Mobile Robot Navigation with Obstacle Avoidance in Unknown Indoor Environment using MATLAB

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Abstract - One of the most recent research areas over the last two decades is the navigation of mobile robots in unknown environments. In this paper, real time navigation for Wheeled Mobile Robot (WMR) using fuzzy logic technique, wireless communication and MATLAB is investigated. Two fuzzy logic controllers (FLCs) with two inputs and two outputs are used to navigate WMR in obstacle ridden environment. Our work combines the behaviors of reaching the target and obstacle avoidance. Goal Seeking Fuzzy Logic Controller (GSFLC) and Fuzzy Logic for Obstacles Avoiding (FLOA) work simultaneously to navigate the robot to its target. The target of this work is to use the WMR in many applications, such as a construction sites or warehouse with dynamic environment. The proposed methods are applied using simulation and experimentation to show the success of the suggested methods.

***Keywords* -** *Robotics, Navigation, Wheeled Mobile Robot, Wireless Communication, Matlab, Fuzzy Logic*

1. Introduction

Unknown indoor environment is one of the main challenges in the navigation operation of the WMR. In order to overcome this challenge, Fuzzy logic [2, 3, 4], neural network [5, 6, 7] and other soft computing techniques, became a ground of the navigation in WMR.
In the last decade, many methods have been proposed for motion of WMR. Despite the progress in autonomous mobile robotics, many problems still happen. Most of the problems are the result of an unknown environment, and uncertainties in the next movement. Many techniques, such as genetic algorithm, fuzzy logic, and neural network are used to deal with these difficulties. In this paper, we faced the above difficulties using the fuzzy logic control for the motion of WMR, wireless for communication, and MATLAB as a development environment. Wireless communication is used to connect the robot and the server during the motion of WMR. Fuzzy logic control has been used in many researchers for motion of WMR.

In [8], fuzzy logic control using different number of membership functions is used to navigate several mobile robots using fuzzy logic in an unknown environment. In [8], authors used and compared FLC with three-membership functions, five-membership functions, and Gaussian membership functions. Tracking control with reactive obstacle avoidance in an unstructured environment controller based on fuzzy logic for differential drive WMR is proposed in [9]. This paper used and compared FLC with five-membership functions, and seven-membership functions. This paper designed navigation method for WMR which involves the kinematics model and fuzzy controller. Then, simulate the proposed solution. Some methods concentrated on reducing the heading angle between the robot and goal. A fuzzy control scheme in [10] is proposed to do that in known and unknown environments. The inputs of FLC in [10] are the heading angle between the target and the robot, and the distances between the robot and the left, front, and right obstacles. Indoor navigation using fuzzy logic and visual sensors with real-life noisy is proposed in [13]. An on-line navigation for WMR is presented in [17, 18]. This paper used two the fuzzy logic controls to navigate the scout2 robot in an unknown dynamic environment. Tracking Fuzzy Logic Controller (TFLC) is used to navigate the WMR to its target and Obstacles Avoiding Fuzzy Logic Controller (OAFLC) is used to avoid the obstacles. The structure of this paper is as follows. Section 2 presents Kinematics Model of WMR. In section 3, we explain the proposed fuzzy logic. The simulation results presented in Section 4. The experimental results presented in Section 5. Section 6 explains conclusion.

2. WMR Kinematics Model

Figure 1 shows the WMR with differential wheels. WMR contains of three wheels, two are driving wheels on forward and the third is castor wheel on backward of the chassis to balance the robot. These two driving wheels are individually driven using actuators to achieve the orientation and motion of the WMR. The kinematic model of WMR described by the following equation [1]:

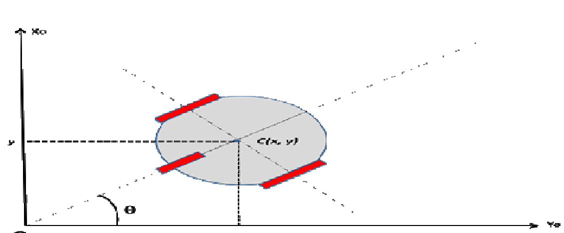

Figure1. Geometric of Wheeled Mobile Robot

$$\begin{cases} \dot{x} = v\cos(\theta) \\ \dot{y} = v\sin(\theta) \\ \dot{\theta} = \omega \end{cases} \quad (1)$$

Where x and y are the position of the WMR, θ is the angle between the positive direction X-axis, i.e. the orientation of the WMR. ω is the angular velocity and v is the linear velocity.

2.1. Dead-Reckoning

In navigation operation, Dead-reckoning uses to calculate the next orientation and position of a wheeled robot. It bases on the orientation and previous position at time k to compute the next orientation and position at time k+1. Using Euler approximation, the equation (1) will be:

$$\begin{cases} x(k+1) = x(k) + v(k)T_s\cos(\theta(k)) \\ y(k+1) = y(k) + v(k)T_s\sin(\theta(k)) \\ \theta(k+1) = \theta(k) + \omega(k)T_s \end{cases} \quad (2)$$

where T_s is the sampling time ($T_s = T_{k+1} - T_k$). We could use the distance traveled by the WMR during T_s and calculate this using encoders' pulses of each DC wheel's motor of WMR. The following equation describes this mathematical equation:

$$\begin{cases} x(k+1) = x(k) + \frac{\pi D}{2}\frac{(\Delta T_L + \Delta T_R)}{T_w}\cos(\theta(k)) \\ y(k+1) = y(k) + \frac{\pi D}{2}\frac{(\Delta T_L + \Delta T_R)}{T_w}\sin(\theta(k)) \\ \theta(k+1) = \theta(k) + \frac{\pi D}{dst}\frac{(\Delta T_R - \Delta T_L)}{T_w} \end{cases} \quad (3)$$

where $\Delta T_L = T_{k+1} - T_k$ is the impulses increment of the encoders during the sampling rate T_s, dst is the distance between two-contact points of the two wheel, D is the diameter of wheels, and T_w is the number of encoder pulses of one rotation.

3. Fuzzy Logic

In this work, on-line navigation method in an unknown indoor environment for WMR using fuzzy logic control, wireless communication and MATLAB is investigated. These techniques used in order to allow smooth motion of WMR in dynamic and unknown environment, which cluttered with obstacles. Goal Seeking Fuzzy Logic Controller (GSFLC) and Fuzzy Logic for Obstacles Avoiding (FLOA) are developed to navigate WMR. GSFLC and FLOA combine the behavior of reaching the target with obstacle avoidance behavior. The process of the fuzzy logic illustrates in figure 2.

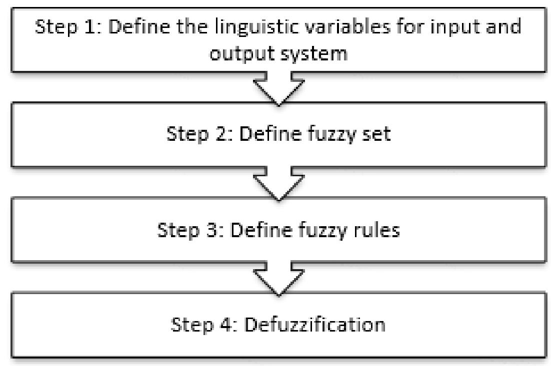

Figure2. Fuzzy Logic Process

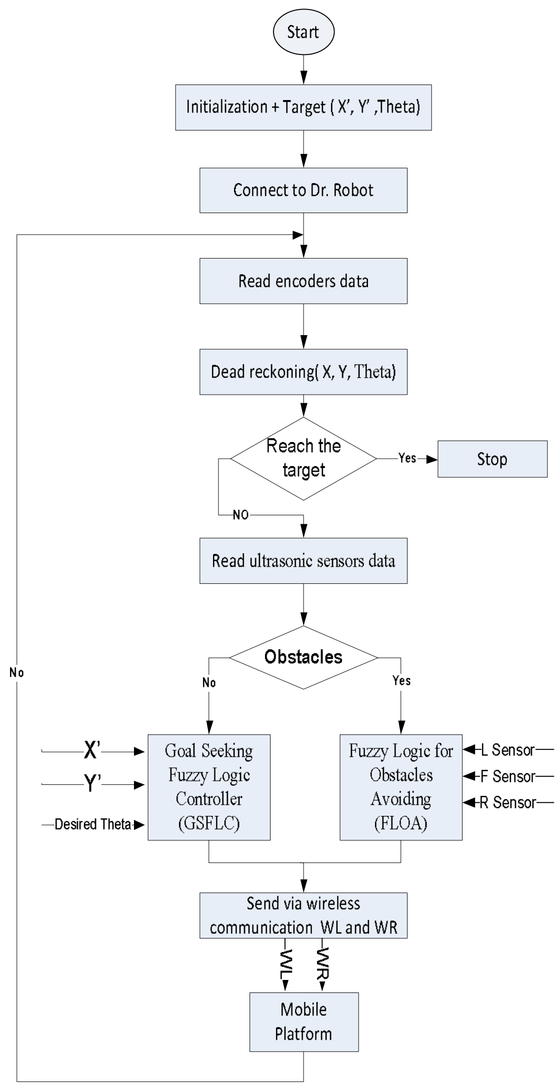

Figure 3. Flowchart of Fuzzy logic algorithm.

According to our work, GSFLC used to move the mobile robot to its goal. In order to pass through the obstacles, the control switches to FLOA if there is any obstacle ahead of the robot. Also the challenge of dynamic and unknown environment is solved by using the FLOA. GSFLC and FLOA work together to control the velocities of for WMR's wheels. Fuzzy controller of GSFLC and FLOA illustrates in figure 3.

3.1. GSFLC

In this work, GSFLC uses to navigate smoothly the mobile robot to its goal. According to figure 2:

- Step 1 uses to define the linguistic variables for input and output. The distance between the target and the robot (Distance), and the error in angle between the target and robot (Er. angle) are the inputs of GSFLC. The outputs of GSFLC are the Right Velocity R_V, and Left Velocity L_V.

- Step 2 uses to define the fuzzy set. GSFLC uses seven membership functions for inputs (Err. Angle and Distance). The notations for fuzzy angle between the target and the robot (Er. angle) are: P: Positive, SP: Small Positive, NPZ: Near Positive Zero, Z: Zero, NNZ: Near Negative Zero, SN: Small Negative and N: Negative. The notations for fuzzy input distance are: VF: Very Far, F: Far, NF: Near Far, M: Medium, N: Near ,NZ: Near Zero, and Z: Zero,. Figure 4 and 5 illustrate the membership functions of the inputs.
  L $_{\textbf{Err. Angle}}$ = {P, SP, NPZ, Z, NNZ, SN, N}
  L $_{\textbf{Distance}}$ = {ZF, F, NF, M, N, NZ, Z}

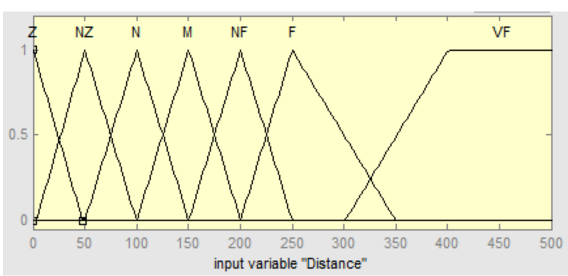

Figure 4. Membership functions for the

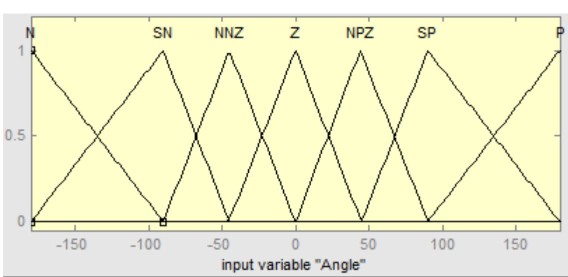

Figure 5. Membership functions for the error in angle.

- Step 3 uses to define the fuzzy rules of the GSFLC. GSFLC uses seven membership functions outputs (velocity of the left LV, and the velocity of the right RV). The notations for the fuzzy rules of GSFLC are: VH: Very High, H: High, NH: Near High, M: Medium, NM: Near Medium, S: Slow, and Z: Zero, and. Figure 6 and 7 illustrate the membership functions of the outputs.
  L $_{\textbf{LV}}$ = {VH, H, NH, M, NM, S, Z}
  L $_{\textbf{RV}}$ = {VH, H, NH, M, NM, S, Z}

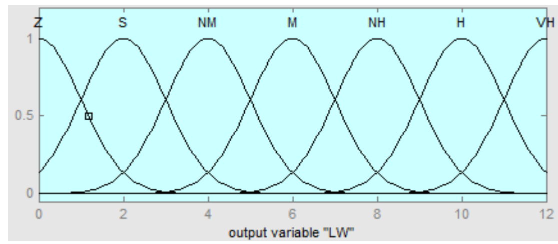

Figure 6. Membership functions of LV

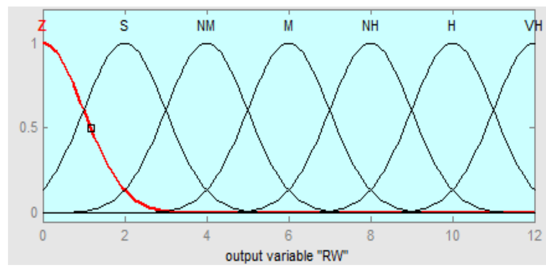

Figure 7. Membership functions of RV

LV and RV of the driving wheels of the WMR are calculated in the defuzzification step. As we mention before, GSFLC uses to navigate WMR to its target, and if there is any obstacle in front of the robot, the control switches to FLOA in order to pass through the obstacles. As we have seen, GSFLC system has two inputs, two outputs and 49 inference rules. Figure 8 illustrate the component of GSFLC. Figure 9 illustrates the inference rules of GSFLC.

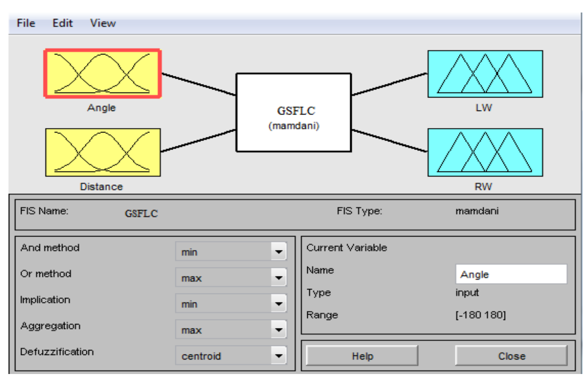

Figure 8. Component of GSFLC

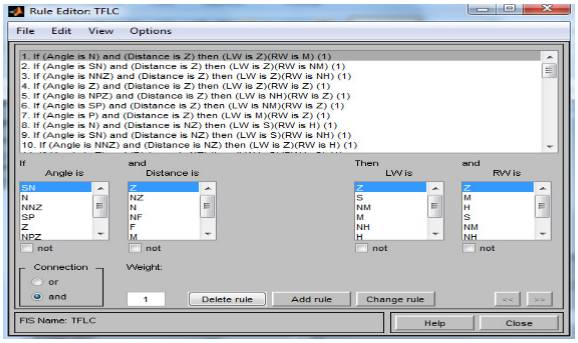

Figure 9. Inference rules of GSFLC

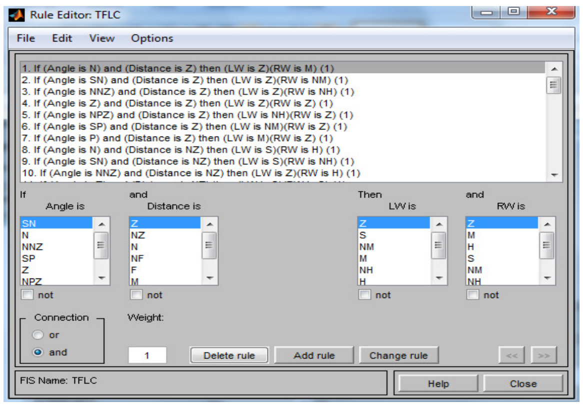

Figure 9. Inference rules of GSFLC

Table 1 .Rule base of the LV, and RV of the motors in GSFLC

Angle / Dis.	N	SN	NNZ	Z	NPZ	SP	P
Z	L^Z	L^Z	L^Z	L^Z	L^{NM}	L^{NM}	L^M
	R^M	R^{NM}	R^{NM}	R^Z	R^Z	R^Z	R^Z
NZ	L^S	L^S	L^Z	L^S	L^M	L^{NH}	L^H
	R^H	R^{NH}	R^M	R^S	R^Z	R^S	R^S
N	L^S	L^S	L^S	L^{NM}	L^{NH}	L^H	L^{VH}
	R^{VH}	R^H	R^{NH}	R^{NM}	R^S	R^S	R^S
M	L^S	L^S	L^S	L^M	L^H	L^H	L^{VH}
	R^{VH}	R^H	R^H	R^M	R^S	R^S	R^S
NF	L^S	L^S	L^{NM}	L^{NH}	L^{NH}	L^H	L^{VH}
	R^{VH}	R^H	R^{NH}	R^{NH}	R^{NM}	R^S	R^S
F	L^S	L^S	L^M	L^H	L^{NH}	L^H	L^{VH}
	R^{VH}	R^H	R^{NH}	R^H	R^M	R^S	R^S
VF	L^S	L^S	L^{NM}	L^{VH}	L^{NH}	L^H	L^{VH}
	R^{VH}	R^H	R^{NH}	R^{VH}	R^{NM}	R^S	R^S

The notation for marking fuzzy rule base using seven membership functions for left and right motor is presented in the table 1.

3.2. FLOA

FLOA is proposed to avoid obstacles. The challenge of dynamic and unknown environment is solved by using the FLOA. FLOA has three inputs; these inputs are the distances between the right, front, and left ultrasonic sensors of the robot and the obstacles.

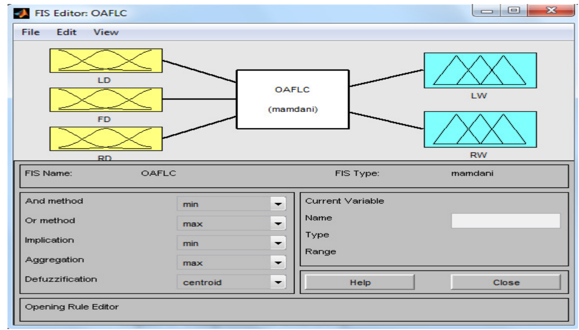

Figure 10. Component of FLOA

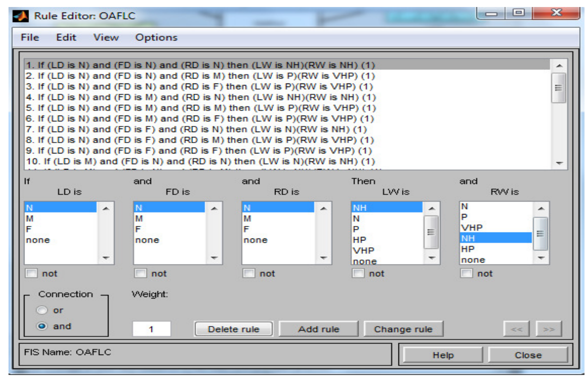

Figure 11. Inference rules of FLOA

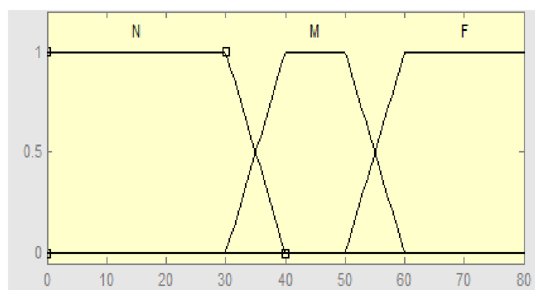

Figure 12. Right, Left, and Front Obstacle Distances

The outputs of FLOA are the left and right velocities of the motors. FLOA implemented with three inputs, two outputs, and 27 inference rules, as illustrate in figures 10. Figure 11 illustrates the inference rules of FLOA. The notations for fuzzy distance between obstacle and the robot the (FD, RD, and LD) are: F: Far, M: Medium and N: Near. Figure 12 illustrates these membership functions.

L $_{LD}$ = {F, M, N}, **L** $_{FD}$ = {F, M, N}, **L** $_{RD}$ = {F, M, N}

FLOA has five membership functions for LV, and Right Velocity RV. The notations for the fuzzy rule base of FLOA are: VHP: Very High, HP: High Positive, P:

Positive, N: Negative and NH: Negative High, and. Figures13 and 14 illustrate the membership functions of LV and RV.

L $_{LV}$ = { VHP, HP, P, N, NH}
L $_{RV}$ ={ VHP, HP, P, N, NH}

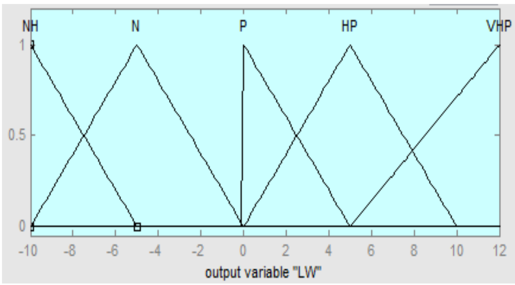

Figure 13. Membership functions for the LV in FLOA

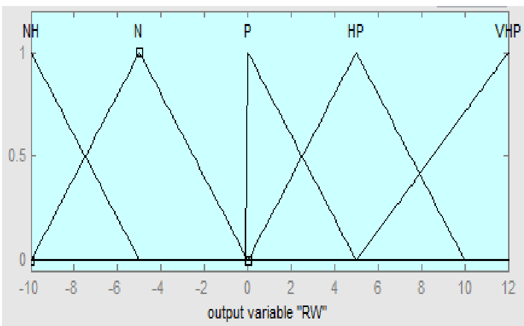

Figure 14. Membership functions for the RV in FLOA

4. Simulation Results

Our simulation carried out using KiKS simulator [14], which is a matlab application. The KiKS gives us an array of reading sensors. We toke the maximum of first and second sensor as a left distance, the maximum of third and fourth sensor as a front distance, and the maximum of fifth and sixth sensor as a right distance. From the position of robot and position of target we compute the distance to target and heading angle. We simulated the performance of behaviors, reaching the target without obstacles and reaching the target with obstacles. Tow fuzzy logic controllers are used (GSFLC and FLOA) on the simulation. . Figure 15 illustrates the first simulation and figure 16 illustrates the second simulation.

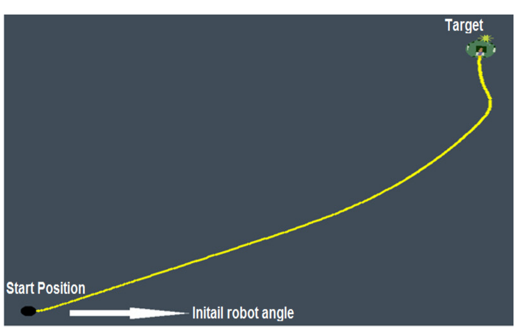

Figure 15. Simulation of scenario without obstacles

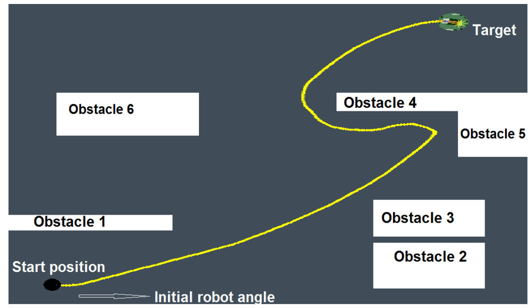

Figure 16. Simulation of **scenario with** obstacles

5. Experimental Results

In our work, we use the Scout-II robot as a mobile robotics platform by Dr Robot Inc [15]. Scout-II is a WMR for research. Scout-II uses Wi-Fi (802.11b/g) for communication. The dimensions of Scout-II are 43.0 cm x 38.0 cm.Scout-II sends all sensor reading to a server at rates of 10Hz [11]. Figure 17 shows the operation environment of Scout-II.

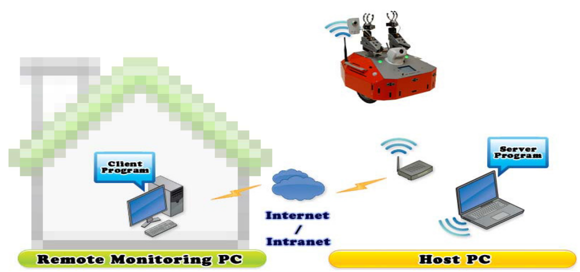

Figure 17. Typical operation environment of Scout-II [11].

In our experiment, we use MATLAB as a programming environment [16], and the wireless communicated successfully up to the range of 213 feet (56 meter) indoor. The parameters of Dead-reckoning in Scout-II are: *dst* = 30.5 cm, D =17 cm, and Tw =800.

In this work two scenarios are experimented. The first one is in environment without obstacles, and the second one is in environment with six obstacles. These obstacles have different forms. We try to reproduce worst case scenario in terms of obstacles configuration. This allows us to test our method rigorously. Figure 18 illustrates the first scenario and figure 19 illustrates the second scenario.

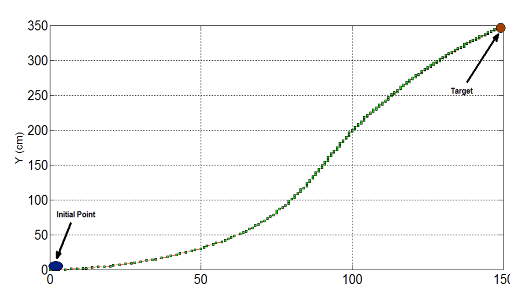

Figure 18. Environment without obstacles

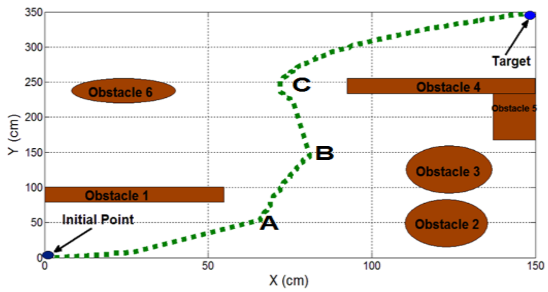

Figure 19. Environment with obstacles.

Assuming that, we want to move the robot to point (150 cm, 350 cm). We used this points with both scenarios. As in figures 18 and 19, robot turns gradually and smoothly toward target point. In both scenarios, the Scout-II moves from the start position (0, 0) to the target position (150 cm, 350 cm). As we explained, there are six obstacles in the second scenario. These obstacles have different shapes. As in figure 19, if the distance between the ultrasonic of the robot and obstacle is less than 80 cm, then the control of the robot changes from the GSFLC to the FLOA to avoid the obstacle. As we see in figure 19, at the point A, B, C the control of the robot turned to the FLOA to avoid the obstacles. Figures 20-25 present the real-time experimental results of both scenarios. Figures 20 and 21 present the first scenario. In the figure 20, Scout-II robot is at the initial point, and at the target point (150 cm, 350 cm) in figure 21.

Figures 22-25 present the real-time experimental results of the scenario of environment with obstacles. The observed difference in the motion path of figures 18 and 19 exists due to the introduction of obstacles. Figures 22 presents Scout-II robot at the initial point. In figure 23, Scout-II is moving around the obstacles 1, 2, and 3. In figure 24, Scout-II is moving around the obstacles 4, 5, and 6. Figure 25 shows the robot at the target point. The real experimentation of figure 18 presented in figures 20 and 21, and the real experimentation of figure 19 presented in figures 22-25.

Figure 20. First scenario (at the initial point)

Figure 21: First scenario (at the target point)

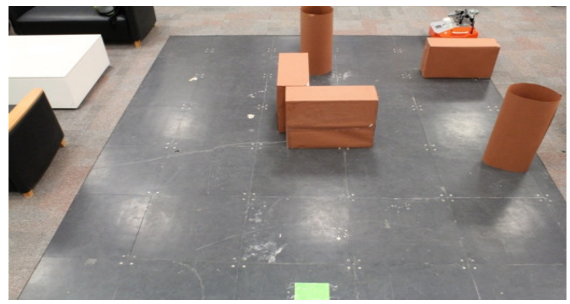

Figure 22: Second scenario (at the initial point)

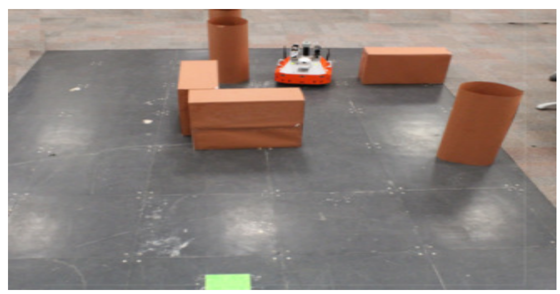

Figure 23: Second scenario (pass through obstacles 1, 2, 3)

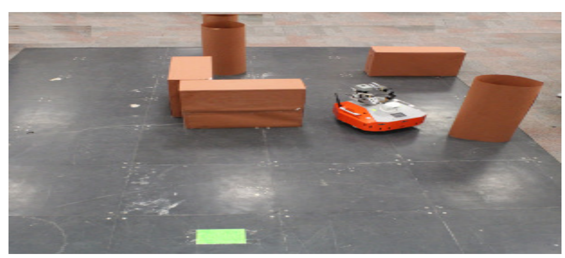

Figure 24: Second scenario (pass through obstacles 3, 4, 5).

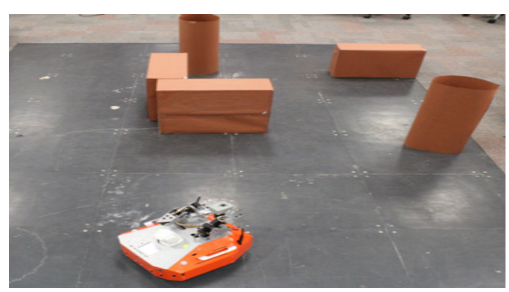

Figure 25: Second scenario (reaching the target)

6. Conclusion

The proposed motion control system has been fully implemented and tested on aWMR in realtime. WMR obstacle avoidance and smooth path generation results indicate the robustness and effectiveness of the proposed method under varying obstacle scenarios. The authors have implemented the GSFLC module and FLOA module as MATLAB modules. This implementation can provide an experimentation platform to the reserachers working in the area of realtime fuzzy logic control of WMR. The results clearly show the robustness of the method to the delayed sensors input. Despite the inherent delay caused due to MATLAB's slow sensor and actuator access, the method was still able to perform the motion control gracefully and follwed realtie constraints.

Acknowledgments

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