NAVIGATION WITH SIMULTANEOUS LOCALIZATION AND MAPPING USING KUKA YOUBOT: SIMULATIONAL STUDY

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A report submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "NAVIGATION WITH SIMULTANEOUS LOCALIZATION AND MAPPING USING KUKA YOUBOT: SIMULATIONAL STUDY is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have checked this report entitled "NAVIGATION WITH SIMULTANEOUS LOCALIZATION AND MAPPING USING KUKA YOUBOT: SIMULATIONAL STUDY" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

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ABSTRACT

The localization and mapping are two major tasks of a mobile robot such as the KUKA Youbot. The problem statement are exploration, mapping and path planning navigation. This report presents simulational study on SLAM using KUKA Youbot. The objectives of this project are to implement SLAM by proposing, implementing and evaluating the performance of the required exploration, sensing and navigation algorithms in a virtual platform. The method that used for exploration is wall follower with Hokuyo laser scanner as obstacle detection. The sensor that used in this project for mapping and localization is using the Hokuyo laser scanner sensor where it is mounted at the base of KUKA Youbot. The mapping and localization is built by using the data information from the Hokuyo laser scanner sensor and odometry of the robot. With data the information, the map can be generating by using Rviz. There are two experiments to be conducted for this project, experiment 1: simultaneous localization and mapping using Hokuyo laser scanner sensor and wall follower, experiment 2: navfn planner navigation tuning. In experiment 1, the result show the proposed method is good in dealing the spiral environment, followed by floor plan and zigzag environment. In experiment 2, the result show with cost neutral of 202, the cost factor needs to be about 0.2 to ensure the input values are spread evenly over the output range, 202 to 252. Lastly, it is concluded that all of the objectives of this project is successfully achieved after all of the experiments are completed.

ABSTRAK

Penyetempatan dan pemetaan adalah dua tugas utama robot mudah alih seperti KUKA Youbot. Kenyataan masalah adalah navigasi penerokaan, pemetaan dan perancangan jalan. Laporan ini membentangkan kajian simulasi pada SLAM menggunakan KUKA Youbot. Objektif projek ini adalah untuk melaksanakan SLAM dengan mencadangkan, melaksanakan dan menilai prestasi algoritma penerokaan, penderiaan dan navigasi yang diperlukan dalam platform maya. Kaedah yang digunakan untuk eksplorasi adalah pengikut dinding dengan pengimbas laser Hokuyo sebagai pengesan penghalang. Sensor yang digunakan dalam projek ini untuk pemetaan dan penyetempatan menggunakan sensor pengimbas laser Hokuyo di mana ia dipasang di pangkal KUKA Youbot. Pemetaan dan penyetempatan dibuat dengan menggunakan maklumat data dari sensor pemindai laser Hokuyo dan odometri robot. Dengan data maklumat itu, peta boleh menjana dengan menggunakan Rviz. Terdapat dua eksperimen yang akan dijalankan untuk projek ini, eksperimen 1: penyetempatan serentak dan pemetaan menggunakan sensor pemindai laser Hokuyo dan pengikut dinding, percubaan 2: penyemakan navigasi perancang navfn. Dalam eksperimen 1, hasil menunjukkan kaedah yang dicadangkan adalah baik dalam menangani persekitaran lingkaran, diikuti dengan pelan lantai dan persekitaran zigzag. Dalam eksperimen 2, keputusan menunjukkan dengan kos neutral sebanyak 202, faktor kos perlu sekitar 0.2 untuk memastikan nilai masukan disebarkan secara merata ke atas julat keluaran, 202 hingga 252. Terakhir, disimpulkan bahawa semua objektif ini projek berjaya dicapai setelah semua eksperimen selesai.

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LIST OF SYMBOLS AND ABBREVIATIONS

SLAM	-	Simulataneous Localization and Mapping
ROS	-	Robot Operating System
LabView	-	Laboratory Virtual Instruments Engineering Workbench
USARSim	-	Unified System for Automation and Robot Sumulation
EKF	-	Extend Lakman Filter
t	-	time
w	-	2πf (frequency)
Rviz	-	Ros Visualization
RMSE	-	Root Mean Square Error
DATMO	-	Dectecion and Tracking of Moving Object
GPS	-	Global Positioning System
xyz	-	Axis X, Axis Y, Axis Z
rpy	-	Roll, Pitch, Yaw
RGB	-	Red, Green, Blue

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Motivation

Robots are finding a way more and more in industrial sector and daily life from robot arm to hybrid robot. In 2017, robot sales increased by 30 percent to 381,355 units from the past five year. The figure below shows the estimated worldwide annual shipments of industrial robot by regions from 2007 to 2017.

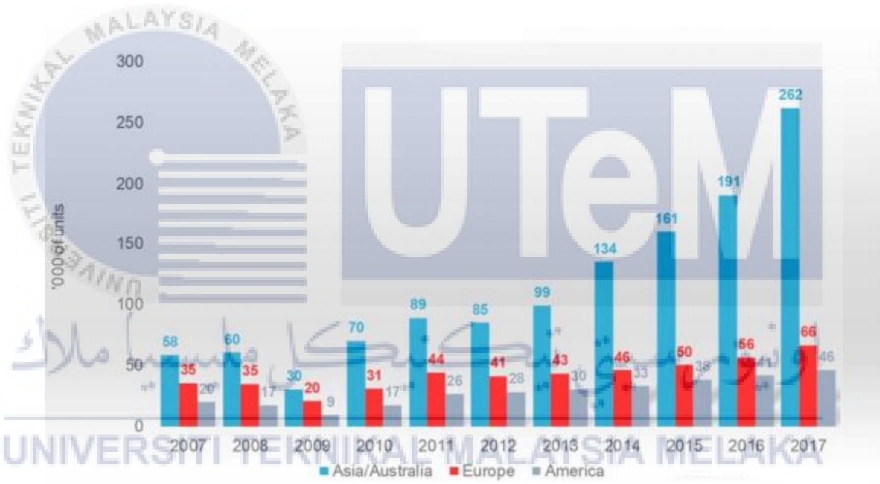


Figure 1.1: Estimated Worldwide Annual Shipments of Industrial Robot

The demand of industrial robot has accelerated since 2010 due to the ongoing trend automation and continued innovative technical improvement in robots. Between 2011 and 2017, the average annual supply doubled to about 236,000 units compared to the average annual supply between 2005 and 2008. From year 2015 to 2017, the average annual increase was about 310,000 units. This phenomenon shows that demand of robots increases [1].

These days, with innovative advances in the exploration of mechanical autonomy, Build a robots to work self-sufficiently in different planets, under oceans and seas and every obscure situations. Taking into account that the robots don't have any data about nature, should to be able to assemble condition map moving and furthermore gauge its area on that map effectively. This activity is called Simultaneous Localization and Mapping (SLAM). SLAM is an important problem that has been broadly researched in robotics. Its contribution towards autonomous robot navigation has attracted researchers towards focusing on this area.

Simultaneous localization and mapping or SLAM is defined as a method that constructing a map in and unknown environment and simultaneously keep and update the location. With the application simultaneous localization and mapping, the mobile can be navigated in a hazardous environment for humans such as nuclear power plant. Apart from that, mobile robots for infotainment for visitors at museum and management at libraries may use this application. The success of these applications depends on the accuracy of sensor, sensor data organize and management, monitoring and controlling robots and map building. Although many algorithms exist today to solve the problem for simultaneous localization and mapping navigations for single robots in static indoor environment, there is still a lot of challenges especially for large dynamic and outdoor environment increase the problems for navigation.

Therefore in order to enhance the performance of SLAM navigation, the path planning of the mobile robot is necessary to allow the mobile robots reach the destination.

1.2 Problem Statement

The exploration problem of SLAM is deciding where to move next in order to build the map as efficiently as possible. The need of the exploration is to move the mobile robot with obstacle free with autonomously especially in an unknown environment. Exploration is generally performed by approximating the unknown environment under hypothetical actions.

To implement the localization and mapping of the mobile robot is bias to the sensing capability and information processing. The limitation of the sensor in term of detection range, update rate and sensitivity give difficulty in quick response and accurate information. Apart from that, complex construction of the environment such as maze and large area environment makes mapping and localization very hard to control. It is important in consider the different environment in designing the mobile robot. The different of construction and complexity of the map is test in the experiment to analyze the performance in different environment.

Finally, the path planning of the mobile robot gives problem to the navigation. This is because it is important to plan a free collision path and shortest path for mobile robot to travel. The plan planning of the mobile robot can be global or local path planning. In this project is using global path planning since it is using the mapping system. However, there is a weakness in global path planning which is bias to the map that been generate by data information of sensor. The navigation tuning is test in the experiment to analyze the performance in term of distance.

In conclusion, implement SLAM based on KUKA YouBot platform, there are 3 element need to be consider to solve the problem, which is the exploration, mapping with localization and navigation.

1.3 Objectives

The objectives of the project are:

1. To develop a simulational setup for Simultaneous Localization and Mapping with KUKA Youbot using ROS.

2. To study and implement a sensory input required for Simultaneous Localization and Mapping using KUKA YouBot in the simulation.

3. To evaluate the performance of the exploration, mapping and navigation using KUKA YouBot in the simulation.

1.4 Scope

The scope of the project is using KUKA Youbot as a tool to implement the navigation with SLAM in simulation. Firstly, the wall follower exploration is used to decide the movement of the robot in order to build the map. Secondly, the Hokuyo laser scanner sensor is used for mapping and localization. The evaluation is analyzed in 5 different structure of environment which are two different floor plan close environment, zigzag close environment, spiral close environment, zigzag and spiral close environment. The performance of the sensor is analyzed by the RMSE between manually mapping navigation and wall follower mapping using Matlab. Lastly, the Navfn planner is used to navigate the robot in the map. The evaluation is analyzed in floor plan close environment based on the shortest distance path from the starting point to the end point. The performance of the Navfn planner is analyzed by comparing the graph of position x and y as an image in Matlab.

The limitations of this project are only static object will be tested and it is only conducted in the virtual environment.

1.5 Summary

In this chapter, there only 4 topics are discussed which motivation, problem statement, objective and scope of the project. The objectives of this project are to implement the navigation with simultaneous localization and mapping using KUKA Youbot in simulation. Besides that, this project also needs to propose a method for exploration, mapping with localization and navigation to implement this project. Lastly, evaluate the performance of the exploration, mapping with localization and navigation. The next chapter is discussed the findings on previous journal related to the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, it explains the overview from previous researcher regarding to the reviews on SLAM, path planning, exploration and laser scanner sensor. The related reviews are explored from internet, books and journals. The information from previous work is very important to guide and lead to successful on this project. Apart from that, it gives us additional knowledge to our future engineering work.

2.2 Simultaneous Localization and Mapping (SLAM)

SLAM is a method that creates a map for an unknown environment and localizes the robot in this map at once. The localization mean the robot is able to know the position and orientation to the predefined map. Mapping means building a map in an unknown environment by sensing from various positions and integrating these measurements.

The problem of SLAM is robot motion models is not accurate, wheel odometry error is cumulative and sensors errors. Map is generated by the information of the sensor on the mobile robot. The pose of the mobile robot need to be known in order to the map from an unknown environment. Use of robot pose estimate can improve the map landmark position estimates. If the robot pose is incorrect, the map will produce incorrectly. However, the global positioning system can help to solve the problem but it is not always available and reliable [2].

The examples of 2D SLAM algorithms are HectorSLAM, Gmapping, CoreSLAM, KartoSLAM and LagoSLAM. However, Gmapping gives the most robust and accurate. Gampping use both laser scan data and odometry data to construct an occupancy grid map of the environment. With well-defined map, the robot is able navigate to the destination with a path algorithms without collision [3].

EKF (Extend Kalman Filter) SLAM algorithm is a method that applying the EKF algorithm to the SLAM problem for small number of unique features. The computation requirements grow quadratic ally to the number of features. It relies on the data association assumption; error in the data association will give divergence and ultimately explosion of the filter. In the case of non-Gaussian noise and strong non-linearity in motion and observation models will not give the optimal solution. With data clustering techniques, extraction of geometric lines and planes, non-linear least square estimate technique, Hough transformation process and Mahalanobis distance based technique, the map update and augmentation process is achieved optimally [4].

VSLAM is a vision based on the SLAM algorithm. The vSLAM algorithm does not require an initial map to detecting and correcting for slippage and collisions. The characteristic of vSLAM is visual landmarks are created and reorganized in the front end, update scheme for robot pose and map is based on a particle filter and a Kalman filter bank and mixed proposal distribution and the dynamic mixture ratio [5].

The research of estimate camera motion from measurements of a continuously expanding set of self-mapped visual features. A Bayesian principle, top down approach to sequential SLAM from motion which takes account of the extra sources of information often neglects to push the real time barrier and demonstrated performance in an indoor scene. The image used for 2D patches are limited in viewpoint- variance and the algorithm would benefits from the use of features such as planner 3D patches whose change in image appearance could be better predicted from different viewpoints [6].

The research of SLAM with detection and tracking of moving object (DATMO). A Bayesian formula is derive to solve the SLAM with DATMO problem. The formula provides a rigorous foundation to understand and solve the SLAM with

DATMO problem. A probalistic approach to this problem was implements with EKF. The approach of this research was exposed to data acquired over a total distance of 100 miles [7].

The research on SLAM in unknown GPS denied environments of multiple mobile robots. Multiple robots SLAM is not mature as single robot SLAM. This report is focusing on sharing raw data among robot. The strength is flexible due to the access to all past measurements; its weakness is the reliance on the availability of delay free communication channels. In contrast, the approach of sharing processed data of the robots, such as map merging and flexibility of sharing raw data may cause overconfidence due to multiple use of a single measurements [8].

The research on SLAM with focusing on probabilistic approach utilizing a feature based description of the environment. A probalistic formula of the SLAM is introduced and s solution based on EKF is shown in the research. The research points out that the role of reliable orientation estimation in keeping EKF-SLAM consistent shown that a scan matching procedure can be used to accomplish. The use of photometric features to increase the discriminative properties of line segments commonly used in indoor EKF-SLAM [9].

In conclusions, SLAM is a technique to helps improve the navigation of mobile robot.

2.3 Path Planning of Mobile Robot

The high flexibility of robot represent the ability in executes different kind of operations or tasks. The robot need to be high flexibility to work like as a human, but compared to human flexibility, robot have many of problem to solve even a simple motion in a workspace. To let the robot move from one point to another, the best path planning must be determined in order to avoid collisions and other limitations.

Planning a path in 2D workspace with non-rotating rigid body can be implementing in real time robots navigating a floor with obstacles, which is bug algorithms. The work principle of this bug algorithm is whenever an obstacle encountered towards the robots when the robot move from initial point to the goal point, the robot will choose a direction and moves around the obstacle until it returns to the original line on which the robots are travelling. With this method, the robot will continue move until it reach the goal. The advantage of this method is easy to implement in a real robot and the disadvantages is it cannot be apply in higher dimension or more complex workspace [10].

The path planning problem can be defined as to find a geometric collision free path for a robot to travel. The curve segments of each connecting pair of points represent the resulting path in the robot configuration space and it cannot be intersect to the obstacle region. These become a considerable in research on finding collision free shortest path. In the static environment, the complete algorithms are to find the collision free path if one exists with given resolution and probability approaching one. This high complexity path planning method makes it to look the weaker notions of completeness and that can be partially adapted to specific problem domains in order to boost performance in those domains [10]. For planning a path in high dimensional spaces, a lightning framework is proposed that consists of two main modules which is planning from scratch module and retrieves and repairs paths stored in a path library module. The library manager can decides whether to store the path based on computation time and generated path that similar to the retrieved path after a path is generated for anew query [11].

The path planning method can be classified as two parts which is global path planning and local path planning. Global path planning defined as prior information of the robot workspace, whereas the local path planning method is about acquired information from sensor in unknown and uncertain environments. With a camera, a predefined image from the robot workspace is determining the 3D environments in 2D environments. To avoid from collision, with fuse of the image based path planning method using Visual Servoing concepts and Artificial Potential Field, it proposed an algorithms that are able to find the shortest and collision free path with respect to the camera frame [12].

A process algebra for modeling and analyze the path planning algorithms that used mCRL2 language and the modal μ-calculus for describing a multi-robot system and its properties to provide feedback to the designer of the system. The mCRL2 toolset verify the properties and correctness in a simple multi robot system. With the proposed path planning algorithm properties, it reaches efficiently in the observation of the experiments [13].

. In conclusion, path planning of a mobile robot is about finding the shortest, optimal and collision free path to travelling. Different method and algorithms is proposed to approach efficiently. However, it have the major problem is that the experiment is conduct in the static environment, it hard to handle in the uncertain environment that dynamic change unexpectedly.

2.4 Exploration

An algorithms aspect for exploration and search is known as field motion planning for autonomous mobile robots. The environment is considered as cellular environment where the robot surrounding is subsided by an integer grid. It distinguishes between simple grid polygons and general grid polygon. The search task is considering as error prone robots and gives performance results that take robot error into account. The quality of a search path is determined by a target point (a point that maximizes among all target point, the ratio between the lengths of the searcher path). By approximating a path with optical search ratio, the general framework is applied to the simple polygon and grid polygons [14].

Every search algorithms need s to address the exploration and exploitation of a search space. Visiting entirely new regions of a search space is called exploration while visiting those regions of a search space within the neighbored of previously visited point is called exploitation. A search algorithms need to establish a good ratio between exploration and exploitation. The balance between exploration and exploitation is achieved by implicit the parameter tuning and parameter control using uniprocess or multiprocess driven approaches. The balance between exploration and exploitation can be controlled by deterministic, adaptive and diversity learning [15].

For a mobile robot to engage in exploration of an unknown environment, it must identify the locations first which will yield new information when visited. The highly accurate dense 3D data from a stereo camera is used. The art visuals odometry based pose estimation use point clouds to drive exploration. The first exploration algorithms that used is an attempt to represent the three dimensional world as a continuous two dimensional surface. The second exploration algorithm is graph based method which based on continuum methods. By solving Laplace's equation over the free space of the partially explored environment, the exploration can be guide by following streamlines in the resulting vector fields. The results show that fully exploring three dimensional environments and outperforming oft-used information gain based approaches. The potential field solution can be used to identify volumes of the workspace which have been fully explored [16].

A study against exploration problem where a robot has to construct a complete map of an unknown environment using a path that is short as possible. The first problem is a robot has to explore n rectangles. The result shows that no deterministic or randomized online algorithms can be better than $\Omega(\sqrt{n})$ -competitive. The second problem is a robot has to explore a grid graph with obstacles in piecemeal fashion. The piecemeal constraint implies that the robot has to return a start node every often [17].

The problem to programming a robot to carry out a systematic exploration in environment using realistic sensors is discussed in this paper. The robot is modeled as a single point moving in a two dimensional configuration space populated with visually opaque and transparent obstacles. The robot is equip with proximity sensors, vision based recognition system and odometry information. An algorithm for systematically exploring a mobile robot environment is used. The proposed exploration algorithm maintains a list of all landmarks the the robot has seen; a landmark in this list will termed visited if the robot has circumnavigated the C-space obstacle containing the landmark. Unfortunately, space limitations have precluded inclusion of important details such as explicit uncertainty models, updating scheme and formal proofs [18].

2.5 Laser Scanner Sensor

The laser innovation, which depends on laser go discovering estimations of the separation between the sensor and the focused on article, can give spatial information of extraordinary exactness. So as to create geo-referenced spatial information, the laser rangefinder estimations must be joined with geo-situating innovation dependent on GPS estimations, and the incorporated instrument, which equipped for taking both sort of estimations is frequently as a lidar system. Mobile lidar is a term broadly utilized for a laser scanner sent on any versatile stage, for example, a van, a vessel, or even a 4 × 4 off-road vehicle, and regularly does not suggest an airborne lidar. Notwithstanding, the general standards of activity are the equivalent for airborne and ground-based portable lidar frameworks and the information handling work processes are fundamentally the same as or practically indistinguishable in the two cases [19].

A relative assessment of millimeter-wave radar and 2D examining lasers in residue and downpour conditions for sensor applications in mechanical autonomy is introduced. A vigorous and dependable strategy for estimating the dimension of suspended residue by deciding the transmission coincident is created and utilized for quantitative evaluation of sensor execution. The criteria of target procurement unwavering quality, exactness and precision under changing ecological conditions are surveyed by means of sensor task in a controlled domain. This condition produced residue and downpour of fluctuating densities. Sensor execution is additionally evaluated for the potential upon computerized landscape mapping and takes truck localization because of sensor practices in these conditions. Preliminaries on an exploration electric face-scoop are conducted to test watched practices. It is reasoned that laser scanners are appropriate for conditions with transmissions surpassing 92-93% per meter for targets nearer than 25m. The radar remained generally by the generated states of downpour (50-70mm/hour) and residue (10m visibility) anyway its exactness (0.1m with a corner reflector and 0.3m on a take truck), free-space mess and sweep rate were insufficient for finding unmodified take trucks for this application [20].

Laser scanners are quickly picking up acknowledgment as a device for three dimensional (3D) demonstrating and investigation in the design, building, and development area. Since 2001, research group has been growing new strategies for investigating and demonstrating laser scanner information, with an accentuation on applications in the area. The work incorporates improving comprehension of the low-level parts of laser scanner information, utilizing examination techniques to dissect laser scanner information and inferred models, and creating displaying and acknowledgment calculations to help the programmed production of structure models from laser filter information [21].

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the methodology of the project is discussed based on the objectives. This chapter covered the process in Navigation with Simultaneous Localization and Mapping Using Kuka Youbot: Simulational Study. This chapter also introduces the method and the sensor used by the KUKA youBot. The below shows the flow chart the procedure to accomplished this project.

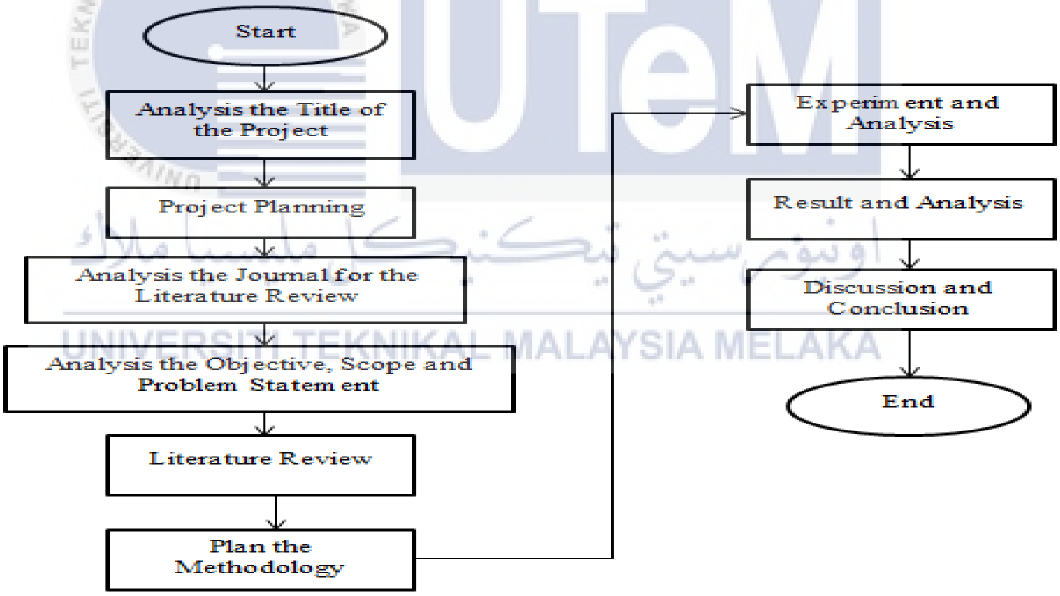


Figure 3.1: Flow Chart for the Project

The figure 3.1 shows that the project starts with analysis the title of the project to determine the concept and background of the project title. Next, the project plan was planned with activity that needed to done in every week from the beginning of the project to the end. After that, analyzed the journal that have been done previous researcher to compare and learn the previous work. Then, the objective, scope and problem statement for the project is set to ensure the project not ran out from the topic. Next, review on the journal for literature review, following by plan the methodology, implement the experiment and analysis, come with a result and discussion. Finally, the conclusion is concluded based on the result and discussion.

3.1.1 K-Chart

Title: Navigation with Simultaneous Localization and Mapping Using Kuka Youbot: Simulational Study

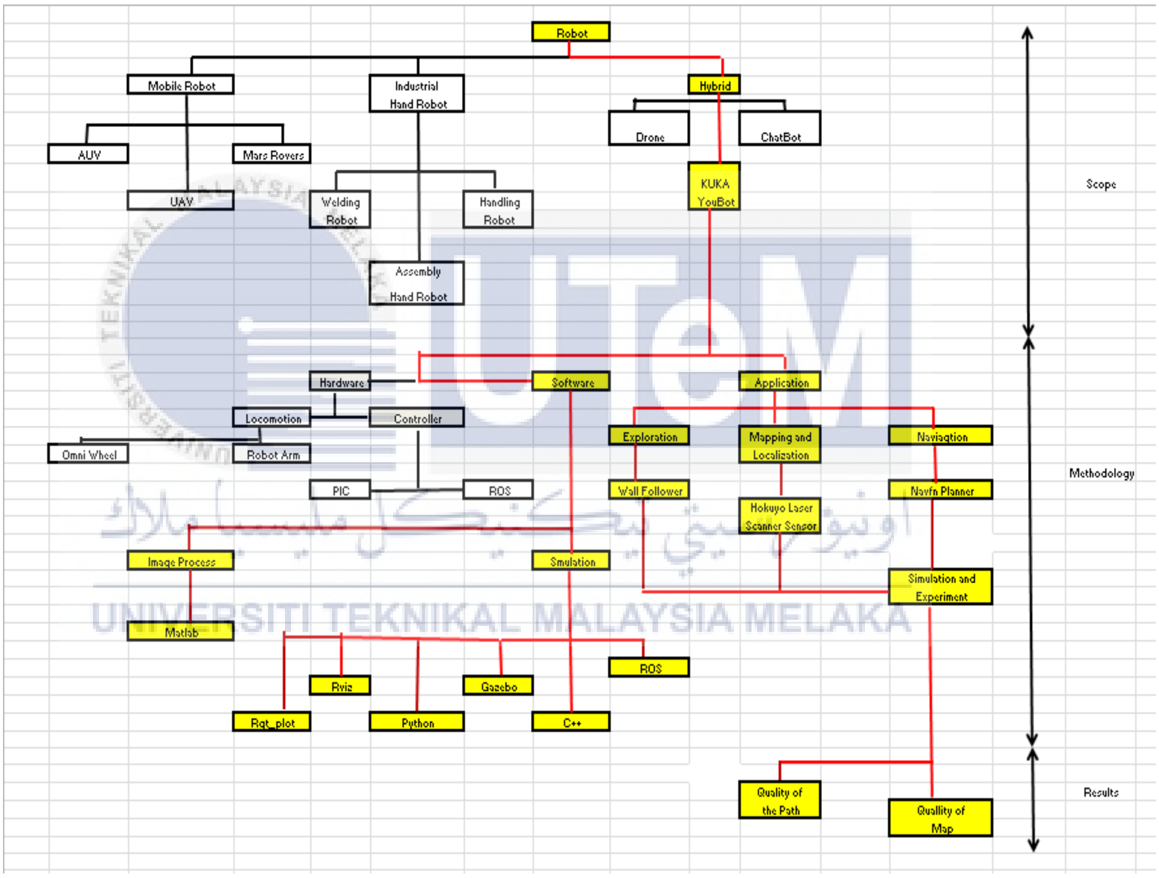


Figure 3.2: K Chart

Figure 3.2 shows the K Chart on the project implementation decision making. The red line represents path that chosen to implement on this project, while black line is the opposite. KUKA YouBot is a hybrid robot that have mobility and robot arm with 5 five degree of freedom. This project is carrier by using only software to analysis. The simulation software use in this project is Rviz and Gazebo. The data is collected by using rqt plot while the image process is using Matlab. The programming language that are used is ROS (Robot Operating System), Python and C++. The application of this project is using wall follower for exploration and Hokuyo laser scanner sensor for mapping and localization. For the navigation, the path is plan by using navfn path planner. The application is test in the simulation for analysis the quality of the map and path.

3.1.2 Hokuyo Laser Scanner Sensor

Hokuyo laser scanner sensor is used for area scanning. The scan area is about 240 degree with a maximum radius of 4m. The data acquired is in the form of range and bearing angle. The figure shows the scan area.

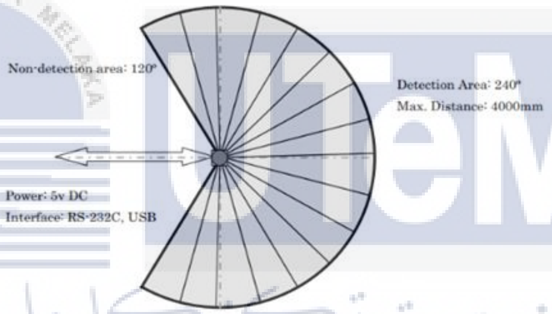


Figure 3.3: Scan Area

The distance can be obtained by calculate the phase different due to the intensity and reflectance of the object. The distance of x and y can be calculated by (3.1):

$$\textbf{Distance} = A.B.(\cos(W.dt) - \cos(2.w.t - w.dt))/2 \quad (3.1)$$

Where,

x = distance*sin(angle)

y = distance*cos(angle)

A=Amplitude of the emitted wave

B= Amplitude of reflected wave

w= $2\pi f$ (frequency)

t=time

3.2 Software Description

3.2.1 ROS (Robot Operating System) Indigo

The ROS indigo as shown in figure 3.4 is an open source, operating system for robot. It provides hardware abstraction, device control, and message passing between processes, implementation of commonly used functionality, package management, tools and libraries for obtaining, building, writing and running code across multiple computers. The programming language is implementing by any modern programming language such as Python, C++, Lisp, Java and Lua.

Figure 3.4: Ros Indigo

3.2.2 Gazebo

The Gazebo as shown in figure 3.5 is a 3D simulator that can efficiently simulate complex environment. It is same to the game engines but Gazebo provides physics simulation at a higher degree of fidelity, sensors and interface for both users and programs. The function of Gazebo is to testing robotics algorithms, design robots and performing regression testing with realistic scenarios. Figure 3.6 show the Gazebo virtual environment.

Figure 3.5: Gazebo

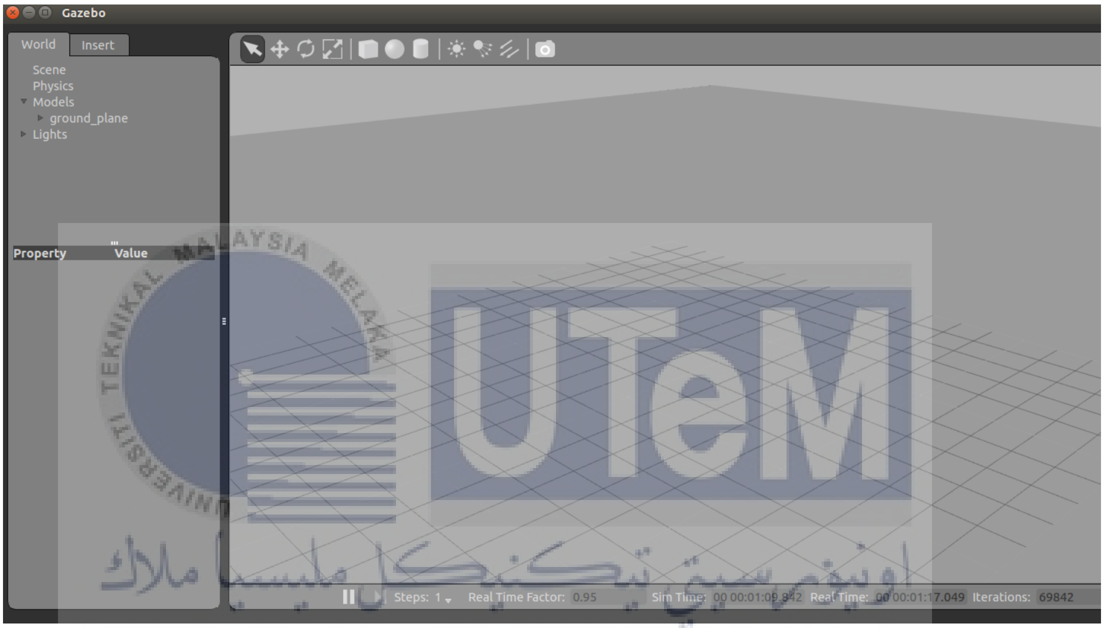


Figure 3.6: Gazebo Virtual Enviroment

3.2.3 Rviz (ROS Visualization)

Rviz as shown in figure 3.7 is a 3D visualizer for displaying sensor data and state information from ROS. It can visualize robot current configuration on a virtual model of the robot. It also can display live representations of sensor values coming over ROS Topics including camera data, infrared distance measurements, sonar data, and more. Figure 3.8 show the Rviz platform.

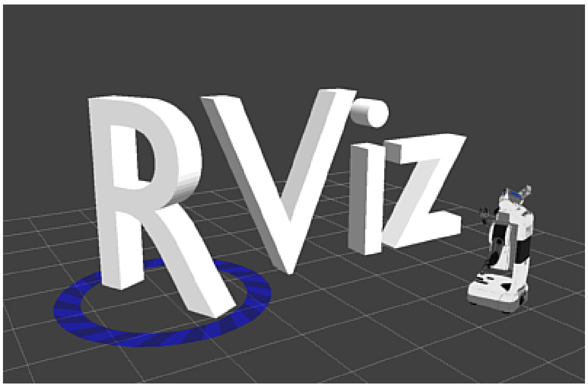


Figure 3.7: Rviz

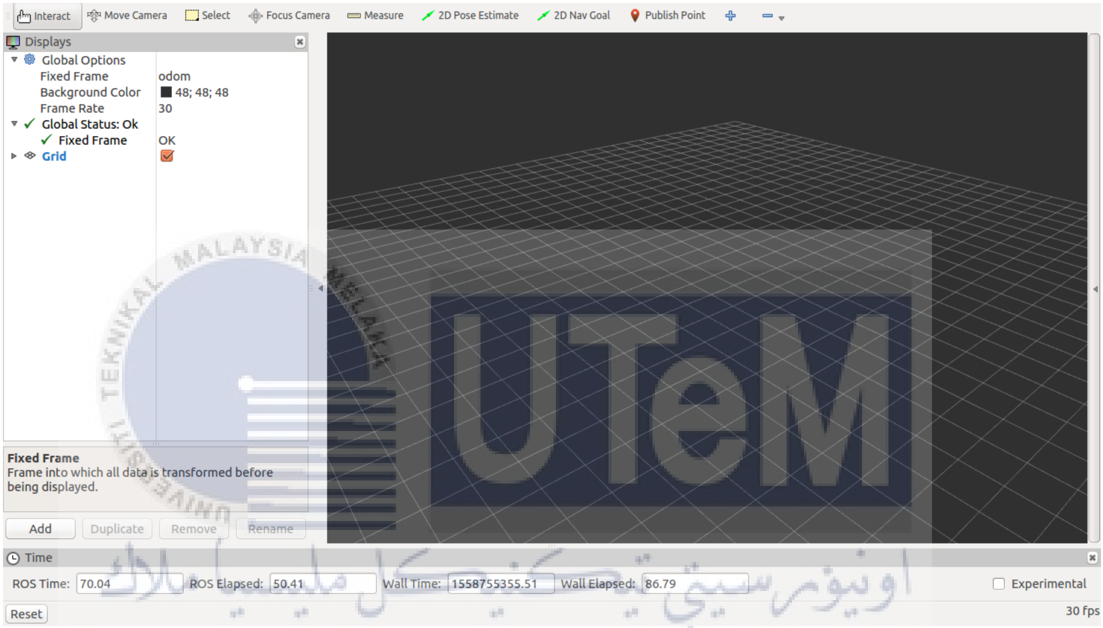


Figure 3.8: Rviz Platform

3.3 KUKA Youbot with Hokuyo Laser Scanner Sensor

The figure 3.9 shows the orthographic view of the KUKA YouBot with Hokuyo Laser scanner sensor.

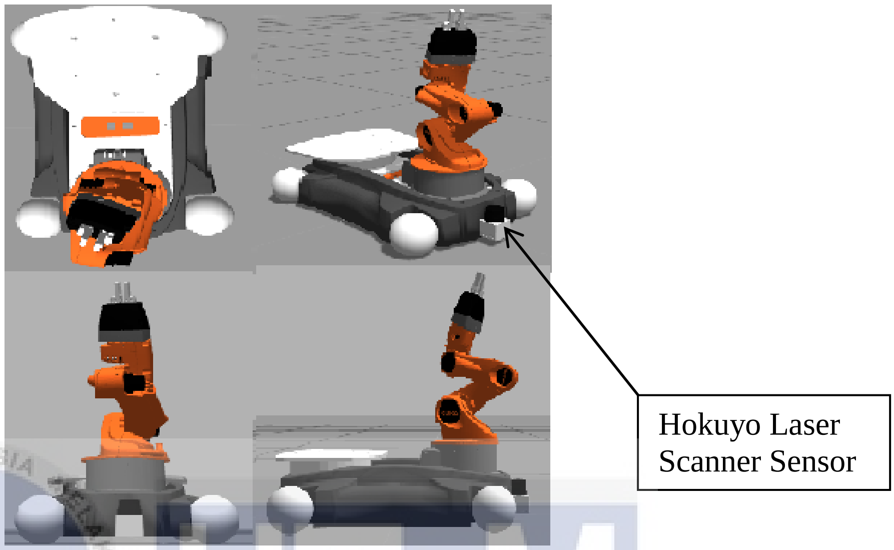


Figure 3.9: Orthographic View of KUKA Youbot

The figure above shows that the Hokuyo laser scanner sensor is located in front of the base of the KUKA Youbot. The position of the sensor is xyz (0.3, 0, -0.03)m and orientation rpy (0, 0, 0) which the parent link is the base of the KUKA Youbot. The sensor have coverage area of 180 degree with 5.6m radius. The figure 3.10 shows the range of the Hokuyo laser scanner sensor. The sensor only have 150 set data, each of the data show the maximum of distance. The figure 3.11 shows when there is an object in front of the sensor and the figure 3.12 show the 150 set of data against distance when there is an object.

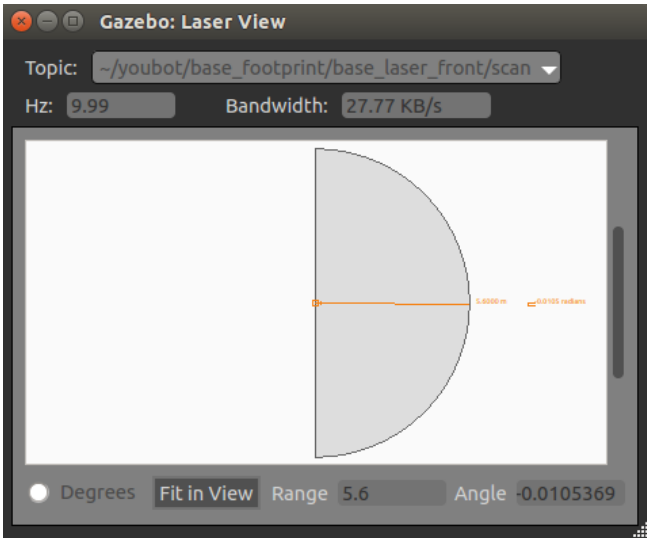


Figure 3.10: Range of Hokuyo Laser Scanner Sensor

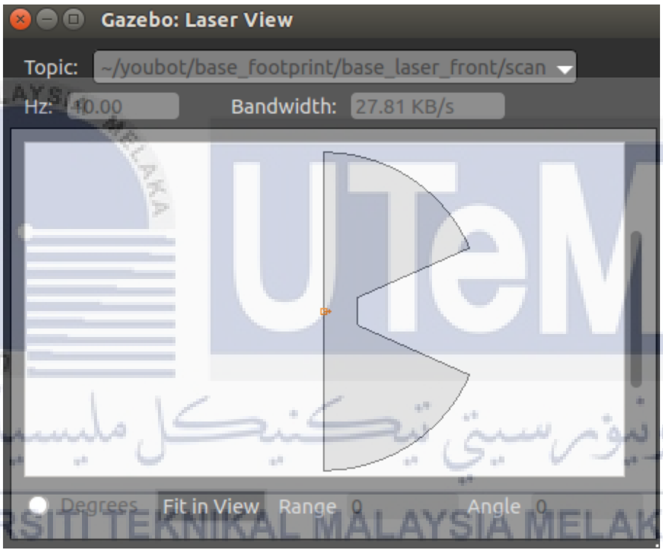


Figure 3.11: Range of Sensor when in Front of Object

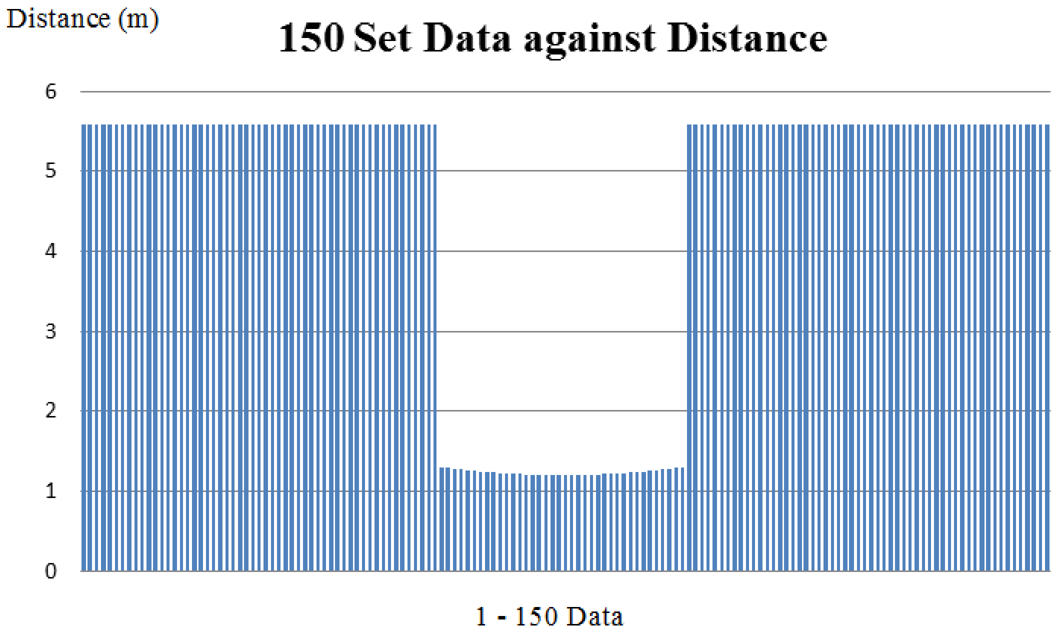


Figure 3.12: An example of the simulated 150 Set Hokuyo Data with Distance with an Object in Front

3.3.1 Wall Follower

The wall follower using Hokuyo laser scanner sensor data information of distance and area as object detection for avoids collision and find the wall. Figure 3.13 shows the region condition of the Hokuyo laser scanner sensor and Table 3.1 shows the case condition of the wall follower.

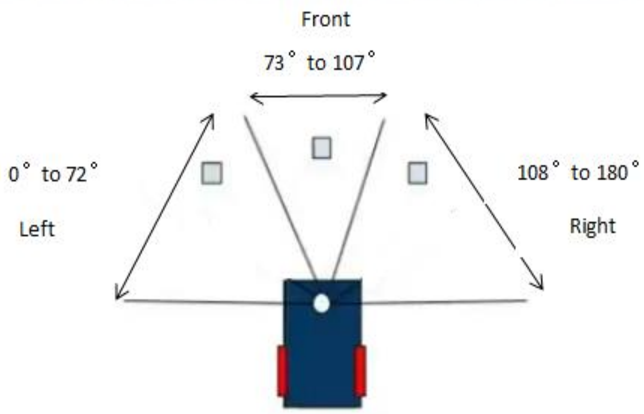


Figure 3.13: Region Condition of Hokuyo Laser Scanner Sensor

Table 3.1: Wall Follower Case Condition

	Radius, r (m)	Left	Front	Right	State	Action
Case 1	0.75	> r	> r	> r	Find the Wall	Turn Right
Case 2	0.75	> r	< r	> r	Turn Left	Turn Left in Place
Case 3	0.75	> r	> r	< r	Follow the Wall	Forward
Case 4	0.75	< r	> r	> r	Find the Wall	Turn Right
Case 5	0.75	> r	< r	< r	Turn Left	Turn Left in Place
Case 6	0.75	< r	< r	> r	Turn Left	Turn Left in Place
Case 7	0.75	< r	< r	< r	Turn Left	Turn Left in Place
Case 8	0.75	< r	> r	< r	Find the Wall	Turn Right

From the figure 3.13, the coverage of area of the Hokuyo laser scanner sensor can be divided by three regions which left from 0 to 72 degree, front from 73 to 107 degree and left from 108 to 180 degree. The table 3.1 shows the 8 case condition of the wall follower with three state and action. KUKA Youbot moved based on the region of the radius of the object detection and take action when the condition is met.

3.4 Exploration: Mapping and Localization

The mapping and localization is built by using the data information from the Hokuyo laser scanner sensor and odometry of the robot. The data information required from the sensor is distance while the odometry is position and orientation. When the robot translates or rotate, the sensor is scanned within the distance and area at the position and the orientation of the robot. In the same time, the data information which is in the 2D point cloud form is published or update to the map server. When there is an obstacle near to the distance of the scan area, the intensity of the scan area is become higher. When there is an obstacle, it will publish as black color while grey color indicate not obstacle.

3.5 Navigation: Navfn Planner

Navfn Planner uses Dijkstra algorithm to find a global path on a costmap with a minimum cost between start to the end point. Dijkstra algorithm is an algorithm for finding the shortest paths between nodes in a graph. The illustration of Dijkstra's algorithm as shown in figure 3.14 is finding a path from a start node (lower left, red) to a goal node (upper right, green). Filled nodes are visited ones, with color representing the distance: the greener, the closer while the blue color is an obstacle.

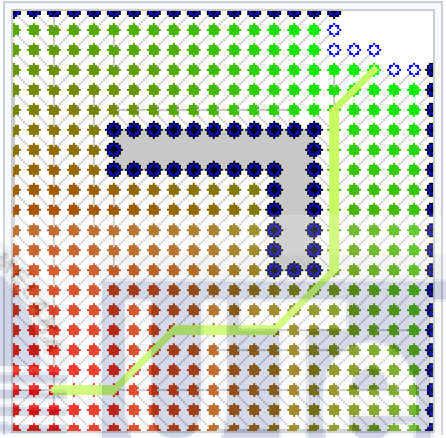


Figure 3.14: Illustration of Dijkstra's Algorithm

Costmap is a map that takes the data from the sensor to build a 2D occupancy grid of the data. Cost is defined as a matrix of the image with rgb from 0 to 255. The cost can be calculated by (3.2):

cost = cost neutral + cost factor * costmap cost value (3.2)

Where,

cost =255= Unknown Cost

cost =254=Forbidden Region

cost=253=Are Obstacle

cost neutral=Open Space Value

cost factor=Translating Costs Of The Costmap Cost Value

costmap cost value=Incoming Costmap Value From 0 To 252

3.6 Experimental Setup

The three main objectives of this project are conducted with experiments to ensure the objectives are achieved. They are summed up as shown in Table 3.2. The experiments are stated as below:

- Experiment 1: Simultaneous Localization and Mapping using Hokuyo Laser Scanner sensor and wall follower

- Experiment 2: Navfn Planner Navigation Tuning with Sensor Data

Table 3.2: Summary of Objectives to Experiments

Objectives / Experiments	Objective 1	Objective 2	Objective 3
Experiment 1	✔	✔	✔
Experiment 2	✔		✔

3.6.1 Experiment 1: Simultaneous Localization and Mapping using Hokuyo Laser Scanner sensor and wall follower

This experiment is to evaluate the performance of the Hokuyo laser scanner sensor in mapping. The purpose of this experiment is to find the RMSE between manual control the KUKA Youbot to mapping by human and mapping using wall follower. The manually control mapped by human will be taken as benchmark in order to compare the wall follower algorithm with human. The experiment is conducted in a virtual environment of Gazebo with 5 different closed environments as shown in Figure 3.15, Figure 3.16, Figure 3.17, Figure 3.18, Figure 3.19.

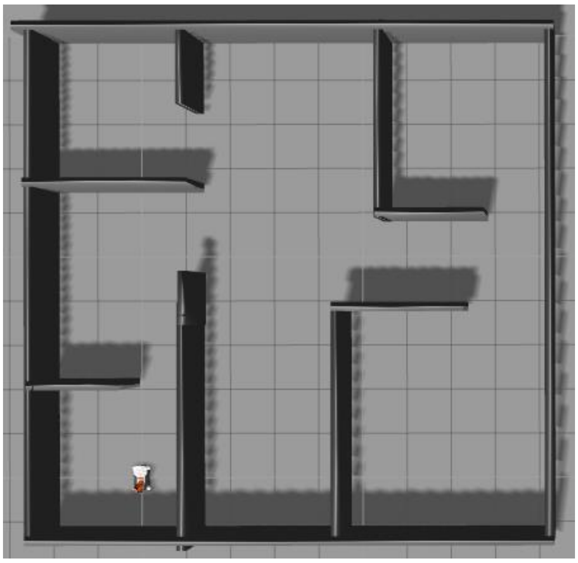


Figure 3.15: Floor Plan Close Environment 1 (11m x 11.5m)

Figure 3.16: Zigzag Close Environment (11.5m x 12m)

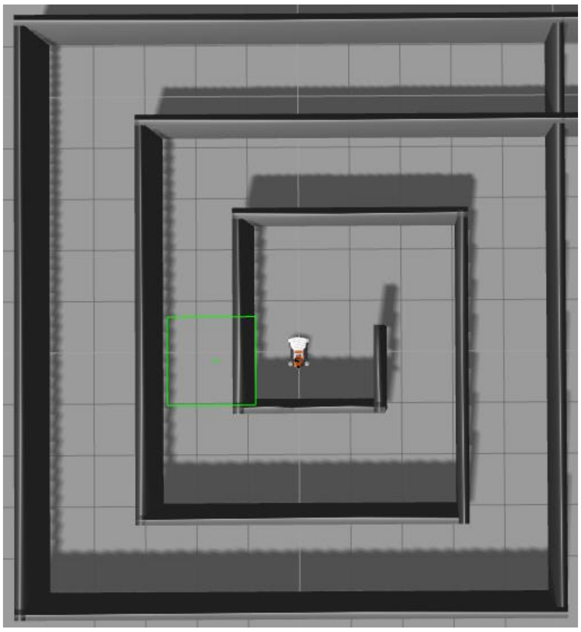


Figure 3.17: Spiral Close Environment (11m x 9.5m)

Figure 3.18: Zigzag and Spiral Close Environment (13.5m x 19.5m)

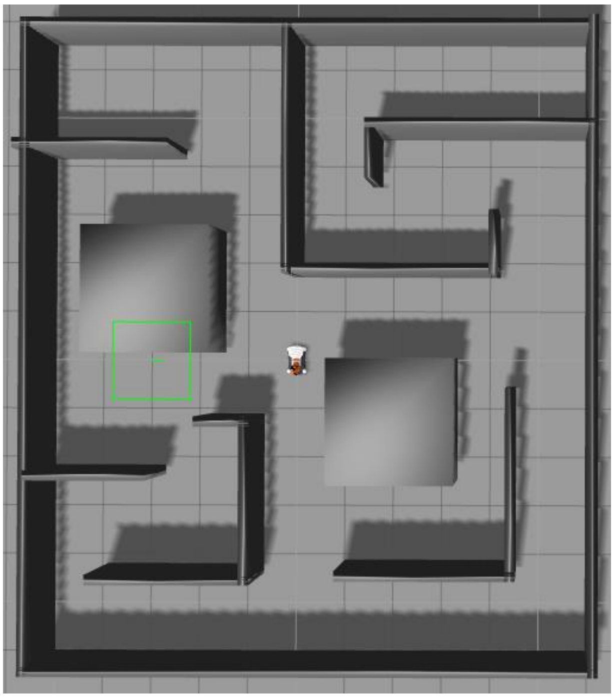


Figure 3.19: Floor Plan Close Environment 2 (13m x 11m)

The experiment starts by manual control the movement of KUKA Youbot map the surrounding of each environment until all the region is completely scanned. The initial position of KUKA Youbot is xy (0, 0) in the Gazebo virtual environment. Next, the experiment starts by using wall follower as the exploration for mapping the environment. The graph of position x and y is plot in rqt plot and sensor data is visualize in the Rviz in the same time. The mapping and exploration for wall follower is stopped when the robot finish one loop where the starting point meet the end point by observed from the graph position x and y. This process is repeated with 3 times in each environment.

3.6.1.1 Experiment 1: Method of Analysis

The manually map result is compared with the map that map obtained using wall follower algorithm. The image is compared by finding the RMSE using equation (3.3) and process as shown in Figure 3.20.

$$\mathbf{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \Delta p_i} \qquad (3.3)$$

Where N and Δp_i are the total number of pixels in the image and difference in each pixel value respectively.

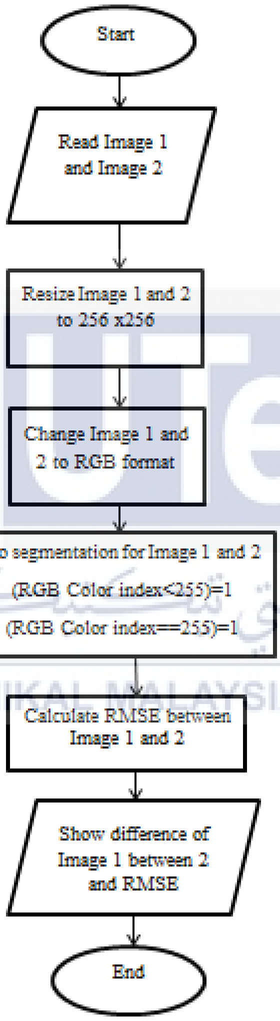


Figure 3.20: Flow Chart of Image Analysis for Experiment 1

3.6.2 Experiment 2: Navfn Planner Navigation Tuning with Sensor Data

This experiment is to evaluate the navigation performance of the Navfn planer in term quality and distance of the path. The purpose of this experiment is to found suitable cost neutral and cost factor as state in (3.2) to avoid the cost become equal to 253, 254 and 255 with shortest distance travelled. Hence, take the condition of incoming costmap value as 252 and cost cannot be over or equal to 253; the data set range is tabulated as shown in table 3.4.

Table 3.3: Experiment 2 Data Set

Cost Neutral, N	Cost Factor, CF	Costmap Cost Value, CCV	Cost = N+CF*CCV
227	0.1	252	252.2
202	0.2	252	252.4
177	0.3	252	252.6
152	0.4	252	252.8
126	0.5	252	252
101	0.6	252	252.2
76	0.7	252	252.4
51	0.8	252	252.6
26	0.9	252	252.8

The experiment is conducted in virtual environment of figure 3.18 in Gazebo. The experiment is start by load the map that generate by sensor information as shown in figure 3.21, where the red x symbol is the goal. Next, launch the Navfn planner and navigate the robot to the goal and the graph of position x and y is plot in rqt plot in the same time. The experiment is repeated with 3 times for each data set.

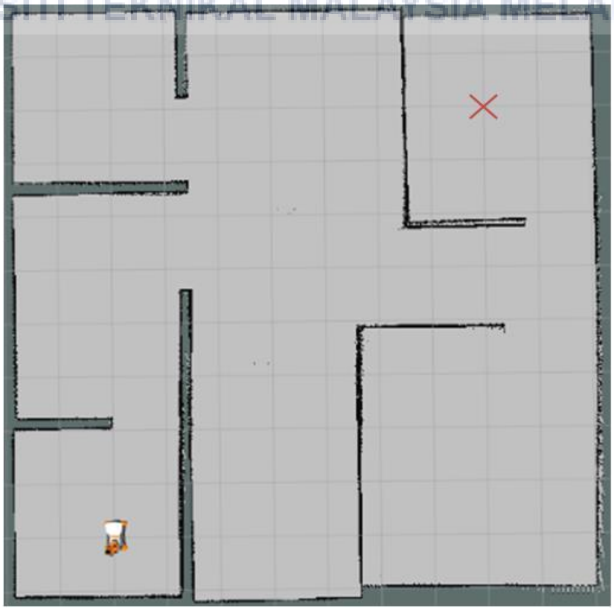


Figure 3.21: Floor Plan Close Environment 1 Map

3.6.2.1 Experiment 2: Method of Analysis

The performance of Navfn planner is analyzed by comparing the graph of position x and y with Matlab. The image is compared by observing which of the graph perform the shortest distance as shown in figure 3.22.

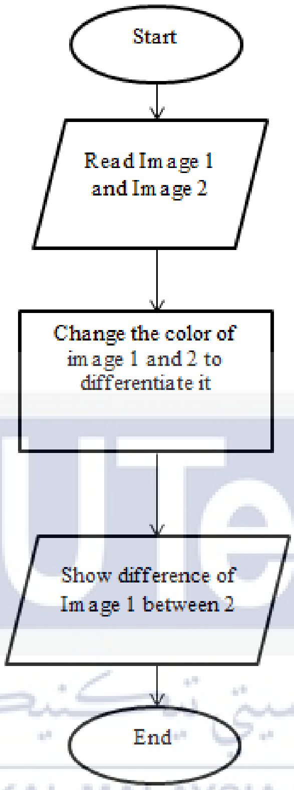


Figure 3.22: Figure 3.23: Flow Chart of Image Analysis for Experiment 2

3.7 Summary

In conclusion, this chapter provides a detailed plan so that the project can be complete on time to achieve the objective of the project. In this project, the information about the software and components used to implement Navigation with SLAM using KUKA Youbot and experiments have been discussed. The performance of exploration, mapping and navigation is tested in the experiments. The next chapter presents the result and discussion of the project.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

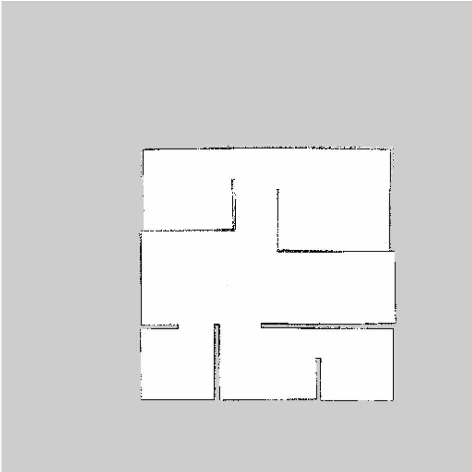
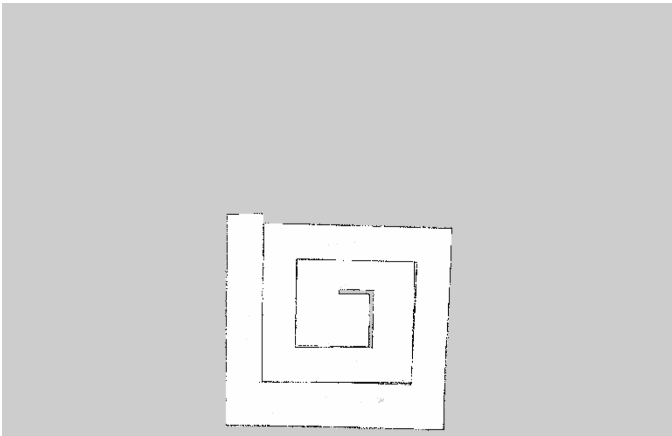
In this chapter, the result and discussion of each experiment are presented. The method for implement this project is using Hokuyo laser scanner sensor for mapping and localization with wall follower as an exploration to an unknown environment. Then, navigate the KUKA Youbot by using Navfn planner with a scanned map. The performance of exploration, mapping and navigation is tested through the experiment. The experiments are conducted in the virtual environment of Gazebo. The data is collected by Rviz and rqt plot and analyzed through Matlab.

4.2 Result

4.2.1 Experiment 1: Simultaneous Localization and Mapping using Hokuyo Laser Scanner sensor and wall follower

This experiment is to evaluate the performance of the Hokuyo laser scanner sensor in mapping. The purpose of this experiment is to found the RMSE between manual control the movement of KUKA Youbot to mapping and mapping using wall follower. The experiment is conducted as shown in Figure 3.15, figure 3.16, figure 3.17, figure 3.18, figure 3.19. The result of the experiment 1 is as shown in Table 4.1 4.2 and 4.3.

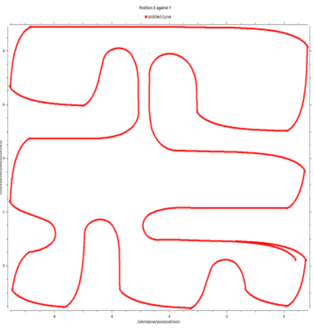
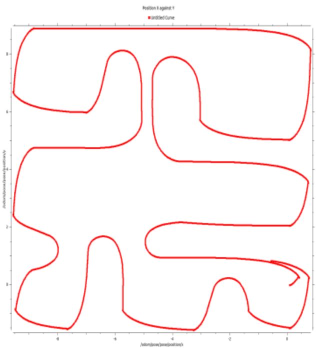
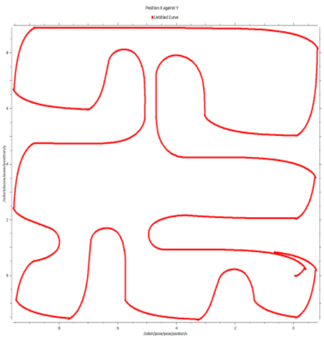
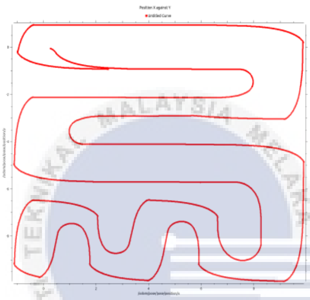
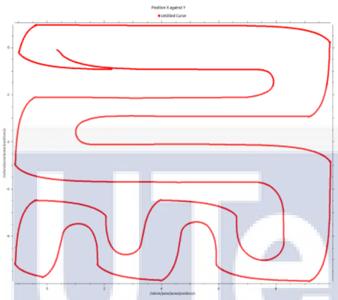
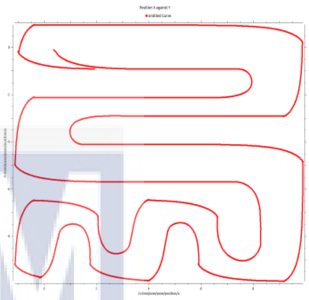
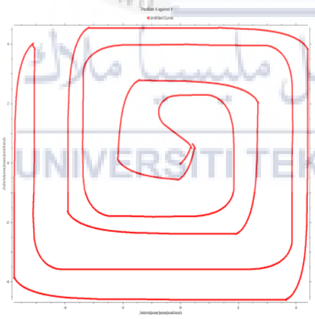
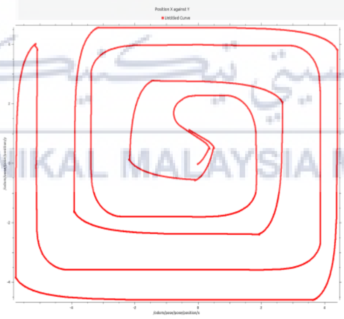
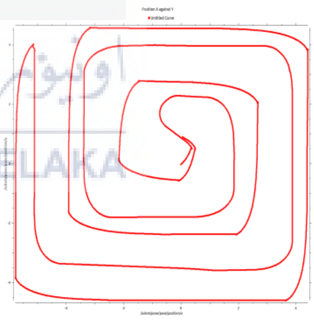
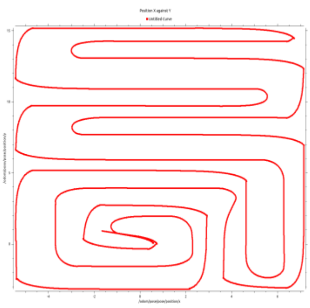
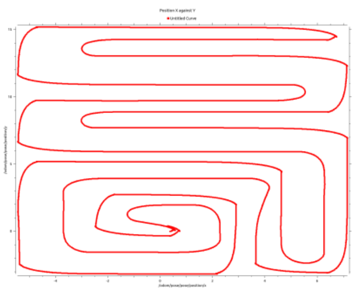
Table 4.1: Manual Navigation Scanned Map

No.	Environment	Map Figure
1	Floor Plan Close Environment 1	
2	Zigzag Closed Environment	
3	Spiral Closed Environment	

No.	Environment	Map Figure
4	Zigzag and Spiral Closed Environment	
5	Floor Plan Closed Environment 2	

Table 4.1 shows the map generated by manually moving the KUKA Youbot around the environment using keyboard to build the map. Understandably the result will be very good and will serve as the benchmark for the results from the wall follower algorithm presented in later section. The black color represents the obstacle, white color represent free obstacle region and grey color represent unknown region.

Table 4.2: Path Travelled by Robot using Wall Follower

No.	Graph of Position X against Y		
	Trial 1	Trial 2	Trial 3
1			
2			
3			
4			

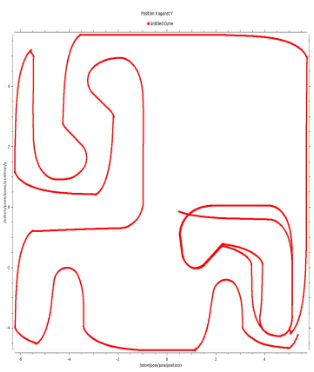
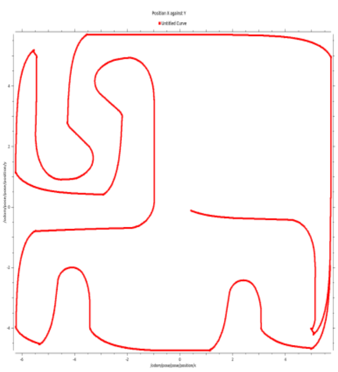
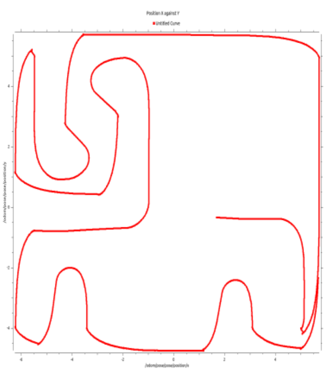
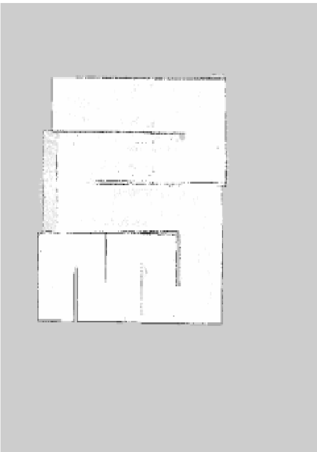
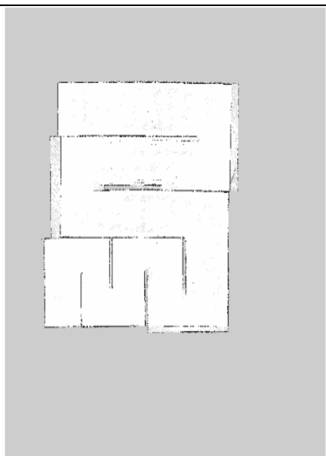
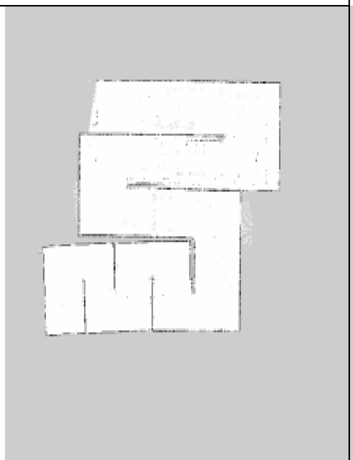
No.	Graph of Position X against Y		
	Trial 1	Trial 2	Trial 3
5			

Table 4.3: Wall Follower Scanned Map

No.	Map Figure		
	Trial 1	Trial 2	Trial 3
1			
2			

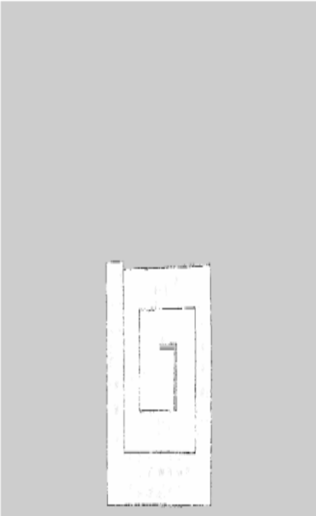
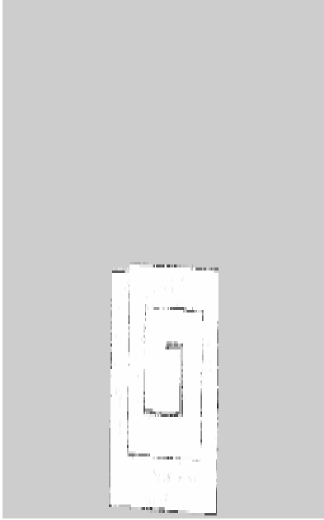
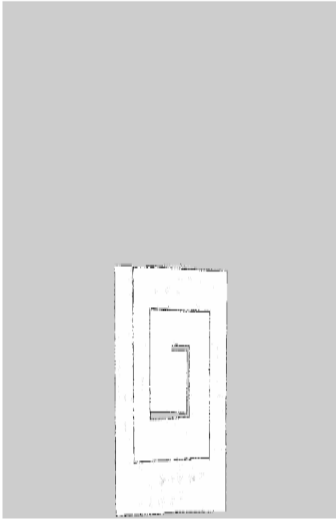
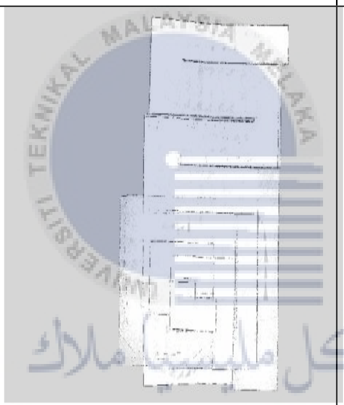
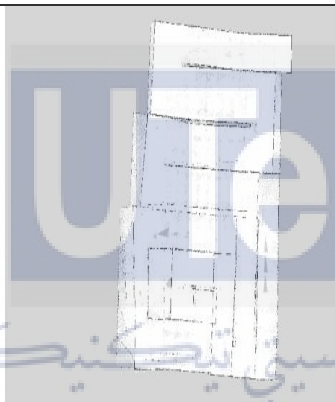
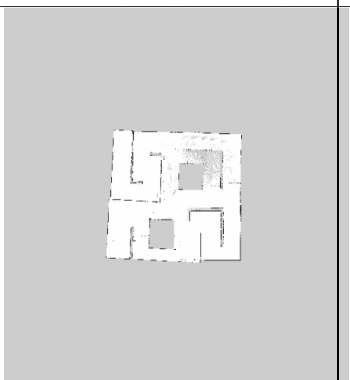
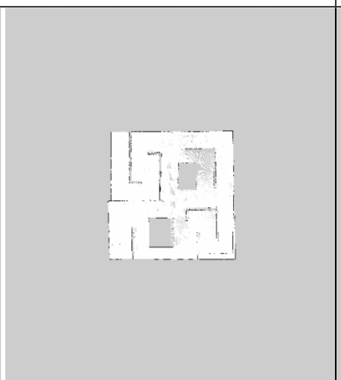
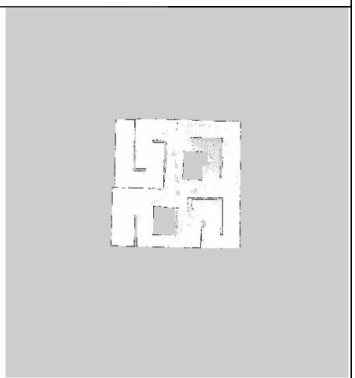
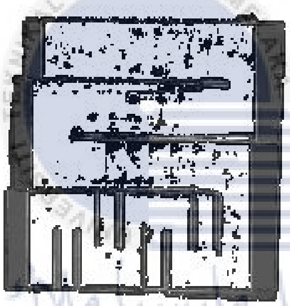
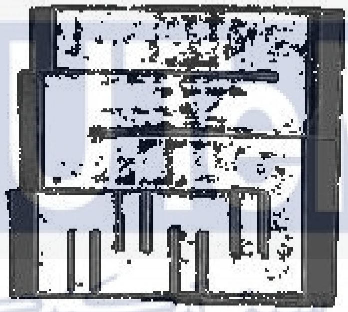
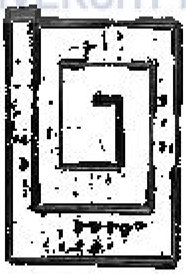
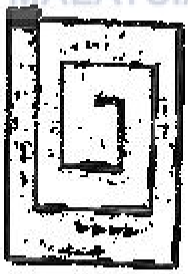
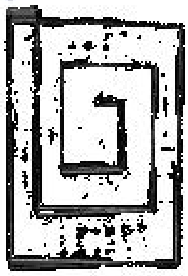
No.	Map Figure		
	Trial 1	Trial 2	Trial 3
3			
4			
5			

Table 4.2 show the graph of position X against Y. The red line represents the path travelled by robot using wall follower. Table 4.3 shows the map is mapped by

using wall follower as an exploration. The experiment is repeated 3 times to found the average root mean square error between the manually scanned map and wall follower scanned map. The map is compare as shown in Table 4.4.

Table 4.4: Difference of Manually and Wall Follower Scanned Map

No.	Map Figure		
	Trial 1	Trial 2	Trial 3
1			
2			
3			

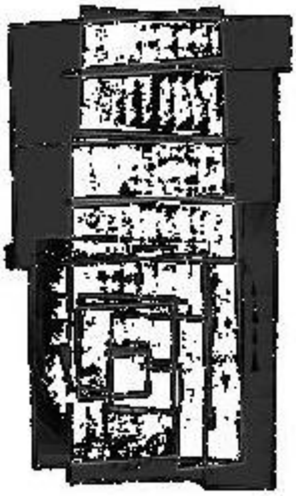
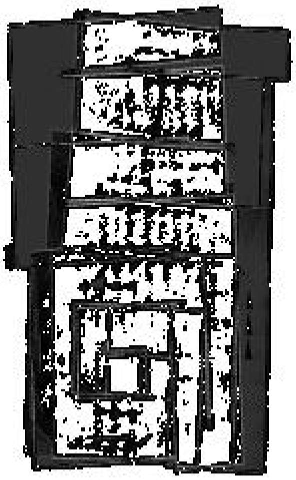
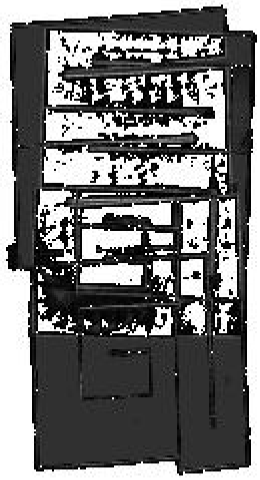
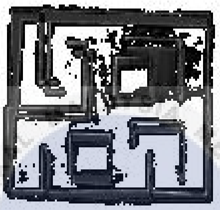
No.	Map Figure		
	Trial 1	Trial 2	Trial 3
4			
5			

Table 4.4 shows the difference of manually and wall follower scanned map. The black color shows the difference while the white color shows the similarity. The RMSE is calculated in table 4.5.

Table 4.5: Root Mean Square Error of Map

No.	Root Mean Square Error			Average of Root Mean Square Error
	1	2	3	
1	0.3734	0.3766	0.3833	0.3778
2	0.3997	0.4002	0.4081	0.4027
3	0.2493	0.2260	0.2458	0.2404
4	0.5674	0.5500	0.5625	0.5600
5	0.3112	0.3169	0.3134	0.3138

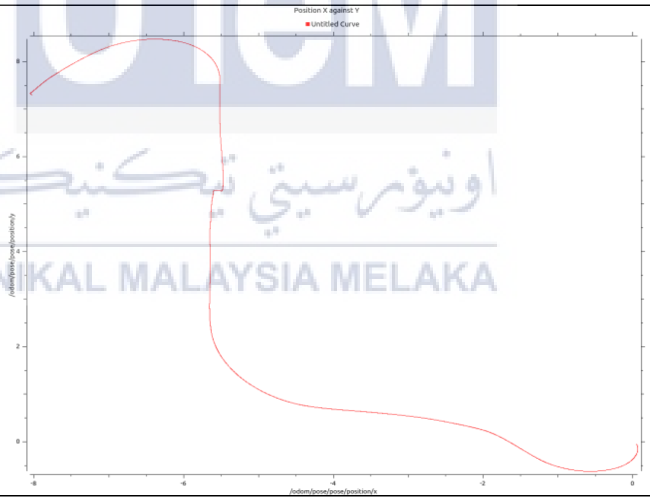
Table 4.5 shows the RMSE of map. The environments no. 3 has the least RMSE while environments no. 4 has highest RMSE and environment no. 2 is the second highest. This shows that it is good at environment no. 3 structure which is spiral environment but weak in environment no. 2 and 4 which consist of zigzag

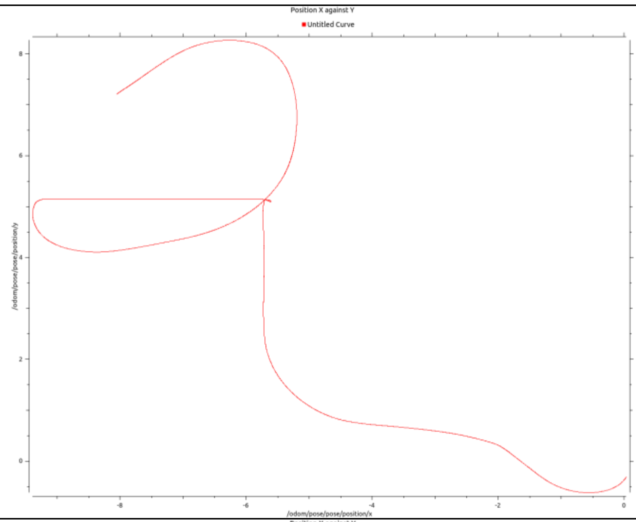
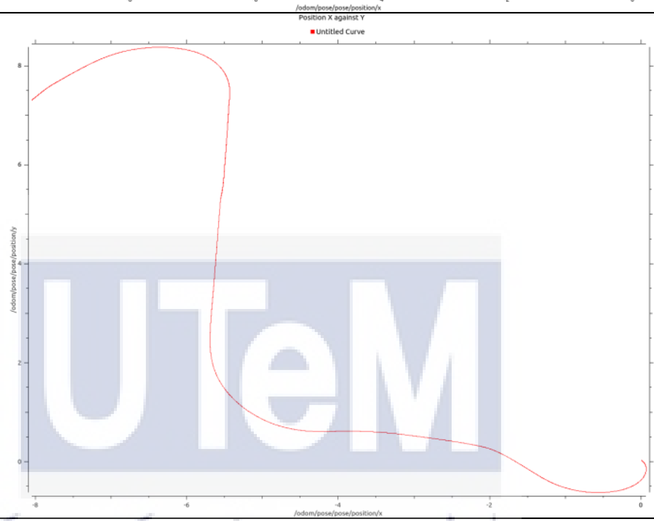
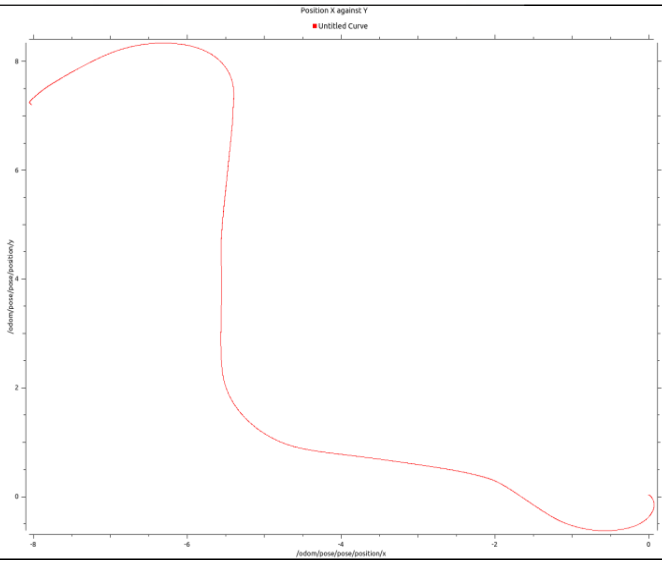
environment. The environment no.1 and 5 show the 0.3778 and 0.3138 RMSE respectively.

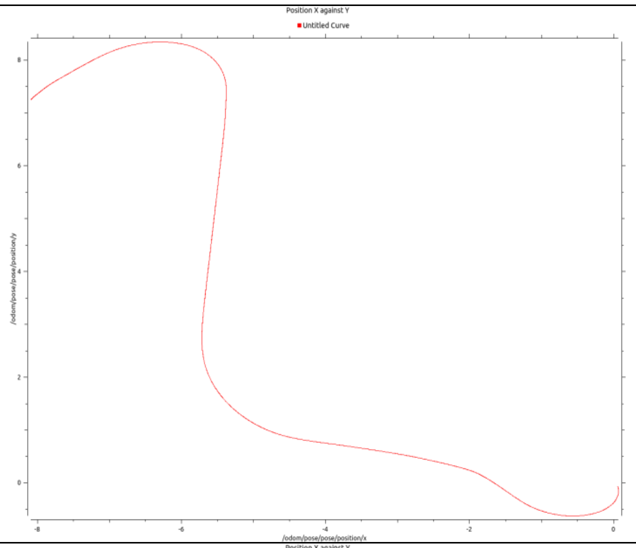
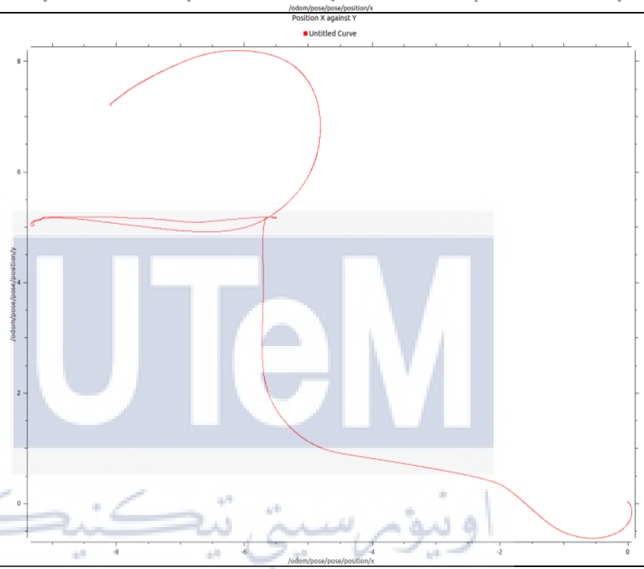
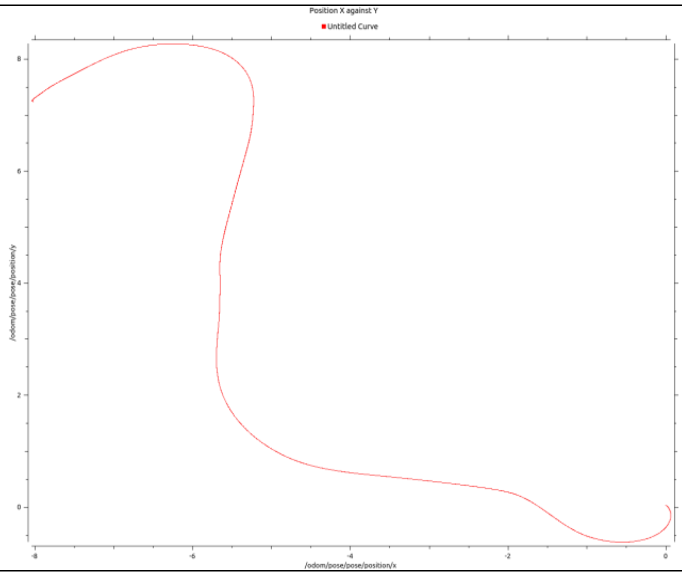
4.2.2 Experiment 2: Navfn Planner Navigation Tuning with Sensor Data

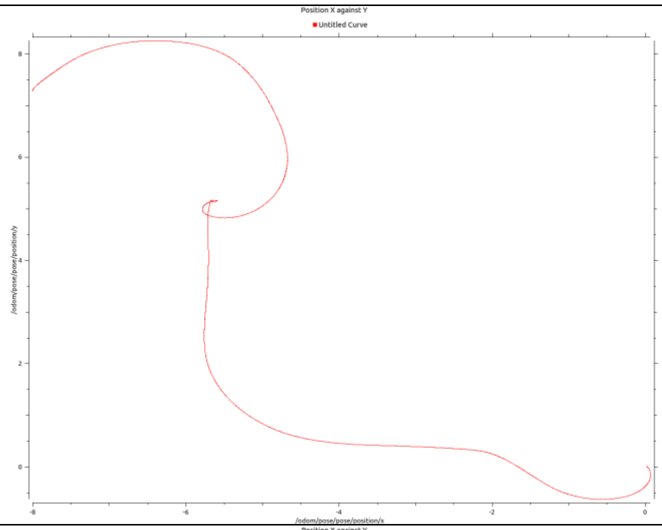
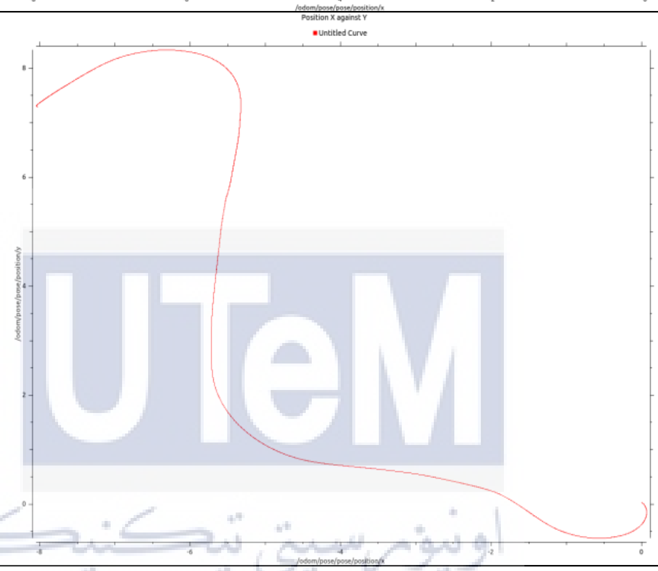
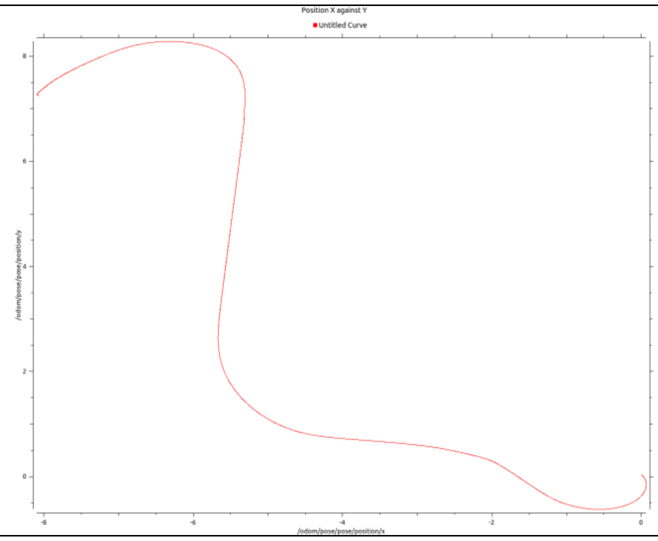
This experiment is to evaluate the performance of the Navfn planer in term quality and distance of the path. The purpose of this experiment is to found suitable cost neutral and cost factor as state in (3.8) to avoid the cost become equal to 253, 254 and 255. The experiment is conducted as shown in figure 3.15 with map as shown in figure 3.21. The result of the experiment 3 is as shown in Table 4.6.

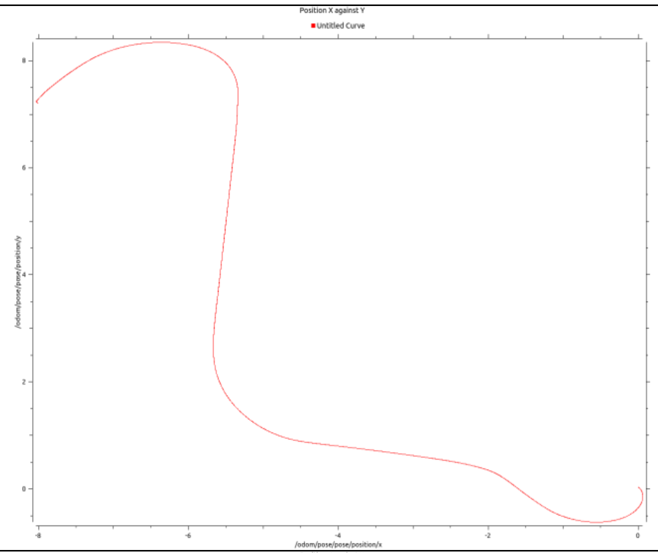
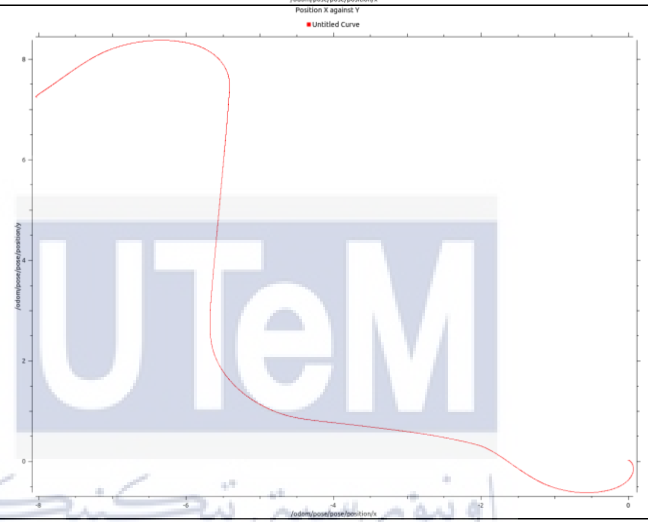
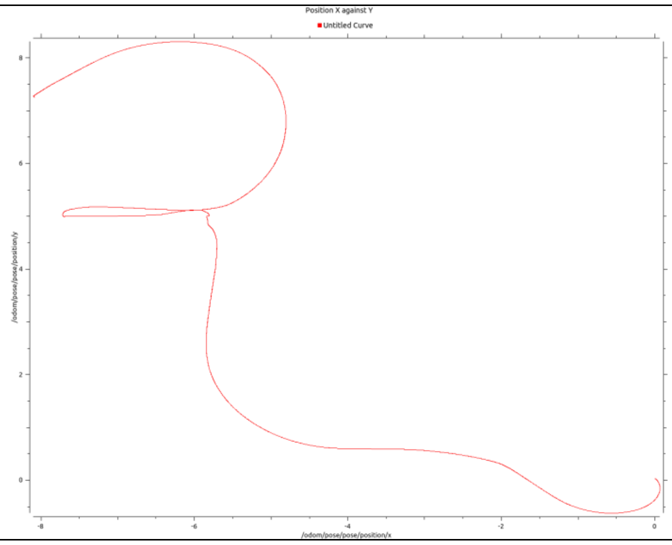
Table 4.6: Experiment 2 Result

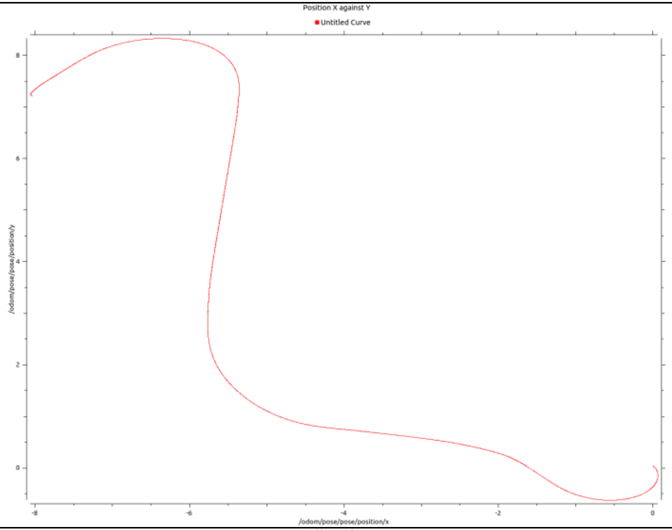
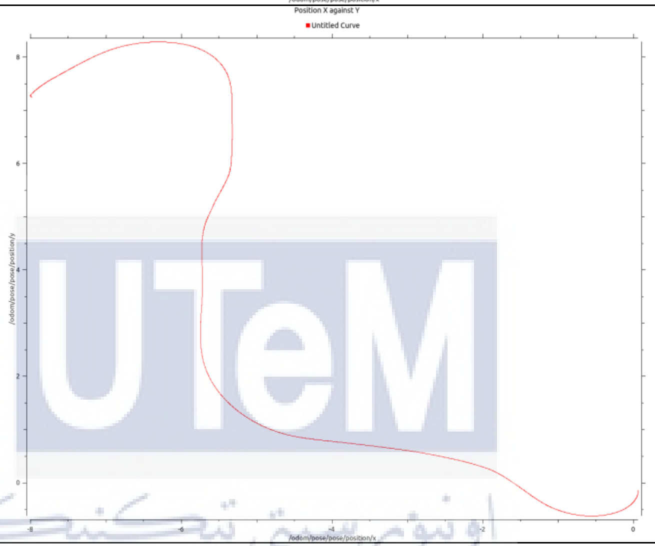
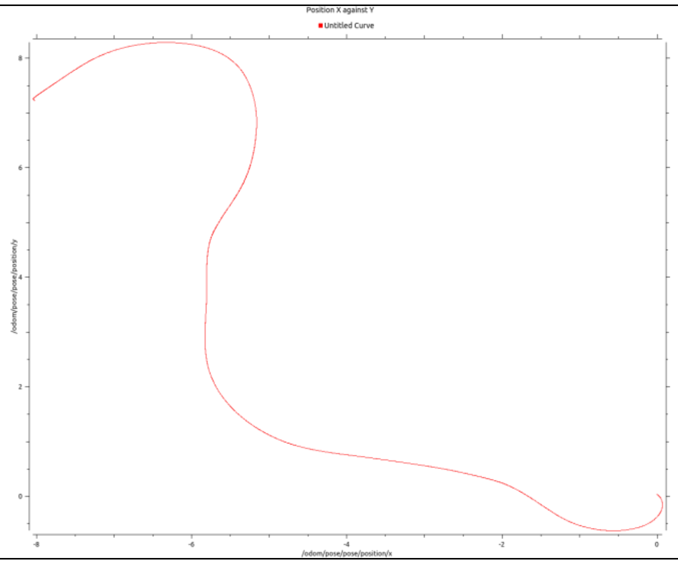
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
227	0.1	a1	

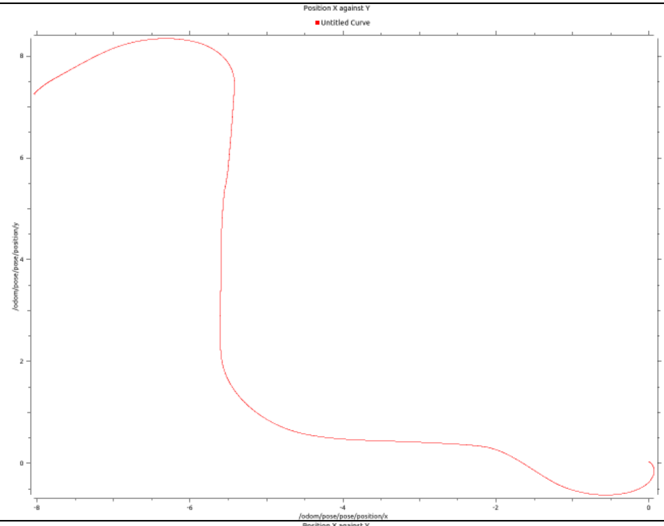
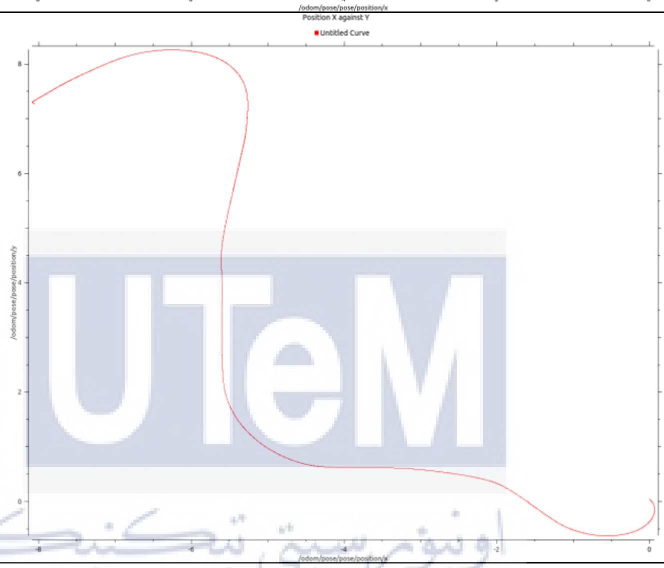
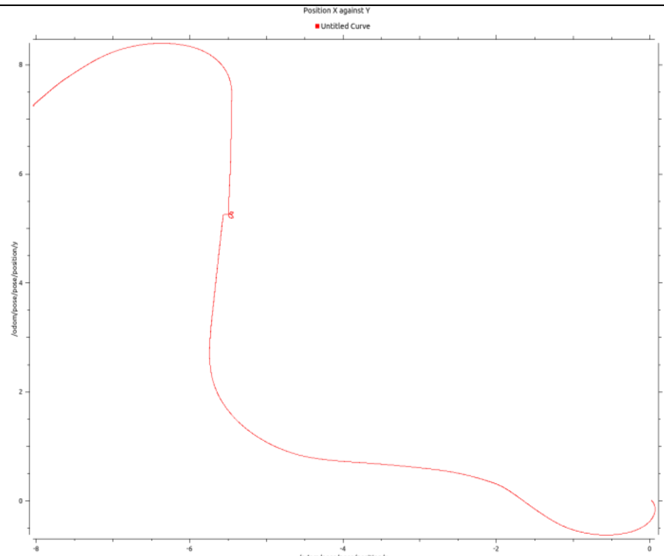
		a2	
		a3	
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
202	0.2	b1	

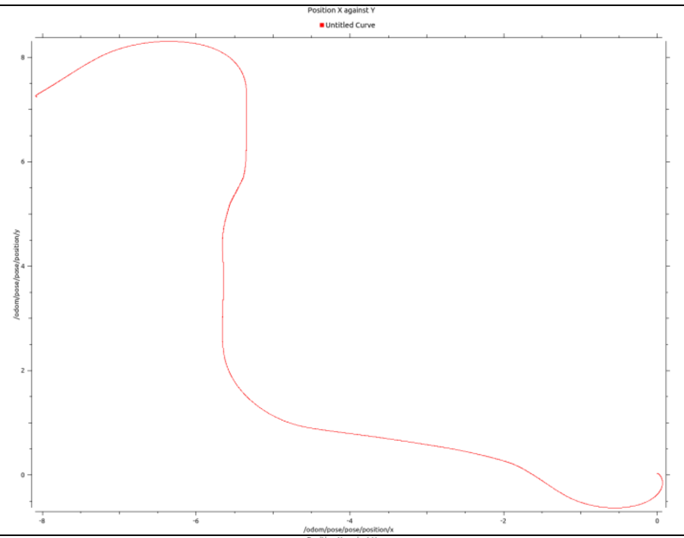
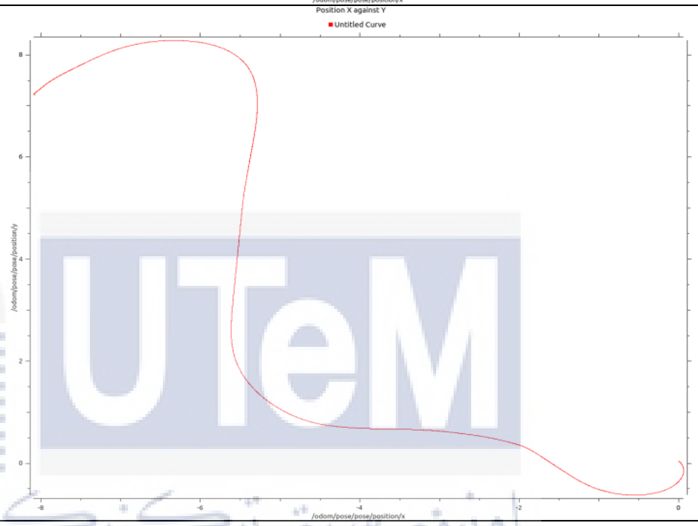
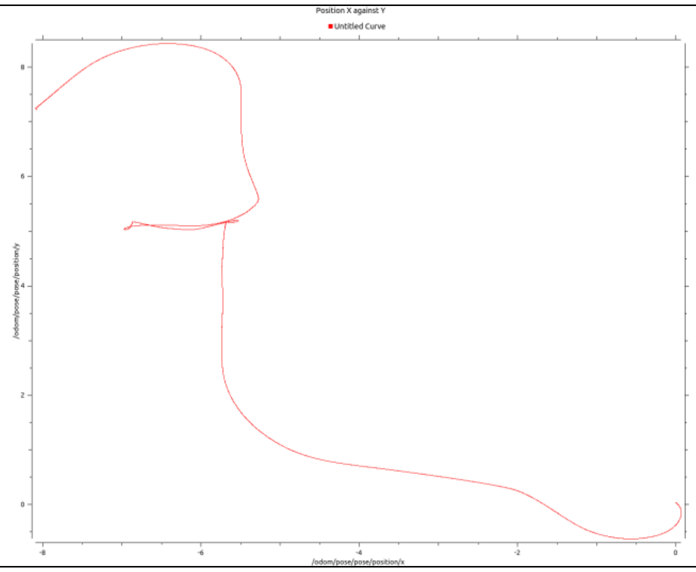
		b2	
		b3	
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
177	0.3	c1	

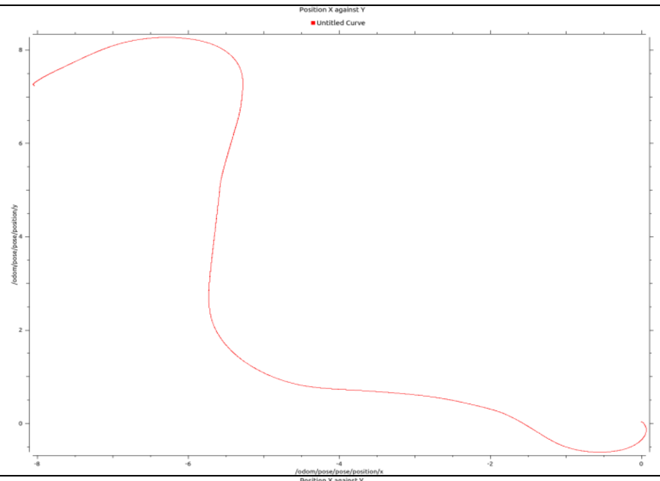
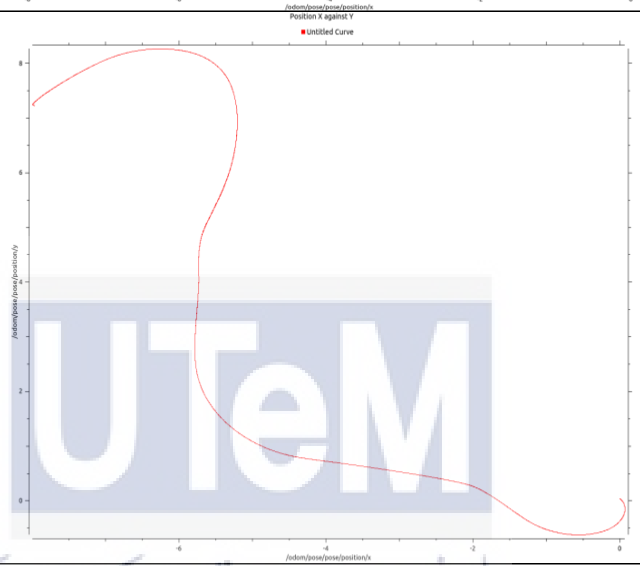
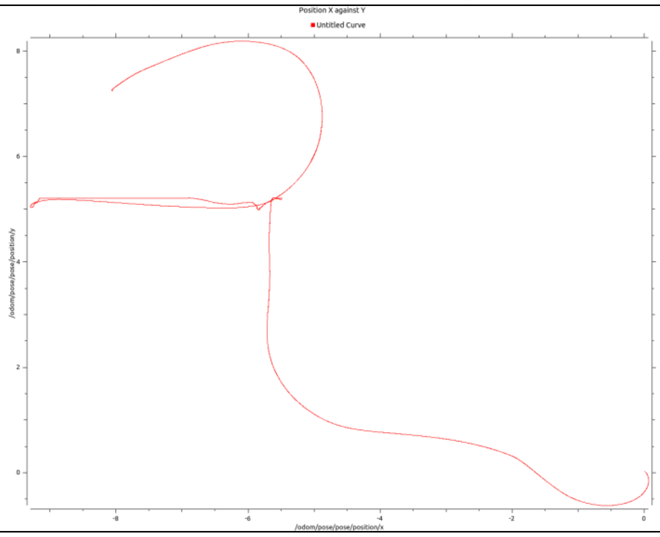
		c2	
		c3	
Cost Neutral	Cost Factor	‘No.’ ‘Number of Times’	Graph of Position X Against Y
152	0.4	d1	

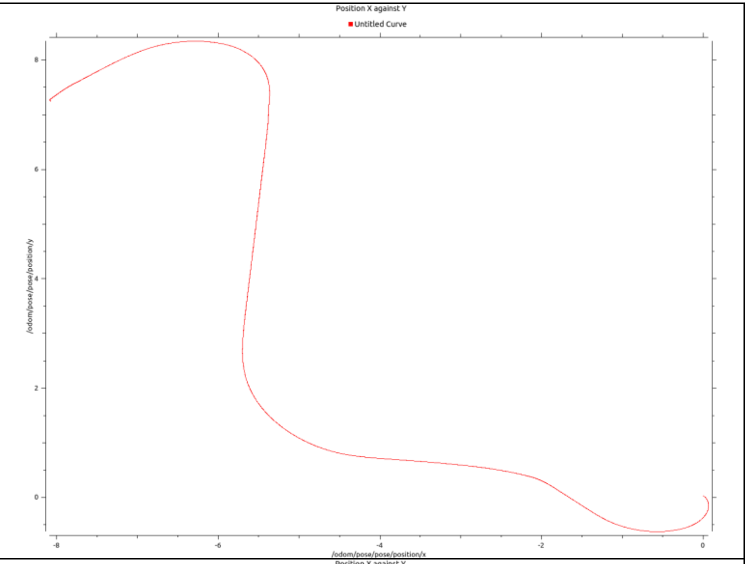
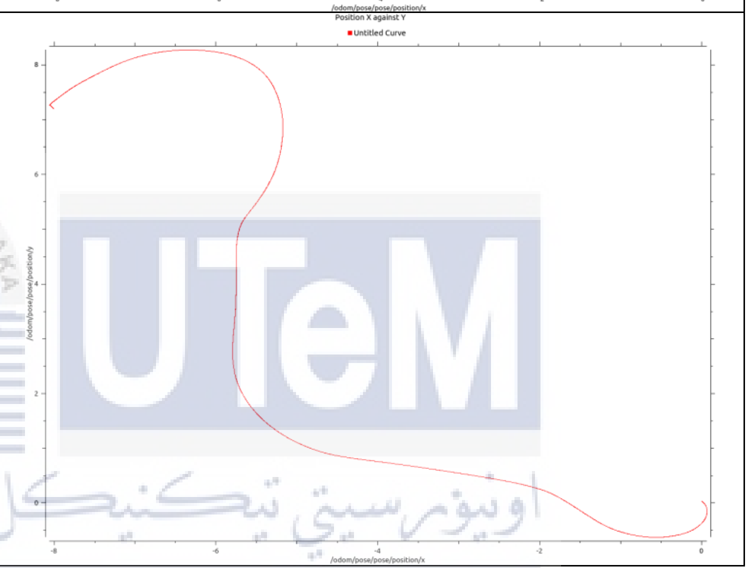
		d2	
		d3	
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
126	0.5	e1	

		e2	
		e3	
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
101	0.6	f1	

		f2	
		f3	
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
76	0.7	g1	

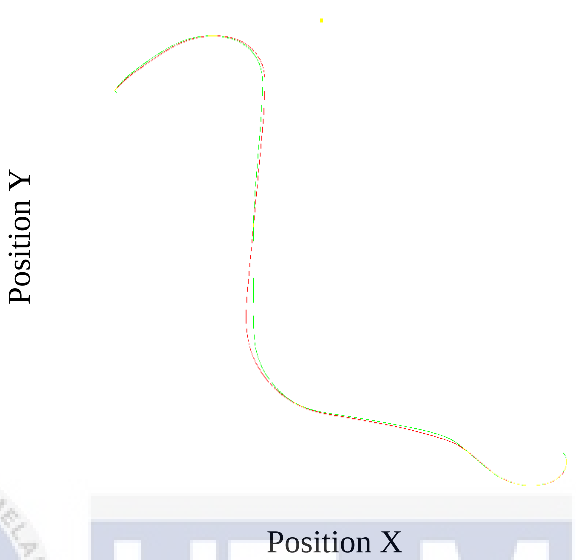
		g2	
		g3	
Cost Neutral	Cost Factor	‘No.’ ‘Number of Times’	Graph of Position X Against Y
51	0.8	h1	

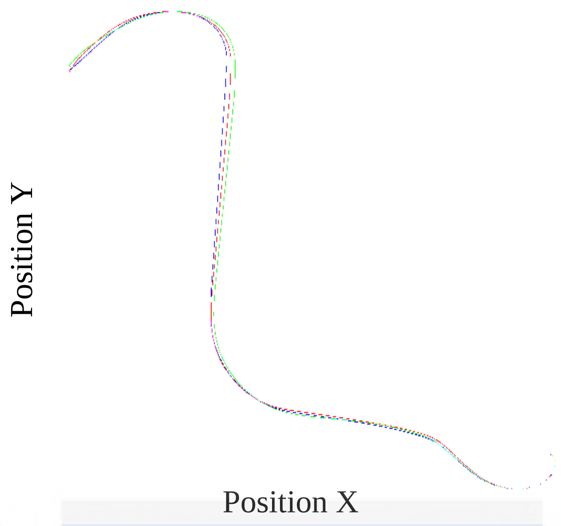
		h2	
		h3	
Cost Neutral	Cost Factor	'No.' 'Number of Times'	Graph of Position X Against Y
26	0.9	i1	

		i2	
		i3	

The graph shown in Table 4.6 is start from the right to the left for each cost neutral and cost factor. The red line represents the path that the robot travels. Next, the best of each is pick by compare the graph of position x against y. Only b1 and b2, c1 and c3, d1, d2 and d3 need to compare while the rest can pick obviously by observe the three graphs. The comparison result is show as in table 4.7, 4.8 and 4.9.

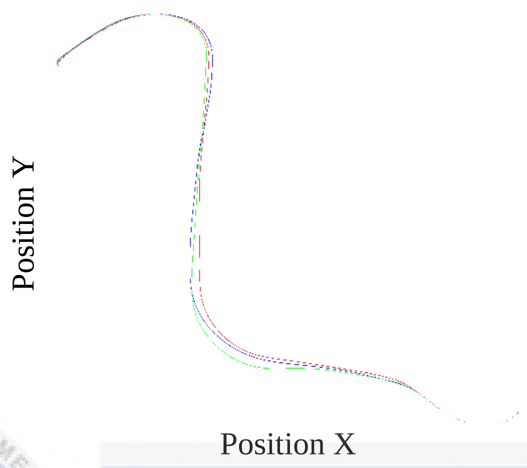
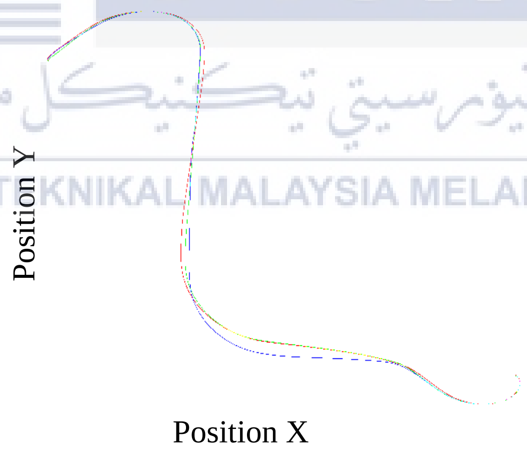
Table 4.7: Comparison: b1 and b2: c1 and c3: d1, d2 and d3

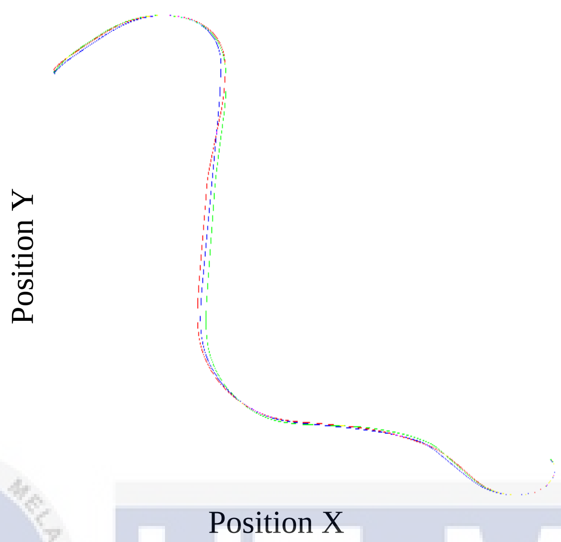
<table>
<tr><th>‘No.’ ‘Number of Times’</th><th>Color</th><th>Comparison Image</th><th>Selected</th></tr>
<tr><td>b1</td><td>Green</td><td rowspan="2">
</td><td rowspan="2">b1</td></tr>
<tr><td>b2</td><td>Red</td></tr>
<tr><td>c1</td><td>Green</td><td rowspan="2">
</td><td rowspan="2">c3</td></tr>
<tr><td>c3</td><td>Red</td></tr>
</table>

‘No.’ ‘Number of Times’	Color	Comparison Image	Selected
d1	Green		d3
d2	Red		
d3	Blue		

From table 4.7, the b1, c3 and d3 is selected to compare to the other while the other that are selected is a3, e2, f2, g3, h2 and i2. The reason for b1 got selected is b2 have bigger radius than b1 when turning the first corner. The reason c3 got selected is c1 have the bigger radius than c3when turning the second corner. The reason for d3 got selected is d1 and d2 have the bigger radius than d3 when turning the second corner. The graph is compare in 3 groups first; the best is picked then compared to each other to find the shortest distance path. The comparison result is show in table 4.8.

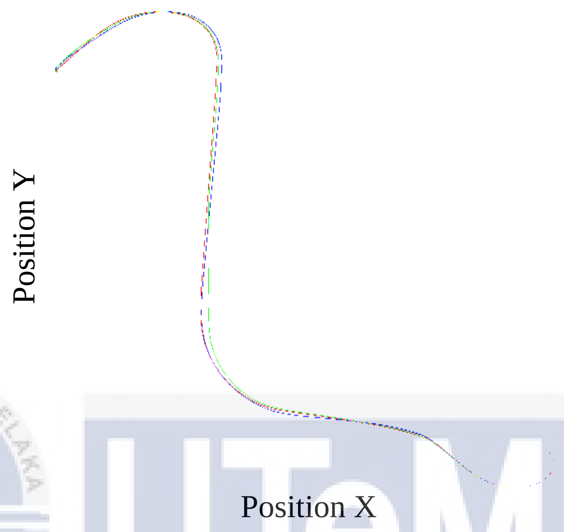
Table 4.8: Comparison: a3, b1 and c3: d3, e2 and f2: g3, h2 and i2

<table>
<tr><th>‘No.’ ‘Number of Times’</th><th>Color</th><th>Comparison Image</th><th>Selected</th></tr>
<tr><td>a3</td><td>Green</td><td rowspan="3">
</td><td rowspan="3">b1</td></tr>
<tr><td>b1</td><td>Red</td></tr>
<tr><td>c3</td><td>Blue</td></tr>
<tr><td>d3</td><td>Green</td><td rowspan="3">
</td><td rowspan="3">d3</td></tr>
<tr><td>e2</td><td>Red</td></tr>
<tr><td>f2</td><td>Blue</td></tr>
</table>

‘No.’ ‘Number of Times’	Color	Comparison Image	Selected
g3	Green		i2
h2	Red		
i2	Blue		

From the table 4.8, the b1, d3 and i2 is selected as a shortest distance path. The reason for b1 being selected is a3 and c3 have the bigger radius than b1 when tuning the first corner. The reason for d3 got selected is e2 and f2 have the bigger radius than d3 when turning the first corner. The reason for i2 being selected is g3 and h2 have the bigger radius than i2 when turning the second corner. Next, the b1, d3 and i2 are compared in table 4.9

Table 4.9: Comparison: b1, d3 and i2

‘No.’ ‘Number of Times’	Color	Comparison Image	Selected
b1	Green		b1
d3	Red		
i3	Blue		

From the table 4.8, b1, d3 and i2 is compare and the b1 is selected as the shortest distance traveled, the reason is d3 and i3 have bigger radius than b1 when turning the first corner. Hence, b1 which have 202 cost neutral and 0.2 cost factor is best performance among to the other. The overall comparison image is show in figure 4.1.

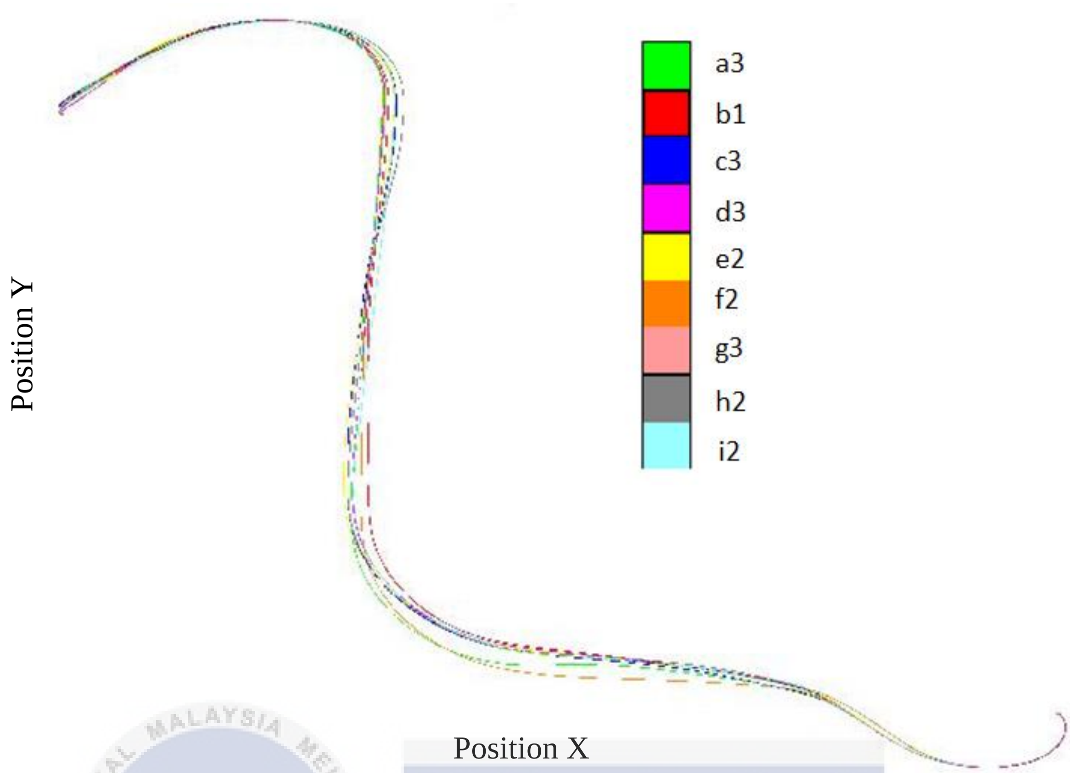


Figure 4.1: Overall Comparison Image

4.3 Discussion

In experiment 1, the result show that manually move the robot by human to built the map of the environment is capable completely scan all the region while the wall follower method does not show completely. The proposed method is good in dealing the spiral environment, followed by floor plan and zigzag environment. The highest root mean square error is 0.5600 while the lowest is 0.2404. The reason for having this result is publishing location of the mobile robot is less accurate and the center of path is not scanned completely. The error can be reduced by increase the time of exploration and mapping. The longer the time of exploration and mapping, it will overlap and adjust the map when there is new information collected by the Hokuyo laser scanner sensor.

In experiment 2, the result show with cost neutral of 202, the cost factor needs to be about 0.2 to ensure the input values are spread evenly over the output range, 202 to 252. If the cost factor is higher, cost values will have a plateau around obstacles and the planner will then treat. The radius when turning a corner is become bigger. Experiments have confirmed the setting of cost factor to too low or too high affect the quality of the path. These paths do not go through a shortest path around the obstacle.

4.4 Summary

In conclusion, this chapter provides the result and discussion on the experiment 1 and 2. The experiment is done in the virtual environment of Gazebo and the data information is collected by Rviz and rqt plot. The experiment 1 is about finding the root mean square error between the manually mapping navigation and wall follower mapping using Hokuyo laser scanner sensor. The experiment 2 is about finding the cost neutral and cost factor that can perform a shortest path from the starting point to the end point. The navigation of simultaneous localization and mapping using KUKA Youbot in an unknown environment can be implementing by using wall follower as exploration and Hokuyo laser scanner sensor as mapping and localization. In addition, the location of the mobile robot can be also known by observed the rqt plot. When the exploration and mapping is done, the mobile robot can be navigated to any point inside the map using the Navfn planner. The next chapter presents the conclusion and recommendation of the project.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project investigated the Navigation with Simultaneous Localization and Mapping Using Kuka Youbot: Simulational Study. The performance of the proposed method is evaluated by experiments. As mentioned in the introduction, the objectives of this project were to develop simulational setup for Simultaneous Localization and Mapping with KUKA Youbot using ROS, propose the sensor and navigation with performance evaluation using KUKA YouBot in simulation.

The following objectives are achieved where the simulational setup for Simultaneous Localization and Mapping with KUKA Youbot using ROS is implemented. The simulation that used in the experiments is Gazebo. The proposed sensor is able performed in the simulation. Besides that, the performance of the exploration, sensor and navigation is evaluated. Overall, the Hokuyo laser scanner sensor as mapping using wall follower has a high root mean square error when dealing the zigzag environment comapre to the manual contol by human. However, it has been discussed by increase the time for exploration can reduce the root mean square error. Next, the best tuning for the Navfn Planner in term of shortest distance path has 202 of cost neutral and 0.2 of cost factor. The sensor data can be visualized in Rviz and odometry data can plot in the rqt plot. The data were compared as an image by using Matlab. Lastly, the proposed method is capable to simulate in the virtual environment which make this application is able to perform in the real life.

5.2 Recomendations

For the recommendation, the real environment simultaneous localization and mapping study is recommended so that it can compare to the virtual environment and actually can work under an unknown environment. Besides that, a non-static object should be added in the environment to test the response of the robot and sensor. Next, increase the detection area of the laser scanner sensor with 360 degree by having each at front and back. The way to handle two laser scanner sensors is to merge the data to become a one map which can decrease the time of exploration. Last but not least, more sophisticated algorithm for exploration and navigation should be considered in order to study the efficiency of the simultaneous localization and mapping.

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APPENDICES A

No.	Activity	2018/2019 (Semester 7) FYP 1																		2018/2019 (Semester 2) FYP 2																
		1	2	3	4	5	6	7	8	9	Mid-Term Break	10	11	12	13	14	15 Study Week	16 Final Exam Week	Semester Break	1	2	3	4	5	6	7	8	Mid-Term Break	9	10	11	12	13	14	15 Study Week	16 Final Exam Week
	Final Year Project 1																																			
1	Title Registration	■																																		
2	FYP Talk	■	■	■	■	■	■																													
3	Logbook Preparation	■	■	■	■	■	■	■	■	■		■	■	■	■	■				■	■	■	■	■	■	■	■		■	■	■	■	■			
4	Discussion with Supervisor	■	■	■	■	■	■	■	■	■		■	■	■	■	■				■	■	■	■	■	■	■	■		■	■	■	■	■			
5	Library and Internet Research			■	■	■	■	■	■	■																										
6	Ros, Rviz and Gazebo Tutorial			■	■	■	■	■	■	■		■	■	■	■	■																				
7	Preparation Draft Report and Slide							■	■	■																										
8	Submission Draft Report											■																								
9	Presentation of FYP 1												■																							
10	Submission Final Draft Report														■																					
	Final Year Project 2																																			
11	Library and Internet Research																			■	■	■	■	■	■	■	■		■	■	■	■				
12	Simulation Experiment																			■	■	■	■	■	■	■	■		■	■	■	■				
13	Reparation of Final Report and Slide																												■	■	■	■				
14	Submission Final Report																																■	■		
15	Presentation of FYP 2																																■	■		

APPENDICES B

PSM2

by Lim Wing Theng

Submission date: 05-Jun-2019 07:46PM (UTC+0800)
Submission ID: 1140252937
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