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Trajectory Tracking of a Mobile Robot System

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ABSTRACT

This paper presents an efficient method of mobile robot navigation in an indoor environment. The robot not only helps workers reduce heavy workload, it also protects workers' physical and mental health from the work-related-stress. However, the navigation of mobile robot in an indoor environment is a challenging task to accomplish due to the requirement to avoid any nearby obstacle during motion. In this paper, the objectives were to design and develop of mobile robot that is able to navigate from one location to another, analyze the accuracy of line following sensor and analyze the trajectory tracking of a mobile robot. In conclusion, the experimental results show that the mobile robot able to reach the target destination successfully without the collision with obstacles, for different types of trajectory patterns using the masking tape width of 18mm with the develop algorithm.

Keywords: *Navigation Mobile Robot, Obstacle Avoidance, Trajectory Movement*

Introduction

Navigation of mobile robot has been widely discussed in the past few years and this issue can be considered as a huge challenge to be accomplished in

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the field of robotics. There are many researchers all over the world that have developed numerous methods to navigate their mobile robot to reach the goal location for either indoor or outdoor environment, while at the same time avoiding any nearby obstacle on the path to the targeted destination. For localisation in outdoor environment, Global positioning System (GPS) has been widely used in tracking people and asset as well as a navigation system for transportation since it provides accurate coordinates and information about a certain place (ref). However, GPS does not perform well in indoor localization because the satellite cannot penetrate through the building. Thus, this makes GPS useless in indoor localization [1]. There are a lot of indoor localization and navigation systems such as Infrared Radiation (IR), Radio Frequency Identification (RFID), Bluetooth, Ultra-wideband (UWB) and Wi-Fi to address the inadequacy of GPS inside a closed environment [2], [3], [4], [5], [6]. Besides that, obstacle avoidance is a one of the crucial factors in designing the mobile robot as it makes the mobile robot reach the targeted destination without any collision with obstacle. For instance, solutions include using different types of sensors such as infrared sensor, ultrasonic sensor and laser range finder as these can be used to detect and avoid the nearby obstacle [7].

Other than that, mobile robot needs to navigate from one place to another to perform tasks within an indoor environment. Thus, well designed mobile robot locomotion is able to help maintain the stability of the structure and smoothen the motion and thus increase the performances 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 [8]. This paper will further discuss the important elements of mobile robot in terms of navigation system, obstacle avoidance sensor, and wheel robot chassis.

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 the Global Positioning System (GPS) is a good positioning system for outdoor environment, poor coverage of satellite signal in indoor environment makes it useless for indoor positioning [9]. Since the network infrastructure is available in every building, Wi-Fi positioning system has more advantages as compared with UWB and RFID [10]. However, the interference with electronic devices operating in 2.4GHz band affects the strength of signal, hence makes the signal unstable thus reduces 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 [11]. However, the cost of UWB infrastructure and hardware is relatively expensive, making it difficult to be used for in a wider scale. As a conclusion, RFID is the best system used for localization and navigation of mobile robot in terms of cost, power consumption and performance [12].

In the field of robotics, obstacle avoidance is the concern for mobile robot to act in an unknown or a dynamic environment as it is the most crucial criteria to accomplish the objective without collision to the subject. Besides that, the price of sensors can be from low to high depending on the performances of sensors for different applications. 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 the 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 angle of ultrasonic sensor is approximately 30 degrees, which is large as compared to infrared sensor and laser rangefinder [13]. 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. Besides that, although laser rangefinder has better performance in terms of accuracy and maximum range, the cost of laser rangefinder is relatively expensive as compared to ultrasonic sensor and infrared sensor [14]. Furthermore, the measurement of ultrasonic sensor is very reliable in any lighting condition whereas infrared sensor is very vulnerable to changes in ambient light. In addition, ultrasonic sensor uses sound instead of light to detect the nearby obstacles, making this a good choice as compared to infrared sensor [15]. As a conclusion, ultrasonic sensor is the best method used for obstacle detection and avoidance in terms of cost, performance and wide angle.

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. In addition, this type of mobile robot can work with human being and sharing the workspace together. Furthermore, there are three classes of wheel which are different in their kinematics, mechanics and dynamics. Therefore, the selection of wheel will influence the overall performances of mobile robot in terms of stability and flexibility. Thus, 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 implement as well as having high durability and high load capacity [16]. 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 to left and right directions more easily in order to avoid obstacles. Although the Mecanum four-wheeled chassis can provides a multi-directional movement as well as low resistance when the mobile robot moves in any direction, the mecanum wheels are relatively expensive and have poor efficiency since not all wheels are used to control and drive the robot [17]. Compared with the two-wheeled design, the ball wheel has a free rotation of 360 degrees and is able to rotate freely with less friction according to the motion of the mobile robot [18]. However, this type of design usually has high traction and more power required to drive the wheels. As a conclusion, two-wheeled chassis with pivoting caster is used for the mobile robot in terms of cost, simplicity and stability

System Overview

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. Furthermore, the platform of the mobile robot is designed with two DC motor installed at the front of the platform and a castor installed at the back of the mobile robot to balance the robot structure. Apart from that, the castor is not driven but move with the two DC motor. The mobile robot is equipped with RFID reader, ultrasonic sensor and line following sensor on the forepart of the robot. The overview of mobile robot is shown in Figure 1.

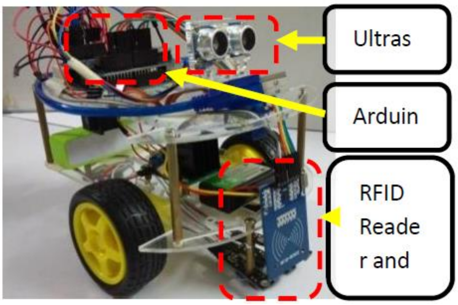


Figure 1: Overview of mobile robot prototype.

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 sends energy to tags for power and thereby the tag sends the data or information back to the reader. After that, the host computer maintains the communication between the Arduino UNO board and reader so that the mobile robot can perform tasks based on the given tag information. The process flow of RFID system is shown in Figure 2.

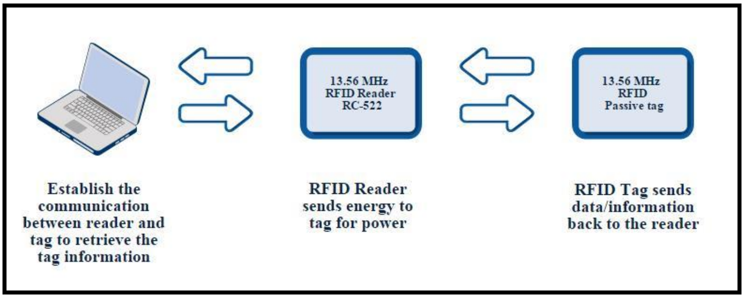


Figure 2: RFID System.

Navigation Process

The first step begins with obtaining the initial and final locations before programing the route for the mobile robot. Then, the mobile robot will move along in the programmed route based on the tag information. Next, the RFID reader will receive the command from the tag and navigate the mobile robot to move towards to the destination. When the mobile robot reaches the targeted destination, it will stop at the particular tag. Otherwise, it will continue to move along the route until it reaches the targeted 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.

Line Following Sensor Method

In order to navigate a mobile robot successfully and accurately from one location to another, a line following method has been implemented in this project to make sure that the mobile robot reaches 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 is able to verify the results that were obtained from the sensors and are far more consistent than if the mobile robot was commanded to go to an unknown location without any reference. Thus, the mobile robot has 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 Figure 4.

Experimental Setup

The 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 test the performance of mobile robot to move along the black line path based on the masking tape width, which are straight line and curve line patterns. 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 widths of masking tape from 14mm to 21mm with increments of 1mm. Besides that, the readings that were obtained from the three line following sensors were recorded for each of the masking tape width through the Arduino serial monitor. The experimental setup for both type of configuration is shown in Figures 5 and 6.

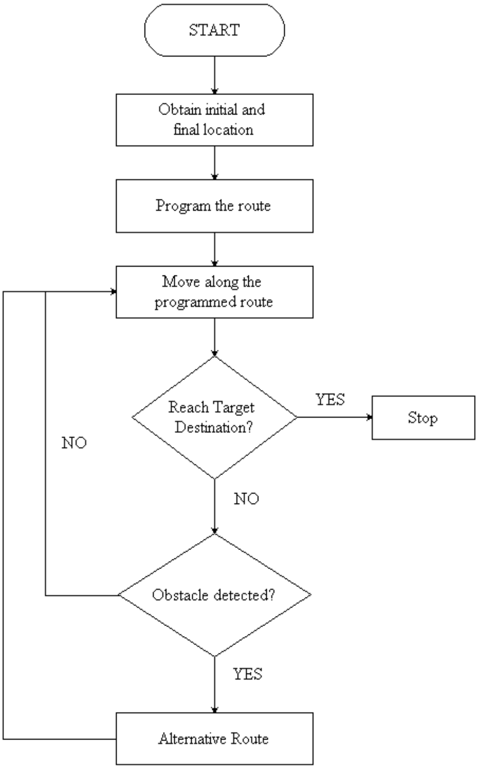


Figure 3: Flowchart of the navigation of mobile robot

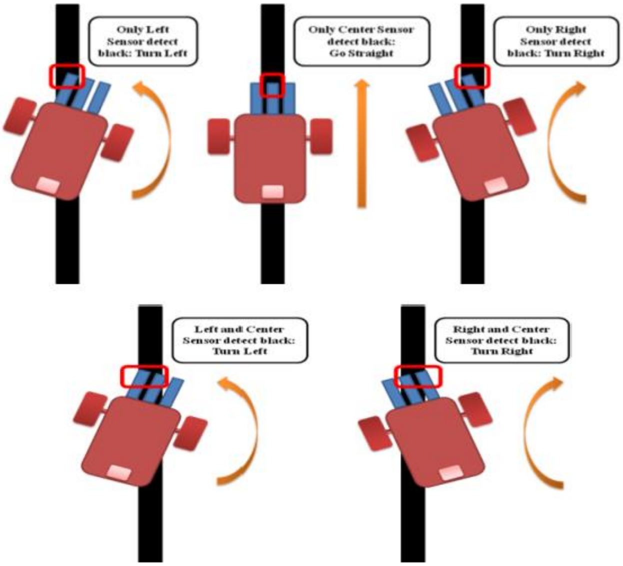
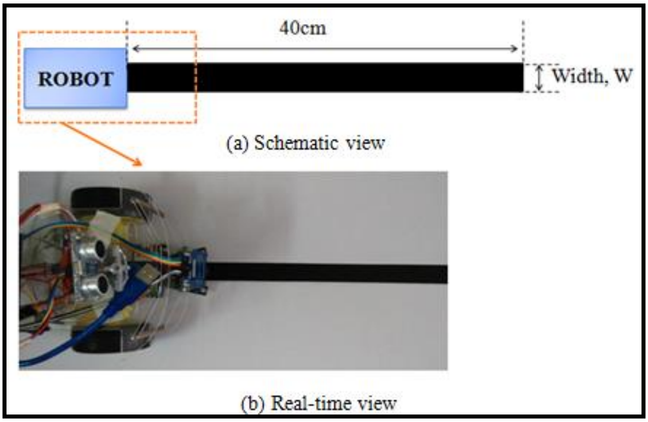


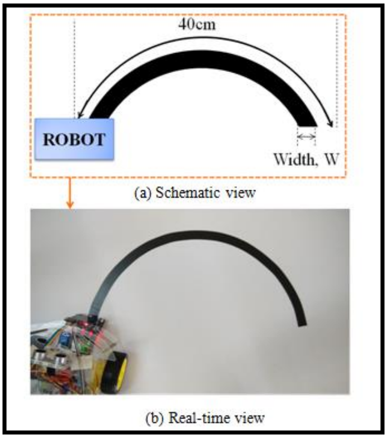
Figure 4: The five possible outcome of mobile robot when it follows the black line path.



(a) Schematic view

(b) Real-time view

Figure 5: Straight line pattern



(a) Schematic view

(b) Real-time view

Figure 6: Curve line pattern

Navigation of Mobile Robot based on Trajectories

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 receiving commands from the passive tag to navigate the mobile robot to reach the destination. The RFID reader is used to receive commands and navigate the mobile robot from one tag location to another based on the information of the RFID passive tag. There are four types of trajectory patterns used for testing the performance of mobile robot, which are square-shaped, s-shaped and triangle-shaped and zigzag-shaped. 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 Figures 7 and 8, using the masking tape width of 18mm.

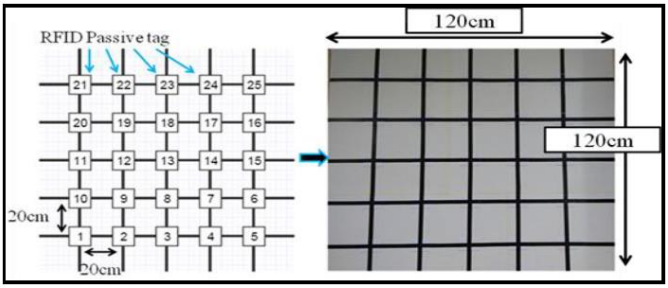
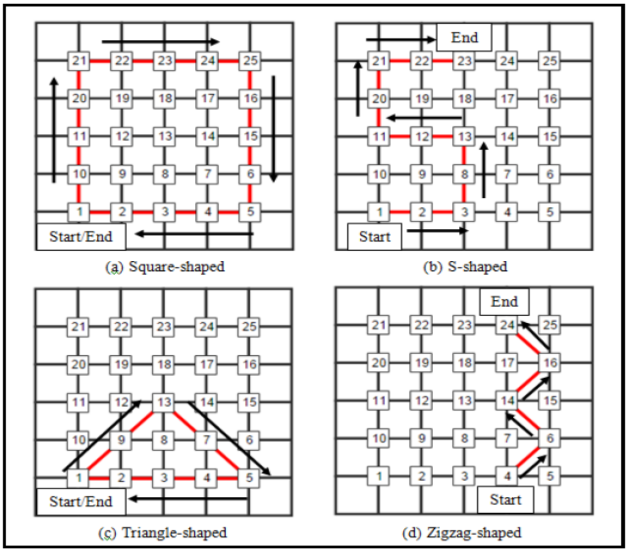


Figure 7: the workspace of mobile robot



(a) Square-shaped (b) S-shaped

(c) Triangle-shaped (d) Zigzag-shaped

Figure 8: Trajectory pattern for mobile robot navigation

Obstacle Avoidance of Mobile Robot

In this setup, there are two sections where the first part focuses on the testing of effective angle of ultrasonic sensor for different range of distance, which are 10cm, 20cm, and 30cm. First of all, the ultrasonic sensor was placed on the breadboard, pointing towards 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 labelled and marked for reference purpose. The experiment was setup as shown in Figure 9.

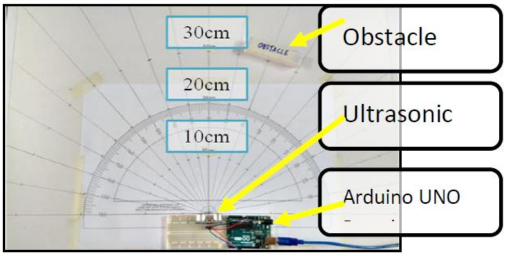


Figure 9: The experimental setup of ultrasonic sensor

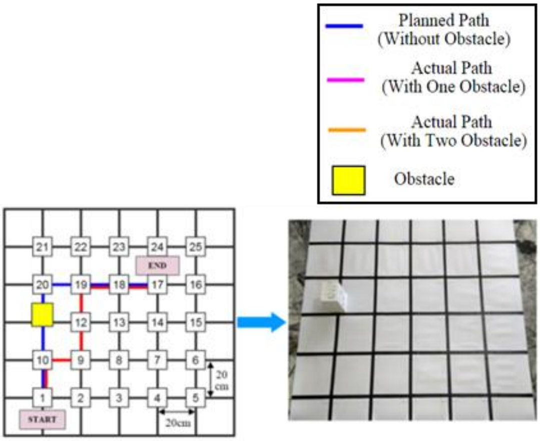
On the other hand, the second part focuses on the obstacle avoidance of mobile robot in a workspace, where stationary obstacles will be placed in a particular location for the mobile robot to detect and avoid obstacle in order to reach the destination without collision. First of all, the mobile robot 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) were placed in the particular location for the mobile robot to detect and avoid obstacle. The experiment was setup as shown in Figure 10 and 11.

Results and Discussions

Effect of Masking Tape Width on the Motion

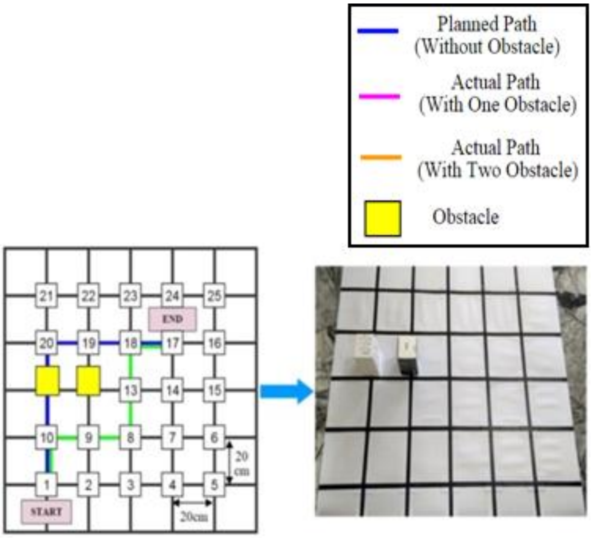
Straight Line Pattern

From Figures 12 and 13, the graph shows the results of straight line pattern for the width of 18mm and 20mm. From Figure 12, the mobile robot was 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 the black line path with the width of 18mm. From Figure 13, although the mobile robot managed to complete the black line path, the oscillation was significantly higher as compared to others as the graph shows fluctuations in between 0.4 seconds and 1.8 seconds. As the width increased, it caused more oscillation to the movement of mobile robot when travelling along the black line path. In conclusion, the width of 18mm yields the best result as the mobile robot is able to complete the straight line pattern path successfully in the shortest time.



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

Figure 10: The workspace of mobile robot for one obstacle avoidance



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

Figure 11: The workspace of mobile robot for two obstacle avoidances

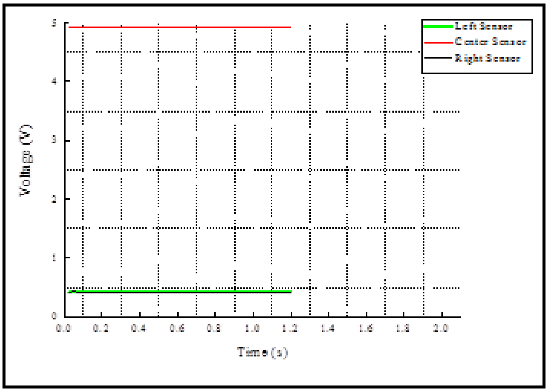


Figure 12: The width of 18mm

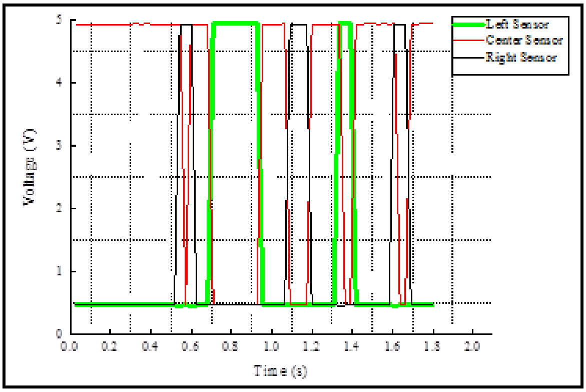


Figure 13: The width of 20mm

Curve Line Pattern

From Figures 14 and 15, the graph shows the results of curve line pattern for the width of 18mm and 20mm. From Figure 14, the width of 18mm produced the best outcome as the graph shows less fluctuations and the center sensor detects the black line all the time. The mobile robot was able to complete the black line path in the shortest time, which is 2.7 seconds. This means that the mobile robot can move stably on the black line path with the width of 18mm. From the Figure 15, although the mobile robot managed to complete the black line path, the oscillation was significantly higher as compared to others as the graph shows fluctuations from the beginning until the end of the path, leading to the longest time taken to complete the path. As the width increased, it caused more oscillation to the movement of mobile robot when travelling along the black line path. In conclusion, the width of 18mm yields the best outcome as the graph shows less fluctuation while the oscillation of mobile robot is smaller and the mobile robot is able to complete the curve like a pattern path in the shortest time.

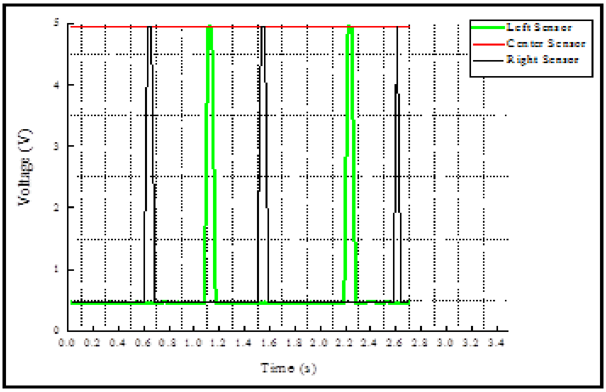


Figure 14: The width of 18mm

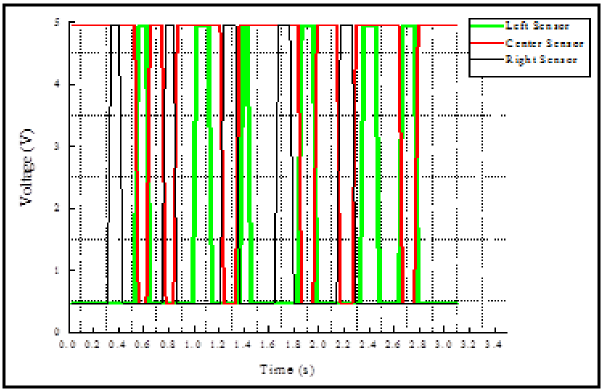


Figure 15: The width of 20mm

Navigation of Mobile Robot based on Trajectory

Square-shaped

From Figure 16, it can be seen that the time taken for the robot to complete the square-shaped falls within the range of time from 11.3 seconds to 11.5 seconds, using the masking tape width of 18mm. This means that the mobile robot performed stably and consistently in completing the path.

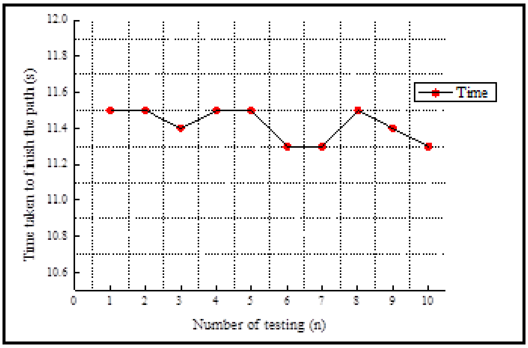


Figure 16: Square-shaped

S-shaped

From Figure 17, the time taken for the robot to complete the s-shaped falls within the range of time from 9.6 seconds to 10.0 seconds, using the masking tape width of 18mm. This means that the mobile robot performed stably and consistently in completing the path.

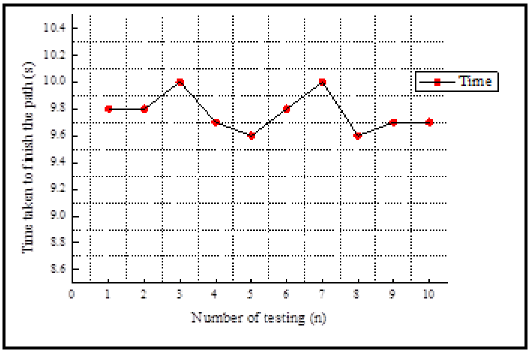


Figure 17: S-shaped

Triangle-shaped

From Figure 18, the time taken for the robot to complete the triangle-shaped falls within the range of time from 8.3 seconds to 8.6 seconds, using the masking tape width of 18mm. This indicates that the mobile robot performed stably and consistently in completing the path.

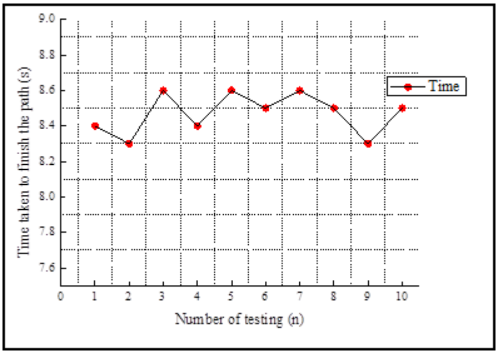


Figure 18: Triangle-shaped

Z-shaped

From Figure 19, it can be seen that the time taken for the robot to complete the zigzag-shaped falls within the range of time from 6.0 seconds to 6.3 seconds, using the masking tape width of 18mm. This means that the mobile robot performed stably and consistently in completing the path.\

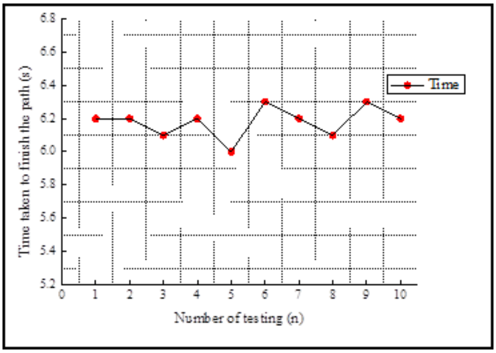


Figure 19: Zigzag-shaped

From Figure 20, the bar chart illustrates the distance and average time taken to complete the path for different types of trajectory patterns, which are square-shaped, s-shaped, triangle-shaped and zigzag-shaped. It implies that that the farther the distance, the longer the average time takes 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 types of trajectory patterns using the masking tape width of 18mm.

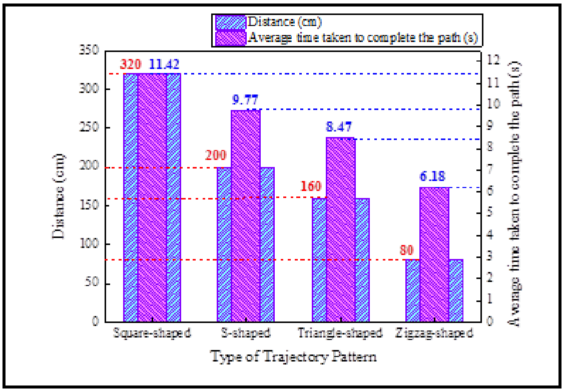


Figure 20: The distance and average time taken for different type trajectory pattern

Obstacle Avoidance of Mobile Robot

Testing the Effective Angle of Ultrasonic Sensor

From Figure 21, the graph shows the comparison for the distance of 10cm, 20cm and 30cm. According to the graph, the effective angle for all the distance range is from 70° to 110° with the value of standard deviation near to zero. This indicates that mobile robot equipped with ultrasonic sensor has an effective angle ranging from 70 degrees up to 110 degrees. This helps the mobile robot to detect and avoid nearby obstacle and move towards to the target destination without collision with the obstacles.

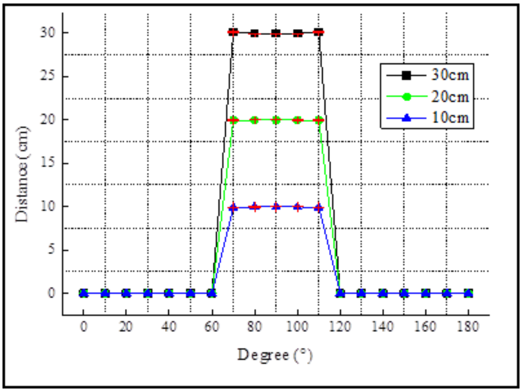


Figure 21: Comparison between the distances of 10cm, 20cm and 30cm

Obstacle Avoidance

The results of actual path tests are shown in Figure 22. First of all, the mobile robot is 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 avoids obstacle that is located 20cm away from the mobile robot, making a right turn to the passive tag number 9 at around 2.4 seconds. After that, the mobile robot makes a 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 make it oscillate more. This means that the oscillation of mobile robot becomes larger in the period of time because of the quick turning direction of the robot itself. Next, the mobile robot continues moving straight to the passive tag number 19 at around 4.8 seconds, in which the mobile robot will make a right turn before it reaches the next passive tag. Moreover, the mobile robot continues the route to the destination and stops at around 6.6 seconds. In conclusion, the mobile robot is able to navigate itself from the start to reach the target destination without collision with the obstacle.

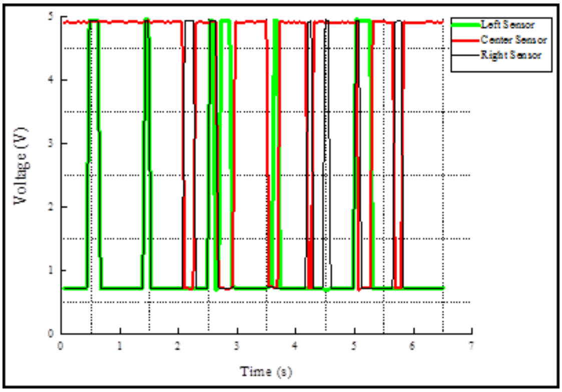


Figure 22: Test for one obstacle avoidance

The results of actual path tests are shown in Figure 23. First of all, the mobile robot is 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 avoids obstacle that is located 20cm away from the mobile robot and thus making a right turn to the passive tag number 9 at around 2.5 seconds.

After that, the mobile robot makes a left turn to the passive tag number 12, however the ultrasonic detects the second obstacle that is located 20cm away from mobile robot and avoids it. Thus the mobile robot turns to the right direction and reaches the passive tag number 8 at around 4.0 second before it turns left 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 oscillate much. This also means that the oscillation of mobile robot becomes larger in the period of time because of the quick turning direction of the robot itself. Next, the mobile robot continues moving straight to the passive tag number 18 at around 6.4 seconds, in which the mobile robot will make a right turn before it reaches the destination and stops at around 8.0 seconds. In conclusion, the mobile robot is able to navigate itself from the start to reach the target destination without collision with the obstacle.

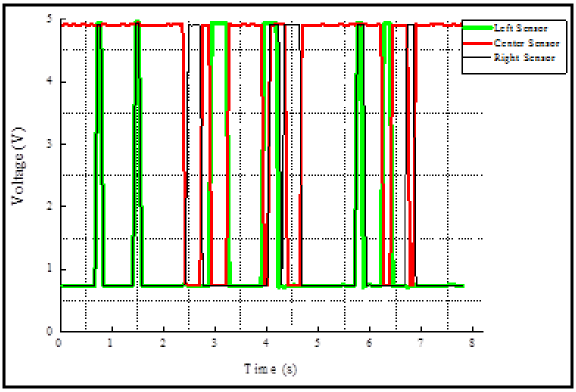


Figure 23: Test for two obstacles avoidance

Conclusion

In this paper, the navigation technique using the Radio Frequency Identification (RFID) for the mobile robot to travel in an indoor environment is discussed. The results show that the mobile robot is able to reach the target destination successfully for different types of trajectory patterns and without the collision with obstacles using the masking tape width of 18mm. For future recommendations, the oscillation of the mobile robot can be eliminated by designing a Proportional-integral-derivative (PID) controller.

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