Behavior based Mobile for Mobile Robots Navigation and Obstacle Avoidance

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***Abstract*—** Nowadays, autonomous mobile robot is used in many applications such as security guards, material transport. One of the most recent research areas in mobile robot is the navigation of mobile robots in unknown environments. In this paper, real time navigation using multi modules fuzzy logic technique is developed to navigate an autonomous mobile robot in dynamic indoor environment. The multi modules fuzzy logic consist of four fuzzy logic modules. Goal Seeking Module (GSM), Static and Dynamic Obstacles Avoidance Module (SDOAM), Emergency Module (EM), and Robot Setting Module (RSM) are combined to perform the behaviors of reaching the target and avoid static and dynamic obstacles. The target of this work is to use the autonomous mobile robots in warehouse with dynamic and unknown environment. Experimental results show the success of the proposed algorithm.

***Keywords*—**Autonomous mobile robot, Fuzzy logic, Robot navigation, wheeled mobile robot and avoid obstacles.

I. Introduction

Nowadays, mobile robots are used in various applications, such as manufacturing [1], [2] indoor security patrols [3] and materials handling in the warehouse [4]-[6]. Dynamic and unknown environment are the main challenge in the navigation operation of the mobile robot. Many traditional mobile robot navigation approaches are not strong and unable to overcome the problems, when new situations arise. Thus, many responsive approaches have been introduced making use of artificial intelligence techniques, where learning, reasoning and problem solving constitute the main issues. Within this scope, the branch of mobile robotics became a ground of application of the advanced intelligent control. It includes methods of fuzzy logic [7]-[9], neural network [10], [11], neuro-fuzzy [12], [13], and other methods.

Even though existing of these approaches, navigation of autonomous mobile robot is still an open area. The challenges are in the unstructured, dynamic and unknown environment. All approaches tried to solve the problems of navigation within one or two complicated modules. In order to overcome the navigation problems and challenges, we distribute the behaviors of mobile robot navigation and dynamic obstacle avoidance between various fuzzy logic modules. In this work, we used the fuzzy logic technique with four modules in order to navigate an autonomous mobile robot in unstructured, dynamic and unknown environment. The contribution of this paper based on distributing the behaviors of mobile robot navigation and dynamic obstacle avoidance between four fuzzy logic modules (GSM, SDOAM, EM, RSM) and switching the control between them. We used Powerbot [21] robot as a mobile robot platform to check the effectiveness of the proposed algorithms. This paper is organized as follows. In Section II, a literature review is presented. Kinematic model of WMR is explained in section III. Fuzzy logic description is presented in section IV. Section V explains the proposed modules. Experimental results are presented in section VI. Conclusion is given in section VII.

II. Literature Review

Many approaches have been proposed for navigation of autonomous mobile robot. Even with the developments in the field of autonomous robotics, many challenges still exist. Most of the challenges are due to dynamic and unknown environment. Various self-control techniques, such as fuzzy logic, neural network, and genetic algorithm are used to deal with dynamic and unknown environment.

A. Fuzzy Logic Approach

Multiple types of inputs: sonar, camera and stored map with fuzzy logic system is used to navigate the mobile robot in [14]. Due to lack of simulation and experimentation, we cannot evaluate how much this scheme is voluble. Because of using many sensors to sense the environment, we do not have any idea on the real time operation. Another fuzzy logic for indoor navigation has been presented in [15]. The authors proposed how to use fuzzy logic control for target tracking control of Wheeled Mobile Robot (WMR). The authors focused on the navigation without caring about the avoiding the obstacles; they just use FLC for motion the WMR. An on-line navigation for WMR is presented in [16]. 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. An indoor navigation system using fuzzy logic control presented in [17]. The authors used the camera and the fuzzy logic to move the robot to its goal. However, the authors concentrated on the navigation without taking into account obstacles avoid; they just use FLC for navigation. A real-time fuzzy logic control scheme for target tracking autonomous mobile robots proposed in [18]. This scheme used infrared sensors and dual robots, the first WMR is the moving target and the second is the tracker [18]. In additional to fuzzy logic control, genetic algorithm and neural network have been used to improve the control scheme. Fuzzy logic control and genetic algorithm are also used in [19] to find the optimal parameters for the fuzzy logic. Four Fuzzy Logic Controller are used to navigate the mobile robot in [22]. These four fuzzy controls form a hierarchical control. Three fuzzy are used for navigation and obstacle avoidance. One is worked as a Supervisor.

B. Neuro-Fuzzy Approach

Navigation system for mobile robot using fuzzy-neural network is proposed in [12]. The authors provides learning abilities for navigation system using the fuzzy–neural network in dynamic environment. This paper focused on its simulation and experimental on the performance time instead of the behaviors. A neuro-fuzzy approach for real time mobile robot navigation is proposed in [20]. This scheme just used the neuro-fuzzy to tune the membership function parameters. In [23], a dynamic neuro-fuzzy system for obstacle avoiding is presented. Simulation results show that this proposed method can make robot reach its target, but it does not show a good interaction behavior.

C. Fuzzy – Genetic Approach

Genetic algorithm and fuzzy logic control are used in [24] to navigate mobile robot. This Genetic is used to tune the fuzzy logic by modifying the shape of membership function. The experimentation result showed that this Geno-Fuzzy system improved the navigation in many case but not for all case of the navigational. Another navigation system using a fuzzy logic controller, gradient method and genetic algorithm is developed in [25]. Multi-Objective Genetic Algorithm (MOGA) for the problem of path planning is presented in [26]. Authors of this paper described how to use two fitness assignments for mobile robot. Another Geno-Fuzzy system for mobile robot navigation is developed in [27]. This system used the genetic algorithm to improve the quality of control system and by finding the optimal parameters of control system.

III. Kinematics Model of WMR

In this research, Powerbot robot is used. Powerbot is a WMR with differential wheels is used as it's shown in fig. 1. WMR has two driving wheels, which are mounted on forward of the chassis on the same axis and one castor wheel, which is mounted on backward of the chassis. The castor wheel uses to balance the mobile robot during the motion. The kinematic model of this kind of mobile robot described by the following nonlinear equation [1]:

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

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

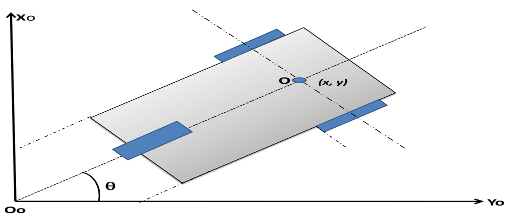
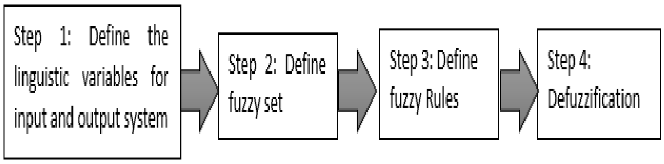


Figure1: Geometric description of WMR.

IV. Fuzzy Logic control

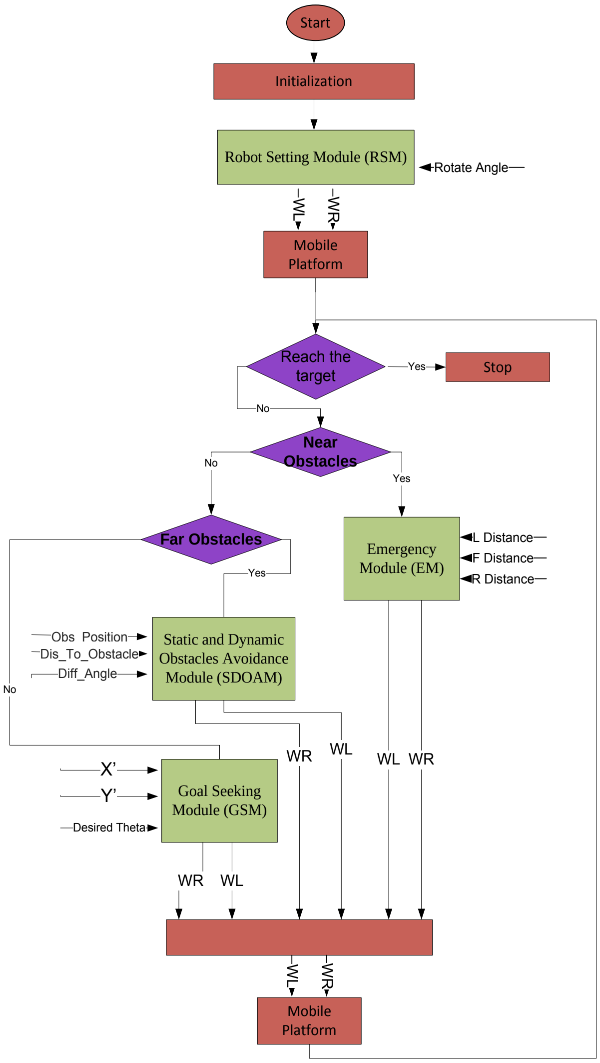
L.A. Zadeh is the father of the fuzzy logic. He introduced the fuzzy logic in 1965, in university of California [7]. Fuzzy logic control has been became an important technique in many areas. In this paper, we used the fuzzy logic technique to implement reaching the target and static and dynamic obstacle avoidance behaviors with mobile robot. In the Fuzzy Logic Process, there are four mean steps. First step defines the linguistic variables for input and output system, second step defines the fuzzy set, the third step defines the fuzzy rules and the last step is the step of defuzzification. The fuzzy logic process is shown in flowchart 1.



Flowchart 1: Fuzzy Logic Process

V. Proposed Model

Our contribution based on distributing the reaching the target and obstacle avoidance behaviors between four modules and switching the control between modules. We used Powerbot robot as a mobile robot platform, Powerbot illustrates in fig. 2.



Flowchart 2: Fuzzy logic Control algorithm.

Four fuzzy logic modules are developed and used to navigate Powerbot to its target. Goal Seeking Module (GSM), Static and Dynamic Obstacles Avoidance Module (SDOAM), Emergency Module (EM), Robot Setting Module (RSM) are combined to perform the behaviors of reaching the target and static and dynamic obstacle avoidance. As in the flowchart 2, the algorithm starts with RSM module. If the Powerbot reaches its target, it stops otherwise the control move to the emergency checking state. If the laser/ultrasonic sensors detect any near (distance between the obstacle and the robot is less than 30 cm) movement obstacle the control switches over to the EM module, otherwise the control checks the SDOAM state. If the laser or the ultrasonic sensors detect any far static or dynamic obstacle (distance between the obstacle and the robot is less than 100 cm and larger 30) the control switches over to the SDOAM module. The output of GSM, EM, RSM, and SDOAM are the left and right velocities of each wheels of the Powerbot.

A. Goal Seeking Module (GSM)

GSM module uses to simulate the goal seeking behaviors, so it navigates the Powerbot robot to its target. The inputs of GSM are the angle between the direction of the robot to the target and the x-axis (error angle), and the distance between the robot and the target as illustrates in fig. 2.

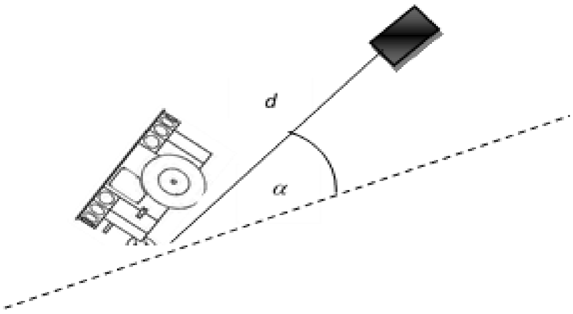


Figure 2: Inputs of GSM

The outputs of GSM are the velocities of the left and right motors. GSM has been implemented using seven membership functions for both input (angle error and distance error). Fig. 3 and 4 illustrate the membership shapes of the inputs. The linguistic variables of the distance error are: Very Far: VF, Far: F, Near Far: NF, Medium: M, Near: N, Near Zero: NZ, and Zero: Z. The linguistic variables of the angle error are: Positive: P, Small Positive: SP, Near Positive Zero: NPZ, Zero: Z, Near Negative Zero: NNZ, Small Negative: SN, and Negative: N.

$\mathbf{L}_{\text{Err. Angle}}$ = {P, SP, NPZ, Z, NNZ, SN, N}

$\mathbf{L}_{\text{Distance}}$ = {VF, F, NF, M, N, NZ, Z }

Left Velocity LV and Right Velocity RV of the motors are the output of the GSM. LV and RV in GSM have been implemented using seven membership functions. Fig. 5 illustrates the membership of LV and RV. The linguistic variables of the LV and RV are: Z: Zero, S: Slow, NM:

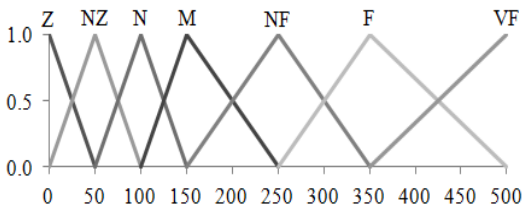


Figure 3: Membership functions for the distance.

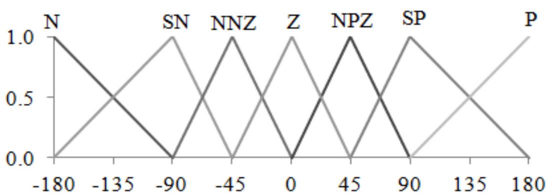


Figure 4: Membership functions for the angle error.

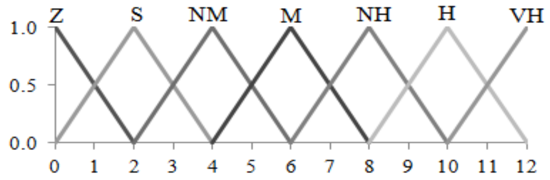


Figure 5: Membership functions of LV and RV

Near Medium, M: Medium, NH: Near High, H: High, and VH: Very High. The influence rules of the LV and RV are defined in Table 1.

Table 1: Fuzzy rules of the LV and RV of GSM.

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^H	L^H	L^{VH}
	R^{VH}	R^H	R^{NH}	R^{NM}	R^S	R^S	R^S
M	L^S	L^M	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^S	L^{NH}	L^H	L^H	L^{VH}
	R^{VH}	R^H	R^H	R^{NH}	R^S	R^S	R^S
F	L^S	L^S	L^S	L^H	L^H	L^H	L^{VH}
	R^{VH}	R^H	R^H	R^H	R^S	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

B. Static and Dynamic Obstacles Avoidance Module (SDOAM)

SDOAM module uses to simulate the avoiding far obstacles (static or dynamic) behaviors. If its location less than 100 and larger than 30 from the robot, obstacle is far. The inputs to SDOAM are: the distance between the robot and the obstacles (Dis_to_obstacle), the position of the obstacle from the view of the robot (Obs_position) and the different in angle between the target and the obstacle from the robot view (Dif_angle). These distances are acquired using laser device and ultra-sonic sensors. Fig. 6 illustrates the input scenario of SDOAM. We combine both the laser to take the advantage of its high accuracy and the ultra-sonic to take the advantage of higher coverage area for any obstacle as illustrates in fig. 12.

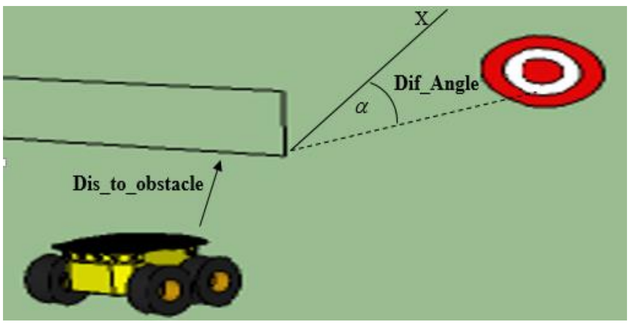


Figure 6: Input scenario of SDOAM

Fig. 7, 8 and 9 illustrate the membership of the inputs. The linguistic variables of the Dis_to_obstacle are Near: N and Far: F. The linguistic variables of the Obs_position are Lift: L and Right: R. The linguistic variables of the Dif_angle are Small: S and Far: F}.

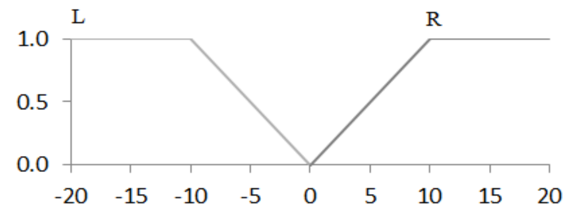


Figure 7: Membership functions for the Obs_position.

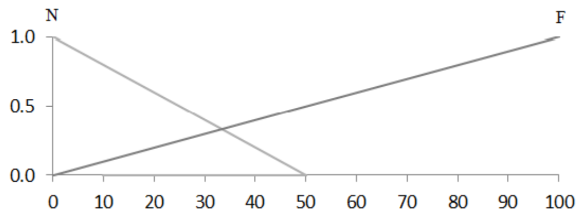


Figure 8: Membership functions Dis_to_obstacle.

The outputs of SDOAM are the velocities of the left LV and the right RV of the motors. LV and RV in SDOAM have been implemented using three membership functions. Fig. 10 illustrates the membership of LV and RV. The linguistic variables of the LV and RV in SDOAM are Small: S, Medium: M and Fast: F. The influence rules of the LV and RV are defined in Table 2.

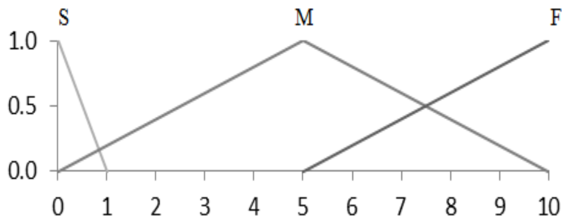


Figure 9: Membership functions for the Dif_angle.

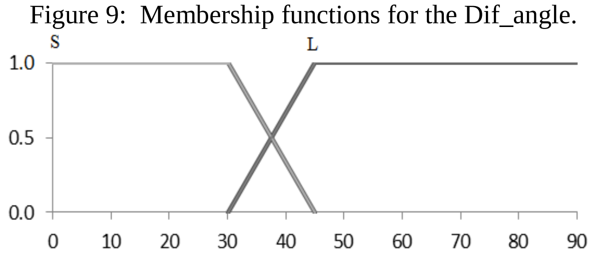


Figure 10: Membership functions LV and RV.

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C. Emergency Module (EM)

EM module uses to simulate the avoiding emergency movement behavior (distance between the obstacle and robot is less than 30 cm). The inputs of EM are the distance between the left, front, and right sides of the robot and the obstacles (LD, RD, and FD). These distances, acquired using laser device and ultra-sonic sensors. We use the laser to take the advantage of its high accuracy and the ultra-sonic to take the advantage of higher coverage area for any obstacle. Refer to the fig. 12 to see the details of the observation ranges for each type of sensor.

Table 2: Fuzzy rules of the LV and RV of SDOAM

Input			Output	
Obs_ position	Dis_to_ obstacle	Dif_ angle	LV	RV
L	F	L	M	S
L	F	S	M	S
L	N	L	M	S
L	N	S	F	S
R	F	L	S	M
R	F	S	S	M
R	N	L	S	F
R	N	S	S	F

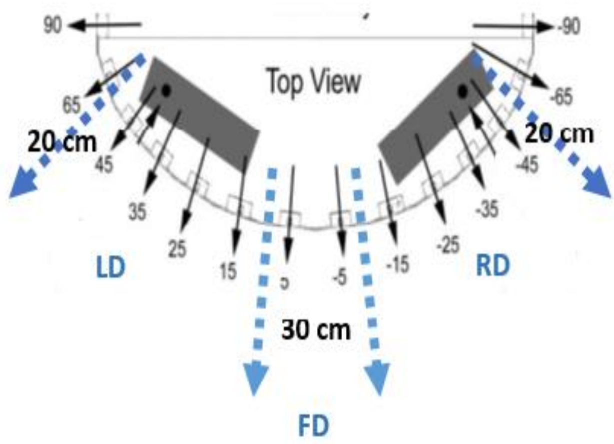

Figure 11: Distance to obstacles of EM.

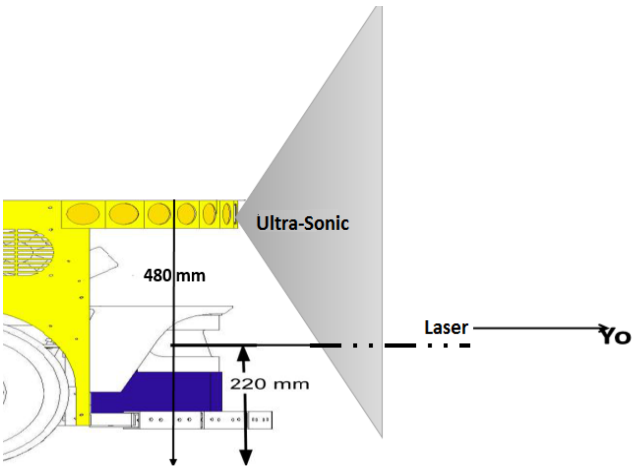

Figure 12: Using of Laser and ultra-sonic

LD is from degree 60 to 10, FD from degree -10 to 10, and RD from -60 to -10 as illustrates in fig. 11. The notations for the LD, RD, and FD are: {N: Near and F: Far}. Fig. 13 illustrates the membership of the LD, RD, and FD of EM module. The outputs of EM module are the velocities of the left LV and the right RV of the motors. LV and RV in EM have been implemented using three membership functions. Fig. 14 illustrates the membership of LV and RV of EM module. The linguistic variables of the LV and RV in EM are High Negative: HN, Negative: N, and High: H. The influence rules of the LV and RV are defined in Table 3.

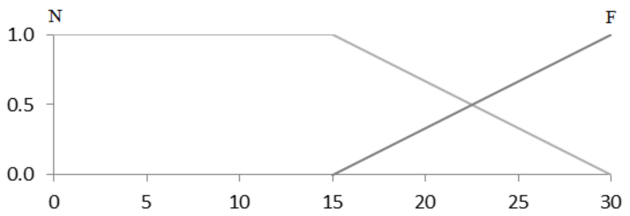

Figure 13: Membership functions for LD, RD, and FD of EM.

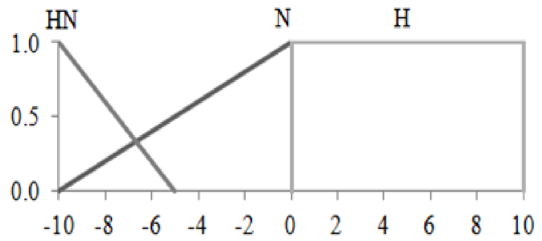

Figure 14: Membership functions for LV and RV of EM module.

Table 3: Fuzzy rules of the LV and RV of EM.

Input			Output	
LD	**FD**	**RD**	**LV**	**RV**
N	N	N	NH	NH
N	N	F	NH	N
N	F	N	NH	NH
N	F	F	NH	N
F	N	N	N	NH
F	N	F	NH	NH
F	F	N	N	NH
F	F	F	H	H

D. Robot Setting Module (RSM)

RSM is used to overcome the problem of existence of close intermediate points (if the distance between the robot and the point <50 cm). RSM used to rotate the robot before the motion. The input of RSM is the rotate angle that the robot should rotate. The linguistic variables of the angle are Negative: N and Positive: P, as it is illustrates in fig. 16. The outputs of RSM is the velocities of the left and right motors. Fig. 15 illustrates the membership of LV and RV. The linguistic variables of the LV and RV in RSM are Forward: FW, Backward: BW. The influence rules of the LV and RV are defined in Table 4.

Table 4: Fuzzy rules of the LV and RV of RSM.

Output / Angle	**LV**	**RV**
Positive	BW	FW
Negative	FW	BW

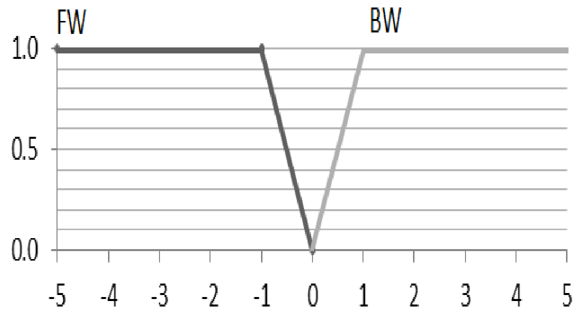

Figure 15: Membership functions of the Left & Right Velocity of RSM.

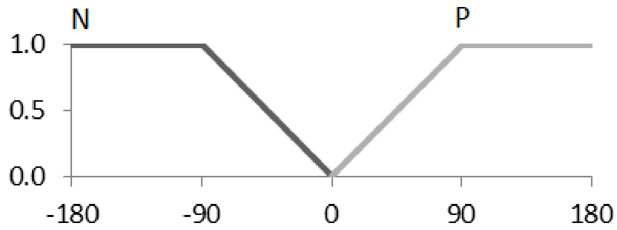

Figure 16: Membership functions for the error in angle of the RSM.

VI. Experimental Results

In this section, we are going to test our proposed method in a real environment with different scenarios. These experimental results will determine the effectiveness and the robustness of the proposed method.

In the experimentation part of our work, we use the Powerbot mobile robot platform, which is developed by Adept MobileRobots Inc [21]. Powerbot is a differential-drive robot for research, which uses C++ as a programming platform language. The proposed methods have been tested using three different environments. In the first scenario, the robot is examined in unknown environment without obstacles as showed in Fig.17, 19, and 20. In the second scenario, the robot is examined in unknown environment with static obstacles, as showed in Fig. 18, 21-23, and 24. In the third scenario, the robot is examined in unknown environment with dynamic obstacles as showed in Fig.25- 26. We moved the robot from the initial point (inside the robotics laboratory room) to the target point, which is outside of the laboratory room via intermediate points, as in table 5. We carry out these points for all scenarios.

In the first scenario and as it is illustrated in Fig.17, the robot smoothly moved from the initial point (0 cm, 0 cm), which is inside the laboratory to outside the laboratory (target point (6.5 cm, -4.8 cm)).The robot is directed gradually toward the target using the GSM. In case of any obstacles (dynamic or static) the control switch to EM or SDOAM module. As we can see in fig. 17, the robot is trying to adjust itself to pass through the door. The door width is 90 cm and the robot width is 66 cm. The real experimentation of Fig. 17 is showed in figures 19 and 20. We have uploaded the video of this scenario to the YouTube: (http://www.youtube.com/watch?v=LvUyuIUZ6xc&feature=youtu.be).

Table 5: Movement points.

Points	X’	Y’
Initial configuration	0 cm	0 cm
First Intermediate	4.8 cm	-2 cm
Second Intermediate	4.8 cm	-4.5cm
Target	6.5 cm	-4.8 cm

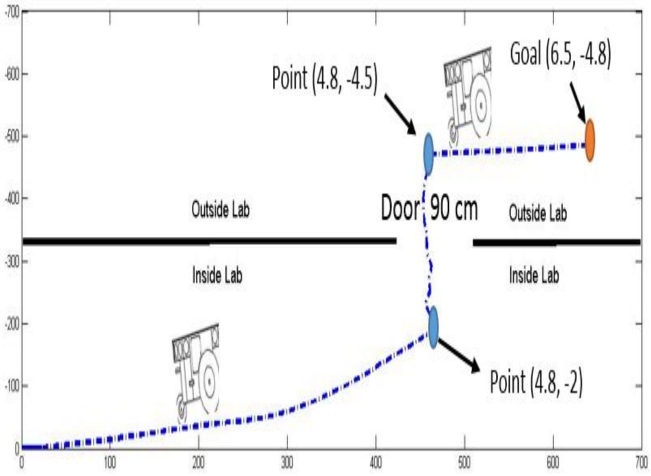

Figure 17: Robot experimentation in environment without obstacles.

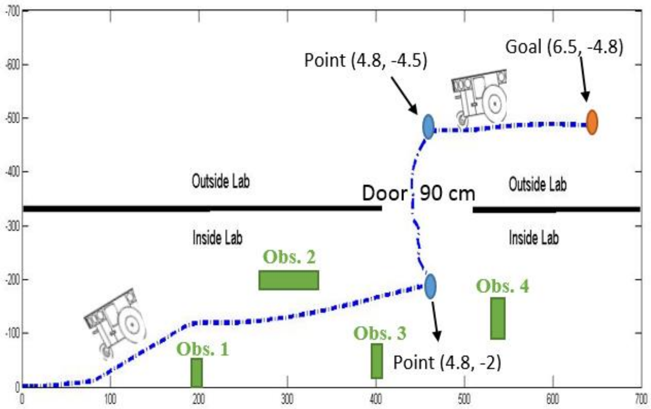

Figure 18: Robot experimentation in unknown environment with static and dynamic obstacles

In the second scenario and as it is illustrated in Fig 18, the robot smoothly moved from the start point P(0,0) inside the laboratory to outside the laboratory P(6.5 cm, -4.8 cm). In case of existing obstacles (dynamic or static) the control switch to EM or SDOAM module, depends on the distance between the obstacle and the robot. In this scenario, we are going to concentrate on obstacles that are far from the robot (30 cm<distance between the robot and obstacles< 100 cm). The robot is moved toward the target using the GSM. In case of any far obstacles (dynamic or static) the control switch to SDOAM module. As we can see in fig. 18, 22, and 23, the robot is trying to adjust itself to avoid the obstacles 1, 2 and 3. The inputs of SDOAM are the distance between the robot and the obstacles Dis_to_obstacle (100 cm< Dis_to_obstacle >30 cm), the position of the obstacle from the view of the robot (left or right) Obs_position, and the different in angle between the target and the obstacle from the robot view Dif_angle. These distances, acquired using laser device and ultra-sonic sensors. Fig. 6 illustrates the input scenario of SDOAM. During the movement of the robot if there is any dynamic obstacle with the distance to the robot less than 30 cm the control switches to EM module. The generated path of the Fig.18 corresponds to the real experimentation of Fig. 21- 24. We have uploaded the video of this scenario to the YouTube:(http://www.youtube.com/watch?v=R5z2n_tcoO8 &feature=youtu.be).The behavior of the robot within the dynamic obstacles is illustrated in fig. 25 and 26. In this scenario, the robot is moved toward the target using the GSM. In case of any near dynamic or static obstacles (0 <distance <30) the control switch to EM to avoid that obstacle. We have uploaded the video of this scenario to the YouTube (http://www.youtube.com/watch?v=4cUZdoeHxdw&feature=youtu.be).

Figure: 19: First scenario (Before Navigation).

Figure 20: First scenario (During navigation).

Figure 21: Second scenario (Before Navigation).

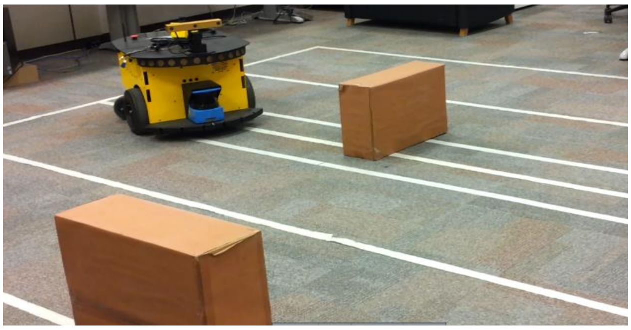

Figure 22: Second scenario (During Navigation).

Figure 23: Second scenario (Pass through obstacles).

Figure 24: Second scenario (Pass through Door).

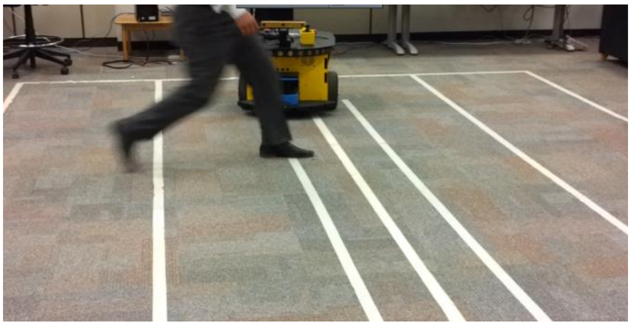

Figure 25: Third scenario (Avoid Dynamic obstacles).

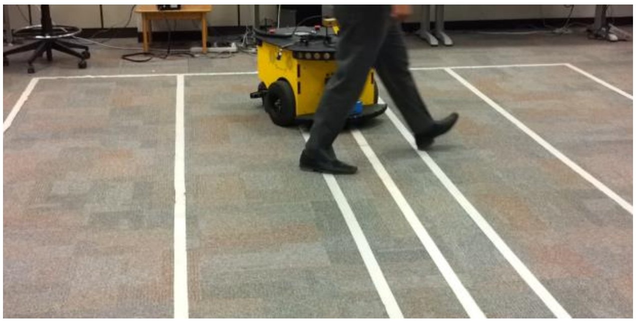

Figure 26: Third scenario (Avoid Dynamic obstacles).

VII. CONCLUSION

In this work, we have distributed navigation and obstacle avoidance behaviors between four fuzzy logic modules and switching the control between them. The proposed work aims to use mobile robots for hospital, library and materials handling in instructed warehouse. Our proposed method is able to navigate the mobile robots in such environment.The proposed method has been tested on PowerBot mobile robot and with three different scenarios, which are close to the scene in warehouse. Depend on the experimental results, the proposed method is effective and robust under varying obstacles scenarios.

For the futur work, the proposed motion method of robot have to be extended to a swarm of mobile robots.

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