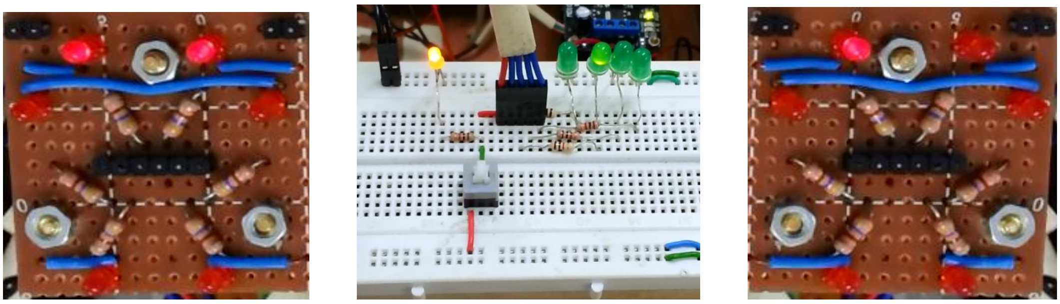

Figure 4.26: Automated Test 1

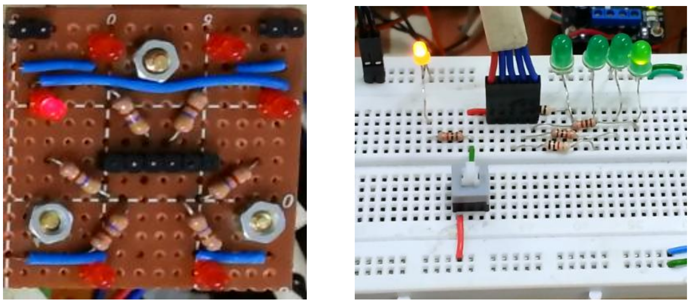

Figure 4.27: Automated Test 2

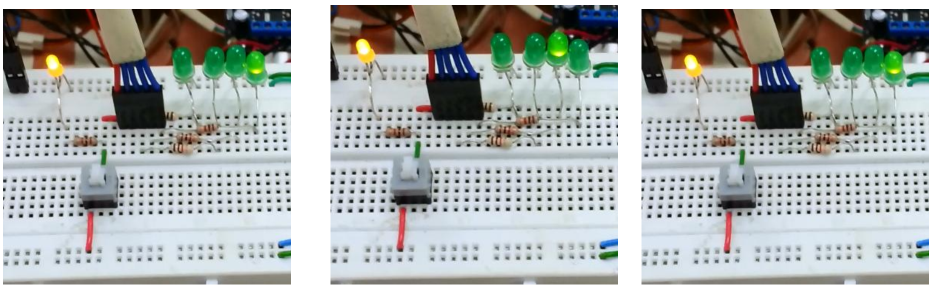

Figure 4.28: Automated Test 3

4.5.4 Discussion on System Test

From the tests presented above, both semi-automated and automated modes were providing satisfied result. The system did follow the programming with the readings from ultrasonic sensors and then outputted the wheelchair motion signal accordingly. Each of the tests had repeated for ten times to ensure that both coding were useable and reliable. From all the tests, failure did happen on the front or back sensors.

Ultrasonic waveforms from the sensors interrupted each other readings. This was due to the similar frequency waveform used in MaxSonar-EZ1. For example, when the front left sensor emitted a waveform and reflected by an obstacle which was not perpendicular to the sensor, the waveform was then reflected to another direction toward the front right sensor. With the reflected waveform, the front right sensor did detect and assumed there was an obstacle located at the front. This situation was presented in Figure 4.29. In order to overcome this situation, RX pin of each of the sensors located at the front and back of wheelchair were connected to the microcontroller of the system. This pin allowed the system to ON/OFF the sensor, so the two sensors that located at the same row (front or back) were set to ON/OFF alternatively. For example, if front left sensor was ON, front right sensor would set to OFF, then front left sensor would take the reading. After that, the front left sensor was set to OFF, while front right sensor was ON and took its reading. A short delay was provided so the sensor had enough time (20 µs) to startup. With this setting, both sensors would never ON at the same time. The short delay time was decided to be 30ms after some try an error and testing. Although this method did improve the result, but it was still having few minor interrupt. This was because the delay time was not long enough which had to be approximate 0.1s. The system did not provide such a long delay because it was going to affect the system response which was one of the main factors in this project.

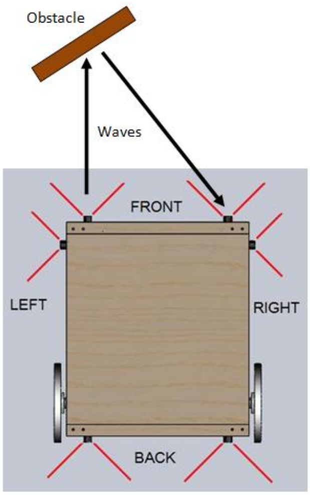

Figure 4.29: Sensor Wave Interruption

4.6 Systems Combination

4.6.1 Introduction

After individual system test, the obstacle detection system was combined with driving system and navigation system to come out with whole semi-automated wheelchair design. In semi-automated mode, the obstacle detection system communicated with the driving system without the interference from the navigation system. On the other hand, both obstacle detection system and navigation system took turn to communicate with the driving system by providing the motion signals in different situation during automated mode. Again, different types of testing were conducted for both automation and semi-automated modes to study about the system behaviour and its reliability.

4.6.2 Semi-Automated Mode

This mode was used when the user was manually control the wheelchair motion. Similar to other existing motorized wheelchair, the driving system included an analog joystick for the user to control the wheelchair motion. As mention previously, the obstacle detection system worked as the supporter to the user in term of safety. It helped the user in detecting an obstacle that tended to block the wheelchair and then prevented the user to control the wheelchair toward the obstacle, which then prevented collision with the obstacle. The obstacle detection system would send signals to the driving system to limit the motion control from the user toward the obstacle direction. For example, when there was an obstacle happened to block at the front of the wheelchair, the user cannot moved the wheelchair to the front anymore. The user either controlled the wheelchair in left or right turning, or the reverse motion to avoid the obstacle. Once the obstacle was no longer blocking the wheelchair, the forward motion was back to control.

Some tests were run through for the semi-automated system to study the behaviour of the wheelchair. Four different obstacles were prepared as shown in Figure 4.30 where the most left was a semi-transparent water bottle with cylindrical shape, followed by a rectangular shoe box and a larger rectangular CPU box. The most right obstacle would be a chair with irregular shape. Water bottle was prepared to represent water bottle and medicine container that occurred in a hospital. On the other hand, two different sizes of box were tested to observe the system detection ability in term of size. Lastly, the chair represented any of the furniture and hospital equipments like trolley that having irregular shape. On the other hand, moving human represented the moving obstacle for the tests.

First of all, the system was tested in term of the sensor range coverage. Before the test was carried out to study the system behaviour, trial and error method was used to determine the best range to be set for the obstacle detection system. The PC box obstacle was used because it was assumed to be the best obstacle for the system to be detected. From the test, the front and back range was set to be 20in, while 15in was set for left and right. A longer range was set for the front because it was widely used, and the forward motion was more likely to achieve the maximum speed. Therefore, a longer distance was needed for the wheelchair to come to a stop. Once the ranges were set, the system was carried on with the other tests.

Since the system limited the motion in four directions, four tests were carried out for each of the directions with the obstacles prepared. By using a contact tachometer as shown in Figure 4.31, the revolution per minute (rpm) of the wheel was determined as shown in Figure 4.32. The maximum speed of the wheelchair was set with the joystick and the rpm was determined to be around 407.0rpm as shown in Figure 4.32. From the rpm, the maximum speed of the wheelchair was determined to be 0.68m/s by using the equation 4.4 as shown below.

$$v = 2\pi r \times rpm \times \frac{1\text{min}}{60s} \tag{4.4}$$

where
v = speed of wheelchair, m/s
r = radius of tachometer wheel, m = 0.016m
rpm = number of revolution per minute, rpm

The objective of this test was to determine whether the wheelchair was able to come to a stop to prevent collision when it was travelling in full speed or half of the full speed for forward and reverse motion. On the other hand, a normal speed was used for left and right turning test. This was a very important factor in this project because it did include the user safety. In this test, the number of collision and non-collision were recorded and the result was studied. As shown in Figure 4.33, one of the obstacles, PC rectangular box was put at the front of the wheelchair with a distance, which was approximate 1.5m. The distance was needed because the wheelchair needed a period to reach its full speed before it reached the obstacle. This distance was determined with the equation 4.5 as shown below. From the rpm measuring by tachometer, the time taken to reach 407.0rpm was about 4s, so the acceleration of the wheelchair can be determined with the equation 4.6. From the calculation, the acceleration was 0.17m/s^2. After that, the distance was calculated with equation 4.5 and the minimum distance needed was 1.36m. By considering factors like wheel slip, the test distance was set to be 1.5m as mention previously.

$$s = ut \times \frac{1}{2} at^2 \tag{4.5}$$

where

s = distance, m

u = initial velocity, m/s = 0m/s

t = time taken, s

a = acceleration, m/s^2

$$a = \frac{v - u}{t} \tag{4.6}$$

where

a = acceleration, m/s^2

s = distance, m

u = initial velocity, m/s = 0m/s

t = time taken, s

The setting in Figure 4.33 showed the full speed test for the PC box obstacle and the result was recorded in Table 4.5. The test was carried on with the half full speed test with forward motion, and then repeated the both tests with the other obstacles. Next, the tests were repeated with reverse motion. After that, a normal speed was used for left and right turning test and the test was also repeated for the four obstacles. Each of the tests was carried out for thirty times to obtain a better result for observation. The result obtained was observed and discussed in the next section

Next, a random moving test was carried out with all the obstacles presented at the wheelchair surrounding as shown in Figure 4.34. By using the joystick prepared by the driving system, the wheelchair was controlled to move from an end to another passing through the obstacles presented randomly. The objective of this test was to determine the reliability of the obstacle detection system according to a random obstacle presented from time to time. The random moving test was repeated for thirty times fore and back and the number of collision and non-collision were recorded. The number of collision and non-collision was calculated when there was an obstacle blocking the current motion. For example, if the wheelchair was turning left, and there was an obstacle tended to block the way, the system suppose to limit the left motion where the wheelchair will come to a stop if the joystick remain the left turning. If the wheelchair comes to a stop without hitting the obstacle, it was counted as non-collision, while it was counted as collision if the wheelchair hit the obstacle. The result for this test was presented in Table 4.6. Again, the result was observed and discussed in the next section.

Figure 4.30: Four Obstacles for Testing

Figure 4.31: Contact Tachometer

Figure 4.32: Determined rpm with Contact Tachometer

Figure 4.33: Full Speed Test with PC Box Obstacle

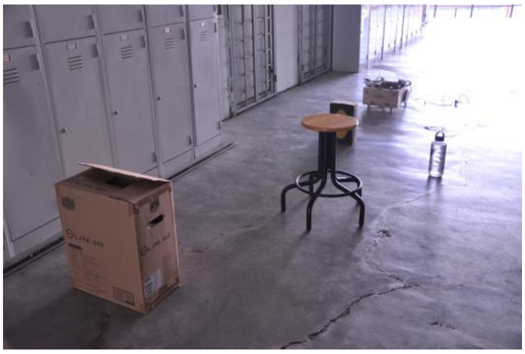

Figure 4.34: Random Moving Test Setting

4.6.2.1 Result and Discussion

The result obtained from the semi-automated system tests were presented and discussed in this section. Table 4.5 showed the result from the range test and the overall outcome showed a satisfied result. For example, there were only nine collision happened over the one hundred and twenty tests on the full speed forward test. In percentage, the result represented 7.5% which mean that there was only 7.5% chance that collision may happened when the wheelchair was moving forward toward an obstacle in full speed. In forward test, two situations, full speed and half full speed was prepared. From the result, the tests were perfect without any collision for both PC and shoe boxes that used as the obstacle. Unfortunately, the collision tended to happen when the obstacle were water bottle and chair. When the wheelchair was tested in full speed, there were six collisions happened for water bottle and three collisions for chair. This result was better when the test came into half full speed where there were only two collisions and one collision happened for water bottle and chair respectively. Besides that, the system showed eight collisions and five collisions when a moving human was the obstacle. On the other hand, almost similar trend of result occurred in reverse motion test. Four and six collisions happened during the full speed test for water bottle and chair respectively, while two and three collisions during the half speed test. The main factor causing such a result was the ultrasonic waveform reflection's behaviour. Due to the round surface of the water bottle and irregular shape of the chair, the waveform tended to reflect to another direction instead of back to the sensor.

In left and right turning test, instead of having perfect zero collision, two collisions happened during the right turning when the shoe box was used. For water bottle and chair, there were also a number of collision happened. Comparing to the forward and reverse motion, more collision happened in turning motion. Besides the behaviour of the waveform reflection, the turning motion was also affecting the sensor ability. When the wheelchair was turning, there was a large change in the sensor coverage. As shown in Figure 4.35, if the obstacle blocking the front and the wheelchair was moving forward, the obstacle was getting closer to the wheelchair according to the speed of wheelchair. The obstacle would reach the threshold set, 20 in and slowly closer to the wheelchair. The situation was different during the turning motion. Figure 4.36 shows the obstacle located at the right of the wheelchair. In the first picture, the obstacle was not in the right sensor coverage. When the wheelchair was turning, the obstacle tended to appear in the coverage in a sudden. Due to this phenomenon, the obstacle had the high possibility to appear in the coverage with the distance that much smaller compare to the threshold set, 15in. This was one of the factor causing the wheelchair collided with the obstacle during the turning motion.

The result was converted into percentage to ease the observation of the result and showed in Table 4.6. From the percentage, all the tests were having a success percentage above 80% except right turning test with the water bottle which was 73.33%. The system was perfect in certain degree where 100% success was achieved in the situation like forward motion with rectangular obstacle. With the percentage result, it can be concluded that the system behaviour was acceptable and satisfied.

Next, Table 4.7 and Figure 4.38 below showed the result for the random moving test. A graph of the result for the number of collision and non-collision was constructed to have a better view of comparison. From the thirty trials, there were total eighty eight times collision happened and one hundred and sixty times where no collision happened. From the eighty eight time of collision, most of them were happened with the chair and water bottle. As discussed about the ultrasonic characteristic previously, the reflection of ultrasonic waveform may diverted to another direction if the obstacle surface was not perpendicular to the sensor. This was why the system unable to detect the obstacle and the system did not limit the motion toward the obstacle. With the number of collision and non-collision, the percentage of collision and non-collision can be calculated with the overall total, two hundred and forty eight times as shown in equation 4.7. From the calculation, the collision percentage was 35.5% while non-collision was 64.5%. There were few factors affecting this result which cause the obstacle detection system became not that reliable.

$$percentage = \frac{number}{total} \tag{4.7}$$

where
percentage = percentage of collision or non-collision
number = number of collision or non-collision
total = total number of events occur = 248

The main factor causing such a result was the imperfect fabrication of the wheelchair. Four of the wheels were not touching the ground equally where the left driving wheel was slightly higher compare to the right driving wheel. This caused the turning motion imperfect especially during the right turning where the left wheel was unable to contact with the floor. Although the driving wheels were being modified to improve the grip level, it was not overcome the problem perfectly. Next, the interruption between the ultrasonic waveform as mention previously was also one of the factors causing the system became unstable. This interruption was causing the test process taking longer time to finish as the front sensor limited the forward motion from time to time without an obstacle.

Besides that, after the random moving test, the author found out that the wheelchair control was facing a problem when there were multiple obstacles occurred at the surrounding. Due to the range setting where a distance was needed to allow the wheelchair come to a stop, the system will limited the motion although the obstacle was still far from the wheelchair. For example, as shown in Figure 4.37, when the wheelchair was 20 in from the front obstacle, it was unable to move any forward as limited by the system. In the situation set like Figure 4.37, there was actually a hole at the front that allowed the wheelchair to escape from the trap if it could move another 10 in forward and then turn left. Therefore, the system was concluded that it was more reliable when it was used under a wide space with lesser obstacles like hospital environment.

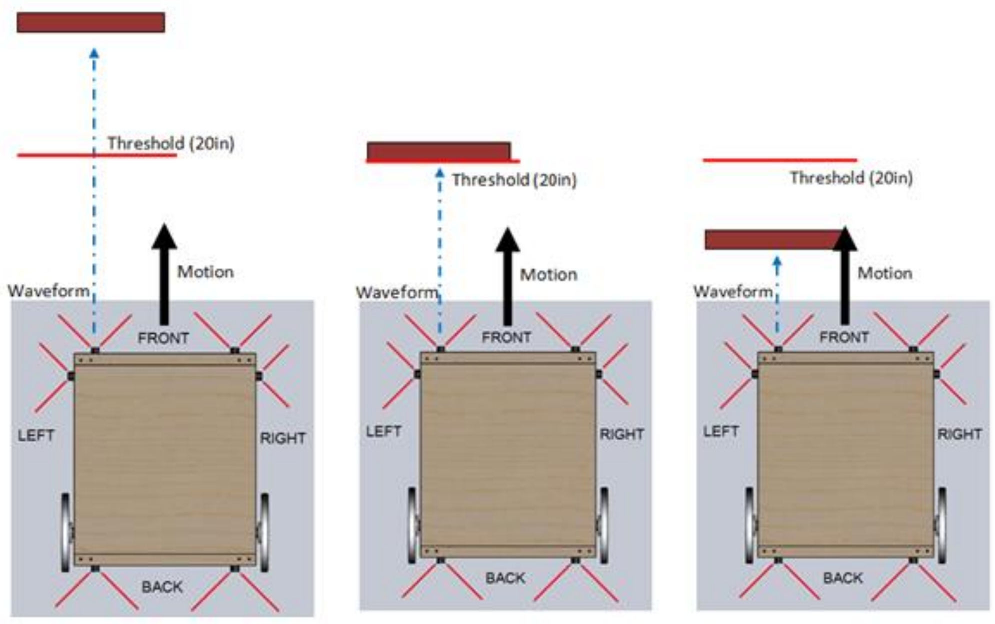

Figure 4.35: Obstacle Detection with Forward Motion

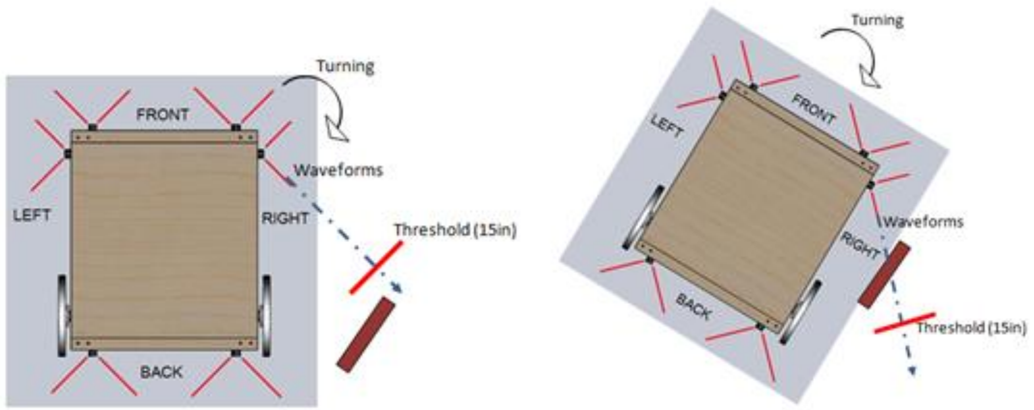

Figure 4.36: Obstacle Detection with Right Turning Motion

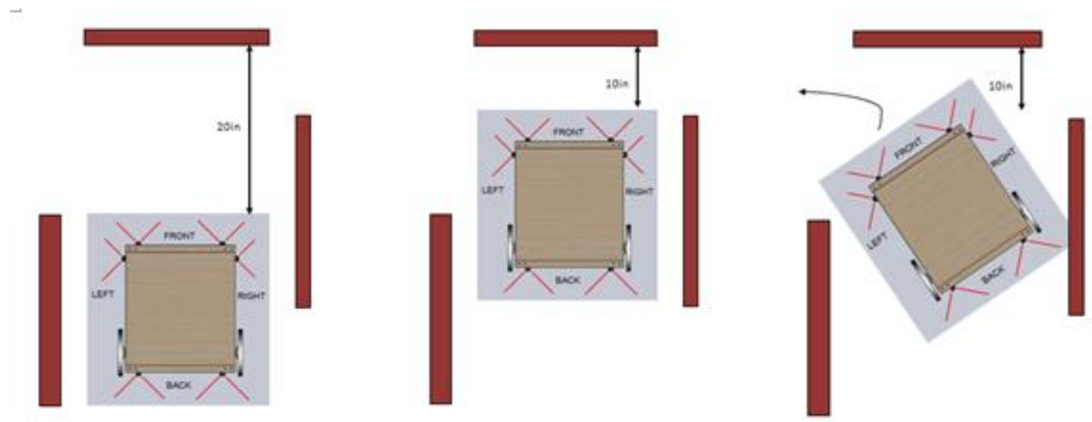

Figure 4.37: Chance to Escape from Trap

Table 4.5: Range Test Result

Tests	Full Speed		Half Full Speed	
Forward	**Collision**	**Non-Collision**	**Collision**	**Non-Collision**
PC Box	0	30	0	30
Shoe Box	0	30	0	30
Transparent Water Bottle	6	24	2	28
Chair with Irregular Shape	3	27	1	29
Human (Moving Obstacle)	8	22	5	25
Total	**17**	**133**	**8**	**142**
Reverse	**Collision**	**Non-Collision**	**Collision**	**Non-Collision**
PC Box	0	30	0	30
Shoe Box	0	30	0	30
Transparent Water Bottle	4	26	2	28
Chair with Irregular Shape	6	24	3	27
Human (Moving Obstacle)	6	24	4	26
Total	**16**	**134**	**9**	**141**
	Left (Normal Speed)		**Right (Normal Speed)**	
PC Box	0	30	0	30

Shoe Box	0	30	2	28
Transparent Water Bottle	6	24	8	22
Chair with Irregular Shape	5	25	4	26
Human (Moving Obstacle)	18	12	20	10
Total	**29**	**121**	**34**	**116**

Table 4.6: Range Test Result in Percentage

Tests	Full Speed		Half Full Speed	
Forward	**Collision (%)**	**Non-Collision (%)**	**Collision (%)**	**Non-Collision (%)**
PC Box	0	100	0	100
Shoe Box	0	100	0	100
Transparent Water Bottle	20	80	6.67	93.33
Chair with Irregular Shape	10	90	3.33	96.67
Human (Moving Obstacle)	26.67	73.33	16.67	83.33
Total	**11.33**	**88.67**	**5.33**	**94.67**
Reverse	**Collision (%)**	**Non-Collision (%)**	**Collision (%)**	**Non-Collision (%)**
PC Box	0	100	0	30
Shoe Box	0	100	0	30
Transparent Water Bottle	13.33	86.67	6.67	93.33
Chair with Irregular Shape	20	80	10	90
Human (Moving Obstacle)	20	80	13.33	86.67
Total	**10.67**	**89.33**	**6**	**94**
	Left (Normal Speed)		**Right (Normal Speed)**	
PC Box	0	100	0	100
Shoe Box	0	100	6.67	93.33
Transparent Water Bottle	20	80	26.67	73.33
Chair with Irregular Shape	16.67	83.33	13.33	86.67
Human (Moving Obstacle)	60	40	66.67	33.33
Total	**19.33**	**80.67**	**22.67**	**77.33**

Table 4.7: Random Moving Test Result

No. of Trial	No. of Collision	No. of Non-Collision
1	2	5
2	3	6
3	1	4
4	2	4
5	1	7
6	4	6
7	3	5

8	2	5
9	5	4
10	3	6
11	2	5
12	5	5
13	1	8
14	4	7
15	2	5
16	3	6
17	6	6
18	5	4
19	4	6
20	3	4
21	1	4
22	2	7
23	4	6
24	5	4
25	3	5
26	2	6
27	2	5
28	1	4
29	3	5
30	4	6
Total	**88**	**160**

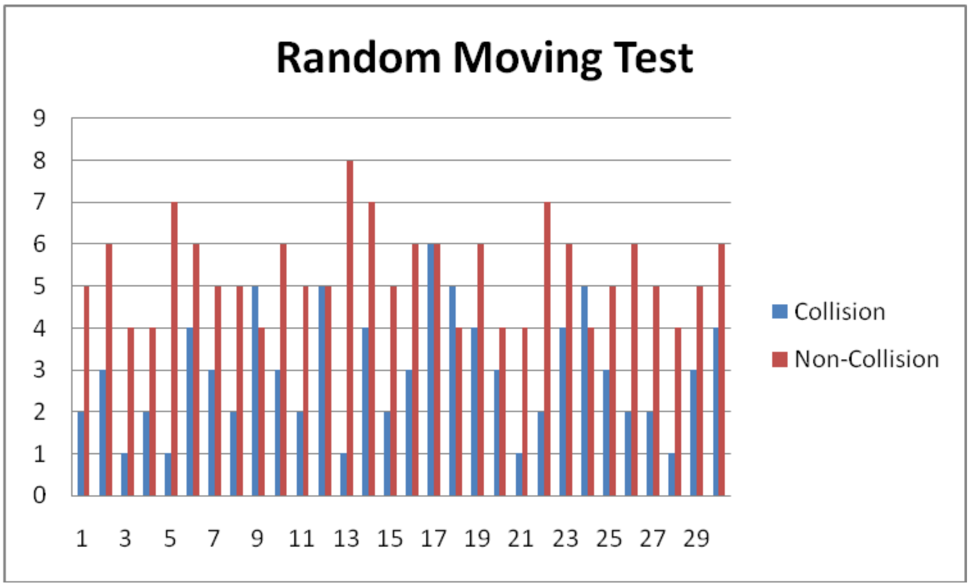

Figure 4.38: Graph of Random Moving Test

4.6.3 Automated Mode

Automated mode was used when the wheelchair was moved by itself without any control from the user. Three systems, navigation system, obstacle detection system and driving system were combined to form the whole system. Navigation system was the one taking command from the user where the user had to set his current location and then the destination. Once the user confirmed his choice, the navigation system started to navigate to the destination with the wheelchair path prepared. During the navigation, obstacle detection system was activated to detect if there was any obstacle happened to block the path. Once an obstacle was detected, the system would run its program and outputted the particular signals to the driving system to avoid the obstacle. The wheelchair would back to the path after the obstacle had been avoided. Once the wheelchair was back to the path, the navigation system was then taken over the wheelchair control, while obstacle detection system was set back to the detecting mode.

Again, trial and error method was used to determine the variables of the coding like the threshold distance to detect an obstacle. After the coding was completed, test was run for thirty times with the four obstacles prepared. Figure 4.39 showed the test setting where the setting was set on the navigation system testing track and an obstacle was put at the front of the wheelchair. The wheelchair was started by input the data of the current location and destination into the navigation system. Once the obstacle prepared was detected by the system, the obstacle detection system was taken over the wheelchair control by communicate with the driving system. As set in the coding, the wheelchair leaned to the right side to avoid the obstacle because the wheelchair path was decided to construct near to the left wall. The result from tests was recorded in Table 4.8 and it was discussed in the next section.

Figure 4.39: Automated System Test

4.6.3.1 Result and Discussion

The result for automated system test was presented in this section where Table 4.8 and Figure 4.40 were prepared. From Table 4.8, the test was perfect for PC box and shoe box where there were zero collision for the thirty trials. Next, there was only two collision happened when water bottle was the obstacle. With the result, the success percentage was calculated to be 93.33% which was considered as a good outcome. Unfortunately, the test becomes worse when the irregular shape chair was used. The system failed to avoid the chair for twenty two times over thirty trials, which gave a 26.67% of success rate only. The main factor causing such a result was the irregular shape of the chair where there was no exact edge that presented as the whole object edge. Due to its hollow design of the chair, the system was confuse on determine front edge and end edge of the obstacle. Therefore, the system was failed to avoid such an obstacle.

Table 4.8: Automated System Test Result

Obstacles	Collision	Non-Collision
PC Box	0	30
Shoe Box	0	30
Transparent Water Bottle	2	28
Chair with Irregular Shape	22	8
Total	**24**	**96**

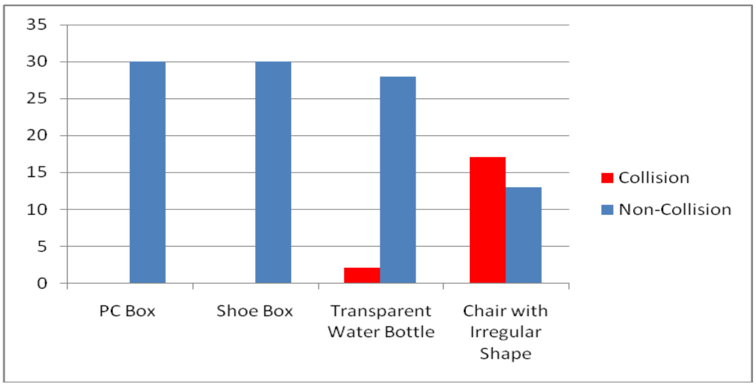

Figure 4.40: Graph of Automated System Test

During earlier stage, instead of using edge detection concept only, the author was combining edge detection and wall following concepts to construct the system. The wall following was applied after the left sensor detected the front edge of the obstacle. The system would then follow the obstacle boundary with the wall following concept until it reached the end edge of the obstacle. Once the end edge was detected by the left sensor, the wheelchair was concluded that it had pass by the obstacle, and the wheelchair was started to move back to the wheelchair path. The algorithm for the previous design was as shown as below, while the flowchart was showed in Figure 4.41.

1. Detect obstacle bloking the front path.
2. Slow down the speed and start to steer to the right.
    a. Front sensor detect obstacle edge. Go to step 3.
    b. If not. Repeat with step 2.
3. Steer another short period to the right.
4. Move forward with slightly to the left steer.
    a. Front sensor detect obstacle. Go to step 3.
    b. If no. Go to step 5.
5. Move along obstacle boundary with left sensor.
    a. Left sensor detect obstacle edge. Go to step 6.
    b. If no. Repeat step 5.
6. Move forward with another short period.
7. Move forward with slightly left steering.

   a. Detect line path (navigation system). Go to step 8.
   b. If no. Repeat step 7.
8. Navigation system takes over the control.

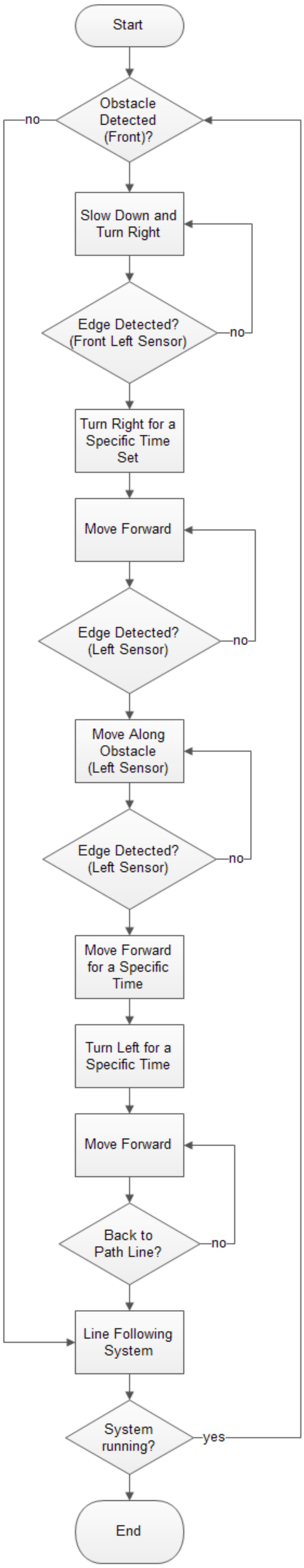

Figure 4.41: Previous Automated Mode Flow Chart

Unfortunately, the system design failed to achieve the objectives. This was because the obstacles prepared were not big enough for the wall following to take part. Instead of finding a larger obstacle, the author concluded that it was impossible for a large obstacle blocking the wheelchair path in a hospital. This was because the path was specially constructed for the wheelchair and large object like furniture will never put on the path. Therefore, the coding was modified to take out the wall following concept and the outcome was as shown in result mentions previously.

Besides that, the surrounding condition for the system to avoid the obstacle must clear from other obstacle. The system was build to avoid only one obstacle in a time. If there was another obstacle tended to occur in the surrounding, the wheelchair may collide with it. Further improvement on the automated system was needed and was discussed in recommendation section.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The result showed in this project was acceptable and satisfied. It did achieve the objectives of the project to a certain degree. I would like to conclude that semi-automated mode achieved its objective in the sense that, it did help the wheelchair preventing collision with the obstacle when the user was controlling. The system cut off the particular motion control instead of giving warning to the user to stop the wheelchair. Deceleration was provided instead of sudden stop to improve the comfortable of the user. On the other hand, automated system was also concluded that it did achieve the objective with the condition that there was only one obstacle occurred in a time and the obstacle must has clear edges. Further study as mentioned in recommendation section shall include in the project to improve the system.

5.2 Recommendations

Although the system was success to a certain degree, it was still can improve to make the system perfect. A better fabrication of prototype may needs on future study so that it is not the main factor affecting the result. Besides that, the automated system has to improve so that it was able to deal with complex environment instead of one obstacle in a time. For example, it may come to a stop first and check the surrounding before take action in avoiding the obstacle that blocking the wheelchair path. Next, the system may improve in the sense that the user was able to change the mode of the system from time to time. For example, if the user is navigating from his room to the cafeteria, he can change to semi-automated system so that he can control the wheelchair to the toilet if needed.

REFERENCES

Bischoff, R., 1999. Advances in the Development of the Humanoid Service Robot HERMES. In *Second International Conference on Field and Service Robotics (FSR'99)*. Pittsburgh, PA. Available at: http://www.rz.unibw-muenchen.de/~161brai.

Borenstein, J. & Koren, Y., 1988. Obstacle avoidance with ultrasonic sensors. *IEEE Journal on Robotics and Automation*, 4(2), pp.213–218. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=2085 [Accessed December 14, 2012].

Fu, G., Menciassi, A. & Dario, P., 2012. Development of a low-cost active 3D triangulation laser scanner for indoor navigation of miniature mobile robots. *Robotics and Autonomous Systems*. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921889012000929 [Accessed July 26, 2012].

Gojić, M., Brezak, M. & Petrović, I., 2011. Embedded computer control system for service mobile robots. In *MIPRO, 2011 Proceedings of the 34th International Convention*. pp. 711–716.

Kamon, I. & Rivlin, E., 1995. Sensory based motion planning with global proofs. In *Proceedings 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems. Human Robot Interaction and Cooperative Robots*. IEEE Comput. Soc. Press, pp. 435–440. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=526253 [Accessed August 27, 2012].

Kinsky, P., Quan, Z. & YiMing, R., 2011. *Obstacle Avoidance Robot*, Available at: http://www.wpi.edu/Pubs/E-project/Available/E-project-082811-171143/unrestricted/Final_Report.pdf.

Mazo, M., 2001. An integral system for assisted mobility [automated wheelchair]. *IEEE Robotics & Automation Magazine*, 8(1), pp.46–56. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=924361 [Accessed August 18, 2012].

Premadi, A. et al., 2009. Application of PIC microcontroller for online monitoring and fiber fault identification. In *2009 International Conference on Electrical Engineering and Informatics*. IEEE, pp. 463–467. Available at:

http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5254693 [Accessed September 6, 2012].

Seki, H. et al., 2008. Practical obstacle avoidance using potential field for a nonholonmic mobile robot with rectangular body. *2008 IEEE International Conference on Emerging Technologies and Factory Automation*, pp.326–332. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4638414.

Yang, D., Xia, J. & Xi'ang, L., 2010. The Research on Intelligent Mobile Robot's Avoiding Obstacle by Ultrasound. *2010 International Conference on Artificial Intelligence and Computational Intelligence*, pp.77–79. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5656592 [Accessed July 27, 2012].

Yi, J. et al., 2009. Intelligent Robot Obstacle Avoidance System Based on Fuzzy Control. In *2009 First International Conference on Information Science and Engineering*. IEEE, pp. 3812–3815. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5454890 [Accessed October 4, 2013].

APPENDICES

APPENDIX A: Coding

```
#include <p18f4520.h>               //include PIC header file
#include <adc.h>                    //include ADC header file

#define Mode PORTCbits.RC7          //Define Mode with RC7 for mode selection
#define Off PORTDbits.RD2           //Define Mode with RD2 to off auto mode

#pragma config OSC = HS             //Set the oscillator to used external oscillator
//XTAL = 20MHz                      //20MHz crystal was used
#pragma config LVP = OFF            //OFF low voltage power to use RB5 as I/O port
#pragma config WDT = OFF            //OFF watchdog timer


int semi_automated(void);           //Declare functions
int automated(void);
unsigned int ADCRead(int x);
void msdelay(unsigned int y);
void ADCInit(void);

int front_left;                     //Declare variables
int front_left_old;
```

```
int front_left_dif;
int front_right;
int left;
int left_old;
int left_dif;
int right;
int back_left;
int back_right;

char count = 0;                     //Declare variables
char next = 1;
char next_1 = 1;

void main(void)
{
        TRISB = 0x00;               //set PORTB as output pin
        TRISC = 0x00;               //set PORTC as output pin
        TRISD = 0x00;               //set PORTD as output pin
        TRISCbits.RC7 = 1;          //set RC7 as input pin, for mode selection

        msdelay(1000);              //delay 1s for sensor calibration

        ADCInit();                  // initialize ADC module

        while(1)
        {
                PORTDbits.RD3 = 1;          //ON front right sensor
                PORTCbits.RC4 = 0;          //OFF front left sensor
                msdelay(50);                //delay 50ms for calibration
                front_right = ADCRead(0);   //take reading from front right ultrasonic
                                            sensor
```

```
right = ADCRead(1);          //take reading from right ultrasonic sensor

PORTDbits.RD3 = 0;           //OFF front right sensor
PORTCbits.RC4 = 1;           //ON front left sensor
msdelay(50);                 //delay 50ms for calibration
front_left = ADCRead(2);     //take reading from front left ultrasonic
                             sensor

left = ADCRead(3);           //Left ultrasonic sensor

PORTCbits.RC5 = 1;           //ON back left sensor
PORTCbits.RC6 = 0;           //OFF back right sensor
msdelay(50);                 //delay 50ms for calibration
back_left = ADCRead(4);      //take reading from back left ultrasonic
                             sensor

PORTCbits.RC5 = 0;           //OFF back left sensor
PORTCbits.RC6 = 1;           //ON back right sensor
msdelay(50);                 //delay 50ms for calibration
back_right = ADCRead(5);     //take reading from back right ultrasonic
                             sensor


if (Mode == 1)                      // automated mode
        {
                automated();        //call automated function
        }


else if (Mode == 0)                 //semi-automated mode
```

```
                {
                        semi_automated();     //call semi-automated function
                }

        }
}

int automated()                                     // automated mode
{
        PORTB = 0b00000000;       //automated mode initialization
        PORTD = 0b00000000;
        front_left_dif = 0;
        left_dif = 0;

        //------Detect Obstacle------//
        if (front_left <= 50 || front_right <= 50) // check obstacle? 25in distance (2bits/in)
        {
                PORTB = 0b00110000;       //ON front left and front right indicator
                PORTD = 0b00100000;       //output lean right signal


        //-----check whether front left sensor detect the front edge-----//
        while (next)
        {
                PORTDbits.RD3 = 0;           //OFF front right sensor
                PORTCbits.RC4 = 1;           //ON front left sensor
                msdelay(50);                 //delay 50ms for calibration
                front_left = ADCRead(2);     //take reading from front left ultrasonic
                                             sensor
                front_left_old = front_left; //set front_left value into front_left_old
                                             variable
```

```
            msdelay(100);           //delay 100ms
            front_left = ADCRead(2);    //take reading from front left ultrasonic
                                        sensor
            front_left_dif = front_left - front_left_old;   //calculate the difference of
            the front left sensor readings

            if (front_left_dif >= 30)   //if the difference larger than 15in (front edge
            detected)
            {
                PORTB = 0b00100000;         //ON front left indicator
                PORTD = 0b10000000;         //output forward signal
                msdelay(2000);              //delay for 2s
                next = 0;                   //jump out of the while loop
            }
        }
}

        //-----check whether left sensor detect the back edge-----//
        while (next_1)
        {
            PORTB = 0b10000000; //ON left indicator
            left = ADCRead(3);    //take reading from left ultrasonic sensor
            left_old = left;      //set left value into left_old variable
            msdelay(100);         //delay 100ms
            left = ADCRead(3);    //take reading from left ultrasonic sensor
            left_dif = left - left_old;     //calculate the difference of the left sensor
                                            readings


        if (left_dif >= 30)     //if the difference larger than 15in (end edge detected)
        {
```

```
            next_1 = 0;     //jump out of the while loop
        }
        }



        PORTB = 0b00000000;         //OFF left indicator
        msdelay(500); //blink left indicator with 500ms duration to show the stage
        PORTB = 0b10000000;         //ON left indicator

        PORTD = 0b01000000;         //output lean left signal
        msdelay(4000);              //delay 4s

        PORTB = 0b00000000;         //OFF front indicator
        msdelay(500); //blink LED front indicator with 500ms duration to show stage
        PORTB = 0b00110000;         //ON front indicator

        PORTD = 0b10000000;          //output forward signal
        while (end)                 //loop until navigation system take over
        {
            If (off == 1)
            end = 1;
        }
}

int semi_automated()            //semi-automated mode
{
        PORTD = 0;                  //semi automated mode initialization

        if (front_left <= 40)       // check obstacle? 20in distance (2bits/in)
        {
            PORTBbits.RB5 = 1;          //ON front left indicator
```

```
        PORTDbits.RD7 = 1;          //limit forward motion
}

else if (front_right <= 40)          // check obstacle? 20in distance(2bits/in)
{
        PORTBbits.RB4 = 1;          //ON front right indicator
        PORTDbits.RD7 = 1;          //limit forward motion
}

else
{
        PORTBbits.RB5 = 0;          //OFF front left indicator
        PORTBbits.RB4 = 0;          //OFF front right indicator
        PORTDbits.RD7 = 0;          //unlimit forward motion
}


if (left <= 30)          // check obstacle? 15in distance(2bits/in)
{
        PORTBbits.RB7 = 1;          // ON left indicator
        PORTDbits.RD6 = 1;          //limit left motion
}

else
{
        PORTBbits.RB7 = 0;          // OFF left indicator
        PORTDbits.RD6 = 0;          //unlimit left motion
}


if (right <= 30)               // check obstacle? 15in distance (2bits/in)
```

```
{
        PORTBbits.RB2 = 1;          //ON right indicator
        PORTDbits.RD5 = 1;          //limit right motion
}

else
{
        PORTBbits.RB2 = 0;          //OFF right indicator
        PORTDbits.RD5 = 0;          //unlimit right motion
}



if (back_left <= 40)          // check obstacle? 20in distance (2bits/in)
{
        PORTBbits.RB6 = 1;          //ON back left indicator
        PORTDbits.RD4 = 1;           //limit reverse motion
}

else if (back_right <= 40)     // check obstacle? 20in distance (2bits/in)
{
        PORTBbits.RB3 = 1;          //ON back right indicator
        PORTDbits.RD4 = 1;          //limit reverse motion
}

else
{
        PORTBbits.RB6 = 0;          //OFF back left indicator
        PORTBbits.RB3 = 0;          //OFF back right indicator
        PORTDbits.RD4 = 0;          //unlimit reverse motion
}
return 0;
```

```
        }
}

void ADCInit(void)
{
        ADCON1 = 0x08; //AN0,1,2,3,4,5 set to Analog, Vdd and Vss as voltage
        reference
        ADCON2 = 0x8a; //Right justified, 2Tad, Fosc/32
}

unsigned int ADCRead(int x)
{
        ADCON0bits.CHS = x;              //Select ADC channel
        ADCON0bits.ADON = 1 ;            //ON ADC
        ADCON0bits.GO_DONE = 1;          //Start ADC progress
        while(ADCON0bits.GO_DONE);       //wait for the conversion to finish
        ADCON0bits.ADON = 0;             //OFF ADC
        return ADRES;
}

//-----provide 10ms per y-----//
void msdelay(unsigned int y)
{
   unsigned int delval;
   while(y)
   {
      delval = 380;
      while(delval--);
                 y--;
   }
}
```

APPENDIX B: Turnitin Report

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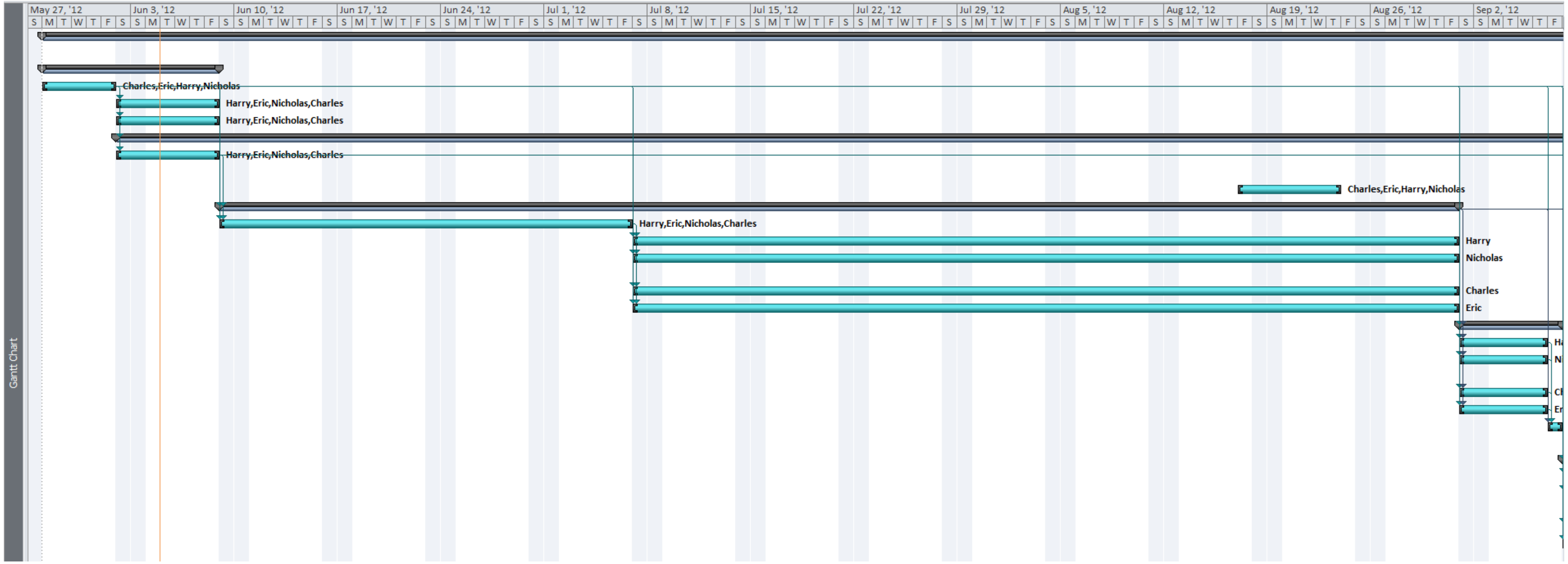
Akbas, . "Generation and analysis of segmentation trees for natural images", Proquest, 2012.

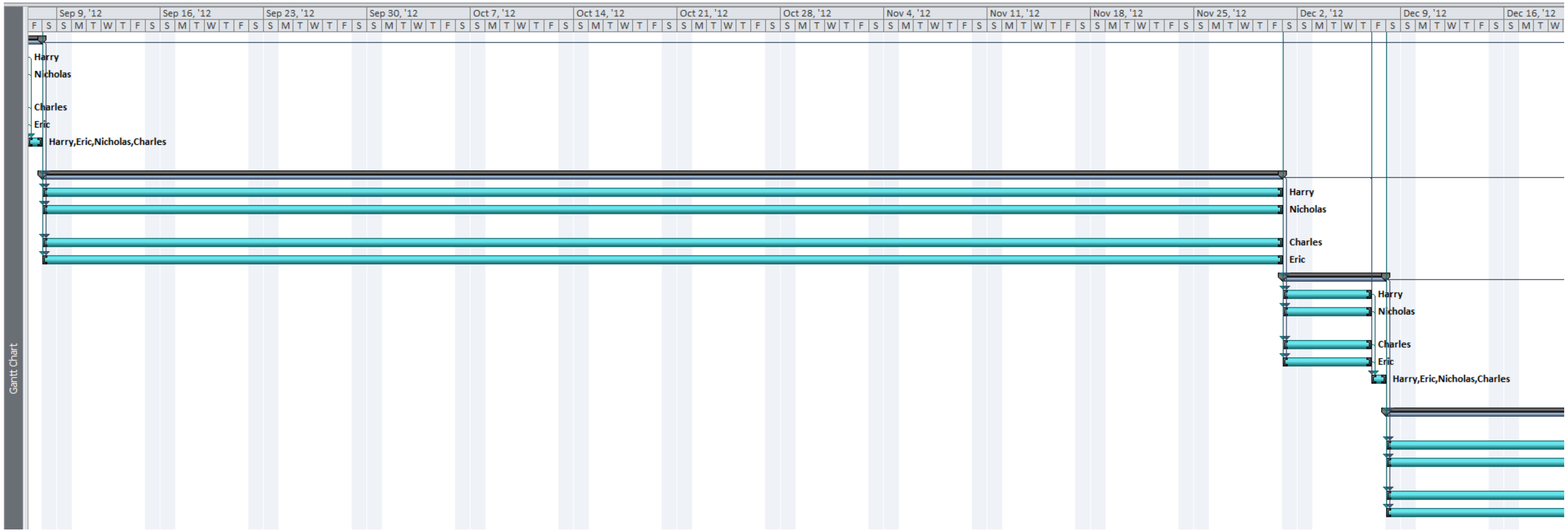
APPENDIX C: Time Schedule

Task Name	Duration	Start	Finish	Predecessors	Resource Names
Intelligent Semi-Automated Wheel Chair	**364 days**	**Mon 5/28/12**	**Mon 5/27/13**		
Research	**12 days**	**Mon 5/28/12**	**Sat 6/9/12**		
Registration of Title	5 days	Mon 5/28/12	Sat 6/2/12		Charles,Eric,Harry,Nicholas
Specification	7 days	Sat 6/2/12	Sat 6/9/12	3	Harry,Eric,Nicholas,Charles
Estimated Cost	7 days	Sat 6/2/12	Sat 6/9/12	3	Harry,Eric,Nicholas,Charles
Designing & Modeling	**293 days**	**Sat 6/2/12**	**Fri 3/22/13**	**3**	
Rough Conceptual Design	7 days	Sat 6/2/12	Sat 6/9/12	3	Harry,Eric,Nicholas,Charles
Detail Conceptual Design	7 days	Fri 3/15/13	Fri 3/22/13	3,7,22,10,16,27	Harry,Eric,Nicholas,Charles
Progress Report	7 days	Fri 8/17/12	Fri 8/24/12		Charles,Eric,Harry,Nicholas
Building	**84 days**	**Sat 6/9/12**	**Sat 9/1/12**	**3,7**	
Base, B	28 days	Sat 6/9/12	Sat 7/7/12	3,7	Harry,Eric,Nicholas,Charles
Controller System, B	56 days	Sat 7/7/12	Sat 9/1/12	3,11	Harry
Semi-Automated Adjustable Chair System, B	56 days	Sat 7/7/12	Sat 9/1/12	3,11	Nicholas
Navigation System, B	56 days	Sat 7/7/12	Sat 9/1/12	3,11	Charles
Obstacle Detection System, B	56 days	Sat 7/7/12	Sat 9/1/12	3,11	Eric
Testing, 1st Stage	**7 days**	**Sat 9/1/12**	**Sat 9/8/12**	**3,10**	
Controller System, T1	6 days	Sat 9/1/12	Fri 9/7/12	3,10	Harry
Semi-Automated Adjustable Chair System, T1	6 days	Sat 9/1/12	Fri 9/7/12	3,10	Nicholas
Navigation System, T1	6 days	Sat 9/1/12	Fri 9/7/12	3,10	Charles
Obstacle Detection System, T1	6 days	Sat 9/1/12	Fri 9/7/12	3,10	Eric
Backup of Programmes & Design, T1	1 day	Fri 9/7/12	Sat 9/8/12	3,10,17,18,19,20	Harry,Eric,Nicholas,Charles
Improvisation	**84 days**	**Sat 9/8/12**	**Sat 12/1/12**	**3,16**	
Controller System, I	84 days	Sat 9/8/12	Sat 12/1/12	3,16	Harry
Semi-Automated Adjustable Chair System, I	84 days	Sat 9/8/12	Sat 12/1/12	3,16	Nicholas
Navigation System, I	84 days	Sat 9/8/12	Sat 12/1/12	3,16	Charles
Obstacle Detection System, I	84 days	Sat 9/8/12	Sat 12/1/12	3,16	Eric
Testing, 2nd Stage	**7 days**	**Sat 12/1/12**	**Sat 12/8/12**	**3,22**	
Controller System, T2	6 days	Sat 12/1/12	Fri 12/7/12	3,22	Harry
Semi-Automated Adjustable Chair System, T2	6 days	Sat 12/1/12	Fri 12/7/12	3,22	Nicholas
Navigation System, T2	6 days	Sat 12/1/12	Fri 12/7/12	3,22	Charles
Obstacle Detection System, T2	6 days	Sat 12/1/12	Fri 12/7/12	3,22	Eric
Backup of Programmes & Design, T2	1 day	Fri 12/7/12	Sat 12/8/12	3,22,28,31,30,29	Harry,Eric,Nicholas,Charles

	Finalization and Final Testing of Product	**97 days**	**Sat 12/8/12**	**Fri 3/15/13**	**3,27**	
	Controller System, F	97 days	Sat 12/8/12	Fri 3/15/13	3,27	Harry
	Semi-Automated Adjustable Chair System, F	97 days	Sat 12/8/12	Fri 3/15/13	3,27	Nicholas
	Navigation System, F	97 days	Sat 12/8/12	Fri 3/15/13	3,27	Charles
	Obstacle Detection System, F	97 days	Sat 12/8/12	Fri 3/15/13	3,27	Eric
	Final Report	**49 days**	**Fri 3/22/13**	**Fri 5/10/13**	**3**	
	Final Report Part I	**21 days**	**Fri 3/22/13**	**Fri 4/12/13**	**3**	
	Controller System, FR1	21 days	Fri 3/22/13	Fri 4/12/13		Harry
	Semi-Automated Adjustable Chair System, FR1	21 days	Fri 3/22/13	Fri 4/12/13		Nicholas
	Navigation System, FR1	21 days	Fri 3/22/13	Fri 4/12/13		Charles
	Obstacle Detection System, FR1	21 days	Fri 3/22/13	Fri 4/12/13		Eric
	Preparation of PowerPoint Slides	3 days	Fri 4/12/13	Mon 4/15/13	3	Harry,Eric,Nicholas,Charles
	Final Report Part II	**25 days**	**Mon 4/15/13**	**Fri 5/10/13**	**3**	
	Controller System, FR2	25 days	Mon 4/15/13	Fri 5/10/13		Harry
	Semi-Automated Adjustable Chair System, FR2	25 days	Mon 4/15/13	Fri 5/10/13		Nicholas
	Navigation System, FR2	25 days	Mon 4/15/13	Fri 5/10/13		Charles
	Obstacle Detection System, FR2	25 days	Mon 4/15/13	Fri 5/10/13		Eric

APPENDIX D: Gantt Chart




Gantt Chart
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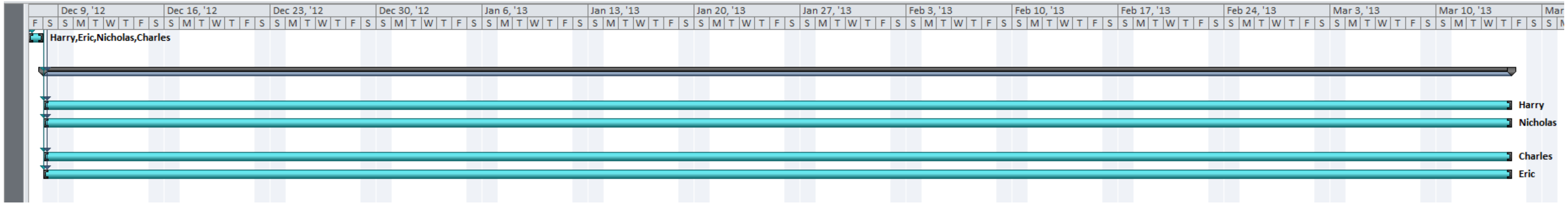
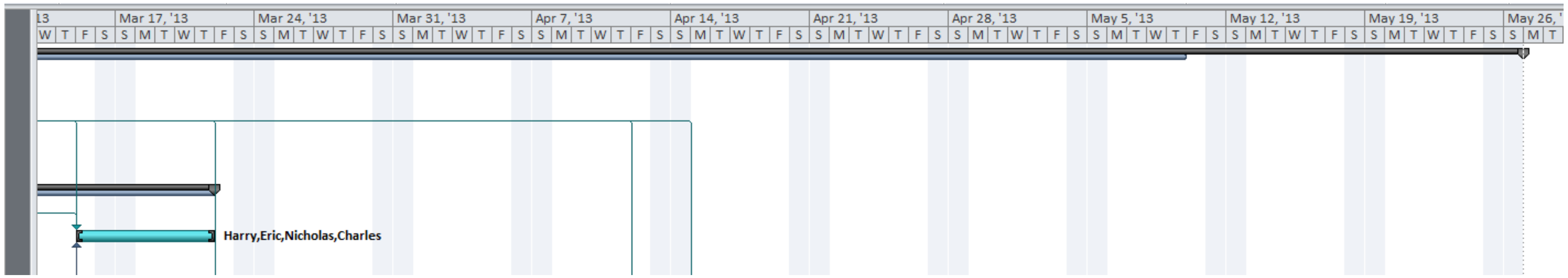
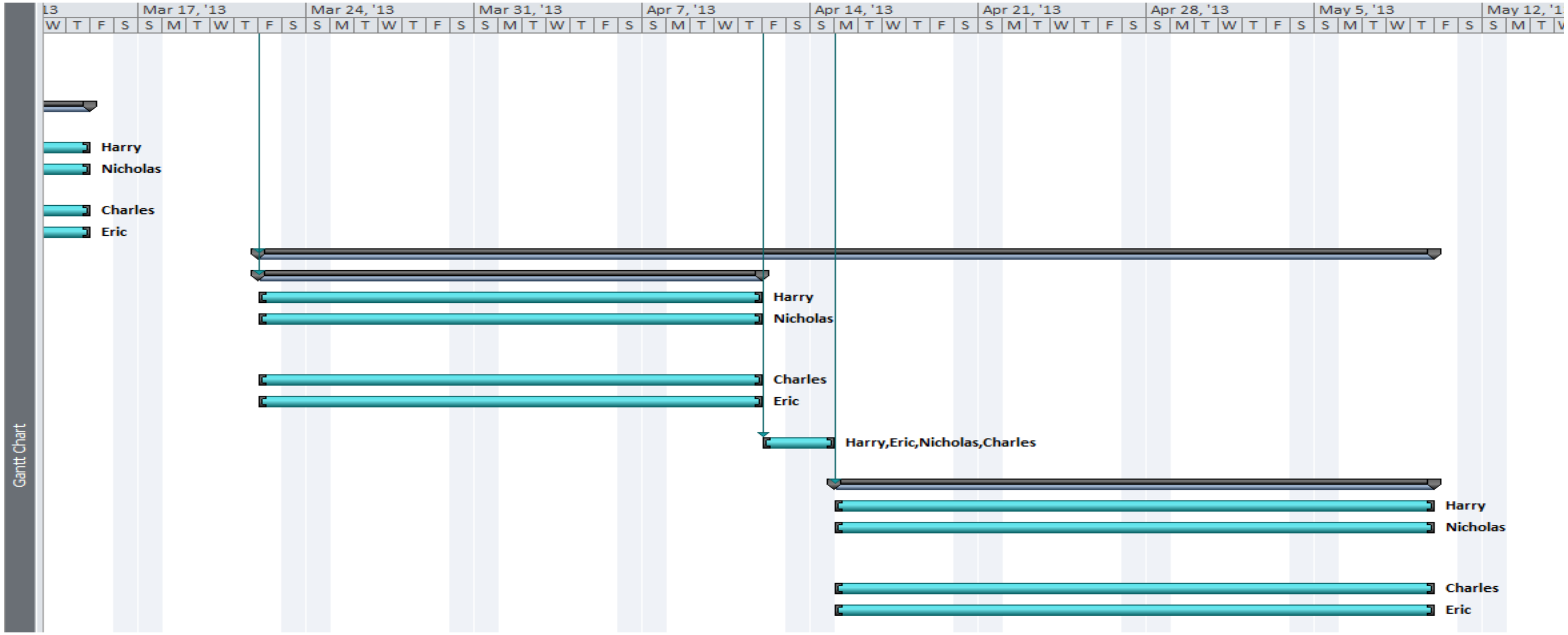
Sep 16, '12
Sep 23, '12
Sep 30, '12
Oct 7, '12
Oct 14, '12
Oct 21, '12
Oct 28, '12
Nov 4, '12
Nov 11, '12
Nov 18, '12
Nov 25, '12
Dec 2, '12
Dec 9, '12
Dec 16, '12
Harry
Nicholas
Charles
Eric
Harry,Eric,Nicholas,Charles
Harry
Nicholas
Charles
Eric
Harry
Nicholas
Charles
Eric
Harry,Eric,Nicholas,Charles


Dec 9, '12
Dec 16, '12
Dec 23, '12
Dec 30, '12
Jan 6, '13
Jan 13, '13
Jan 20, '13
Jan 27, '13
Feb 3, '13
Feb 10, '13
Feb 17, '13
Feb 24, '13
Mar 3, '13
Mar 10, '13
Harry,Eric,Nicholas,Charles
Harry
Nicholas
Charles
Eric


Mar 17, '13
Mar 24, '13
Mar 31, '13
Apr 7, '13
Apr 14, '13
Apr 21, '13
Apr 28, '13
May 5, '13
May 12, '13
May 19, '13
Harry,Eric,Nicholas,Charles


Gantt Chart
Mar 17, '13
Mar 24, '13
Mar 31, '13
Apr 7, '13
Apr 14, '13
Apr 21, '13
Apr 28, '13
May 5, '13
Harry
Nicholas
Charles
Eric
Harry
Nicholas
Charles
Eric
Harry,Eric,Nicholas,Charles
Harry
Nicholas
Charles
Eric