" I hereby declare that I have read through this report entitle "Design and Development of Mobile Robot for Interoffice Documents Delivery" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering"

Signature : ....

Supervisor's Name : ....

Date : ....

DESIGN AND DEVELOPMENT OF MOBILE ROBOT FOR INTEROFFICE DOCUMENTS DELIVERY

SOO KOK YEW

A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2015

“I declare that this report entitle “Design and Development of Mobile Robot for Interoffice Documents Delivery” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

ACKNOWLEDGEMENT

Through this report I would like to express my special thanks of gratitude to everyone that had helped me to complete the final year project. First and foremost, I would like sincerely thank my supervisor, Dr. Mariam Md Ghazaly for her guidance and support throughout this study that lead to successful project. Her willingness to give her time so generously has been very much appreciated. Besides that, I would like to thank Engr. Mohd Rusdy Bin Yaacob who is my previous supervisor had helped me a lot in gaining more engineering knowledge through his technical talk and valuable suggestions during the research work. There are very much of engineering knowledge I had gained throughout final year project will be much useful for me to become a successful engineer in the future. Last but not the least, I would like to thank my parents for their love and supporting me spiritually throughout my life.

ABSTRACT

Nowadays, mobile robot is become increasingly common in our workplace and the development of mobile robot has become one of the crucial factors that able to help worker doing simple repetitive task such as delivery documents from one department to another. The mobile robot not only helps worker reduced the heavy workload, they can even protect their physical and mental health that comes from the work-related-stress. However, navigation of mobile robot in an indoor environment is a challenging task to accomplish and it also required to avoid any nearby obstacle during the way to the target destination. This makes the design and development of mobile robot become more difficult to achieve. In this project, the objectives are to design and develop of mobile robot that able to navigate from one location to another, analyze the accuracy of line following sensor and analyze the trajectory movement of mobile robot. For the methodology, there are some important elements for the mobile robot configuration, which is Radio Frequency Identification (RFID) reader with the passive tag, line following sensor, ultrasonic sensor and acrylic board as a main base for the mobile robot. The first experiment is to determine the accuracy of line following sensor towards different width of masking tape whereas the second experiment is to identify the feasibility of navigation method by using the Radio Frequency Identification (RFID) reader and passive tag for mobile robot. Besides that, there are two sections in experiment 3 where first part focus on testing the effective angle of ultrasonic sensor while second part focus on the obstacle avoidance of mobile robot. In conclusion, the experimental result shows that the proposed method can be done successfully with the supported data.

ABSTRAK

Pada masa kini, robot telah menjadi semakin biasa di tempat kerja dan pembangunan robot telah menjadi salah satu faktor penting yang dapat membantu pekerja melakukan tugas yang berulang-ulang yang mudah seperti dokumen penghantaran dari satu jabatan yang lain. Robot bukan sahaja membantu pekerja mengurangkan beban kerja yang berat, mereka juga boleh melindungi kesihatan fizikal dan mental mereka yang datang dari yang berkaitan dengan kerja-kerja. Walau bagaimanapun, navigasi robot dalam persekitaran yang tertutup merupakan satu tugas yang mencabar untuk mencapai dan ia juga diperlukan untuk mengelakkan sebarang halangan berdekatan semasa perjalanan ke destinasi sasaran. Ini menjadikan reka bentuk dan pembangunan robot menjadi lebih sukar untuk dicapai. Dalam projek ini, objektif adalah untuk mereka bentuk dan membangunkan robot yang mampu untuk navigasi dari satu lokasi ke lokasi lain, menganalisis ketepatan sensor dan menganalisis pergerakan trajektori yang robot. Untuk kaedah ini, terdapat beberapa elemen yang penting untuk konfigurasi robot, yang merupakan Radio Frequency Identification (RFID) dengan tag pasif, talian berikut sensor, sensor ultrasonik dan papan acrylic sebagai asas utama untuk robot. Eksperimen pertama adalah untuk menentukan ketepatan talian berikut sensor ke arah lebar yang berbeza pita pelekat manakala percubaan kedua adalah untuk mengenal pasti kemungkinan kaedah navigasi dengan menggunakan Radio Frequency Identification (RFID) dengan tag pasif untuk robot. Selain itu, terdapat dua bahagian dalam eksperimen 3 di mana bahagian pertama tumpuan terhadap menguji sudut yang berkesan sensor ultrasonik manakala bahagian kedua tumpuan kepada mengelakkan halangan robot. Kesimpulannya, hasil eksperimen menunjukkan bahawa kaedah yang dicadangkan boleh dilakukan dengan jayanya dengan data yang disokong.

TABLE OF CONTENTS

CHAPTER **TITLE** **PAGE**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RFID - Radio Frequency Identification

PWM - Pulse Width Modulation

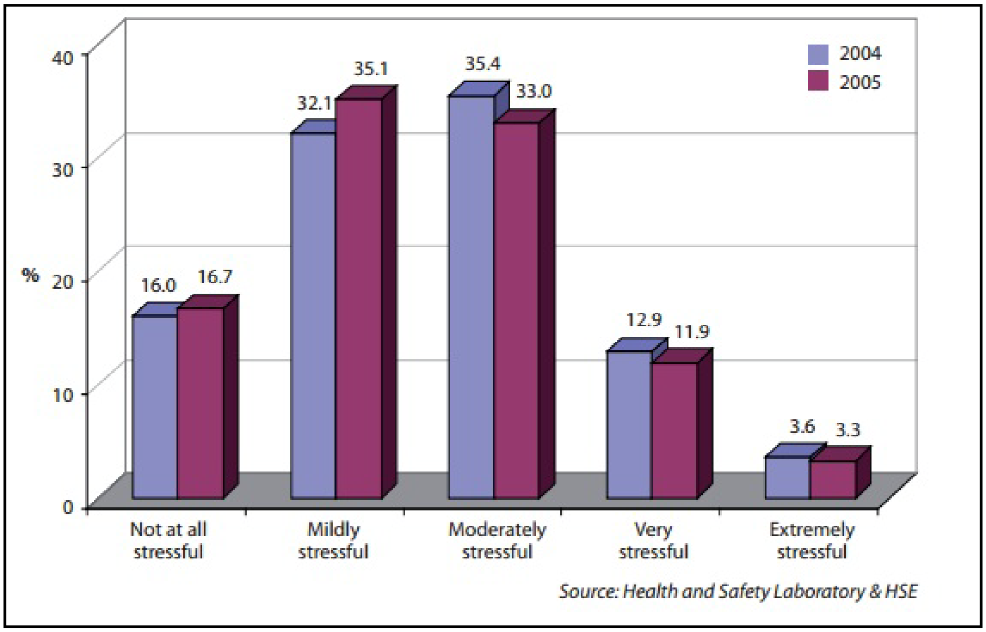
LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

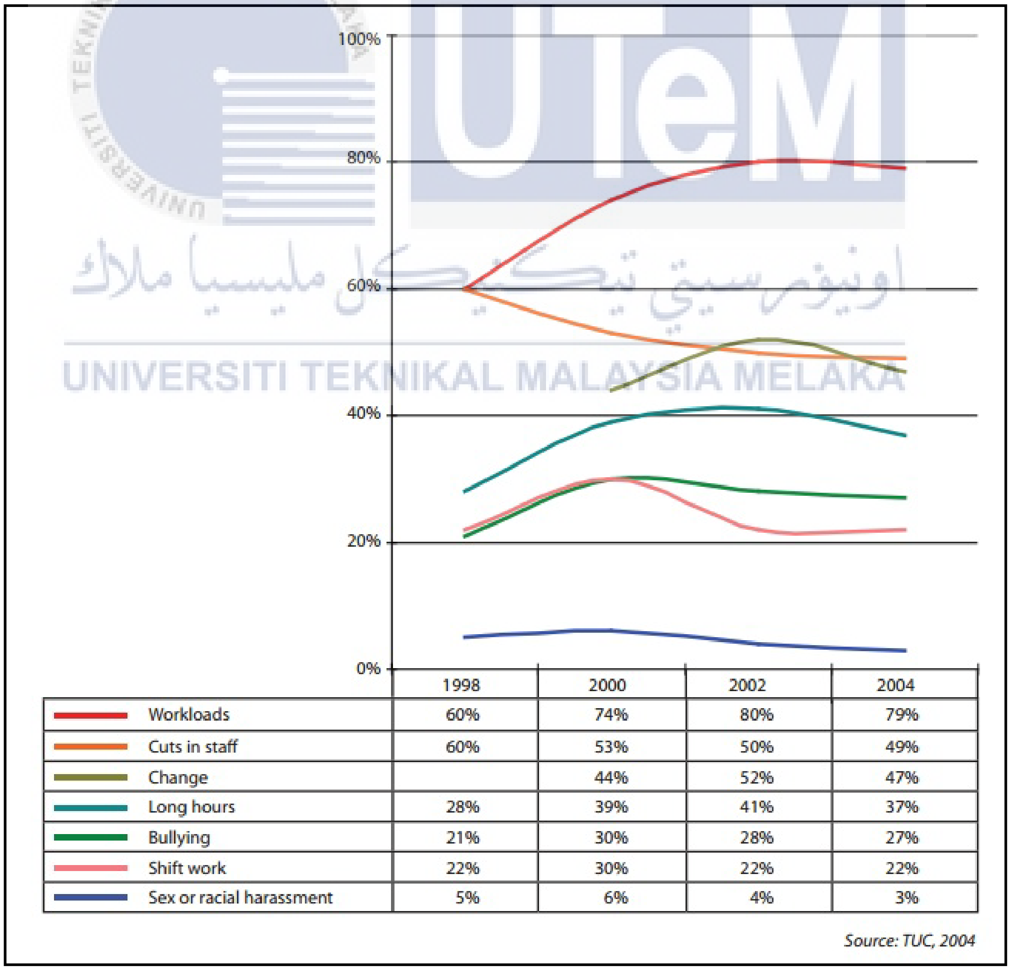
1.1 MOTIVATION

According to the Health and Safety Executive (2005), the statistics revealed that in the UK more than 500,000 people experiencing stress related to work and this level of stress can lead to illness. In the previous of 12 months, 245,000 people feeling anxiety when they first dealing with work-related stress. In addition, the results show that 15% people thought their job was very stressful or extremely stressful as shown in Figure 1.1. The main factor that causes work-related stress is workload which means the amount of work need to be done by worker. According to the Trades Union Trends Survey (2004), it can be seen that the workload have the highest percentages among the four different years as compared to other factors of work-related stress as shown in Figure 1.2. Hence, this project aim to design and develop a mobile robot for the benefit of worker in order to help them reduces workload.



Source: Health and Safety Laboratory & HSE

Figure 1.1: The level of stress among UK workers [1]



	1998	2000	2002	2004
▬ Workloads	60%	74%	80%	79%
▬ Cuts in staff	60%	53%	50%	49%
▬ Change		44%	52%	47%
▬ Long hours	28%	39%	41%	37%
▬ Bullying	21%	30%	28%	27%
▬ Shift work	22%	30%	22%	22%
▬ Sex or racial harassment	5%	6%	4%	3%

Source: TUC, 2004

Figure 1.2: Factors of work-related stress [1]

1.2 PROBLEM STATEMENT

Work-related stress is a growing problem around the world and most challenging issue in the occupational safety and health. Work-related stress that affects not only the mental health and well being of employees, it will also subsequently affect the productivity of an organization. Workload is a most critical factor that linked to work-related stress due to the excessive of workload, it has became a leading source of work-related stress for employees, thus makes them have poor performances in workplace. A safe and healthy working environment will lead to increase working efficiency in order to have a greater job satisfaction. For that reason, mobile robot is developing for interoffice documents delivery to improve the performance and efficiency of employee while create a systematic work environment in order to makes the job more pleasurable and satisfying. Apart from that, navigation of mobile robot in indoor environment is a challenging issue to accomplish. The problem of navigation of mobile robot has been widely discussed in recent years in the field of robotics. Such problems have several difficulties and complexities that are unobserved and unidentified, besides the ambiguity of how this can be solved since a mobile robot may encounter various forms of obstacles that must be bypassed in an intelligent manner.

1.3 OBJECTIVES

- To design and develop of mobile robot that is able to navigate itself from one office to another for documents delivery.
- To analyze the accuracy of the line following sensor towards different width of masking tape.
- To analyze the trajectory movement of mobile robot so that it is able to reach the target destination without collision with obstacle.

1.4 SCOPE

The scope of this project is to implement the navigation strategy using the RFID system for the mobile robot to move around in an indoor environment. In addition, the mobile robot is equipped with three line following sensor for the mobile robot to follow a black line path. This mobile robot is applicable to the interoffice documents delivery but limited to one floor only. Moreover, this mobile robot can move only on smooth flat surfaces. During the development stage, the mobile robot is able to handle and carry documents with approximately 500 grams due to the small scale designation. It can be expand to larger scale to handle and carry documents more than 500 grams. Furthermore, the mobile robot is equipped with the ultrasonic sensor to detect and avoid nearby obstacle in order to reach the target destination without collision. Therefore, some stationary obstacles are introduced in the navigation environment in order to satisfy the reliability of the mobile robot during the navigation process.

1.5 CHAPTER OVERVIEW

In Chapter 1, Introduction, this chapter describes the background of the project which includes motivation, problem statement, objectives, and the scope of the project.

In Chapter 2, Literature Review, this chapter describes the previous research work on knowledge sharing. Based on the findings, the element that relevant to my project will be compared and analyzed in order to select the suitable components to be used in the project.

In Chapter 3, Methodology, this chapter describes about research methodology that perform for the development of mobile robot which includes the project planning, system, methods and experimental setup.

In Chapter 4, Result and Discussion, this chapter explained about the findings based on the data taken in experiment. The findings for each of the experiment will required to achieve the objectives of the project.

In Chapter 5, Conclusion and Recommendation, this chapter discussed about the achievement of the project and recommendation for future improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Navigation of mobile robot has been widely discussed in the past few years and this issue can be consider as a huge challenge to be accomplish in the field of robotics. There are many researchers over the world have developed numerous method to navigate their mobile robot reach the goal location for indoor and outdoor environment while at the same time avoid any nearby obstacle on the path to target destination. For localization in outdoor environment, Global positioning System (GPS) have been widely used in tracking people and asset as well as a navigation system for transportation since it provide accurate coordinate and information about a certain place. However, GPS does not perform well in indoor localization because the satellite cannot penetrate through the building thus making the GPS useless in indoor localization [2]. There is a lot of indoor localization and navigation system such as Infrared Radiation (IR), Radio Frequency Identification (RFID), Bluetooth, Ultra wideband (UWB) and WiFi to address the inadequacy of GPS inside a closed environment [3], [4], [5], [6], [7]. Besides that, obstacle avoidance is a one of the crucial factor in designing the mobile robot as it makes the mobile robot reach the target destination without any collision with obstacle. By using different types of sensor such as infrared sensor, ultrasonic sensor and laser range finder can used to detect and avoid the nearby obstacle [8].

Other than that, mobile robot needs to navigate from one place to another place to perform task within an indoor environment, so that, well designed mobile robot locomotion able to help maintain the stability of the structure and smoothen the motion of sensor and thus increase the performance of the mobile robot. Several designs of wheel robot chassis such as two-wheel chassis, mecanum four wheel chassis and ball wheel chassis are used in designing the base of the mobile robot [9]. This chapter will be further discussed about the important element of mobile robot in terms of navigation system, obstacle avoidance sensor, and wheel robot chassis.

2.2 NAVIGATION SYSTEM

Based on the research, Radio Frequency Identification (RFID) is a most suitable system used for localization and navigation of mobile robot due to its ease of use, inexpensive cost and flexibility. Although Global Positioning System (GPS) is a good positioning system for outdoor environment, however, poor coverage of satellite signal in indoor environment hence making it useless for indoor positioning [10]. Since the network infrastructure available in every building, Wi-Fi positioning system has more advantages compared with UWB and RFID [11]. However, the interference with electronic devices that operate in 2.4GHz band will affected the strength of signal, hence makes the signal unstable thus lower the accuracy of positioning. In addition, the Wi-Fi tags are more expensive than RFID tags in terms of cost and price. Compared with RFID, Ultra-Wideband (UWB) provides better positioning accuracy which makes it better for high precision positioning in indoor environment [13]. However, the cost of UWB infrastructure and hardware are relatively expensive hence making it difficult used for wide-scale. As a conclusion, RFID is a best system used for localization and navigation of mobile robot in terms of cost, power consumption and performance [12]. The summary of localization and navigation system is shown in Table 2.1.

Table 2.1: Summary of localization and navigation system

Title	System	Accuracy	Coverage	Power consumption	Cost	Remark
Survey of Wireless Indoor Positioning Techniques and Systems [10]	GPS	5 - 10m	Good outdoor Poor indoor	High	High	(1) Satellite based Positioning. (2) Processing time and computation is slow.
Indoor Localization and Tracking: Methods, Technologies and Research Challenges [11]	Wi-Fi	1 - 10m	Indoor	High	High	(1) Initial deployment is expensive. (2) Interfere possible with other appliances in the 2.4 GHz band.
An Intelligent Mobile Robot Navigation Technique Using RFID Technology [12]	RFID	1 - 5m	Good Indoor	Low	Low	(1) Real time location system. (2) Response time is high.
An Ultra-Wideband Local Positioning System for Highly Complex Indoor Environments [13]	UWB	1cm - 1m	Good Indoor	High	Very High	(1) High cost of infrastructure deployment. (2) High precision in positioning.

2.3 OBSTACLE AVOIDANCE SENSOR

In the field of robotics, obstacle avoidance is the concern for mobile robot to act in an unknown or dynamic environment as it is the most crucial criteria to accomplish the objective without collision to the subject. There are various research studies regarding the issue of obstacle avoidance in designing the mobile robot platform so that it can be more reliable performed obstacle avoidance. Besides that, the price of sensors can be from low to high depend on the performances of sensors for different application. In addition, each of the sensors has its own unique and specification to carry out the various task based on the given situation.

Based on the research, ultrasonic sensor is a most suitable method used for obstacle avoidance within an indoor environment. Unlike laser rangefinder and infrared sensor, the ultrasonic sensor has relatively wide working angles. The effective working angles of ultrasonic sensor have approximate 30^o which is large compared with infrared sensor and laser rangefinder [14]. Since the ultrasonic sensor is mounted on a servo motor on the front end of mobile robot, it is able to scan the surrounding environment more thoroughly and effectively to avoid any nearby obstacle. Although laser rangefinder have better performance in terms of accuracy and maximum range, but the cost of laser rangefinder is relatively expensive compared with ultrasonic sensor and infrared sensor [15]. Furthermore, the measurement of ultrasonic sensor is very reliable in any lighting conditions whereas infrared sensor is very vulnerable to changes in ambient light. In addition, ultrasonic sensor use sound instead of light for ranging to detect the nearby obstacles, making this a good choice compared with infrared sensor [16]. As a conclusion, ultrasonic sensor is a best method used for obstacle detection and avoidance in terms of cost, performance and wide angle. The summary of obstacle avoidance sensor is shown in Table 2.2.

Table 2.2: Summary of obstacle avoidance sensor

Title	Sensor	Directivity	Accuracy	Cost	Remark
Obstacle avoidance for a mobile exploration robot using a single ultrasonic range sensor [14]	Ultrasonic	approximate 30^o	Relatively accurate but accuracy lessens with distance, with the measurement angle and with temperature and pressure conditions.	Low	Work in any lighting conditions.
Obstacle Avoidance Fuzzy System for Mobile Robot with IR Sensors [15]	Infrared	approximate 5^o	Relatively accurate but accuracy lessens over distance.	Low	Vulnerable to changes in ambient light.
An Obstacle Identification Algorithm For A Laser Range Finder-Based Obstacle Detector [16]	Laser Rangefinder	around one degree or half degree (most directional)	Accurate to within a few centimeters over measurements of several meters.	Very high	Cannot detect objects that reflect lasers such as windows.

2.4 WHEEL ROBOT CHASSIS

In order for the mobile robot to move from one location to another along the path, the mobile robot requires locomotion mechanism that will operate it to move around in an environment. Mobile robot with great mobility can accomplish more tasks since it used to be more flexible, thereby the mobile robot can move stably to the new place even the environment is not specially designed for them. In addition, there type of mobile robot can work with the human being and sharing the workspace together. Furthermore, there are three classes of wheel which is different in their kinematics, mechanics and dynamics. Therefore, the selection of wheel will influence the overall performances of mobile robot in terms of the stability and flexibility. The type of wheel and its functional need to be taken into account when designing the mobile robot platform.

Based on the research, the two-wheeled chassis with pivoting caster is the most suitable architecture because the robot is statically stable and easy to implementation as well as high durability and high load capacity [17]. Since the ultrasonic sensor is mounted on a servo motor on the front end of mobile robot to scan the surrounding environment, the caster allows it to turn the left and right direction more easily in order to avoid obstacle. Although the Mecanum four-wheeled chassis can provides multi-directional movement as well as low resistance when the mobile robot moves in any direction, however the mecanum wheels are relatively expensive and have a poor efficiency since not all wheels are used to control and drive the robot [18]. Compared with the two-wheeled design, the ball wheel has a free rotation of 360 degree and it is able to rotate freely according to the mobile robot motion, however this type of design usually have high traction and more power required to drive the wheels [19]. As a conclusion, two-wheeled chassis with pivoting caster is used for the mobile robot in terms of cost, simplicity and stability. The summary of wheel robot chassis is shown in Table 2.3.

Table 2.3: Summary of wheel robot chassis

Title	Type	Cost	Advantages	Disadvantages
Autonomous Mobile Robot Mechanical Design [17]	Two-wheeled chassis with pivoting caster	Low	Easy to implementation, high durability, and high load capacity. The caster allows the mobile robot to turn direction more easily.	Not suitable used for irregular and uneven surface.
Design and Control of Mobile Robot with Mecanum Wheel [18]	Mecanum four-wheeled chassis	High	The mecanum wheels provide low resistance when the mobile robot moves in any direction. (multi-directional)	Poor efficient of wheel rotation and mecanum wheels are very expensive.
Design and Prototyping of Autonomous Ball Wheel Mobile Robots [19]	Ball wheeled chassis	Medium	The ball wheel has 360 degree of freedom and it is able to rotate freely according to the mobile robot motion.	High traction – more power are required to drive the ball wheels.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This section is described about the research methodology that performs for the development of the mobile robot which is able to navigate itself from one location to another. The following section includes the project planning, system, methods, and procedures so that specialist or professor who may not belong to this field able to understand the rationale for the experimental approaches as well as how the experiments were performed.

3.2 PROJECT PLANNING

First of all, a clear motivation and problem statement are identified for the project in order to start a successful project. Motivation is an essential factor to helping an individual to maintain the effort required to complete the project. Moreover, a problem statement is a concise statement of the problems which states the existing problem to be solved. Next, objective sets a clear goal that need to achieve in this project whereas scope sets a clear boundary of the project by defining the limits and constraints of the project. Based on the previous research that related to this project, a literature review has been organized and summarized as well as synthesis the idea of others in terms of system, methods, design architecture and how the experiments were conducted. During the design and development process, the process includes the selection of components, testing the components and construction of prototype. After finish the construction, the prototype is required to testing the validity and stability as well as evaluating the performances of prototype based on the data collected from experiments and then interpret findings. Therefore, presentation and demonstration of this project is shown to supervisor and panel for evaluation. The flowchart of the whole project is shown in Figure 3.1.

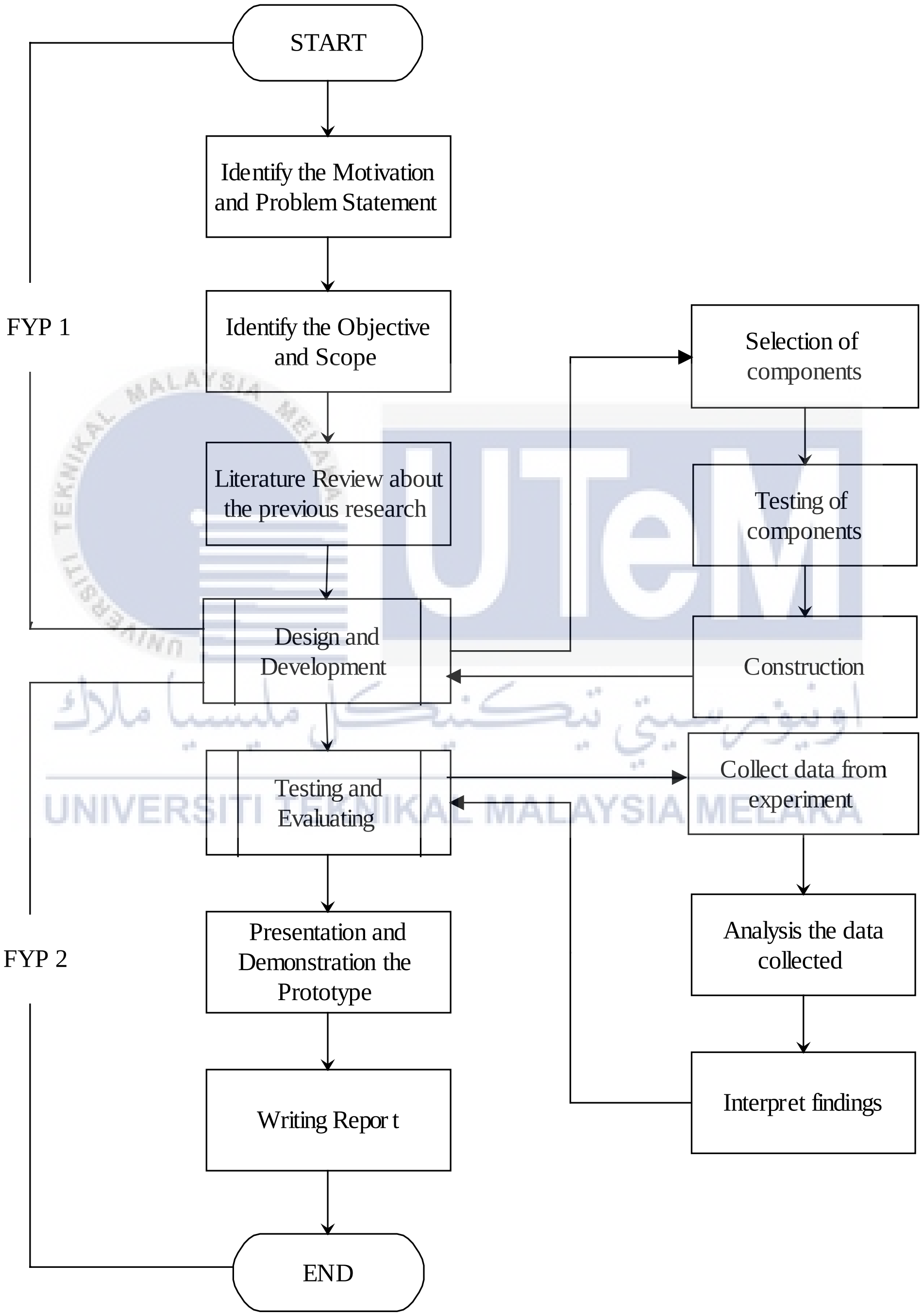


Figure 3.1: Flowchart of the whole project

3.3 GANTT CHART

The Gantt chart is a project management tool for planning and scheduling project and it can be act as a guideline to achieve the desired result within the time frame. Gantt chart is useful when monitoring the progress of the project based on the allocated task at that particular week.

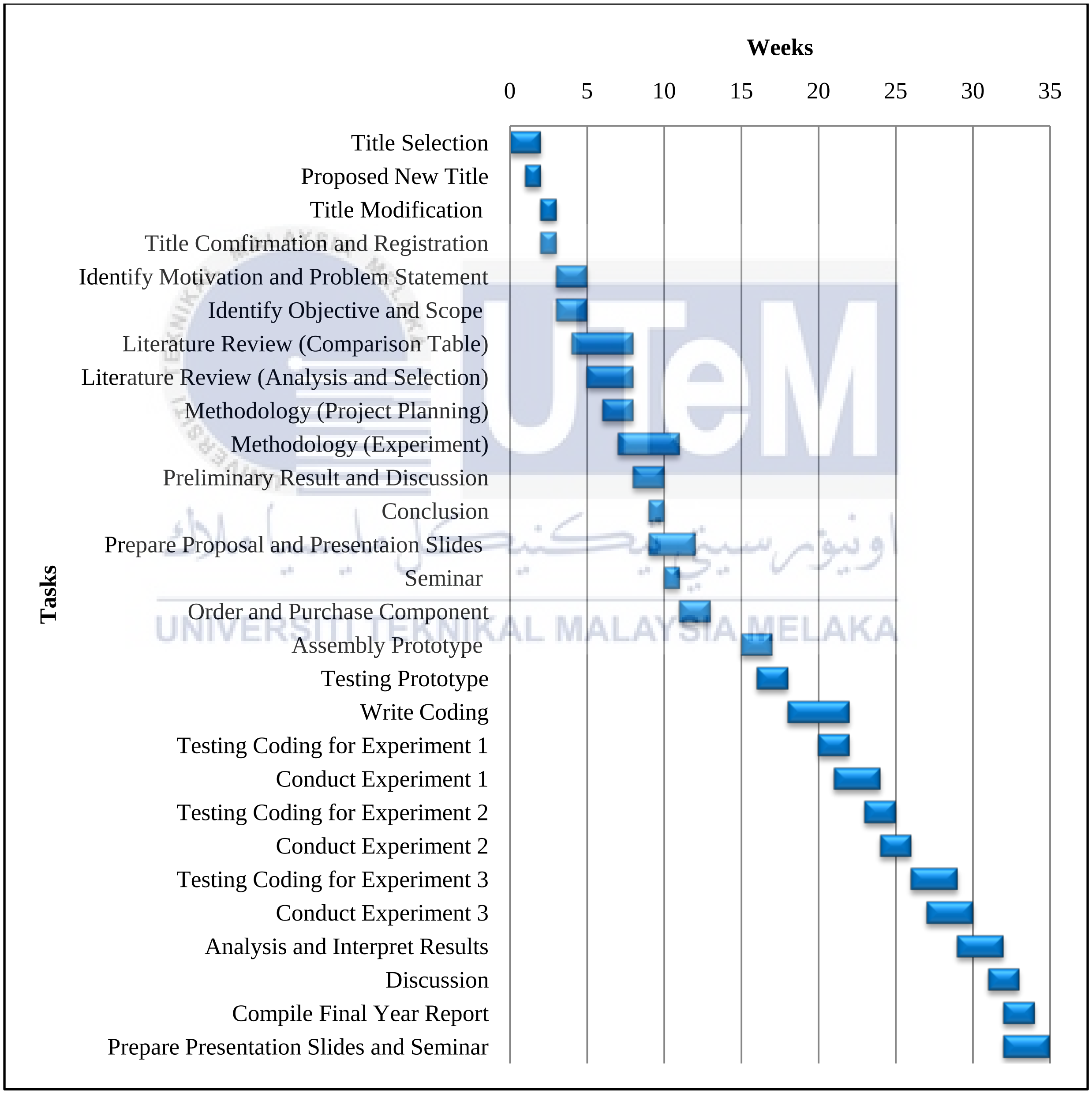


Figure 3.2: Gantt chart of the project

3.4 SYSTEM DESCRIPTION

3.4.1 RFID System

RFID system consists of three main components which are RFID reader (interrogators), RFID tags (transponders), and host computer with appropriate application software. First of all, the host computer is used to establish a communication between the reader and tag to retrieve the tag information. Next, the reader will sends energy to tags for power and thereby the tag will sends the data or information back to the reader. After that, the host computer will maintain the communication between the Arduino UNO board and reader so that the mobile robot can perform task based on the given tag information. Besides that, there are three types of RFID tags which are active tag, semi-passive tag and passive tag. A passive RFID tag is least complex and cheapest among the all three types of tags. Since the passive RFID tag does not have internal power supplies and rely on the RFID reader, it uses the electromagnetic filed from the reader to power up its internal circuit. The process flow of RFID system is shown in Figure 3.3.

Figure 3.3: RFID System

3.4.2 Navigation process

First of all, obtain the initial and final location before program the route for the mobile robot. Then, mobile robot will move along in the programmed route based on the tag information. The RFID reader will receive the command from the tag and navigates the mobile robot to move toward to the destination. When the mobile robot reaches the target destination, it will stop at the particular tag. Otherwise, it will continue to move along the route until reaches the target destination. During the navigation process, the ultrasonic sensor will detect and avoid the obstacle by choosing the alternative path. The flowchart of the process is shown in Figure 3.4.

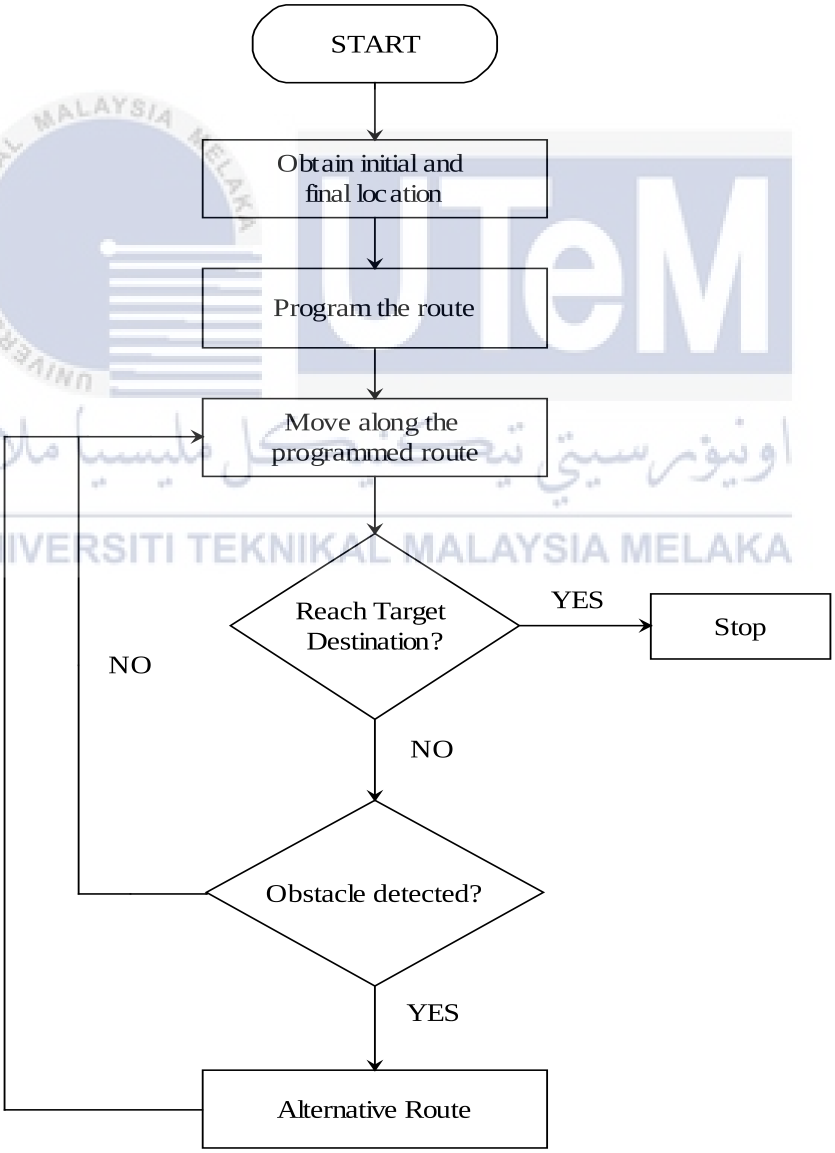


Figure 3.4: Flowchart of the navigation of mobile robot

3.5 MOBILE ROBOT MECHANICAL DESIGN

3.5.1 Mobile Robot Platform Design

As the weight of the mobile robot is a concern and a cheap acrylic board is obtainable, it is decided to use an acrylic board as the basic structure of the mobile robot to hold the circuit board, sensors, and motors. Acrylic board is a light yet strong material as it won't crack and split easily. Using acrylic board as opposed to steel significantly reduces the weight of the mobile robot and gives a strong and solid base to hold other components. Furthermore, the platform of the mobile robot is designed with two DC motor were installed at the front of the platform and a castor were installed at the back of the mobile robot to balance the robot structure. The castor is not driven but simply goes along with the two DC motor. This type of wheel configuration is known as differential drive which the velocity difference between the two DC motor drive the mobile robot to the desire path and direction. For instance, if both the wheels are driven in the same speed and direction, then the mobile robot will move in a straight line. Otherwise, if both the wheels are driven at different speed and direction, then the mobile robot will drive to the left or right direction. The movement of a differential-drive wheeled mobile robot is shown in Figure 3.5.

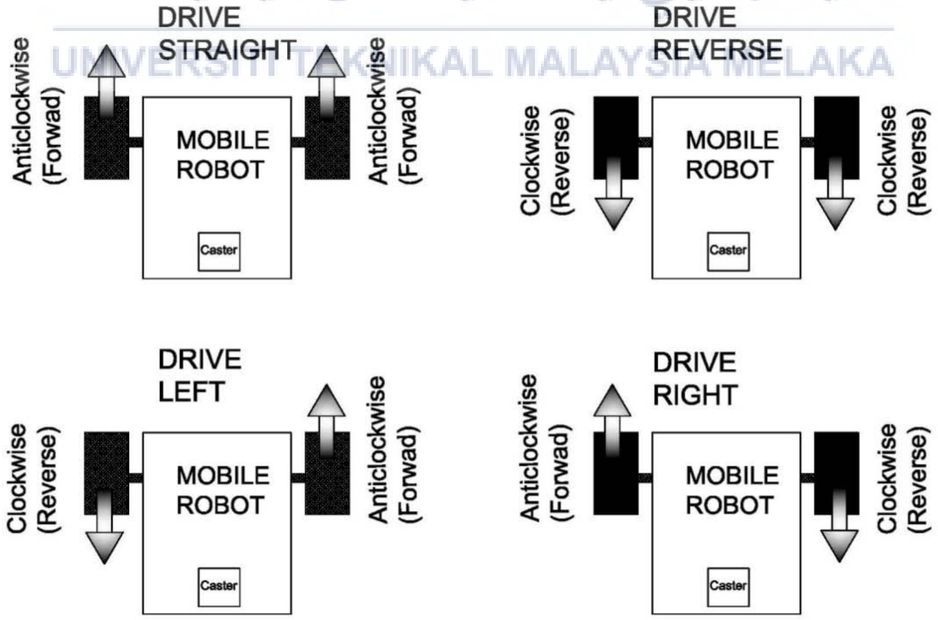


Figure 3.5: Differential drive of mobile robot

3.6 LINE FOLLOWING SENSOR METHOD

In order to navigate a mobile robot successfully and accurately from one location to another location, a line following method have been implement in this project to make sure that the mobile robot reach the goal location. Following line is the most effective method for the mobile robot to follow the black line path where it is a determined path. Also, a good and well-defined programming able to verify the results that obtained from the sensors are far more consistent than if the mobile robot was command to go unknown location without any reference. The mobile robot have been equipped with three line following sensors on the forepart to follow the black line path. There are five possible outcomes if the robot is well-functioning as shown in the Figure 3.6.

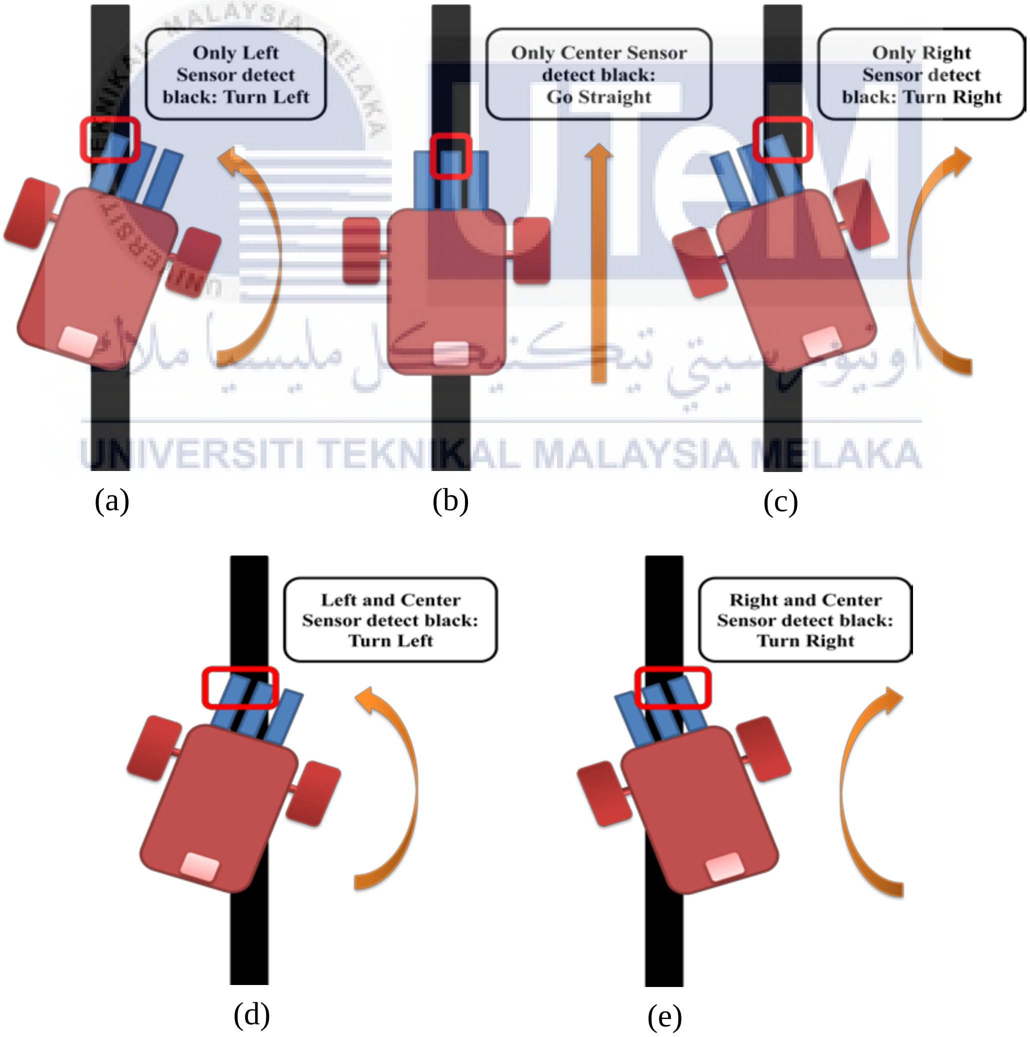


Figure 3.6: The five possible outcome of mobile robot when follow the black line path

3.7 MOBILE ROBOT PROTOTYPE

The mobile robot was equipped with RFID reader, ultrasonic sensor and line following sensor on the forepart of the robot to follow the black line path while receive command from the passive tag to navigate the mobile robot to reach the destination. The top view, front view, side view and back view of mobile robot were shown in the Figure 3.7, 3.8, 3.9 and 3.10.

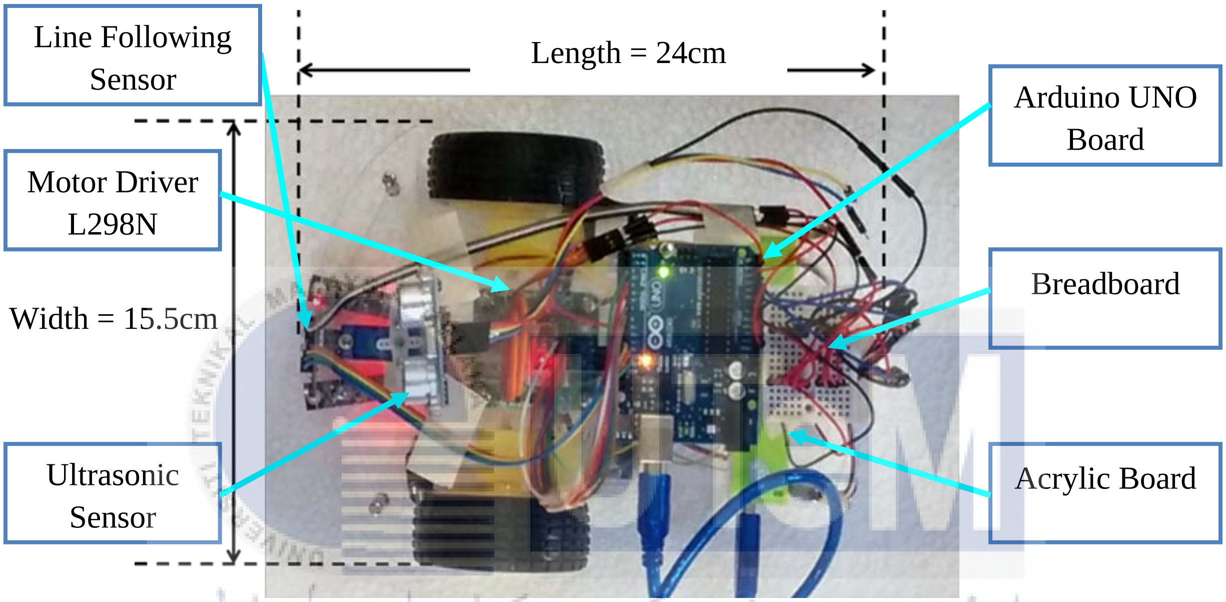


Figure 3.7: Top view of mobile robot

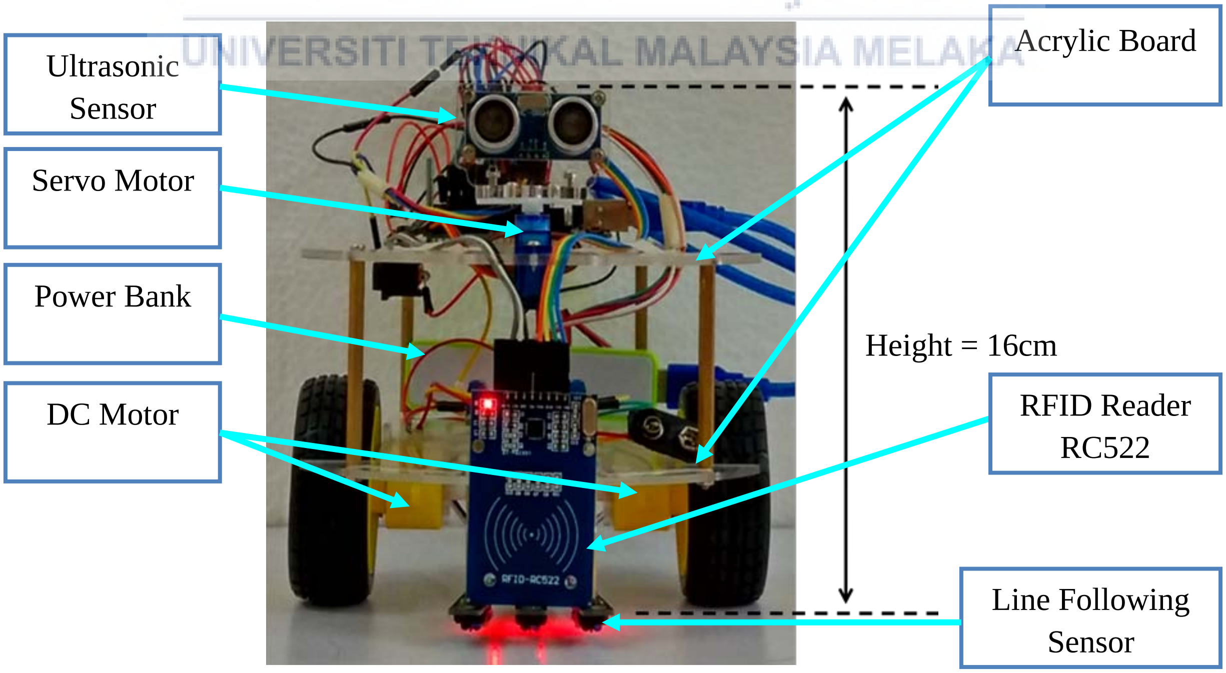


Figure 3.8: Front view of mobile robot

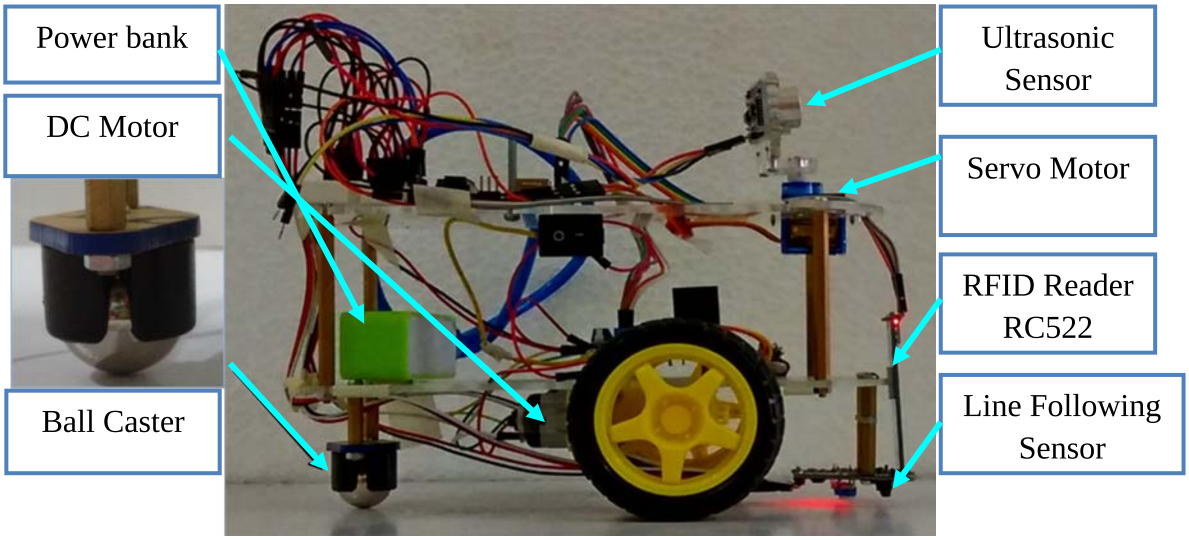


Figure 3.9: Side view of mobile robot

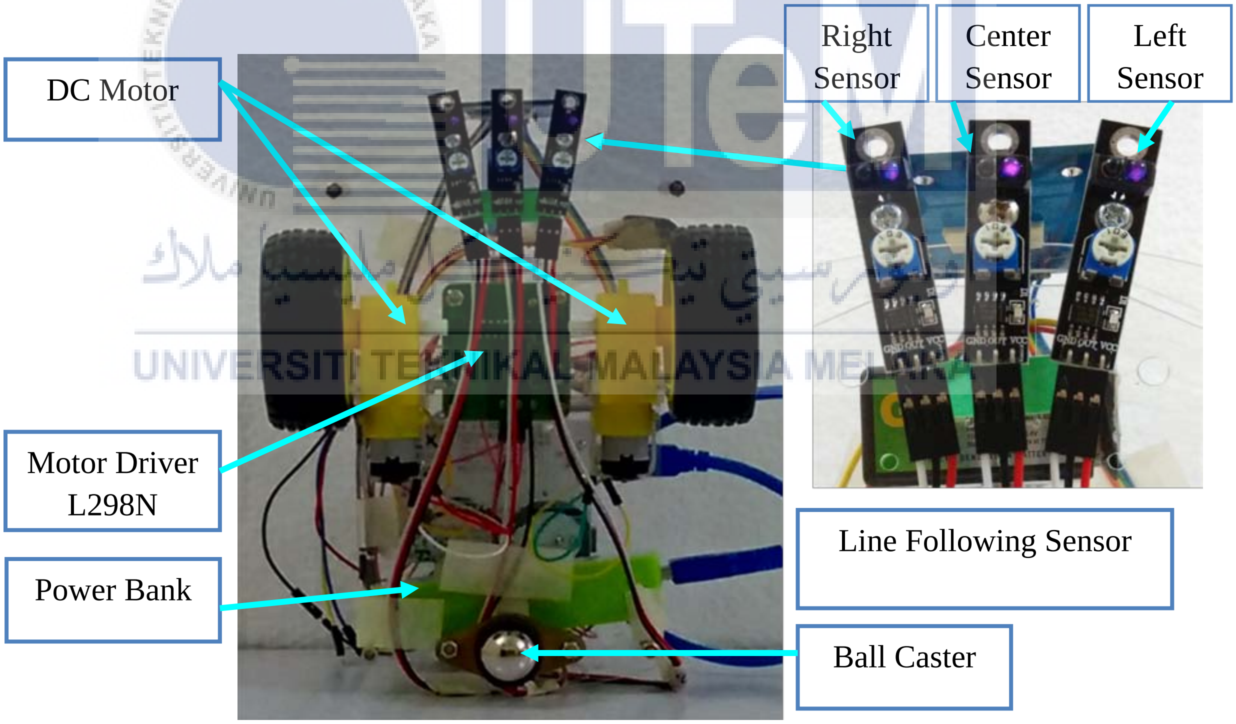


Figure 3.10: Back view of mobile robot

3.8 HARDWARE

A. RFID-RC522 RFID Module

The RFID reader is used in the prototype as shown in Figure 3.11. The function of the RFID reader is to interrogate RFID tags so that the mobile robot able to perform task based on the data or information stored in the passive tags. The specification of RFID reader is shown in the Table 3.1.

Figure 3.11: RFID-RC522

Table 3.1: The specification of RFID-RC522

Item	Specification
Working current	13 - 26mA/ DC 3.3V
Standby current	10 -13mA/DC 3.3V
Working frequency	13.56MHz
Card reading distance	0 ~ 30mm
Protocol	SPI
Data communication speed	Maximum 10Mbit/s
Card types supported	mifare1 S50, mifare1 S70, mifare UltraLight
Dimension [W x L]	40mm × 60mm

B. RFID Passive Tag

The RFID passive tag is used in the experimental setup as shown in Figure 3.12. The passive tag is designed to work with the RFID reader, hence the reader able to retrieve the data or information that is stored in the tag. The specification of RFID passive tag is shown in the Table 3.2.

Figure 3.12: RFID Passive Tag

Table 3.2: The specification of RFID passive tag

Item	Specification
Operating frequency	13.56MHz
Byte of Memory	1K (1024)
Card Type	Mifare ISO14443A 1K Classic card
Dimension [W x L]	54mm × 85mm

C. I R Line Following Sensor

The line following sensor is used in the prototype as shown in Figure 3.13. The line following sensor is used for line tracking purpose which will gives robot the ability to detect and follow the black line path. The specification of line following sensor is shown in the Table 3.3.

Figure 3.13: Line Following Sensor

Table 3.3: The specification of line following sensor

Item	Specification
Detection distance	1.5cm
Power supply	3.3 to 5VDC
Operating current	18 to 20mA at 5V
Output	Black = Logic HIGH, White = Logic LOW
Dimension [W x L x H]	10mm x 42mm x 6mm

D. Ultrasonic Sensor HC-SR04

The ultrasonic sensor is used in the prototype as shown in Figure 3.14. The function of the ultrasonic sensor is to assist mobile robot to detect and avoid nearby obstacle during the route to the target destination. The specification of ultrasonic sensor is shown in the Table 3.4.

Figure 3.14: Ultrasonic Sensor

Table 3.4: The specification of ultrasonic sensor

Item	Specification
Power Supply	5V DC
Working Current	15mA
Effective Angle	30°
Ranging Distance	2cm – 400 cm
Resolution	up to 0.3 cm
Dimension [W x L x H]	45mm x 20mm x 15mm

E. Arduino UNO Board

The Arduino UNO board is used in the prototype as shown in Figure 3.15. The Arduino UNO board is a specially designed board for programming and prototyping. The specification of Arduino UNO is shown in the Table 3.5.

Figure 3.15: Arduino UNO board

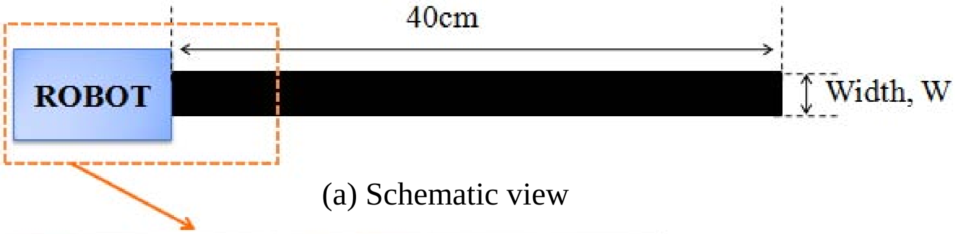
Table 3.5: The specification of Arduino UNO board

Item	Specification
Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage	7-12V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Clock Speed	16 MHz
Dimension [W x L]	53.4mm x 68.6mm

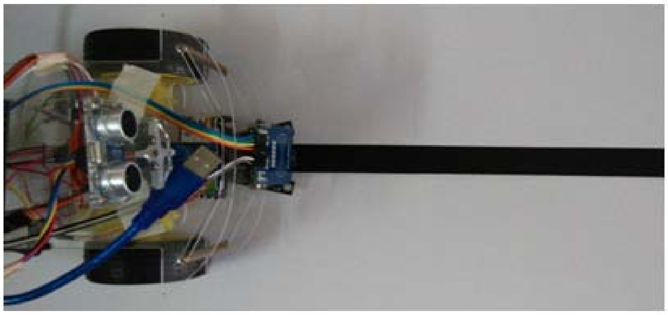
3.9 EXPERIMENT SETUP

3.9.1 Effect of Masking Tape Width on the Motion

In this setup, the mobile robot was equipped with line following sensor on the forepart of robot to follow the black line path. There are two types of configuration setup used to testing the performance of mobile robot to move along the black line path based on the masking tape width, which is straight line and curve line pattern. The objective of this experiment to determine the accuracy of line following sensor for the mobile robot to move along the black line path based on the different width of masking tape. In addition, the second objective of this experiment is to calculate the average and standard deviation for each of the masking tape width in order to discover the most suitable width for the movement of mobile robot. The experiment was carried out in an indoor environment where the black masking tape pasted on the workspace to create a straight line and curve line pattern path. The experimental setup for both type of configuration is shown in the Figure 3.16 and Figure 3.17. First of all, a masking tape with width of 14mm and length of 40cm were pasted on the workspace for both the configuration setup. After that, the experiment was repeated using different width of masking tape from 14mm to 21mm with increment of 1mm. Besides that, the readings that obtained from the three line following sensors were recorded for each of the masking tape width through the Arduino serial monitor. The results for both the straight line and curve line pattern were recorded and tabulated as shown in the Table from 4.2 to 4.7.

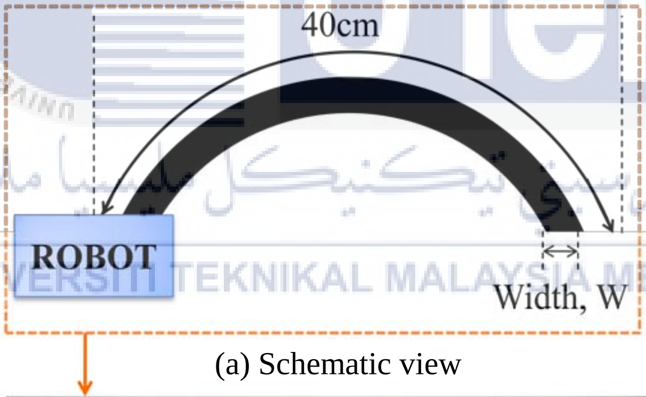


(a) Schematic view

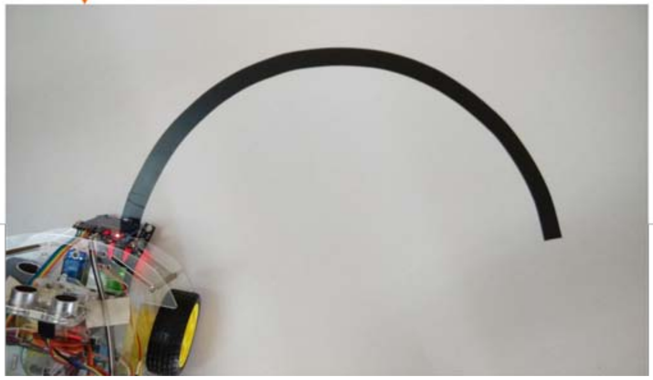


(b) Real-time view

Figure 3.16: The experimental setup for straight line pattern



(a) Schematic view



(b) Real-time view

Figure 3.17: The experimental setup for curve line pattern

3.9.2 Navigation of Mobile Robot based on Trajectory

In this setup, the mobile robot was equipped with the RFID reader and line following sensor on the forepart of the robot to follow the black line path while receive command from the passive tag to navigate the mobile robot to reach the destination. The RFID reader is used for receiving command and navigates the mobile robot from one tag location to another based on the information of the RFID passive tag. There are four types of trajectory pattern used for testing the performance of mobile robot, which are square-shaped, s-shaped and triangle-shaped and zigzag-shaped. The objective of this experiment is to identify the feasibility of navigation method by using the RFID reader and passive tag for mobile robot. First of all, the experiment was carried out in an indoor environment where the passive RFID tags will be deployed. Next, the totals of 25 passive RFID tags were laid on the workspace in a grid-like pattern over an area measuring 120 cm × 120 cm, with a spacing of 20 cm. The experiment was setup as shown in the Figure 3.18 and 3.19. Based on the result in experiment 1, the width of 18mm was chosen as the best outcome for the mobile robot to move smoothly and stably in a black line path. Therefore, a masking tape with width of 18mm was pasted on the workspace in a grid-like pattern in between the passive tags. For each trajectory pattern, the experiment was repeated for 10 times in order to record the time taken for the mobile robot to complete the path. The results were recorded and tabulated in the Table from 4.9 to 4.13.

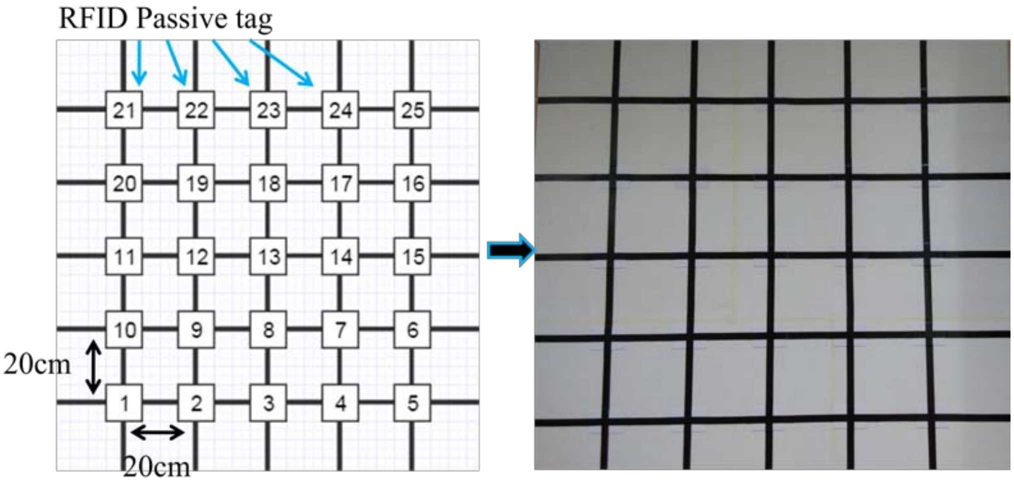
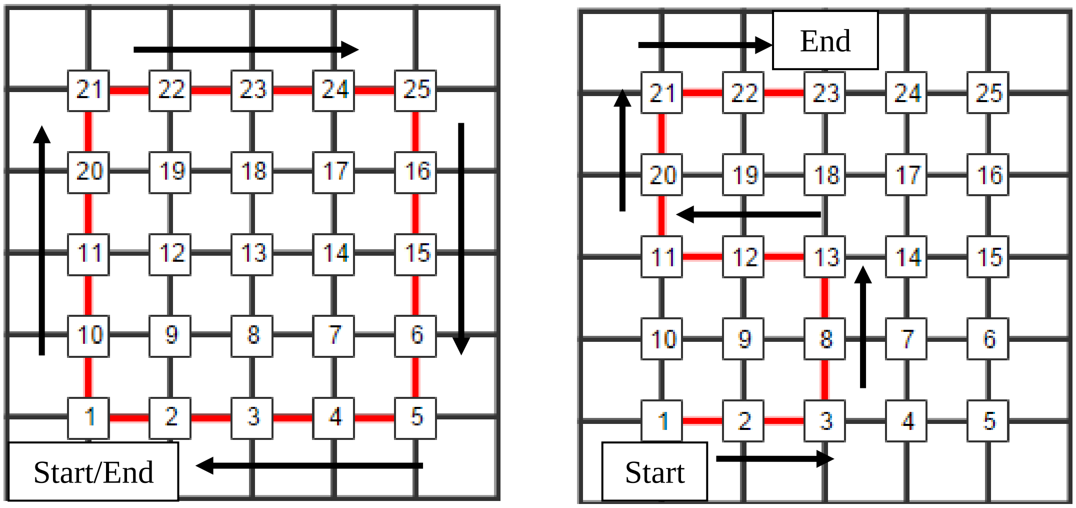
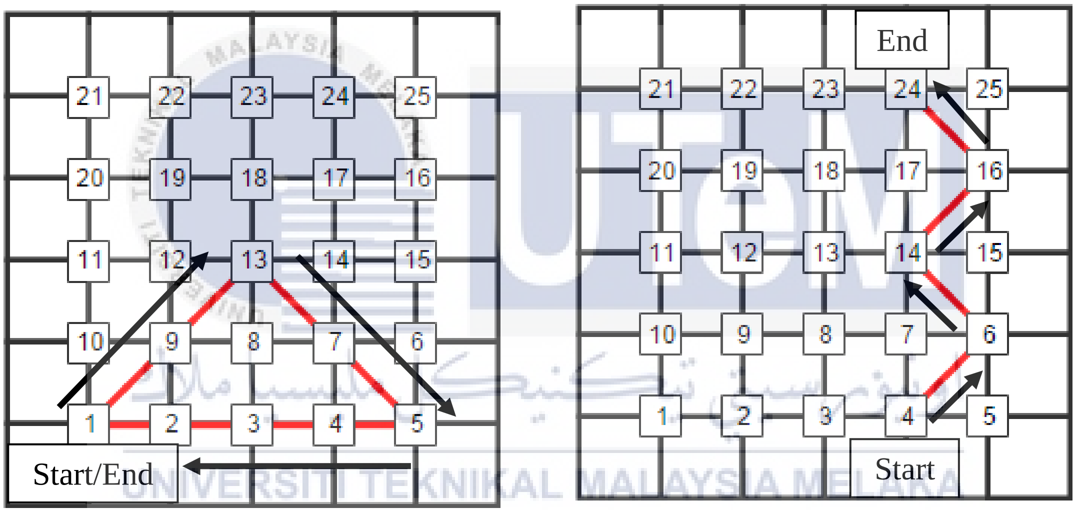


Figure 3.18: The workspace of mobile robot



(a) Square-shaped

(b) S-shaped



(c) Triangle-shaped

(d) Zigzag-shaped

Figure 3.19: Trajectory pattern for mobile robot navigation

For each of the trajectory pattern the sequence is stated as below:

(a) Square-shaped : 1 → 10→ 11 → 20 → 21→ 22→ 23 → 24 → 25 → 16
→ 15 → 6 → 5 → 4→ 3 → 2 → 1

(b) S-shaped : 1 → 2 → 3 → 8 → 13 → 12 → 11 → 20 → 21 → 22 → 23

(c) Triangle-shaped : 1 → 9 → 13 → 7 → 5 → 4 → 3 → 2 → 1

(d) Zigzag-shaped : 4 → 6 → 14 → 16 → 24

3.9.3 Obstacle Avoidance of Mobile Robot

In this setup, there are two sections where first part focuses on the testing of effective angle of ultrasonic sensor for different range of distance, which are 10cm, 20cm, and 30cm. The objective of this experiment is to determine the effective angle of ultrasonic sensor for different range of distance. First of all, the ultrasonic sensor was placed on the breadboard which is pointing toward 90° and the obstacle (2.4cm x 9.6cm x 2.2cm) was located 10cm from the sensor. The experiment was carried out in a workspace where the angles from 0° to 180° were labeled and marked for reference purpose. After that, the experiment was repeated for different range of distance, which are 20cm and 30cm. The experiment was setup as shown in the Figure 3.20. The results were recorded and tabulated in the Table from 4.16 to 4.18. On the other hand, second part focus on the obstacle avoidance of mobile robot in a workspace, where stationary obstacles will be placed in a particular location for the mobile robot to detect and avoid obstacle in order to reach the destination without collision. The objective of this experiment is to testing the feasibility of ultrasonic sensor for the mobile robot to detect and avoid the obstacle in an intelligent manner. First of all, the mobile robot was equipped with RFID reader, line following sensor and ultrasonic sensor on the forepart of the robot. The experiment was carried out in an indoor environment where the two obstacles (8.2cm x 15cm x 9.5cm) are placed in the particular location for the mobile robot to detect and avoid obstacle. The experiment was setup as shown in the Figure 3.21 and 3.22. The results were recorded and tabulated in the Table from 4.19 to 4.21.

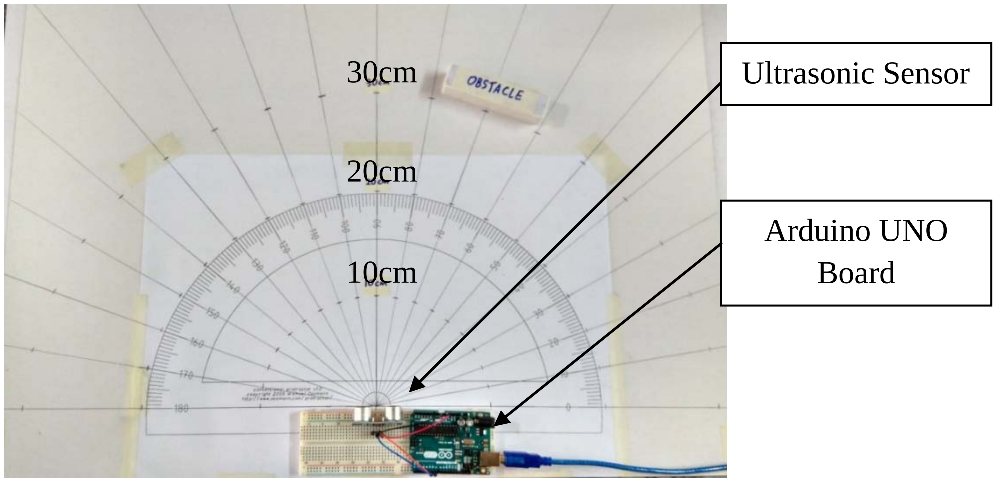
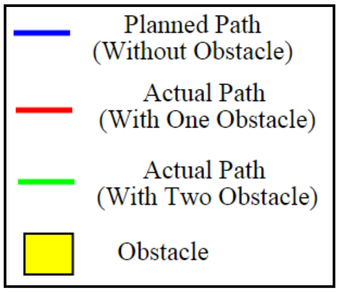
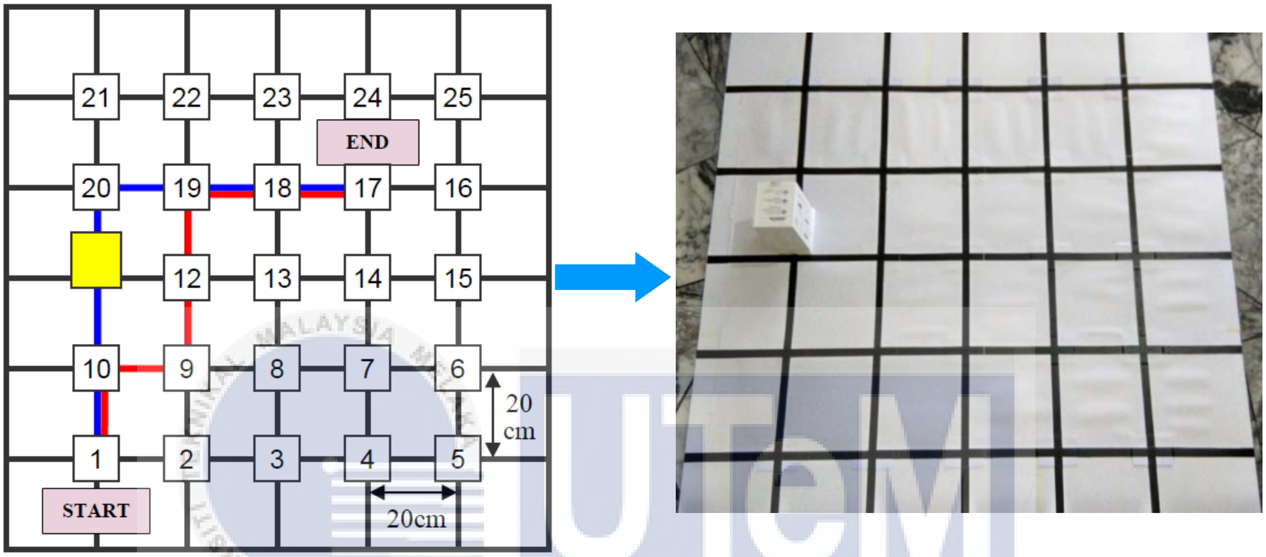


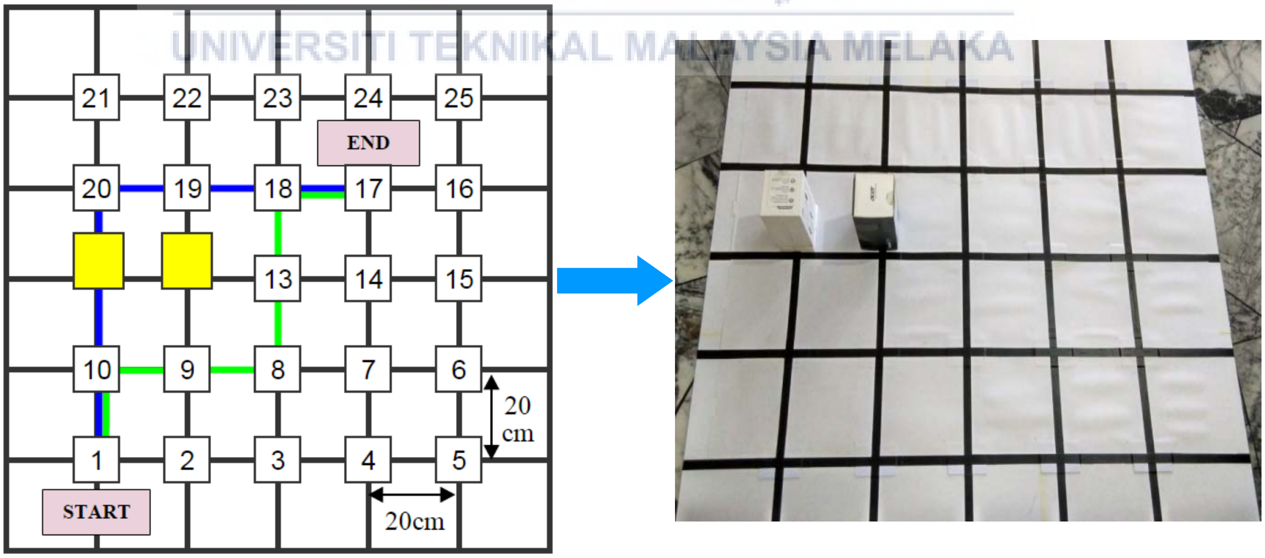
Figure 3.20: The experimental setup of ultrasonic sensor





(a) Schematic view of one obstacle (b) Real-time view of one obstacle

Figure 3.21: The workspace of mobile robot for one obstacle avoidance



(a) Schematic view of two obstacles (b) Real-time view of two obstacles

Figure 3.22: The workspace of mobile robot for two obstacle avoidance

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This section is explained about the result and discussion based on the data taken from the experiment. The following section includes effect of masking tapes on the motion, navigation of mobile robot based on trajectory and obstacle avoidance of mobile robot so that specialist or professor who may not belong to this field able to understand the rationale for the experimental approaches as well as how the data were analyzed.

4.2 EFFECT OF MASKING TAPE WIDTH ON THE MOTION

The experiment of effect of masking tape width on the motion is done to achieve the objective 2 which is to analyze the accuracy of the line following sensor towards different width of masking tape. The position of the three line following sensors which represent the left sensor, center sensor and right sensor are placed in forepart of the prototype as shown in the Figure 3.7. The setup for the two different type of configuration setup which is straight line pattern and curve line pattern are shown in the Figure 3.16 and Figure 3.17. Table 4.1 shows the summary of the experiment of masking tape width that has been done for both patterns.

Table 4.1: The summary of experiment of masking tape width for both patterns

Pattern	Masking Tape Width (mm)							
	14	15	16	17	18	19	20	21
Straight line	✓	✓	✓	✓	✓	✓	✓	✓
Curve line	✓	✓	✓	✓	✓	✓	✓	✓

4.2.1 Straight Line Pattern

From the Figure 4.1 to Figure 4.8, the graph shows that the results of straight line pattern for different width of masking tapes that covers the width from 14mm to 21mm. From the Figure 4.1 and 4.2, it can be seen that the mobile robot move smoothly on 14mm and 15mm wide black line for a period of time, which means that the mobile robot able to stay on course. However, the mobile robot did not complete the black line path due to the blind spot between the sensors, thus making it sudden stop in the middle before reach the end. From the Figure 4.3, 4.4, 4.5, and 4.6, the mobile robot able to complete the black line path in the shortest time, which is 1.2 seconds. This means that the mobile robot can move stably on black line path with the width of 16mm, 17mm, 18mm and 19mm. From the Figure 4.7 and 4.8, although the mobile robot managed to complete the black line path, but the oscillation is significantly higher compared to others as the graph shows fluctuations in between 0.4 seconds and 1.8 seconds. As the width increases, it will cause more oscillation to the movement of mobile robot when travel the black line path. In conclusion, the width covers from the 16mm to 19mm yield the best result as the mobile robot able to complete the straight line pattern path successfully in the shortest time.

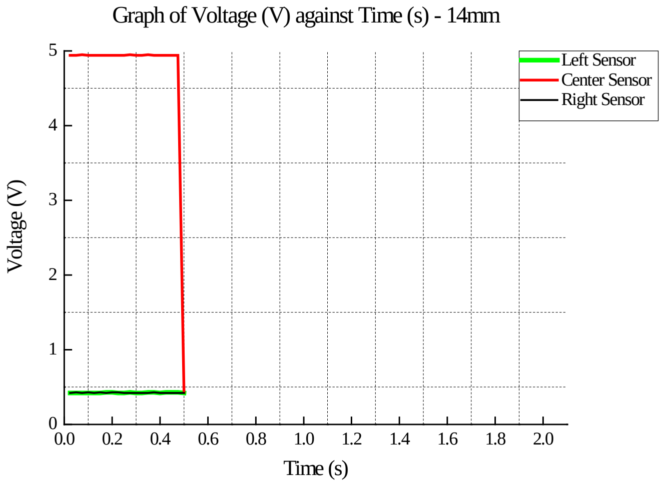


Figure 4.1: Width of 14mm

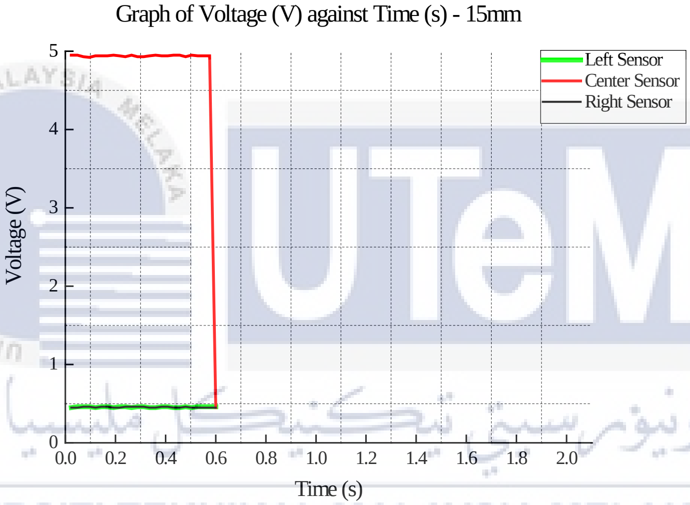


Figure 4.2: Width of 15mm

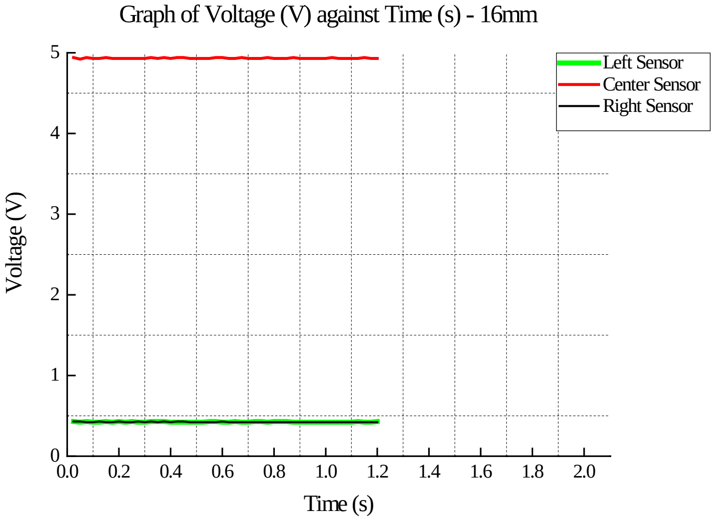


Figure 4.3: Width of 16mm

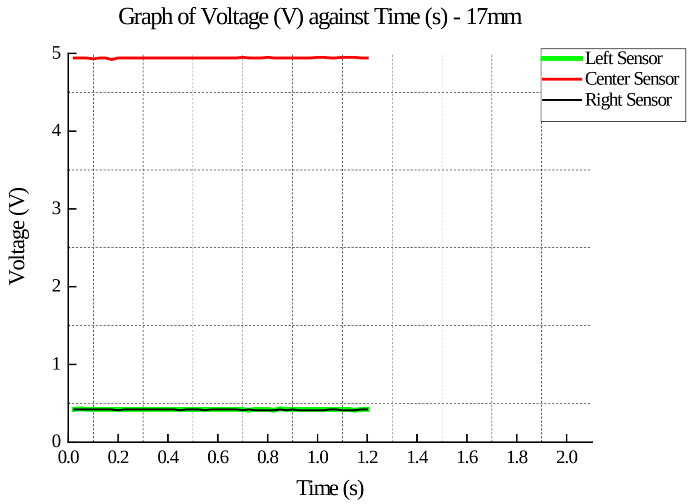


Figure 4.4: Width of 17mm

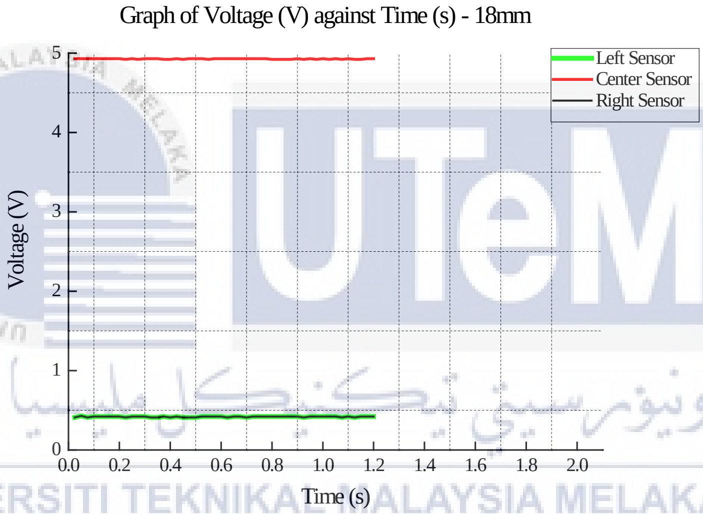


Figure 4.5: Width of 18mm

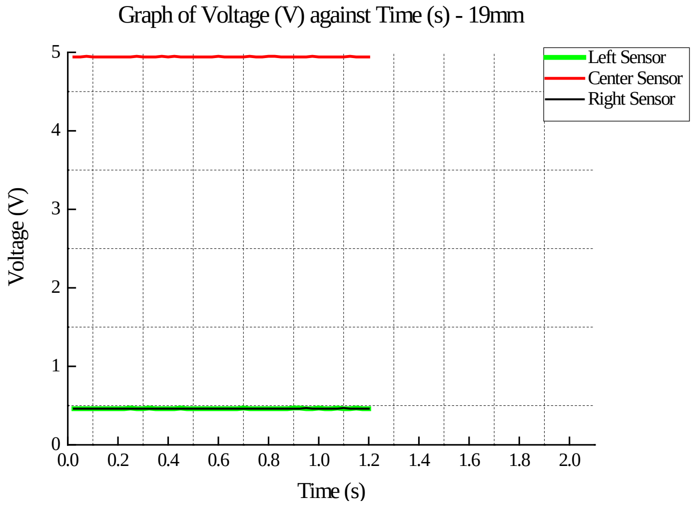


Figure 4.6: Width of 19mm

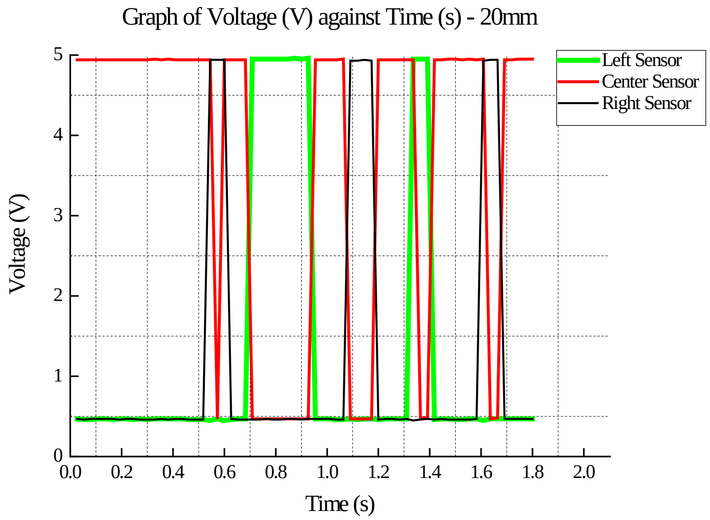


Figure 4.7: Width of 20mm

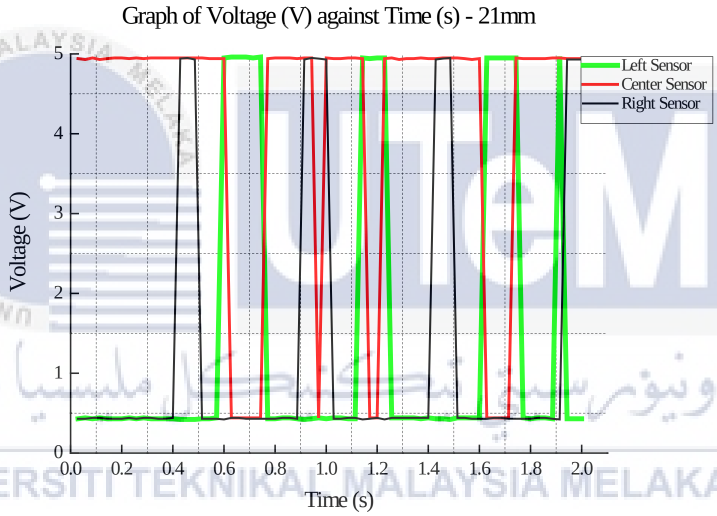


Figure 4.8: Width of 21mm

4.2.1.1 Standard Deviation of Straight Line Pattern

From the Table 4.2, Table 4.3 and Table 4.4, the table shows the average and standard deviation of the three sensors that calculated based on the data taken in experiment. After that, the graphs for left sensor, center sensor and right sensor are plotted as shown in the Figure 4.9, 4.10 and 4.11. From the Figure 4.9, 4.10, and 4.11, it can be seen that the width covers from 16mm to 19mm has standard deviation of zero value as shows in the graph of left, center and right sensor. This means that the readings obtained from the three sensors are consistent and uniform. Even though the width of 14mm and 15mm has standard deviation of zero value for the left and right sensor, however, the readings collected from the center sensor is not regular. This is because the mobile robot did not manage to stay on course until the end of the path and it stopped in the middle. For the width of 20mm and 21mm, the value of standard deviation among these three sensors shows significantly higher if compared to others. This shows that the oscillation of mobile robot is quite large and thus making the readings received from the three sensors is inconsistent and unstable. Therefore, the more inconsistent the readings collected from the three sensors, the higher the value of standard deviation. In contrast, the more consistent the readings obtained from the three sensors, the lower the value of standard deviation, thus the more accurate the results. Based on the results, it can be concluded that the width covers from 16mm to 19mm was chosen as the best result for the mobile robot to move smoothly and stably in a straight line pattern.

Table 4.2: The average and standard deviation for left sensor

Width(mm)	Average (V)	Standard Deviation
14	0.42	0.00
15	0.46	0.00
16	0.42	0.00
17	0.42	0.00
18	0.42	0.00
19	0.46	0.00
20	1.28	1.74
21	1.47	1.91

Table 4.3: The average and standard deviation for center sensor

Width(mm)	Average (V)	Standard Deviation
14	4.72	1.01
15	4.76	0.90
16	4.93	0.00
17	4.94	0.00
18	4.93	0.00
19	4.94	0.00
20	3.72	2.01
21	4.17	1.71

Table 4.4: The average and standard deviation for right sensor

Width(mm)	Average (V)	Standard Deviation
14	0.42	0.00
15	0.45	0.00
16	0.42	0.00
17	0.42	0.00
18	0.42	0.00
19	0.46	0.00
20	1.14	1.62
21	1.27	1.76

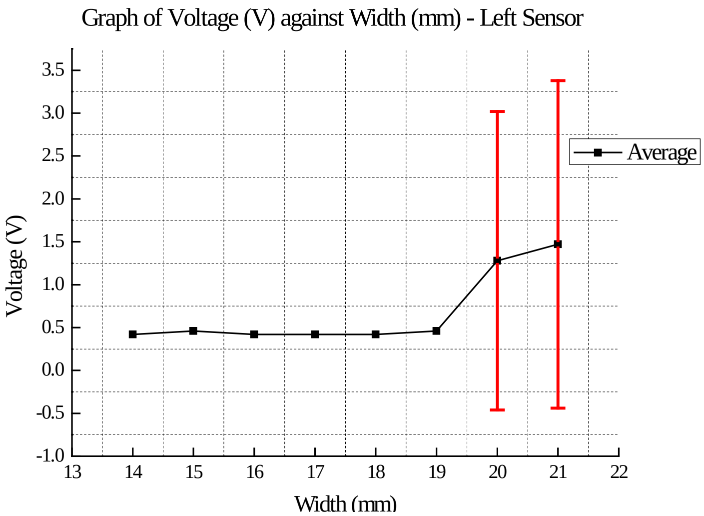


Figure 4.9: Left Sensor

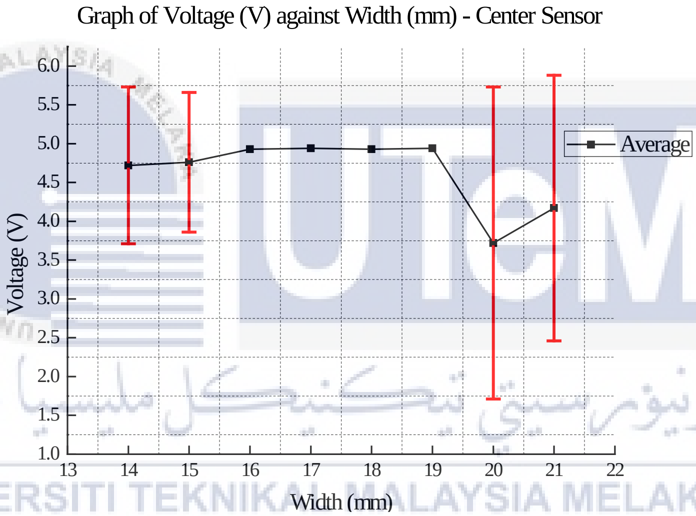


Figure 4.10: Center Sensor

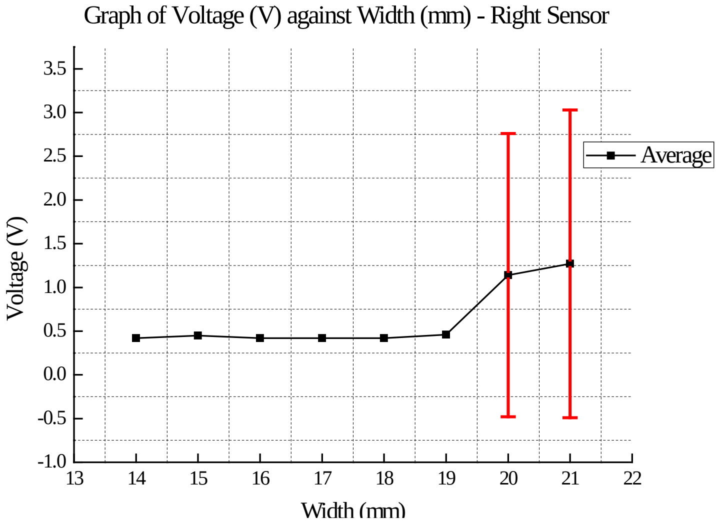


Figure 4.11: Right Sensor

4.2.2 CURVE LINE PATTERN

From the Figure 4.12 to Figure 4.19, the graph shows that the results of curve line pattern for different width of masking tapes that covers the width from 14mm to 21mm. From the Figure 4.12, 4.13, and 4.14, it can be seen that the mobile robot has a small oscillation covers from 14m to 16mm, which means the mobile robot did not stays on the course and it stray away from the center. Also, the mobile robot did not manage to complete the black line path due to the blind spot between the sensors, thus making it goes off the path. From the Figure 4.15, 4.16, and 4.17, the width of 18mm produce the best outcome among these three graphs as the graph shows less fluctuate and the center sensor detect the black line all the time as well as the mobile robot able to complete black line path in the shortest time, which is 2.7 seconds. This means that the mobile robot can move stably on black line path with the width of 18mm. From the Figure 4.18 and 4.19, although the mobile robot managed to complete the black line path, but the oscillation is significantly higher compared to others as the graph shows fluctuations from the beginning until the end of the path, which lead to the longest time taken to complete the path. As the width increases, it will cause more oscillation to the movement of mobile robot when travel the black line path. In conclusion, the width of 18mm yields the best outcome as the graph shows less fluctuates and the oscillation of mobile robot is smaller and the mobile robot able to complete the curve like pattern path in a shortest time.

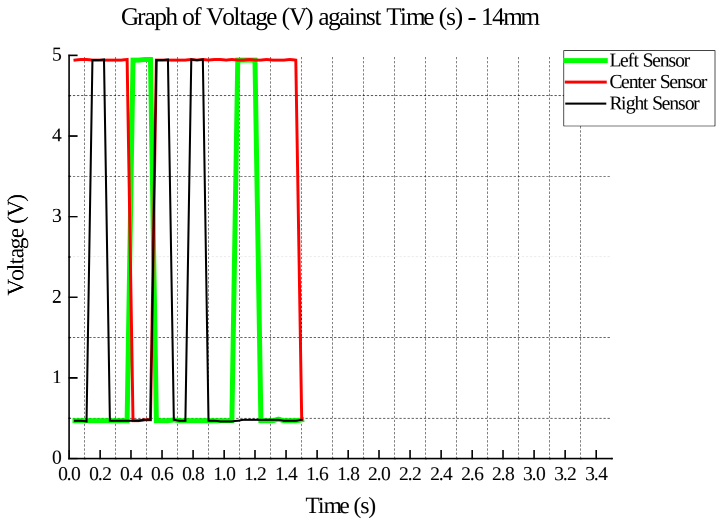


Figure 4.12: Width of 14mm

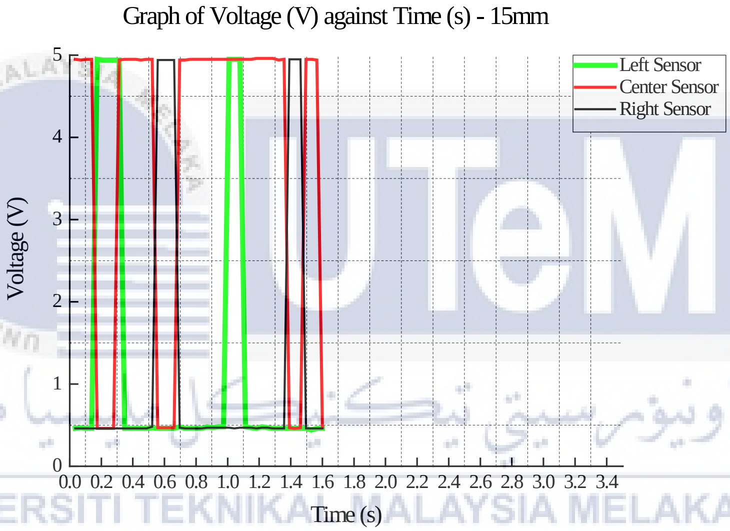


Figure 4.13: Width of 15mm

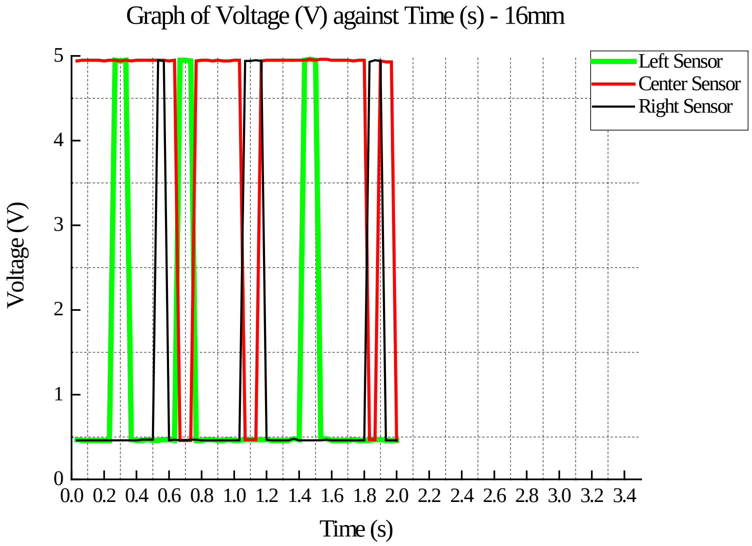


Figure 4.14: Width of 16mm

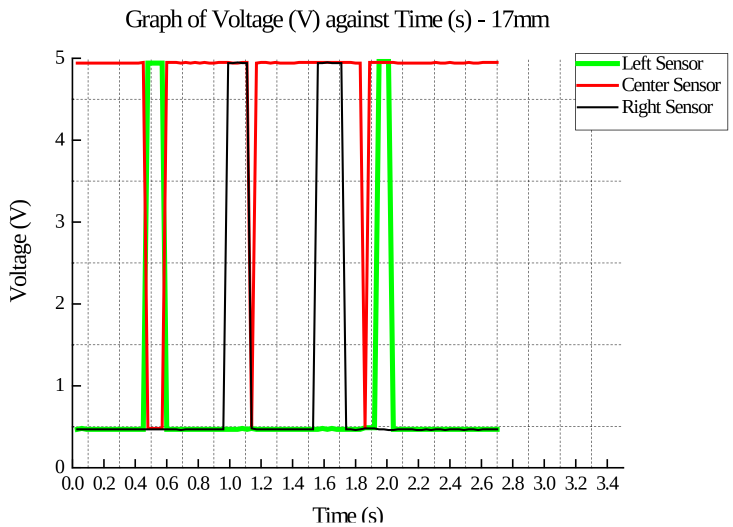


Figure 4.15: Width of 17mm

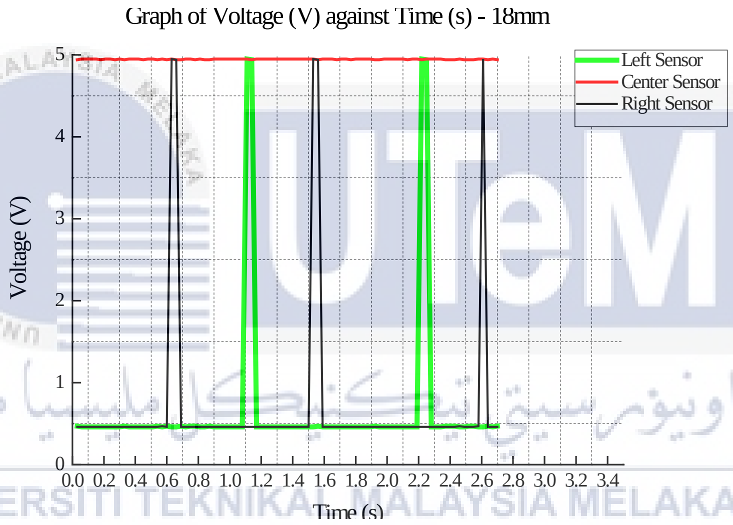


Figure 4.16: Width of 18mm

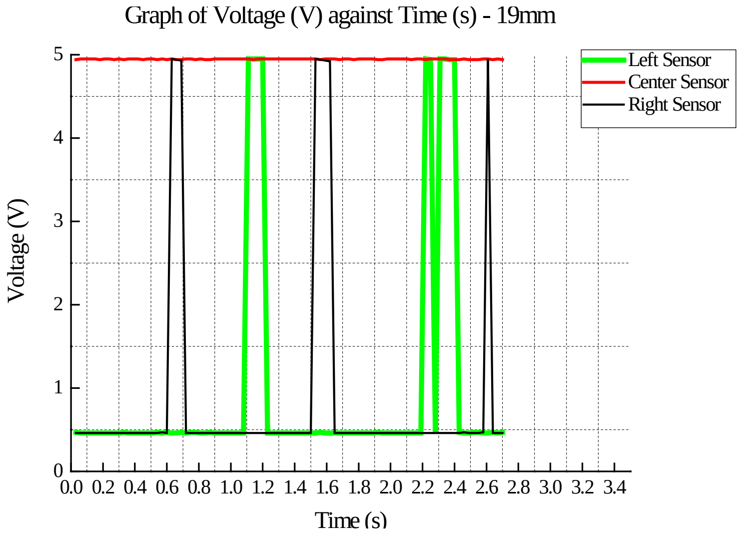


Figure 4.17: Width of 19mm

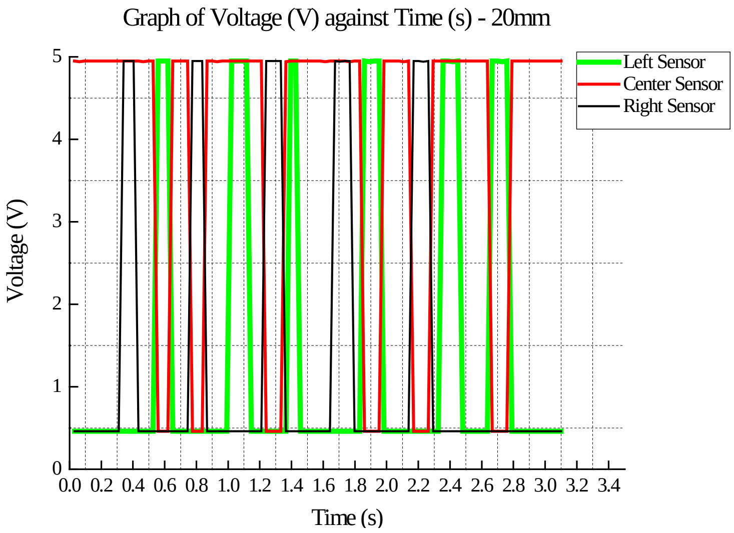


Figure 4.18: Width of 20mm

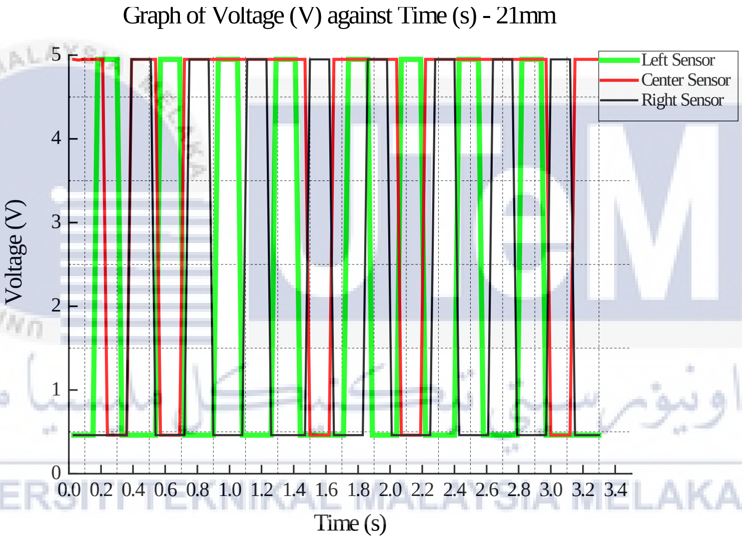


Figure 4.19: Width of 21mm

4.2.2.1 Standard Deviation of Curve line Pattern

From the Table 4.5, Table 4.6 and Table 4.7, the table shows the average and standard deviation of the three sensors that calculated based on the data taken in experiment. After that, the graphs for left sensor, center sensor and right sensor are plotted as shown in the Figure 4.20, 4.21 and 4.22. From the Figure 4.20, 4.21 and 4.22, it can be seen that the width of 18mm has standard deviation of zero value as shows in the graph of center sensor, whereas the graph of left and right sensor shows the lowest value of standard deviation if compare to others, which is 0.93 and 1.03 respectively. This means that the robot stays on track even though it shows some minor oscillations during the run. Despite the oscillations, the mobile robot was able to complete the black line path in the shortest time. For the width of 20mm and 21mm, the value of standard deviation among these three sensors is significantly higher compared to others. This shows that the oscillation of mobile robot is quite large and thus making the readings received from the three sensors is inconsistent and unstable. Therefore, the more inconsistent the readings collected from the three sensors, the higher the value of standard deviation. In contrast, the more consistent the readings obtained from the three sensors, the lower the value of standard deviation, thus the more accurate the results. As a conclusion, the width of 18mm was chosen as the best result for the mobile robot to move smoothly and stably in a curve line pattern.

Based on findings, it can be concluded that the width of 18mm was selected because it produce the best result for the mobile robot to move in two different types of pattern, which is straight line and curve line. The results show that the mobile robot able to complete the black line path in both patterns with high stability and minor oscillation.

Table 4.5: The average and standard deviation for left sensor

Width(mm)	Average (V)	Standard Deviation
14	1.37	1.81
15	1.24	1.72
16	1.14	1.61
17	0.82	1.21
18	0.66	0.93
19	0.96	1.42
20	1.40	1.84
21	2.09	2.17

Table 4.6: The average and standard deviation for center sensor

Width(mm)	Average (V)	Standard Deviation
14	4.39	1.50
15	3.78	1.99
16	4.28	1.61
17	4.65	1.12
18	4.95	0.00
19	4.95	0.00
20	3.96	1.87
21	3.93	1.89

Table 4.7: The average and standard deviation for right sensor

Width(mm)	Average (V)	Standard Deviation
14	1.48	1.89
15	1.15	1.63
16	1.13	1.61
17	1.02	1.47
18	0.71	1.03
19	0.86	1.28
20	1.27	1.73
21	2.09	2.17

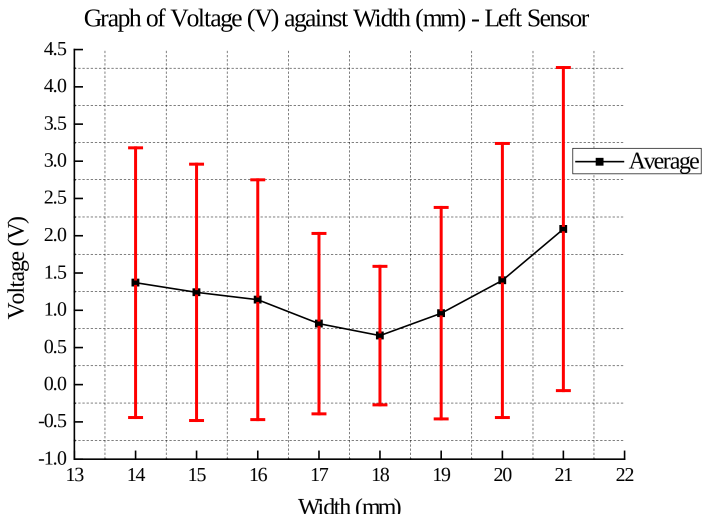


Figure 4.20: Left Sensor

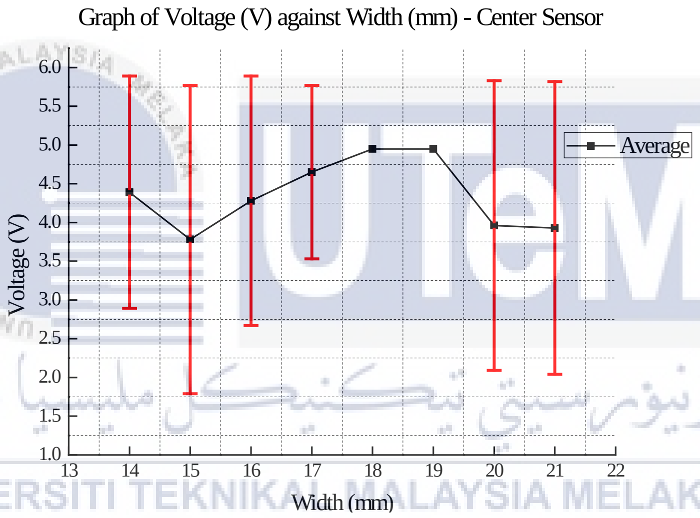


Figure 4.21: Center Sensor

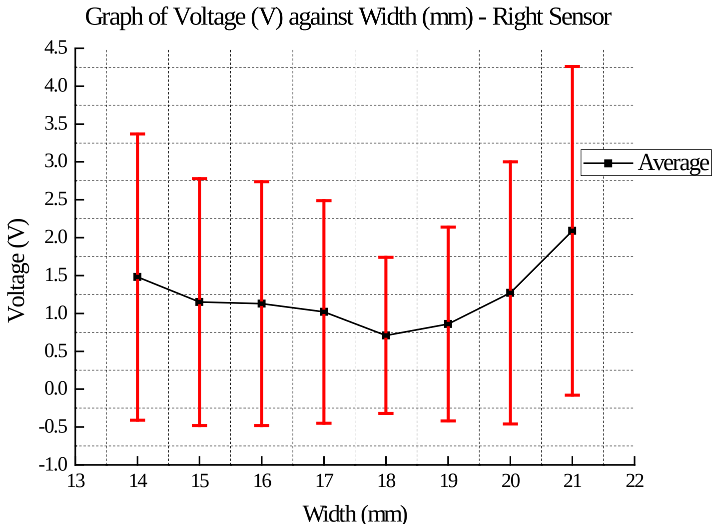


Figure 4.22: Right Sensor

4.3 NAVIGATION OF MOBILE ROBOT BASED ON TRAJECTORY

The experiment of navigation of mobile robot based on trajectory is done to achieve the objective 1 which is to design and develop of mobile robot that is able to navigate itself from one office to another for documents delivery. The RFID reader is used to navigate the mobile robot to reach the target destination and it is installed in forepart of the prototype as shown in the Figure 3.8. There are four types of trajectory pattern for the mobile robot navigation, which are square-shaped, s-shaped, triangle-shaped and zigzag-shaped. The setup for each of the trajectory pattern is shown in the Figure 3.18 and 3.19. Table 4.8 shows the summary of each of the trajectory pattern for mobile robot navigation.

Table 4.8: The summary of trajectory pattern for mobile robot navigation

Trajectory Pattern	Time taken to complete the path from start to end (s)
Square-shaped	✓
S-shaped	✓
Triangle-shaped	✓
Zigzag-shaped	✓

4.3.1 Square-shaped

The time taken for the mobile robot to complete the square-shaped path were recorded as shown in Table 4.9. From the Figure 4.23, it can be seen that the time taken for the robot to complete the square-shaped falls within range of time from 11.3 seconds to 11.5 seconds. This means that the mobile robot performed stably and consistently in completing the path.

Table 4.9: The time taken for the mobile robot to complete the Square-shaped path

No.	Time taken to complete the path from start to finish (s)	Observation
1	11.5	Complete
2	11.5	Complete
3	11.4	Complete
4	11.5	Complete
5	11.5	Complete
6	11.3	Complete
7	11.3	Complete
8	11.5	Complete
9	11.4	Complete
10	11.3	Complete
Average	11.42	

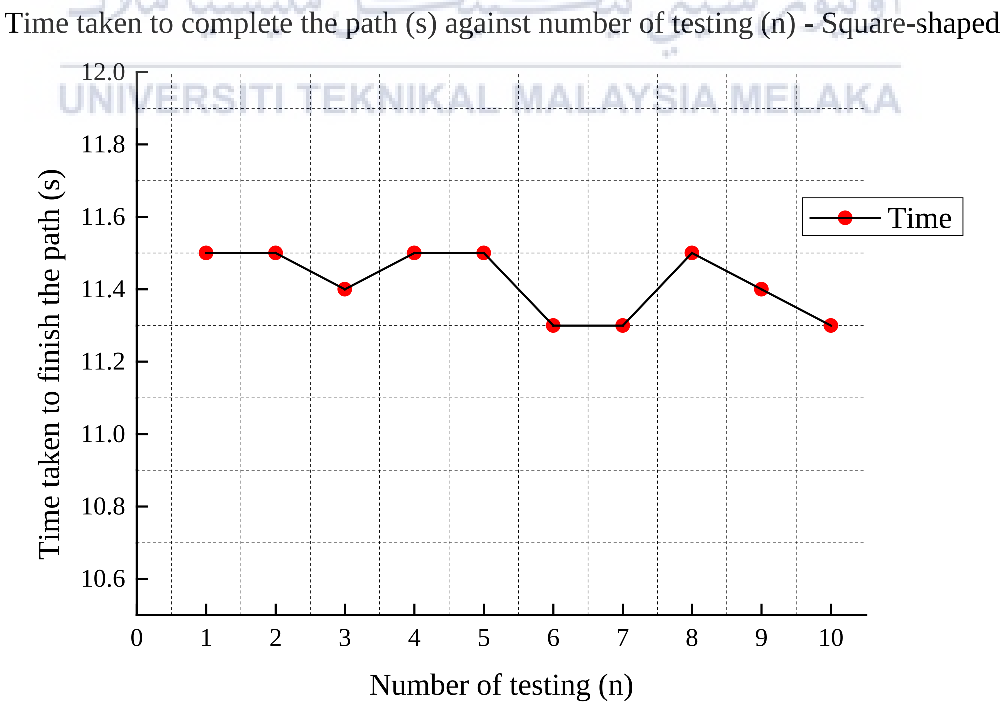


Figure 4.23: Square-shaped

4.3.2 S-shaped

The time taken for the mobile robot to complete the s-shaped path were recorded as shown in Table 4.10. From the Figure 4.24, it can be seen that the time taken for the robot to complete the s-shaped falls within range of time from 9.6 seconds to 10.0 seconds. This means that the mobile robot performed stably and consistently in completing the path.

Table 4.10: The time taken for the mobile robot to complete the S-shaped path

No.	Time taken to complete the path from start to finish (s)	Observation
1	9.8	Complete
2	9.8	Complete
3	10	Complete
4	9.7	Complete
5	9.6	Complete
6	9.8	Complete
7	10	Complete
8	9.6	Complete
9	9.7	Complete
10	9.7	Complete
Average	9.77	

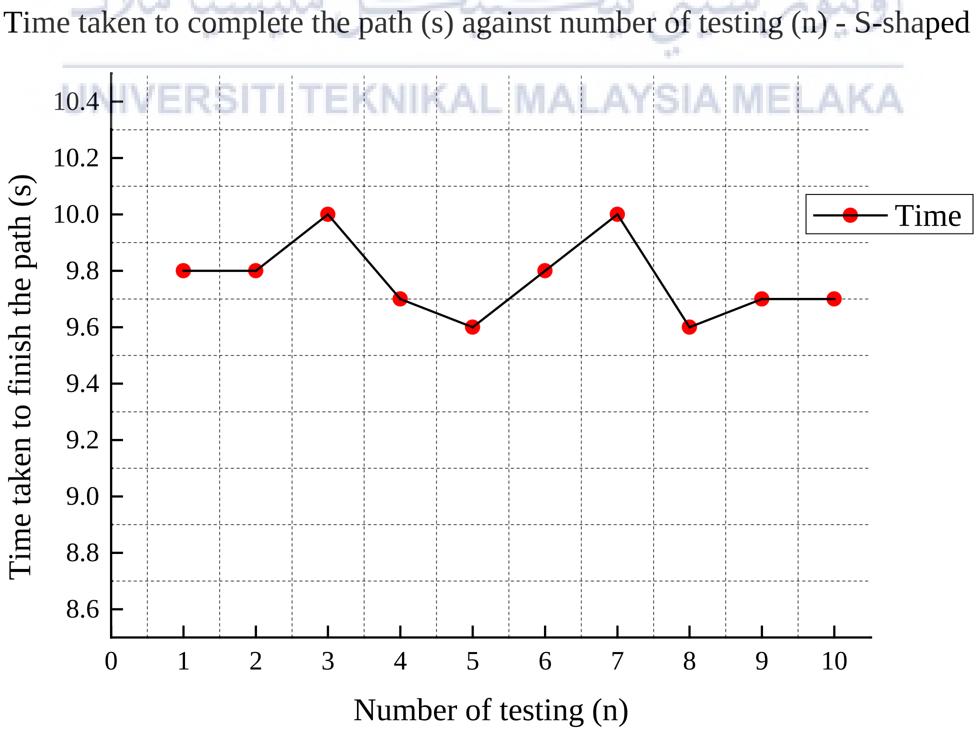


Figure 4.24: S-shaped

4.3.3 Triangle-shaped

The time taken for the mobile robot to complete the triangle-shaped path were recorded as shown in Table 4.11. From the Figure 4.25, it can be seen that the time taken for the robot to complete the triangle-shaped falls within range of time from 8.3 seconds to 8.6 seconds. This means that the mobile robot performed stably and consistently in completing the path.

Table 4.11: The time taken for the mobile robot to complete the Triangle-shaped path

No.	Time taken to complete the path from start to finish (s)	Observation
1	8.4	Complete
2	8.3	Complete
3	8.6	Complete
4	8.4	Complete
5	8.6	Complete
6	8.5	Complete
7	8.6	Complete
8	8.5	Complete
9	8.3	Complete
10	8.5	Complete
Average	8.47	

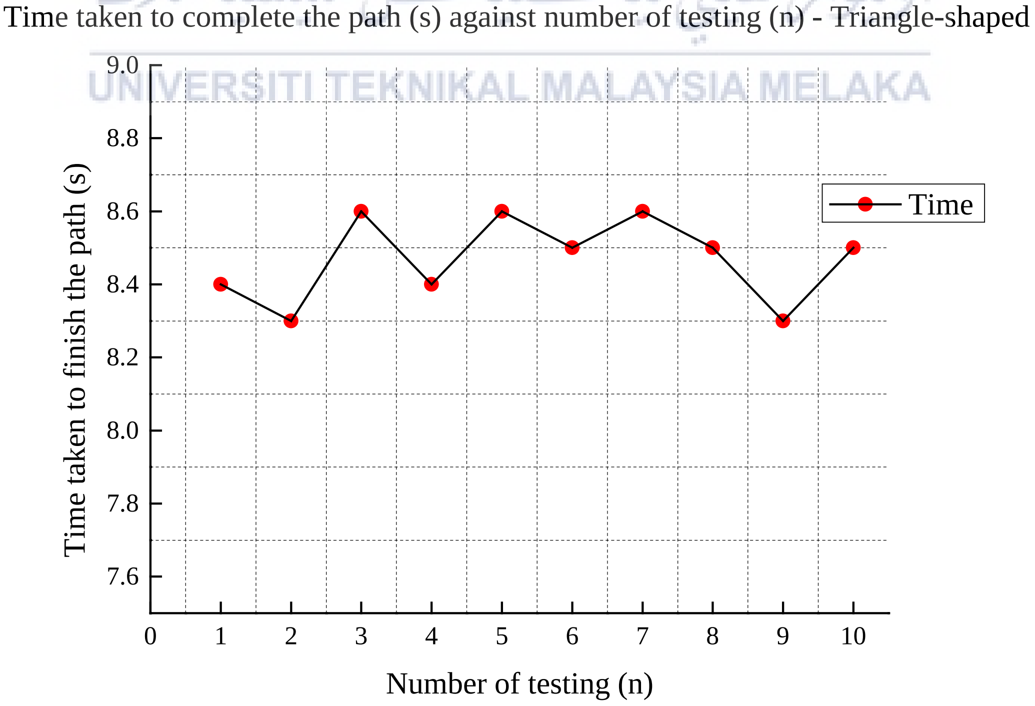


Figure 4.25: Triangle-shaped

4.3.4 Zigzag-shaped

The time taken for the mobile robot to complete the zigzag-shaped path were recorded as shown in Table 4.12. From the Figure 4.26, it can be seen that the time taken for the robot to complete the zigzag-shaped falls within range of time from 6.0 seconds to 6.3 seconds. This means that the mobile robot performed stably and consistently in completing the path.

Table 4.12: The time taken for the mobile robot to complete the Zigzag-shaped path

No.	Time taken to complete the path from start to finish (s)	Observation
1	6.2	Complete
2	6.2	Complete
3	6.1	Complete
4	6.2	Complete
5	6.0	Complete
6	6.3	Complete
7	6.2	Complete
8	6.1	Complete
9	6.3	Complete
10	6.2	Complete
Average	6.18	

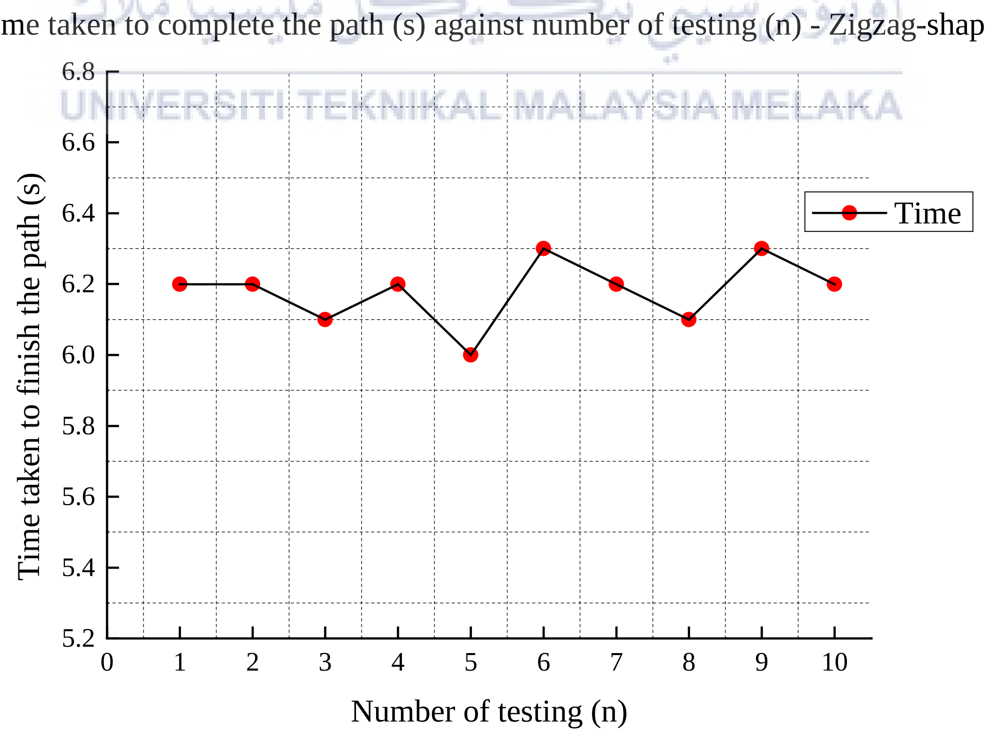


Figure 4.26: Zigzag-shaped

4.3.5 Conclusion for Different Trajectory Pattern

The distance and average time taken for each of the trajectory pattern were recorded as shown in Table 4.13. From the Figure 4.27, the bar chart illustrates the distance and average time taken to complete the path for different type of trajectory pattern, which are square-shaped, s-shaped, triangle-shaped and zigzag-shaped. It implies that that the farther the distance, the longer the average time taken for the mobile robot to complete the path and vice versa. Based on the findings, it can be concluded that the mobile robot performed stably and consistently even in different type of trajectory pattern.

Table 4.13: The distance and average time taken for each of the trajectory pattern

Type of trajectory pattern	Distance (cm)	Average time taken to complete the path (s)
Square-shaped	320	11.42
S-shaped	200	9.77
Triangle-shaped	160	8.47
Zigzag-shaped	80	6.18

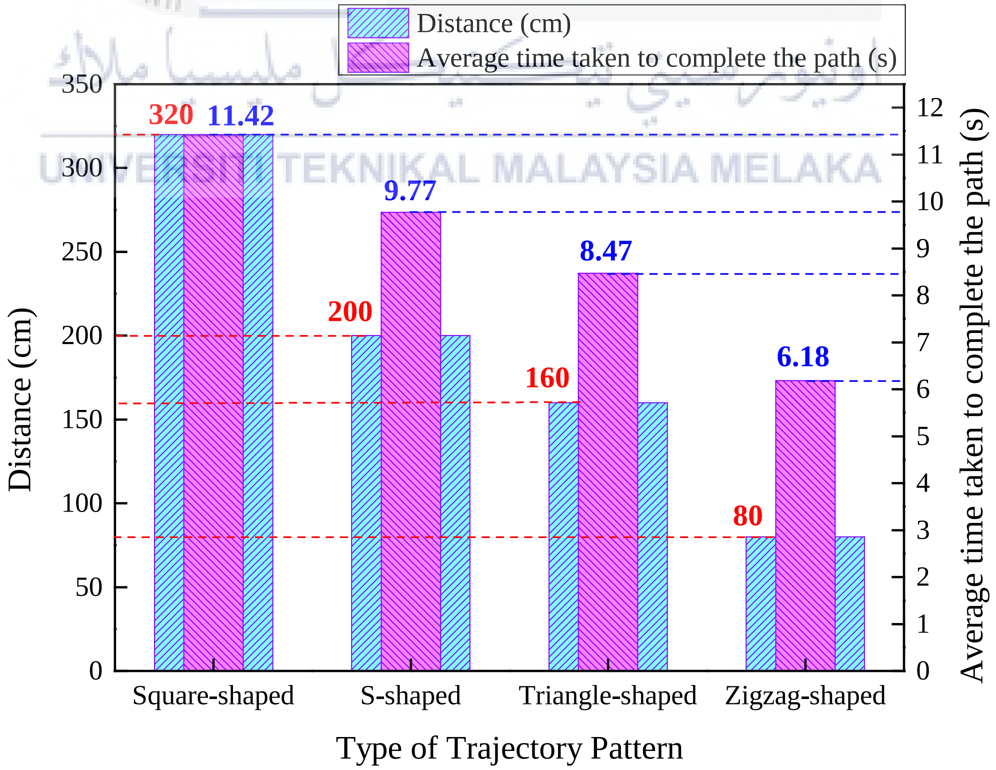


Figure 4.27: The distance and average time taken for different type trajectory pattern

4.4 OBSTACLE AVOIDANCE OF MOBILE ROBOT

The experiment of obstacle avoidance of mobile robot is done to achieve the objective 3 which is to analyze the trajectory movement of mobile robot so that it is able to reach the target destination without collision with obstacles. The ultrasonic sensor is used to detect and avoid nearby obstacle during the way to target destination and it is equipped in forepart of the prototype as shown in the Figure 3.8. In order to achieve the objective, there are two sections where first part is to testing the effective angle of ultrasonic sensor for range of distance while the second part is to focus on the obstacle avoidance of mobile robot in a workspace. The setup for the ultrasonic sensor is shown in the Figure 3.20. Also, the setup for the obstacle avoidance of mobile robot in a workspace is shown in the Figure 3.21 and 3.22. Table 4.14 shows the summary of testing the effective angle of ultrasonic sensor for different distance. Table 4.15 shows the summary of obstacle avoidance of mobile robot in a workspace.

Table 4.14: The summary of testing the effective angle of ultrasonic sensor for different distance

Degree	Distance (cm)		
	10	20	30
0° to 180° with the increments of 10°	✓	✓	✓

Table 4.15: The summary of obstacle avoidance of mobile robot in a workspace

Situation	Time taken for the mobile robot the reach the RFID passive tag
Planned Path (Without obstacle)	✓
Actual Path (With one obstacle)	✓
Actual Path (With two obstacles)	✓

4.4.1 Testing the Effective Angle of Ultrasonic Sensor

This section is briefing about the effective angle of ultrasonic sensor for different range of distance, which are 10cm, 20cm and 30cm. The following section will be further discussing the findings based on the data taken in experiment.

4.4.1.1 Distance of 10cm

From the Table 4.16, the table shows the average and standard deviation for the distance of 10cm that calculated based on the data taken in experiment. After that, the graph of distance against degree is plotted as shown in the Figure 4.28. Based on the findings, it can be seen that the effective angle is from 70° to 110° with the value of standard deviation near to zero. This means that the readings obtained from the sensor are consistent and accurate.

Table 4.16: The average and standard deviation for the distance of 10cm

Degree (◦)	Distance (cm)					Average (cm)	Standard Deviation
	1	2	3	4	5		
0	0	0	0	0	0	0.00	0.00
10	0	0	0	0	0	0.00	0.00
20	0	0	0	0	0	0.00	0.00
30	0	0	0	0	0	0.00	0.00
40	0	0	0	0	0	0.00	0.00
50	0	0	0	0	0	0.00	0.00
60	0	0	0	0	0	0.00	0.00
70	9.95	9.92	9.93	9.94	9.91	9.93	0.02
80	9.96	9.98	9.95	9.97	9.97	9.97	0.01
90	9.95	9.98	9.97	9.98	9.97	9.97	0.01
100	9.98	9.96	9.97	9.97	9.98	9.97	0.01
110	9.93	9.91	9.95	9.94	9.94	9.93	0.02
120	0	0	0	0	0	0.00	0.00
130	0	0	0	0	0	0.00	0.00
140	0	0	0	0	0	0.00	0.00
150	0	0	0	0	0	0.00	0.00
160	0	0	0	0	0	0.00	0.00
170	0	0	0	0	0	0.00	0.00
180	0	0	0	0	0	0.00	0.00

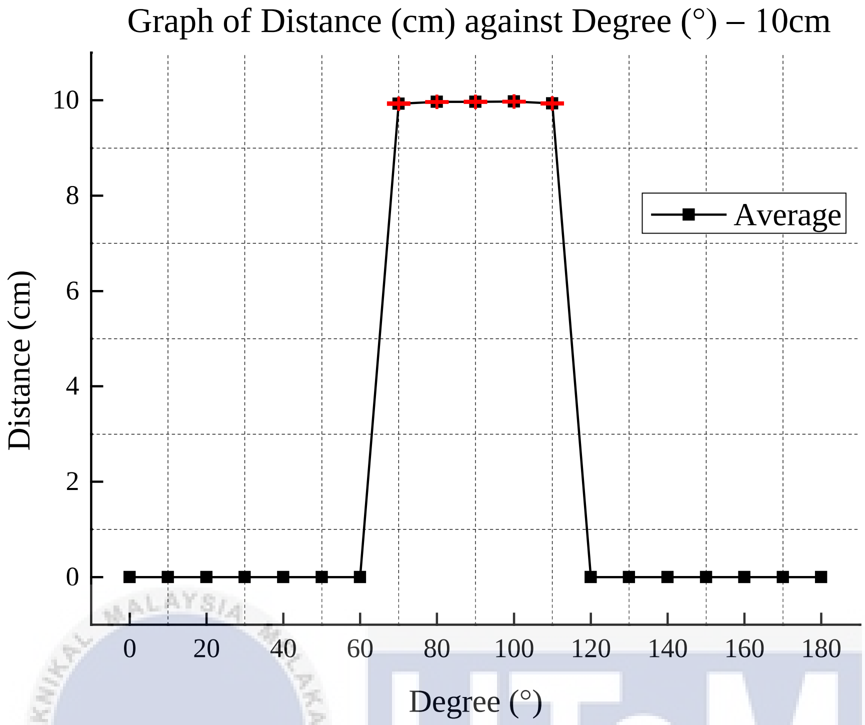


Figure 4.28: Distance of 10cm

4.4.1.2 Distance of 20cm

From the Table 4.17, the table shows the average and standard deviation for the distance of 20cm that calculated based on the data taken in experiment. After that, the graph of distance against degree is plotted as shown in the Figure 4.29. Based on the findings, it can be seen that the effective angle is from 70° to 110° with the value of standard deviation near to zero. This shows that the readings obtained from the sensor are consistent and accurate.

Table 4.17: The average and standard deviation for the distance of 20cm

Degree (◦)	Distance (cm)					Average (cm)	Standard Deviation
	1	2	3	4	5		
0	0	0	0	0	0	0.00	0.00
10	0	0	0	0	0	0.00	0.00
20	0	0	0	0	0	0.00	0.00
30	0	0	0	0	0	0.00	0.00
40	0	0	0	0	0	0.00	0.00
50	0	0	0	0	0	0.00	0.00
60	0	0	0	0	0	0.00	0.00
70	19.93	19.97	19.96	19.96	19.95	19.95	0.02
80	19.99	19.98	19.97	19.97	19.98	19.98	0.01
90	19.98	19.98	19.99	19.98	19.99	19.98	0.01
100	19.97	19.99	19.96	19.98	19.97	19.97	0.01
110	19.97	19.93	19.95	19.96	19.98	19.96	0.02
120	0	0	0	0	0	0.00	0.00
130	0	0	0	0	0	0.00	0.00
140	0	0	0	0	0	0.00	0.00
150	0	0	0	0	0	0.00	0.00
160	0	0	0	0	0	0.00	0.00
170	0	0	0	0	0	0.00	0.00
180	0	0	0	0	0	0.00	0.00

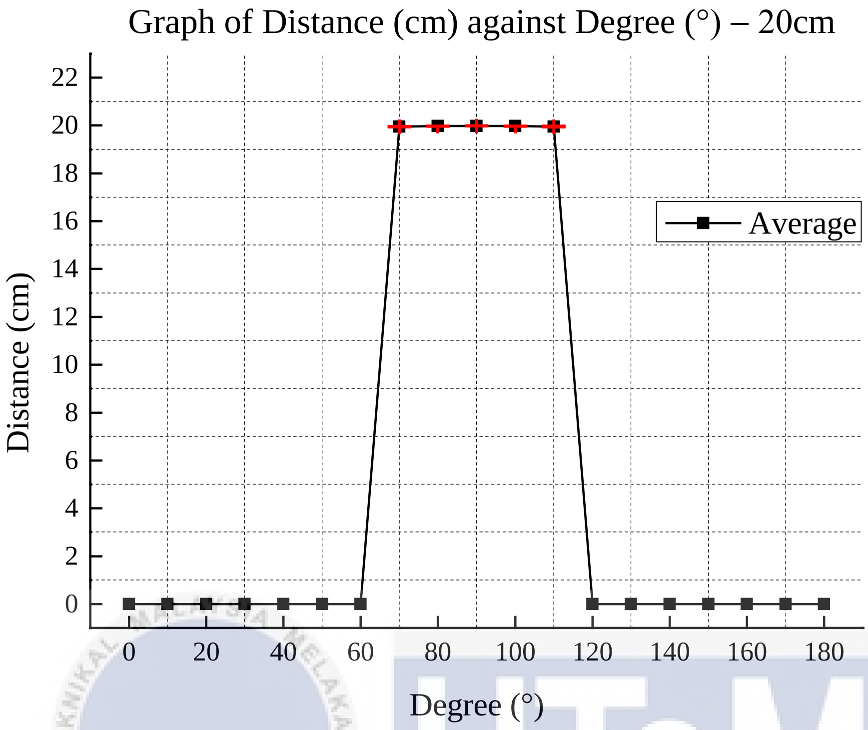


Figure 4.29: Distance of 20cm

4.4.1.3 Distance of 30cm

From the Table 4.18, the table shows the average and standard deviation for the distance of 20cm that calculated based on the data taken in experiment. After that, the graph of distance against degree is plotted as shown in the Figure 4.30. Based on the findings, it can be seen that the effective angle is from 70° to 110° with the value of standard deviation near to zero. This indicates that the readings obtained from the sensor are consistent and accurate.

Table 4.18: The average and standard deviation for the distance of 30cm

Degree (◦)	Distance (cm)					Average (cm)	Standard Deviation
	1	2	3	4	5		
0	0	0	0	0	0	0.00	0.00
10	0	0	0	0	0	0.00	0.00
20	0	0	0	0	0	0.00	0.00
30	0	0	0	0	0	0.00	0.00
40	0	0	0	0	0	0.00	0.00
50	0	0	0	0	0	0.00	0.00
60	0	0	0	0	0	0.00	0.00
70	30.1	30.15	30.12	30.12	30.14	30.13	0.02
80	29.97	29.98	29.97	29.99	29.98	29.98	0.01
90	29.98	29.99	29.98	29.98	29.99	29.98	0.01
100	29.99	29.98	29.97	29.98	29.97	29.98	0.01
110	30.11	30.13	30.12	30.15	30.15	30.13	0.02
120	0	0	0	0	0	0.00	0.00
130	0	0	0	0	0	0.00	0.00
140	0	0	0	0	0	0.00	0.00
150	0	0	0	0	0	0.00	0.00
160	0	0	0	0	0	0.00	0.00
170	0	0	0	0	0	0.00	0.00
180	0	0	0	0	0	0.00	0.00

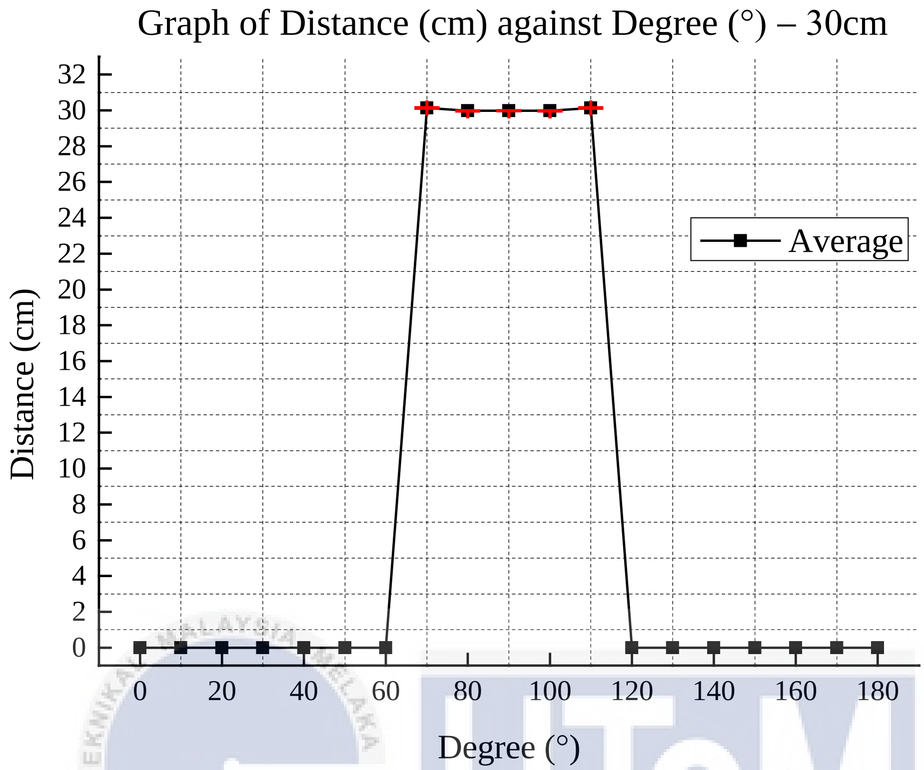


Figure 4.30: Distance of 30cm

4.4.1.4 Comparison between distance of 10cm, 20cm and 30cm

From the Figure 4.31, the graph shows the comparison for the distance of 10cm, 20cm and 30cm. According to the graph, it can be seen that the effective angle for all the distance range is from 70° to 110° with the value of standard deviation near to zero. This indicate that mobile robot that equipped with ultrasonic sensor have a effective angle range from 70 degree up to 110 degree. This helps the mobile robot to detect and avoid nearby obstacle and move toward to the target destination without collision with the obstacles.

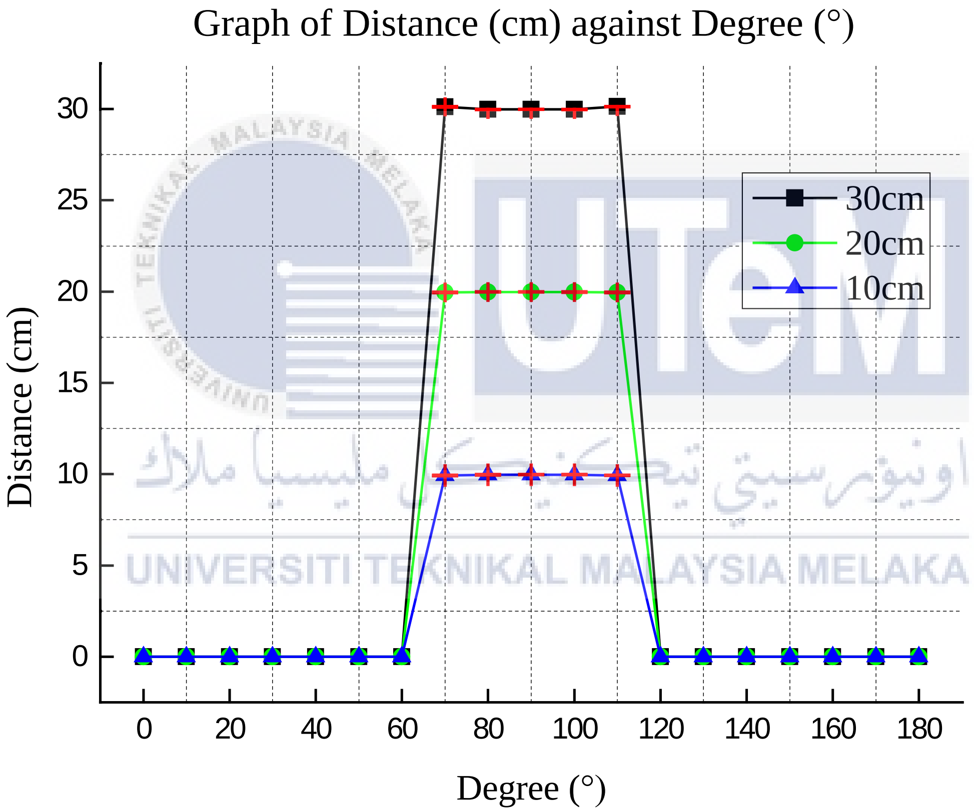


Figure 4.31: Comparison between the distance of 10cm, 20cm and 30cm

4.4.2 Obstacle Avoidance

This section is explained about the obstacle avoidance of mobile robot in a workspace which including planned path (without obstacle) and actual path with one or two obstacles. The following section will be further discussing the findings based on the data taken in experiment.

4.4.2.1 Planned Path (Without Obstacle)

The time taken for the mobile robot the reach the particular passive tag is shown in the Table 4.19. The results of planned path tests are shown in the Figure 4.32, 4.33 and 4.34. From the Figure 4.32, 4.33 and 4.34, the graph shows the similar pattern for the planned path that without obstacle. First of all, the mobile robot was passed to passive tag number 10 at around 1.2 seconds with some minor oscillation before it reaches the next passive tag. After that, the mobile robot continue moving straight to the passive tag number 20 at around 3.3 seconds, which here the mobile robot will making a right turn before it reaches the next passive tag. There is major oscillation occurred right after the mobile robot perform the turning to the right. Next, the mobile robot continues the route to the destination and stopped at around 5.8 seconds. In conclusion, the mobile robot is able to navigate itself from start to reach the target destination.

Table 4.19: Time taken for the mobile robot the reach the particular passive tag

RFID Passive Tag Number	Time taken for the mobile robot the reach the RFID passive tag		
	1	2	3
1	0	0	0
10	1.2	1.2	1.1
20	3.3	3.4	3.5
17	5.8	5.8	5.6

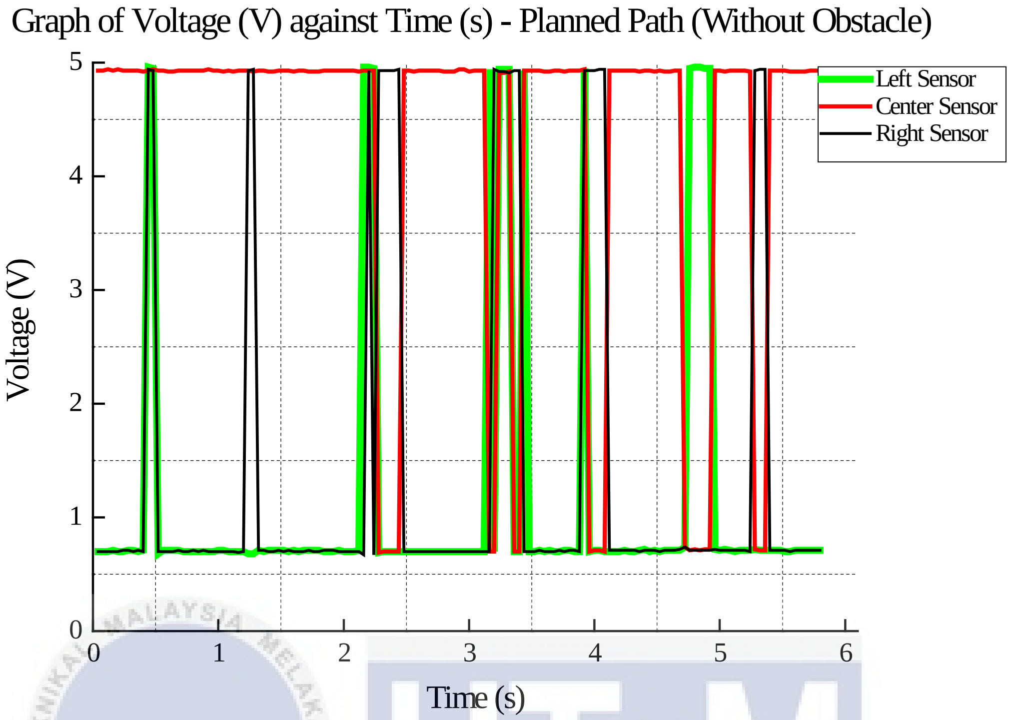


Figure 4.32: First test of planned path

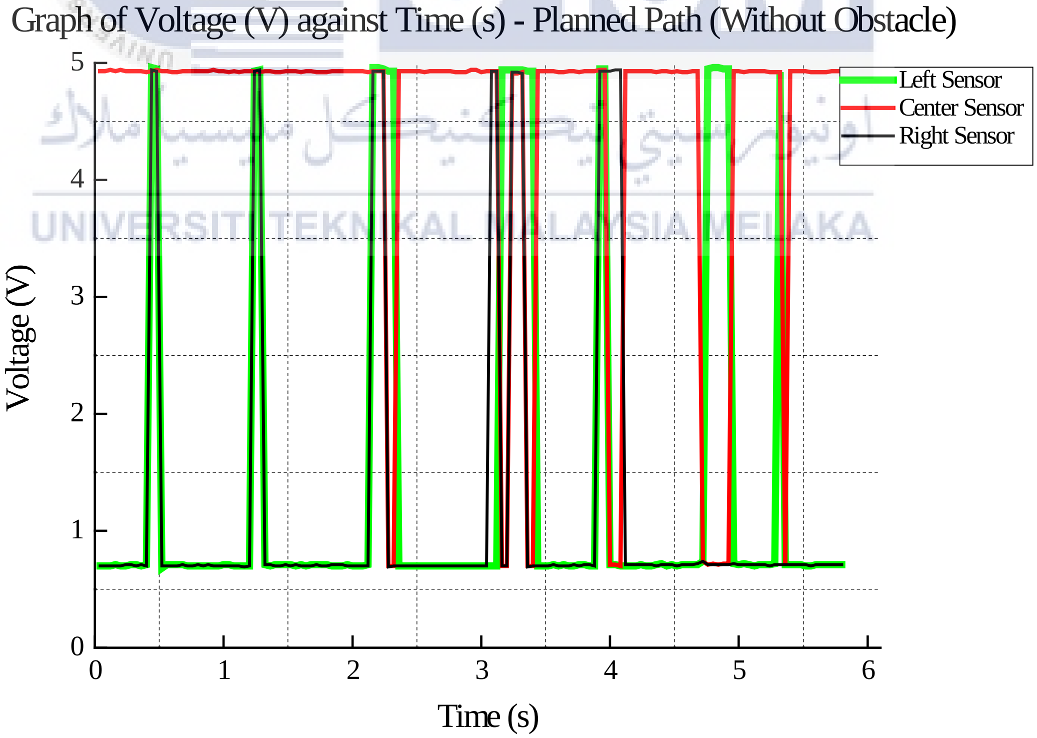


Figure 4.33: Second test of planned path

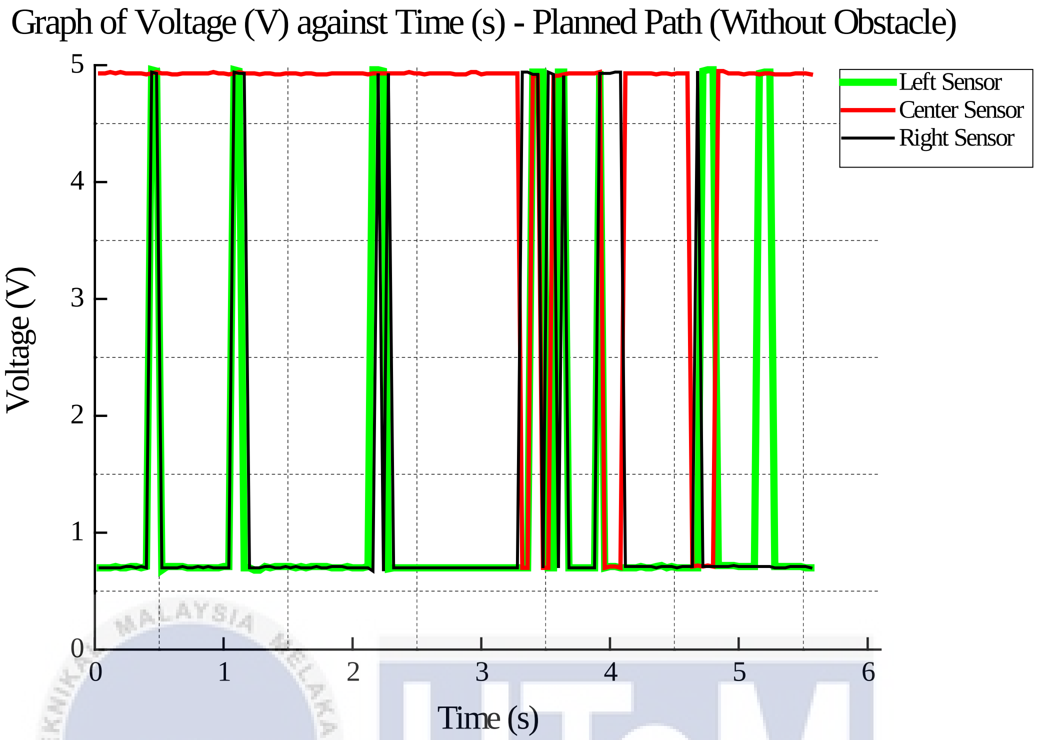


Figure 4.34: Third test of planned path

4.4.2.2 Actual Path (With One Obstacle)

The time taken for the mobile robot the reach the particular passive tag is shown in the Table 4.20. The results of actual path tests are shown in the Figure 4.35, 4.36 and 4.37. From the Figure 4.35, 4.36 and 4.37, the graph shows the similar pattern for the actual path that with one obstacle. First of all, the mobile robot was passed to passive tag number 10 at around 1.4 seconds with some minor oscillation before it reaches the next passive tag. However, the ultrasonic sensor detects and avoid obstacle that located 20cm away from the mobile robot and thus it making right turn to the passive tag number 9 at around 2.4 seconds. After that, the mobile robot making left turn to the passive tag number 12. In this short period of time, the graphs show fluctuations in between 2.2 seconds to 3.5 seconds due to the number of turning of mobile robot, thus making it oscillation much. This means the oscillation of mobile robot become larger in the period of time because of the quick turning direction of robot itself. Next, the mobile robot continues moving straight to the passive tag number 19 at around 4.8 seconds, which here the mobile robot will making right turn before it reaches the next passive tag. Next, the mobile robot continues the route to the destination and stopped at around 6.6 seconds. In conclusion, the mobile robot is able to navigate itself from start to reach the target destination without collision with the obstacle.

Table 4.20: Time taken for the mobile robot the reach the particular passive tag

RFID Passive Tag Number	Time taken for the mobile robot the reach the RFID passive tag		
	1	2	3
1	0	0	0
10	1.4	1.5	1.5
9	2.2	2.4	2.2
19	4.8	4.9	5.1
17	6.5	6.8	6.6

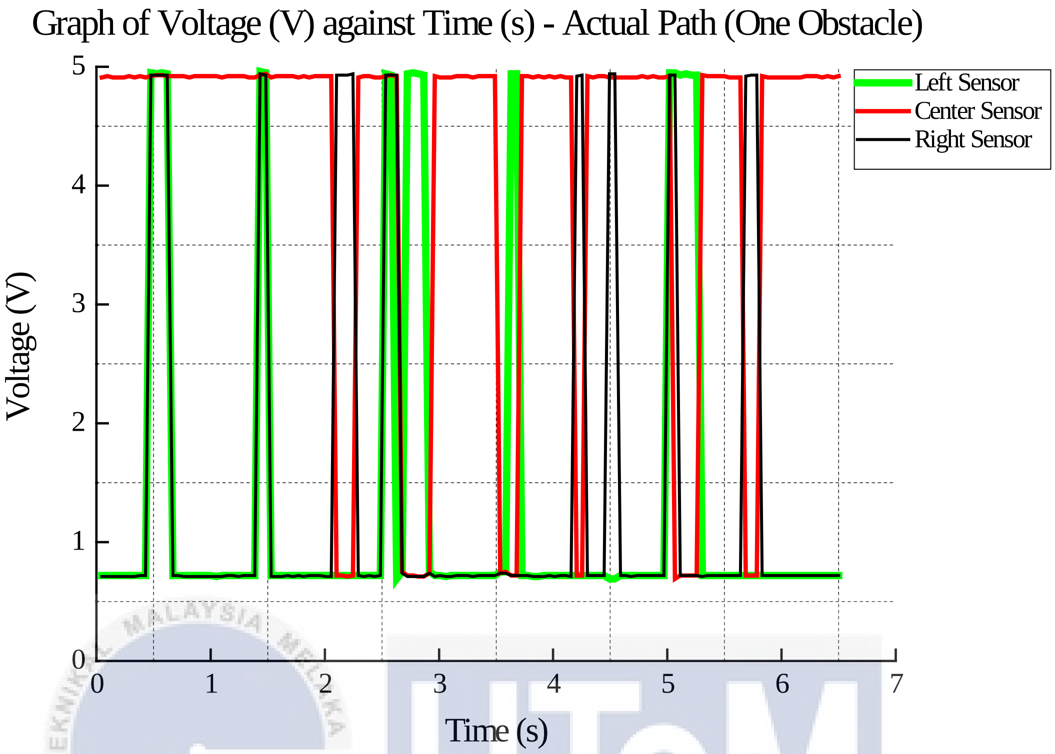


Figure 4.35: First test of actual path (with one obstacle)

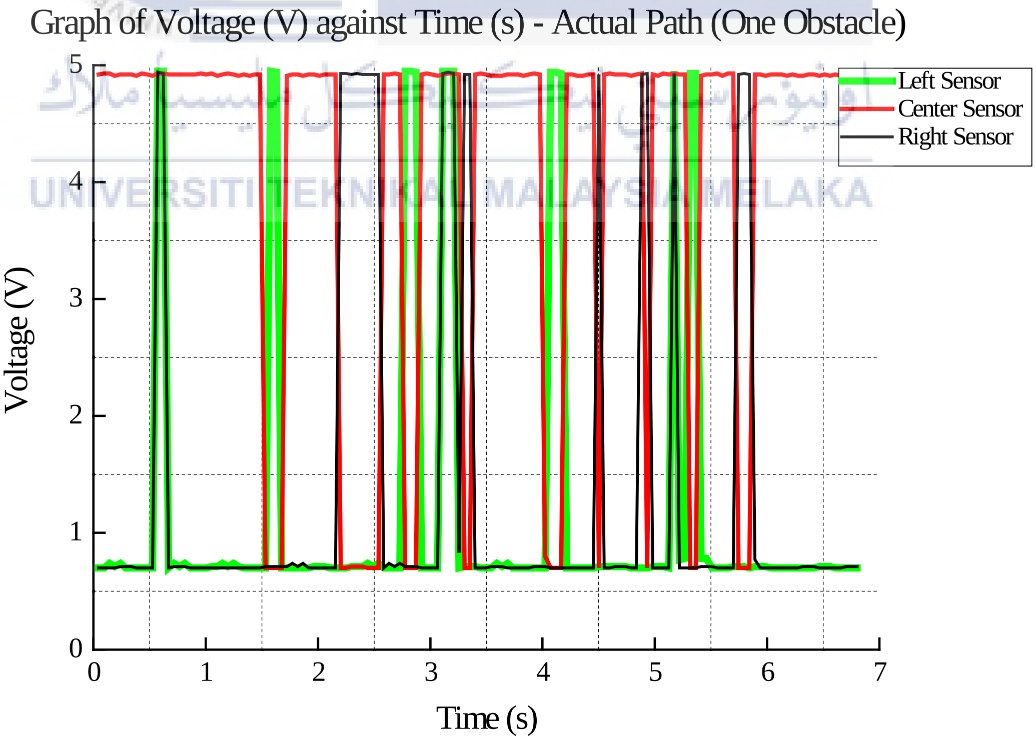


Figure 4.36: Second test of actual path (with one obstacle)

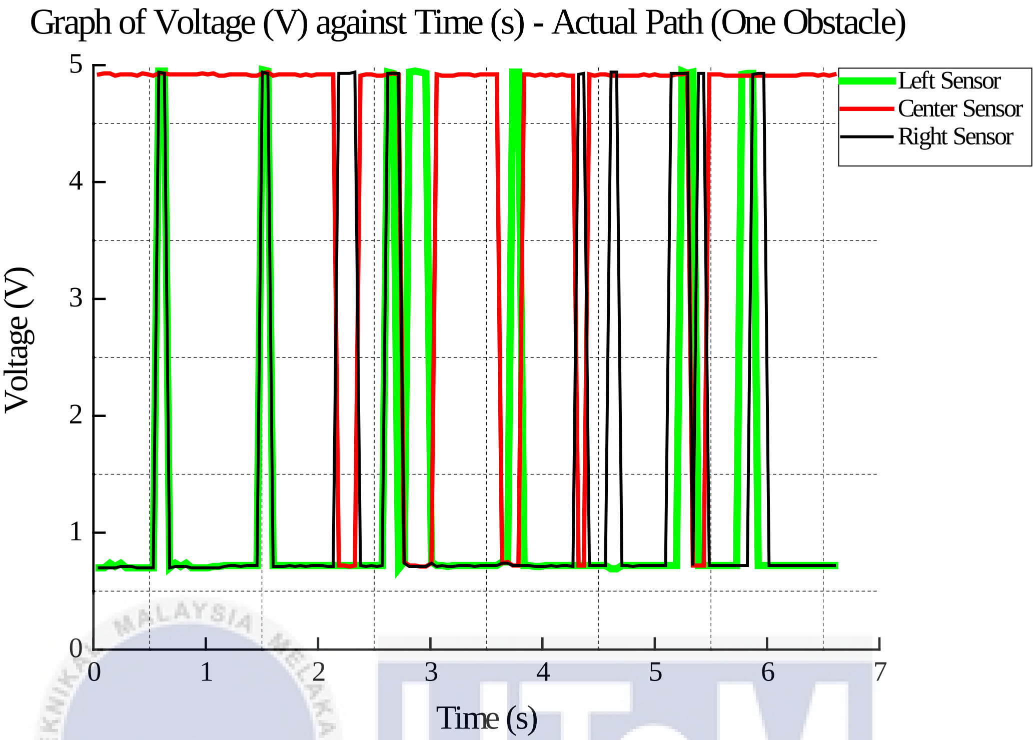


Figure 4.37: Third test of actual path (with one obstacle)

4.4.2.3 Actual Path (With Two Obstacles)

The time taken for the mobile robot the reach the particular passive tag is shown in the Table 4.21. The results of actual path tests are shown in the Figure 4.38, 4.39 and 4.40. From the Figure 4.38, 4.39 and 4.40, the graph shows the similar pattern for the actual path that with two obstacles. First of all, the mobile robot was passed to passive tag number 10 at around 1.5 seconds with some minor oscillation before it reaches the next passive tag. However, the ultrasonic sensor detects and avoid obstacle that located 20cm away from the mobile robot and thus it making right turn to the passive tag number 9 at around 2.5 seconds. After that, the mobile robot making left turn to the passive tag number 12. But, the ultrasonic detects the second obstacle that located 20cm away from mobile robot and avoids it. So, the mobile robot turns to right direction and reaches the passive tag number 8 at around 4.0 second before it turn left direction to the passive tag number 13. In this short period of time, the graphs show fluctuations in between 2.5 seconds to 4.5 seconds due to the number of turning of mobile robot, thus making it oscillation much. This means the oscillation of mobile robot become larger in the period of time because of the quick turning direction of robot itself. Next, the mobile robot continues moving straight to the passive tag number 18 at around 6.4 seconds, which here the mobile robot will making right turn before it reaches the destination and stopped at around 8.0 seconds. In conclusion, the mobile robot is able to navigate itself from start to reach the target destination without collision with the obstacle.

Table 4.21: Time taken for the mobile robot the reach the particular passive tag

RFID Passive Tag Number	Time taken for the mobile robot the reach the RIFD passive tag		
	1	2	3
1	0	0	0
10	1.5	1.6	1.5
9	2.4	2.5	2.4
8	4	3.8	3.9
18	6.4	6.6	5.5
17	7.8	8	7.8

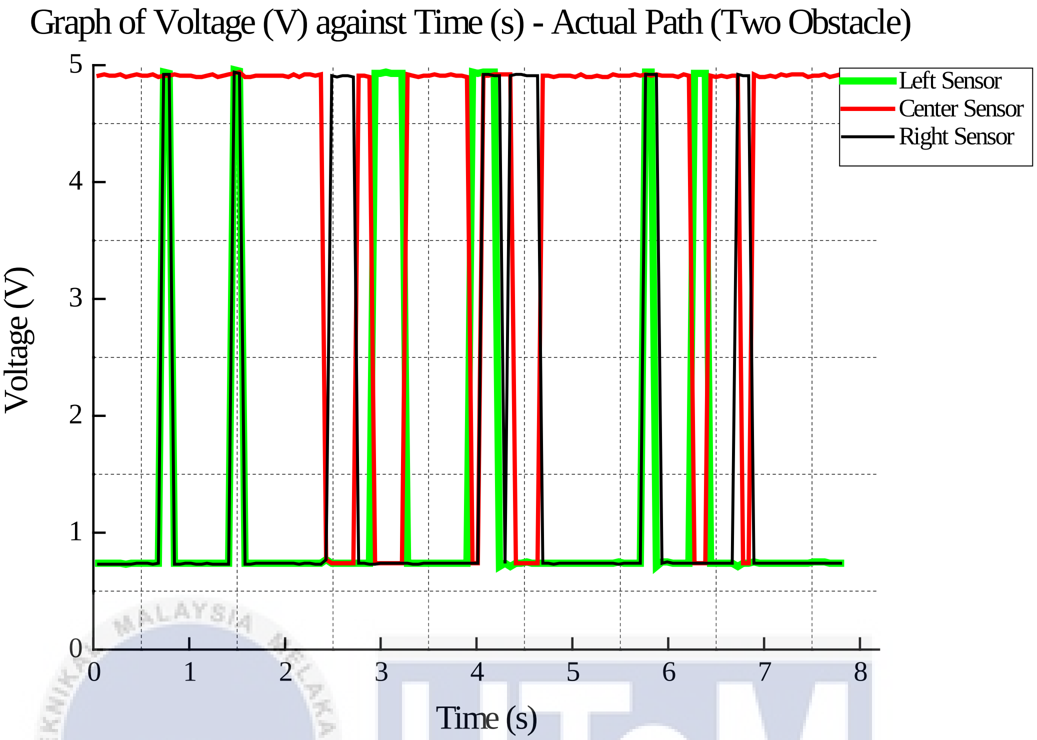


Figure 4.38: First test of actual path (with two obstacles)

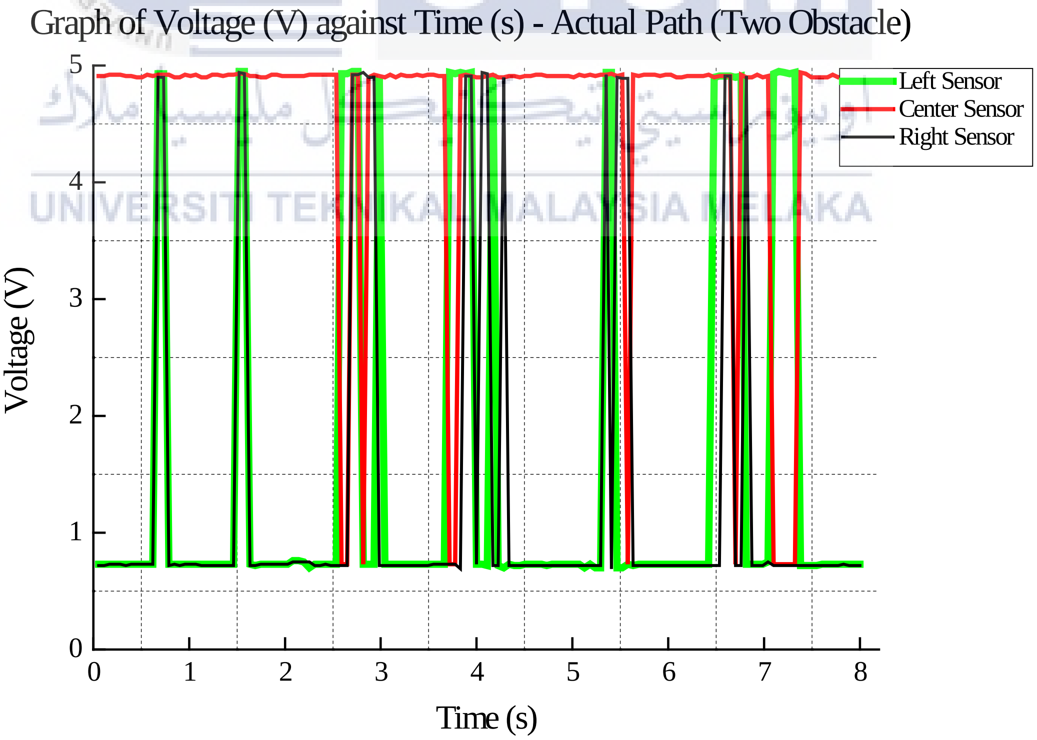


Figure 4.39: Second test of actual path (with two obstacles)

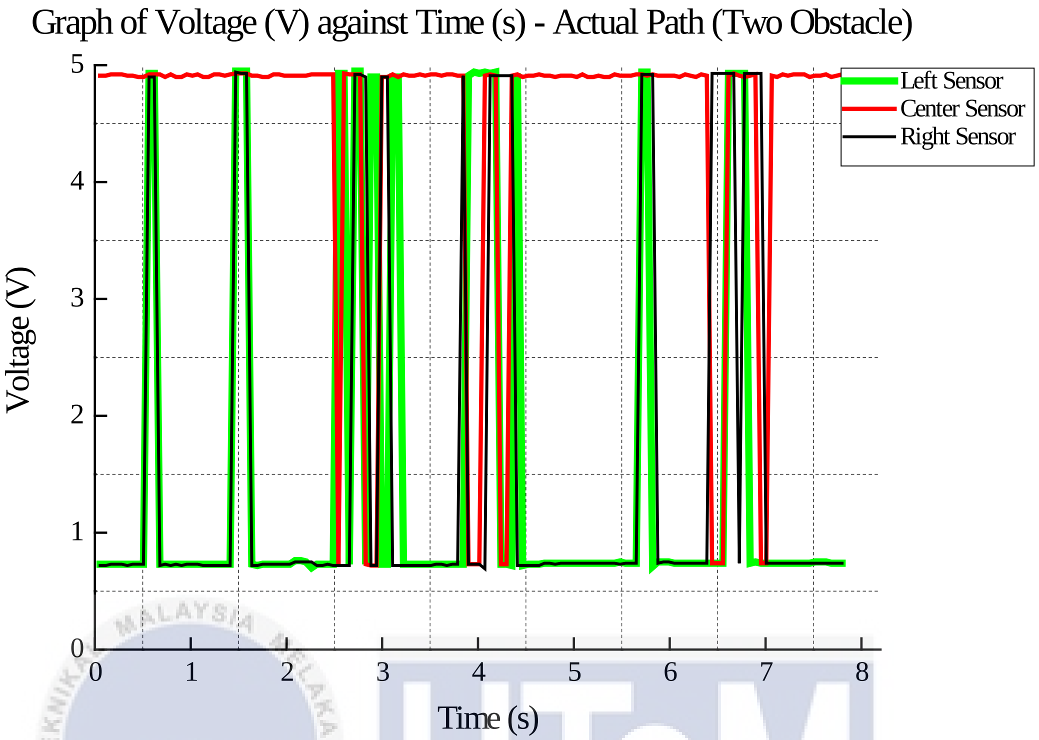


Figure 4.40: Third test of actual path (with two obstacles)

4.4.2.4 Conclusion for the findings

Based on findings, the mobile robot is able to reach the target destination without collision with obstacles. However, the mobile robot tends to oscillate after quick turning. This is due to the fact that the mobile robot has a tendency to not turn accurately to align with the black line path before setting off. Hence, the mobile robot will tries to get aligned with the black line path which subsequently causes the oscillations.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The existence of mobile robot can be used in every workplace due to its simplicity and applicability. Mobile robot not only able to assist worker perform daily repetitive task such as delivery documents from one office to another, but it will also help worker reduced work-related stress that originated from the heavy workload. Unfortunately, navigation of mobile robot in indoor environment is a challenge task to be accomplished.

In this project, all of the objectives have been achieved. The first objective is to design and develop of mobile robot that is able to navigate itself from one office to another for documents delivery. An experiment has been carried out to navigate the mobile robot from one location to another by using the Radio Frequency Identification (RFID) and passive tag. With this implementation, the results shows that the mobile robot able to reach the target destination successfully. The second objective is to analyze the accuracy of the line following sensor towards different width of masking tape. The width of 18mm was chosen as the best result for the mobile robot to move smoothly and stably in a straight line and curve line pattern. Besides that, the last objective is to analyze the trajectory movement of mobile robot so that it is able to reach the target destination without collision with obstacle. The results shows that the mobile robot capable to detect and avoid obstacle by choosing the alternative path to reach the target destination without collision with obstacles.

As a conclusion, some of the mechatronics element that had been learned was applied to this project. For the future work, the project will continue to improve and stabilize the performance of mobile robot in order to eliminates the oscillation that caused by the quick turning of robot.

5.2 Recommendation

The oscillation of the mobile robot can eliminate by designing a Proportional-integral-derivative (PID) controller which it can calculate the error value as the difference between a measured and a desired set point. The PID controller is able to stabilize the performance of the mobile robot so that it won’t tends to oscillate in a jerky manner, thereby the mobile robot can run steadily and smoothly in black line path. Furthermore, PID controller is a control system that can be used to obtain the desired robot response based on changes in the environment. In addition, the sensors will identify the changes of the environment, the program will calculate the desired final result and the actuator will make necessary changes about it. In conclusion, PID controller will helps to solve the oscillation problem of mobile robot in an intelligent manner as to making it more robust.

REFERENCES

[1] Ricardo Blaug, Amy Kenyon and Rohit Lekhi, "Stress at Work," The University of Lancaster, UK, Final Rep., February 2007.

[2] Y. Gu, A. Lo, and I. Niemegeers, “A survey of indoor positioning systems for wireless personal networks,” IEEE Communications Surveys and Tutorials, vol. 11, no. 1, pp. 13–32, 2009.

[3] J. Xiao, Z. Liu, Y. Yang, D. Liu, and H. Xu, “Comparison and analysis of indoor wireless positioning techniques,” in Proceedings of the International Conference on Computer Science and Service System (CSSS '11), pp. 293–296, June 2011.

[4] F. Seco, A. R. Jiménez, C. Prieto, J. Roa, and K. Koutsou, “A survey of mathematical methods for indoor localization,” in Proceedings of the 6th IEEE International Symposium on Intelligent Signal Processing (WISP '09), pp. 9–14, August 2009.

[5] F. Subhan, H. Hasbullah, A. Rozyyev, and S. T. Bakhsh, “Indoor positioning in Bluetooth networks using fingerprinting and lateration approach,” in Proceedings of the International Conference on Information Science and Applications (ICISA '11), April 2011.

[6] Z. Li, W. Dehaene, and G. Gielen, “System design for ultra-low-power UWB-based indoor localization,” in Proceedings of the IEEE International Conference on Ultra-Wideband (ICUWB '07), pp. 580–585, September 2007.

[7] M. B. Ismail, A. F. A. Boud, and W. N. W. Ibrahim, “Implementation of location determination in a wireless local area network (WLAN) environment,” in Proceedings of the 10th International Conference on Advanced Communication Technology (ICACT '34), pp. 894–899, February 2008.

[8] Modi S.,"Comparison of three obstacle avoidance methods for an autonomous guided vehicle", M.Sc. Thesis Department of Mechanical, Industrial and Nuclear Engineering, University of Cincinnati, 2002.

[9] S. Böttcher, "Principles of Robot Locomotion", in Proc. Human Robot Interaction Seminar SS2006, Univ. of Dortmund, 2006.

[10] Hui Liu; Darabi, H.; Banerjee, P.; Jing Liu, "Survey of Wireless Indoor Positioning Techniques and Systems," Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, vol.37, no.6, pp.1067, 1080, Nov. 2007.

[11] Stojanović, D., Stojanović, N.. Indoor Localization and Tracking: Methods, Technologies and Research Challenges. Facta Universitatis, Series: Automatic Control And Robotics, North America, 13, May. 2014.

[12] Gueaieb, W.; Miah, Md.S., "An Intelligent Mobile Robot Navigation Technique Using RFID Technology," Instrumentation and Measurement, IEEE Transactions on , vol.57, no.9, pp.1908,1917, Sept. 2008.

[13] Waldmann, B.; Weigel, R.; Ebelt, R.; Vossiek, M., "An ultra-wideband local positioning system for highly complex indoor environments," Localization and GNSS (ICL-GNSS), 2012 International Conference on, vol., no., pp.1, 5, 25-27 June 2012.

[14] Kalmegh, S.K.; Samra, D.H.; Rasegaonkar, N.M., "Obstacle avoidance for a mobile exploration robot using a single ultrasonic range sensor," Emerging Trends in Robotics and Communication Technologies (INTERACT), 2010 International Conference on , vol., no., pp.8,11, 3-5 Dec. 2010.

[15] C. G. Rusu and I. T. Birou, "Obstacle Avoidance Fuzzy System for Mobile Robot with IR Sensors", 10th International Conference, (2010) May 27-29.

[16] M. Kise, Q. Zhang, and N. Noguchi, "An obstacle identification algorithm for a laser range finder-based obstacle detector," Transactions of the American Society of Agricultural Engineers, vol. 48, no. 3, pp. 1269–1278, 2005.

[17] Goris, K., “Autonomous Mobile Robot Mechanical Design”, Master’s Thesis, Vrijie University Brussels, 2004 -2005.

[18] Kyung-Lyong Han; Oh-Kyu Choi; Jinwook Kim; Hyosin Kim; Lee, J.S., "Design and control of mobile robot with Mecanum wheel," ICCAS-SICE, 2009 , vol., no., pp.2932,2937, 18-21 Aug. 2009.

[19] H. Ghariblu ,A. Moharrami, B. Ghalamchi, "Design and prototyping of ball wheel mobile robots", Mechanism and Machine Theory Journal, 2012, Under review.

APPENDICES

APPENDIX A

Coding for Line Following of the Mobile Robot

```
#define analog    A0
#define analog    A1
#define analog    A2

void loop()
{
int ls = analogRead(A2);
int cs = analogRead(A1);
int rs = analogRead(A0);
  if((ls < 550)&&(cs >= 550)&&(rs < 550))
  {
    forward();
  }
  else if((ls >= 550)&&(cs >= 550)&&(rs < 550))
  {
    turn_left();
  }
  else if((ls >= 550)&&(cs < 550)&&(rs < 550))
  {
    turn_left1();
  }
  else if((ls < 550)&&(cs >= 550)&&(rs >= 550))
  {
    turn_right();
  }
  else if((ls < 550)&&(cs < 550)&&(rs >= 550))
  {
    turn_right1();
  }
  else
  {
     stop1();
  }
  }
```

APPENDIX B

Coding for the RFID-RC522 Reader

```
#include <SPI.h>
#include <MFRC522.h>
#define SS_PIN 10
#define RST_PIN A3
MFRC522 mfrc522(SS_PIN, RST_PIN);

void setup()
{
  Serial.begin(9600);
  SPI.begin();
  mfrc522.PCD_Init();
  Serial.println("Scan the Passive tag");
}

void loop()
{
   if ( ! mfrc522.PICC_IsNewCardPresent())
  {
    return;
  }

  if ( ! mfrc522.PICC_ReadCardSerial())
 {
    return;
  }

mfrc522.PICC_DumpToSerial(&(mfrc522.uid));
 }
```

APPENDIX C

Coding for the Ultrasonic Sensor

```
#include <NewPing.h>
#define TRIGGER_PIN  5  .
#define ECHO_PIN     6
#define MAX_DISTANCE 50
NewPing sonar(TRIGGER_PIN, ECHO_PIN, MAX_DISTANCE);

void setup()
{
  Serial.begin(9600);
}

void loop()
{
  delay(50);
  float uS = sonar.ping();
  Serial.print("Ping: ");
  Serial.print(uS / US_ROUNDTRIP_CM); distance range)
  Serial.println("cm");
  delay(600);
}
```