Mobile Robot Obstacle Avoidance in Various Type of Static Environments Using Fuzzy Logic Approach

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Abstract—**Autonomous mobile robot is a mobile robot that can move without human supervision. The use of autonomous mobile robots has increased in various fields such as in the industrial, agricultural, and military sectors. This paper presents the development of a mobile robot that uses Fuzzy Logic approach to control a robot's movement in an area cluttered with static obstacles. In the experiment presented herewith, the controller was programmed with 256 Fuzzy Logic rules and the input to the system is from an E-puck robot that is equipped with infrared sensors. Webot Pro and Matlab are the software used in the development and simulation of the robot. The mobile robot was designed to move and avoid static obstacles. The performance of the mobile robot was evaluated from the way it avoids the obstacles, and the time taken when it move from a starting point to an end point. The results showed that the robot could avoid the obstacle successfully in various types of static environments. This research also indicated that WEBOT and Mathlab are suitable tools that could be use to develop and simulate mobile robot navigation system.**

Keywords- Mobile Robot; Fuzzy Logic; Obstacle avoidance; autonomous

I. INTRODUCTION

The growing interest in autonomous mobile robot lead to the development of various types of mobile robot control methods and algorithms. The ability of mobile robot to navigate autonomously has improved tremendously due to the improvement of various path planning and obstacle avoidance algorithms developed by recent researchers. In the area of artificial intelligence (AI), Fuzzy Logic is often used in autonomous mobile robot for obstacle avoidance.

Fuzzy logic control is quite suitable for low cost mobile robots that do not require very complex navigation since fuzzy logic is a combination of many forms of logic values of the inputs. The controller that uses the fuzzy logic approach will measure all inputs and analyze them before computing the output [1]. In this investigation, an E - puck robot with eight infrared sensors was used. The Fuzzy Logic controller takes the input from all infrared sensors and makes the rule for E-puck robot to move in the environment and avoid all static obstacles.

The Fuzzy Logic method itself has several types. Examples of Fuzzy Logic approach are zero order Takagi-Sugeno and Mamdani Fuzzy Logic controllers. Farooq et. al. [2] compared the performance of zero order Takagi-Sugeno and Mamdani Fuzzy Logic controllers for obstacle avoidance behavior in mobile robot navigation. Both the Fuzzy Logic controllers were designed using MATLAB Fuzzy Logic toolbox and implemented in a AT89C52 microcontroller. The performance comparison between the zero order Takagi-Sugeno and Mamdani Fuzzy Logic controllers was made based on the smoothness of robot motion generated by the controllers and the memory utilized for their implementation in real time. Examples of the use of Fuzzy Logic based Controller for Mobile Robot Navigation is by Raguraman et. al., Jeffrilet.al and El-Teleity [3,4,5]. These researches showed that Fuzzy Logic control is well suited for controlling a mobile robot, as it is capable of making inferences even under uncertainty conditions. In addition, Fuzzy Logic controller can be combined with other artificial intelligence based controllers such as like Neural Network that can producer better controllers [3, 4].

The Fuzzy Logic approach has been proven a simple and powerful technique for control problems. Fuzzy Logic control approach is able to copy human experience and provide the best method to control a system without requiring or dependent on accurate model equations. Another advantage of Fuzzy Logic is that it can handle any perturbation in the system [5]. Applying it through behavior based modular architecture comes with great simplification in design process.

In addition, Maria Javed et. al. [6] proved that using Fuzzy Logic control based approach; robots are capable of chasing a moving target successfully. The performance of the Fuzzy Logic control based robot is also better than its conventional counterpart in terms of stability and distance from the target [6]. The objective of this research was to develop a Fuzzy Logic Controller for mobile robot that can avoid obstacles in various types of static environments. The secondary objective of this research is to gauge the suitability of using Webot and Mathlab software to test and simulate the design. As the number of rules will influence the input and output of the system thus the performance of the robot while it is moving in the attempt to reach its goal while avoiding the obstacles, it is hope that the software will enable easy and fast simulation and modelling of various static environments.

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II. SCOPE OF WORK

Webot Pro and Matlab were the main software used for this project. Webot Pro was suitable as it has a Graphical User Interface (GUI) that allows users to easily create the environment, robot and solid obstacles, For this research, Webot Pro was used to create the various types of environment that consist of static obstacles in various configuration and an E-puck robot. Matlab was used for creating rules for the E-puck robot motion control based on Fuzzy Logic approach. The world/environment in Webot Pro world was developed based on E-puck path. The obstacles are located on world floor and E-puck robot can move freely on the floor and at the same time avoid obstacles based on Fuzzy Logic rules. All of the obstacles are set as solid, thus the E-puck robot is unable to go through the obstacle. It must go around/circumnavigate the obstacles based on fuzzy logic rules.

The E-puck robot was developed with eight (8) infrared (IR) sensors around it to detect obstacles in its path. Every sensor has a reading between 0 and 3200 depending on the distance between the sensor and any solid obstacle. Initial reading for each IR sensor is 0. As the robot moves closer to an obstacle, that is the sensor is closer to a solid obstacle, the output of the sensor will increase. The threshold value of each of the infrared sensor was set to 800. Thus, when the infrared sensor reading is 800 and above, the Fuzzy Logic rule will be implemented/take the action. The fuzzy rule was created using the Fuzzy Logic toolbars in Matlab.

III. METHODOLOGY

The overall simulation process was divided into several steps, which are a) environment modeling, b) robot modeling and c) Fuzzy Logic design. In environment modeling, the type of environments created are i) simple environment, ii) average environment, iii) complex environment and 3 different types of obstacles in the 3 environments. Subsequently the robot was added into the created environment/world. The robot was selected from the robot scene tree of the WEBOT software. After the robot was chosen, the controller of the robot was created. For this research, the Fuzzy Logic method was chosen to be implemented in the robot controller. Finally the following test were create out to evaluate the mobile robot performance in the created environments. The test carried out were to investigate:

1. the capability of the robot to navigate and avoid an obstacle using fuzzy logic rules.
2. the capability of the robot to navigate and avoid obstacles in 3 different environments using fuzzy logic rules.
3. the capability of the robot to navigate an environment with the same complexity but with different types of obstacles.
4. The performance of the robot when the fuzzy logic rules based on input from individual sensors versus group of sensors. That is, to compare the robot's performance when programmed with two different sets of Fuzzy Logic rules.

A. Environment Modelling

Webot Pro simulation software was used to create an environment for the robot. A new world can be created by using the new project directory. A new project directory, will enable all the data and the project to be saved in a folder.

For this research 3 environments with; 3 different types of obstacle section, different types of obstacles were created and obstacles were then added in these environments. Every environment has 11 obstacles in the path. First environment is box obstacles, second is sphere obstacles and the third is sphere obstacles.

B. Robot Modelling

The E-puck (Differential Wheels) robot was selected from the WEBOT software. It is deemed suitable for this project as it was designed as a mobile robot for learning. E-puck has a diameter of 70mm, height of 50mm and weighs 200 g. For this research , it was equipped with 8 IR sensors to detect any obstacle abound it. The range of its IR sensors is between 0 and 3200. In this project, every IR sensor is working independently and the 256 rules have been set to all IR sensors.

In the comparison section, E-puck was programmed with two sets of Fuzzy Logic rule. The first is the Fuzzy Logic rules for all the sensors. That is, all sensors have their own rules and the possibility of all rules is from 0000 0000 up to 1111 1111. The total rules in the Fuzzy Logic are 256 rules. The second set consists of rules for several sensors in the E-puck robot that was combined together and works as a group. Thus the total number of rules for the E-puck robot becomes less. Figure 1 shows the E Puck configuration of IR sensors denoted ps1 till ps2 and the multiple groups of sensors with 2 sensor per group.

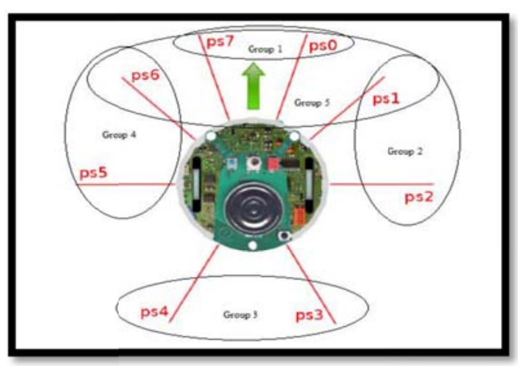

Figure 1. E-Puck Infrared Sensors and Sensor groups.

C. Fuzzy Logic Design

In this project, all the IR sensors are working independently and the possibility for all sensors is measured. Since there are 8 sensors, the possibility of states for all 8 sensors are 2^8=256. Thus the Fuzzy Logic rules for the IR sensors are 256 rules ranging from 0000 0000 to 1111 1111. The sensors in this project have inputs that ranged between 0 and 3200. The thresholds for every sensor were set to 800. Thus, when the IR sensor value is more than 800, the Fuzzy Logic rules will be activated. The action or output of the Fuzzy Logic controller is set to move the robot as below:

- Go Forward
- Turn right + 45^0
- Turn right + 90^0
- Turn left - 45^0
- Turn left – 90^0

Figure 2 shows the Mamdani Systems Using the Fuzzy Logic Toolbox. The Fuzzy Logic has 8 inputs representing the 8 IR sensors, 256 rules from 0000 0000 to 1111 1111 and 5 outputs. Figure 3, shows the input to the Fuzzy Logic. The input range is between 0 and 3500 and the threshold has been set to 800. The y-axis thresholds have been set to 0 to avoid confusion when the Fuzzy Logic makes a decision. Figure 5 shows the output of Fuzzy Logic. The areas under the graphs have the same value and all nodes for all graphs do not touch with one another. Fuzzy Logic cannot make a decision if the nodes in the graphs touched with one another.

Figure 5 shows examples of the 256 Fuzzy Logic rules. An example of a rule is, '*if (ps0 is x-detect) and (ps1 is x-detect) and (ps2 is x-detect) and (ps3 is x-detect) and (ps4 is x-detect) and (ps5 is x-detect) and (ps6 is x-detect) and (ps7 is x-detect) then (output1 is 0)* '. When output is 0, the robot will move straight with no angle and if the output is +45, the robot go right with an angle of $+45^{0.}$

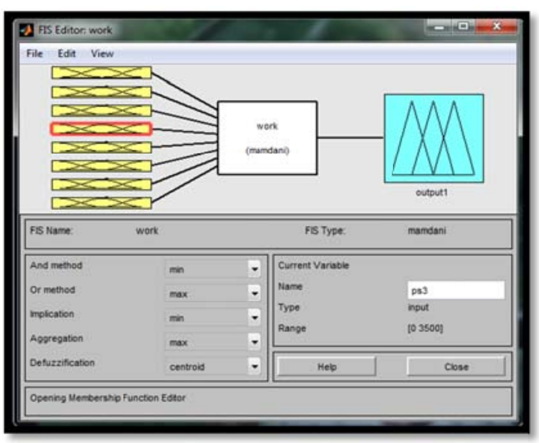

Figure 2. Fuzzy Logic Toolbox

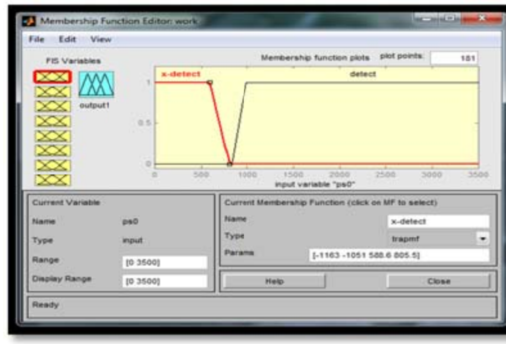

Figure 3. Input of Fuzzy Logic

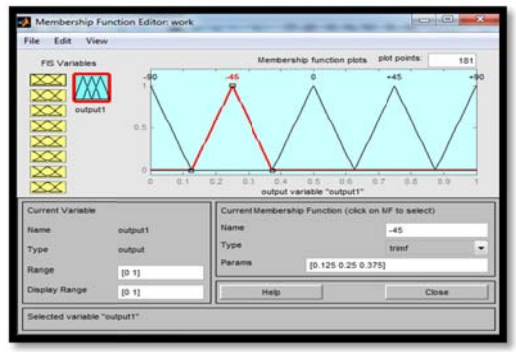

Figure 4. Output of Fuzzy Logic

Figure 5. Fuzzy Logic Rules

IV. Results And Discussion

A. E-Puck movement and sensor outcomes avoiding a cylindrical obstacle.

Figures 6, 8, and 10 shows how the E-puck robot moves to avoid cylinder obstacles and Figures 7, 9, and 11 are bar graphs that show the distance sensors reading for all 8 sensors. As depicted in Figure 6, in the first phase when the robot encounters the obstacle, sensors 6 and 8 received a signal and will activate the motor right tire to turn anti clockwise and left tire clockwise. This will make the E-puck move 45 degrees right to avoid the obstacle. Then after E-puck robot move 45 degrees to the right as shown in figure 8, only sensor 6 detects the obstacle and move it straight. This is because for this Fuzzy Logic rules, E-puck will go straight if only sensor 6 detects the obstacle. The E-puck will go straight to the wall until sensor 2 and 3 detect the wall as shown in Figure 11. Then the E-puck robot moves 45 degrees left.

From the figures, it shows that the E-puck can avoid cylinder obstacles. The degree of E-puck movement depends on which sensor senses the obstacles. In addition, the shape of obstacles will also influence the E-puck movement.

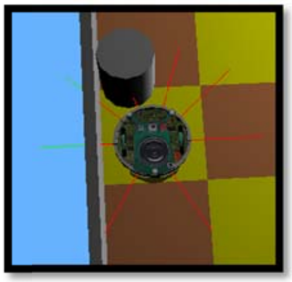

Figure 6.

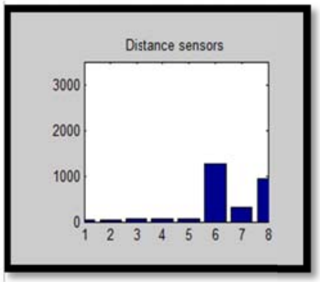

Figure 7

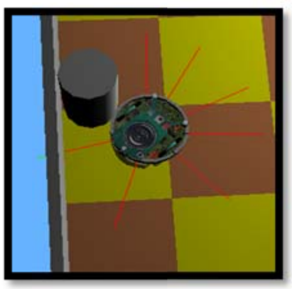

Figure 8

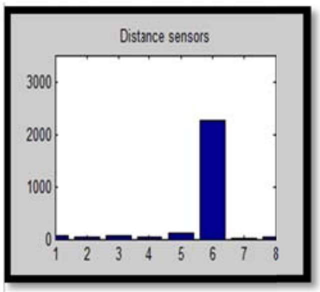

Figure 9

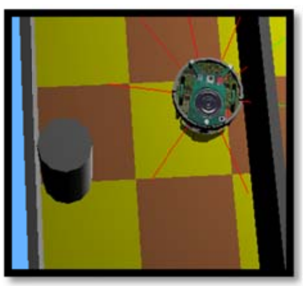

Figure 10

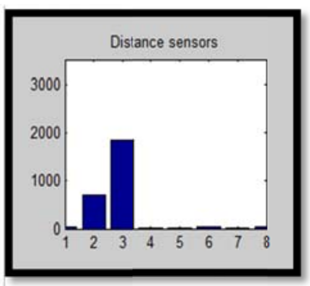

Figure 11

B. E-puck performance in an environment with different complexities of obstacles.

To further test the system, environments with different complexities of obstacles were created. The simulation involves the robot navigating in the same environment but each of the three created environment has a different number of obstacles. Figures 13, 14 and15 shows the 3 environments termed simple environment, average environment and complex environment. These environments have different numbers of obstacles in the same environment field.

Table 1 tabulates the time that the E-Puck robot takes to reach the end point from the start point as it navigates through each environment while avoiding the obstacles. As shown, the Fuzzy Logic controller based E-puck robot could avoid all obstacles in the different environments. However, as the number of obstacles increase, that is the environment is more complex, the time to reach target/destination also increased.

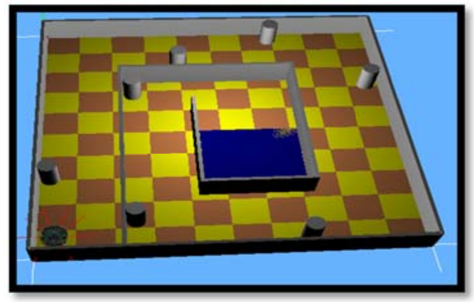

Figure 12: Simple environment

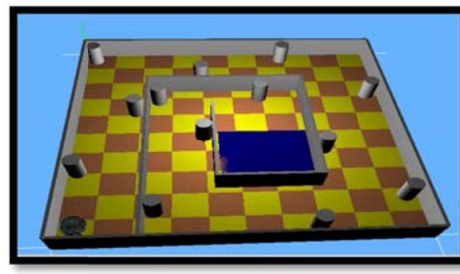

Figure 13: Average environment

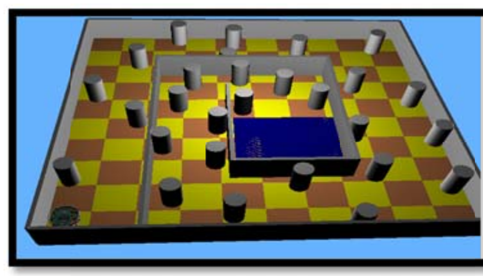

Figure 14: Complex environment

TABLE I. RESULT E-PUCK ROBOT TROUGH ALL ENVIRONMENTS

	Number of trials	Time	Behavior
Simple Environment	10	1m, 22.6s	Successfully avoided all solid objects
Average Environment	10	1m, 23.3s	Successfully avoided all solid objects
Complex Environment	10	2m, 16.7s	Successfully avoided all solid objects

Where: m = minute , s = second

In the simple and average environments, the E-puck robot can easily reach the target. The robot had some difficulty in the complex environment as shown in Figure 14. In this environment, although it successfully reached the target point, in certain parts within the environment, such as the corner side and the area between the wall and the cylinder, the robot had some difficulty. Figure 15 below show the example of E-puck robot reaches the final point in a complex environment that is the blue surface.

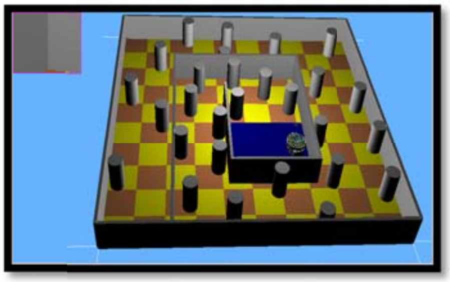

Figure 15: Complex environment (final point)

C. E-puck performance in 3 environments with different types of obstacles.

Figures 16, 17 and 18 shows 3 different environments that are populated with the same number of obstacles of different shapes. The obstacles are Box, Sphere and cylindrical shaped. Within each environment, the obstacles were placed at the same position. The results of E-puck robot performance in navigating from start to end is tabulated in Table II.

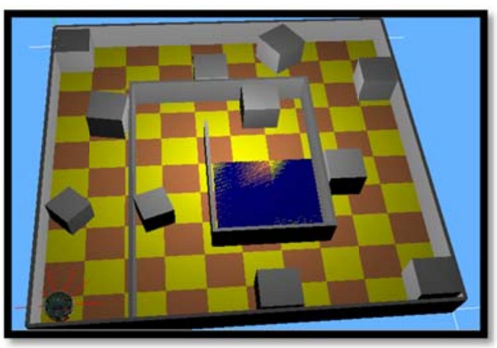

Figure 16: Box obstacles

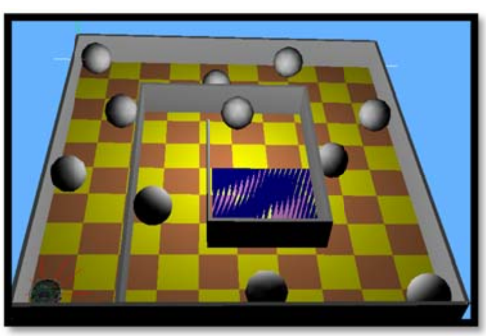

Figure 17: Sphere obstacles

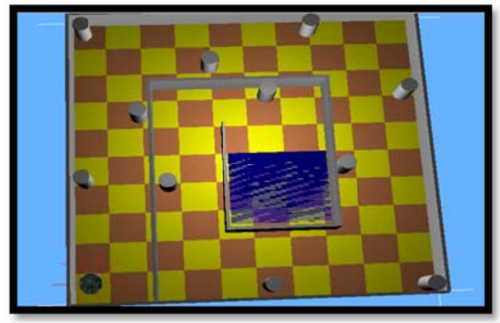

Figure 18: Cylinder obstacles

TABLE II. RESULT E-PUCK ROBOT TROUGH ALL VARIOUS TYPES OBSTACLE

	Number of trials	Time	Behavior
Box obstacles	10	1m, 26.7s	Successfully avoided all solid objects
Sphere obstacles	10	3m, 0.6s	Successfully avoided all solid objects
Cylinder Obstacles	10	1m, 25.7s	Successfully avoided all solid objects

Where: m = minute, s = second

As depicted in Table II, the result shows that the E-Puck robot requires different time to avoid different type of obstacles. The E-puck robot was fastest in the environment with cylinder shape, followed by the box shape and slowest in the sphere obstacle environment.

It is because the shape of cylinder that make E-puck robot move only 45 degrees to avoid the obstacle compare to box, E-puck must move 90 degrees to avoid the obstacle. For a sphere, since a sphere has curves, the IR sensor had some difficulty to detect the spherical obstacle. The E-puck robot move around the sphere obstacle first before avoids it. Thus it can be concluded that that the shape of the obstacles will influence the E-puck navigation speed.

D. E-puck performance. Camparision of different set of Fuzzy logic rules.

The movement of the the E-puck robots differ significantly when the first set of the Fuzzy Logic rules was used. In this case, the sensors were analysed individually and the total number of rules were 256 . The second set consists of rules for several sensors in the E-puck robot that was combined together and works as a group. Thus the total number of rules for the E-puck robot becomes less but more complex. The E-pucks robots were tested in the same environments, and with and without obstacles. Figure 19 shows the environment with the obstacles. Table III tabulates the results of the test.

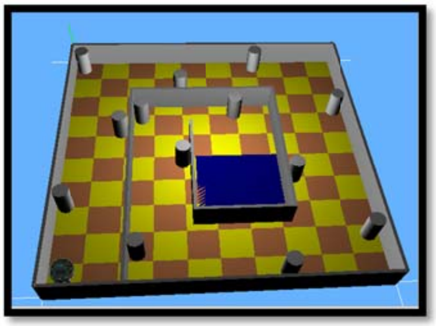

Figure 19: Path circuit for E-puck with obstacle

TABLE III. E-PUCK PERFORMANCE

Types of Fuzzy Logic / Path Circuit	Sensors grouped into pairs (4 Pairs)		Individual sensors	
	T	B	T	B
Without Obstacles	1m, 25 s	Successfully avoided all solid objects	1m, 19s	Successfully avoided all solid objects
With Obstacles	X	Could not reach target.	1m, 24s	Successfully avoided all solid objects

Where: T = Time, m = minute , s = second , B = Behaviors

X = Could not reach the destination

As depicted in Table III, when the fuzzy logic controller was programmed using rules that assumed sensors grouped in pairs, the results was not as good (E-puck could not reach target in an environment with obstacles) as when the set of rules that considers the sensors as individual sensors. The reason is due to the less number of Fuzzy logic rules but more complex rules when the sensors are grouped in 4 pairs of 2 sensors each.

V. CONCLUSION AND RECOMMENDATION

This paper presents the development of a Fuzzy Logic Controller for E-puck robots using Webot and Mathlab Software for the development and simulation of the design. The investigation indicates that both software are suitable and can be used for robot navigation simulation purposes. In addition the results showed that a Fuzzy Logic controller could be used to enable a robot with minimal sensor to navigate in the created environment. By applying the concept of Fuzzy Logic rules and use it for E-puck robot, the robot was able to move and avoid obstacles in its path.

ACKNOWLEDGMENT

The authors would like to acknowledge and express much appreciation to Universiti Teknologi Mara (UiTM) for the Research Intensive Faculty (RIF) Grant (600-RMI/DANA5/3/RIF (303/2012).

REFERENCES

[1] A. L. Howell, R. T. R. McGrann, and R. R. Eckert, "Teaching concepts in Fuzzy Logic using low cost robots, PDAs, and custom software," in Frontiers in Education Conference, 2008. FIE 2008. 38th Annual, 2008, pp. T3H-7-T3H-11.

[2] U. Farooq, K. M. Hasan, G. Abbas, and M. U. Asad, "Comparative analysis of zero order Sugeno and Mamdani Fuzzy Logic controllers for obstacle avoidance behavior in mobile robot navigation," in Current Trends in Information Technology (CTIT), 2011 International Conference and Workshop on, 2011, pp. 113-119.

[3] S. M. Raguraman, D. Tamilselvi, and N. Shivakumar, "Mobile robot navigation using Fuzzy Logic controller," in Control, Automation, Communication and Energy Conservation, 2009. INCACEC 2009. 2009 International Conference on, 2009, pp. 1-5.

[4] M. A. Jeffril and N. Sariff, "The integration of Fuzzy Logic and artificial neural network methods for mobile robot obstacle avoidance in a static environment," in System Engineering and Technology (ICSET), 2013 IEEE 3rd International Conference on, 2013, pp. 325-330.

[5] S. A. L. El-Teleity, Z. B. Nossair, H. M. A. K. Mansour, and A. TagElDein, "Fuzzy Logic control of an autonomous mobile robot," in Methods and Models in Automation and Robotics (MMAR), 2011 16th International Conference on, 2011, pp. 188-193.

[6] M. Javed, K. M. Hasan, and T. Izhar, "Simulation of a Fuzzy Logic controller based chasing robot," in Electrical Engineering, 2009. ICEE '09. Third International Conference on, 2009, pp. 1-4.