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Designing of Goal Seeking and Obstacle Avoidance Behaviors for a Mobile Robot Using Fuzzy Techniques

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Abstract- This paper describes fuzzy logic approach to mobile robot behavior design. An autonomous mobile robot must be able to move safely in a crowded unknown environment for reaching a desired goal. A successful way of structuring the navigation task in order to deal with the problem is within behavior based navigation approaches. In this paper, individual behavior design will be addressed using fuzzy logic technique. The obtained results show that the navigator is able to perform successful navigation task in various unknown environment.

Keywords: Mobile Robot, Behavior Design, Goal Seeking, Obstacle Avoidance.

INTRODUCTION

Robots are no longer confined to engineered, well protected sealed corners, but they are currently employed in places closer to the human. Robots are getting out of factories and are finding their way into our homes and to populated places such as, museum halls, office buildings, schools, airports, shopping malls and hospitals…etc. The gained benefit comes along with the necessity to design the robot in a way that it is able to respond to a list of complex situations. This includes at least the ability to navigate autonomously, avoiding modeled and un-modeled obstacles especially in crowded and unpredictably changing environment. Navigation may be defined as the task to computing the configuration sequences allowing the robot to move from a start position to desired goal by avoiding collision with the environment obstacles [1]. When the environment of the robot is obstacle free, the problem becomes less complex to handle. But as the environment becomes complex, motion planning needs much more treatments to allow the robot to move between its current and final configurations without any collision with the surrounding environment. An important problem in autonomous navigation is the need to deal with the large amount of uncertainties that has to do with the sensory information received by the robot as well as with the fact that the environment in which such robots operate contains elements of dynamics and variability that limit the utility of prior knowledge.
Fuzzy theory has the features that enable it to cope with uncertain, incomplete and approximate information. Thus, fuzzy logic stirs more and more interest amongst researchers in the field of robot navigation. Further, in the majority of fuzzy logic applications in navigation, a mathematical model of the dynamics of the robot environment is needed in the design process of the motion controller. Fuzzy logic is a mathematical tool that can manipulate human reasoning, concepts and linguistic terms. It suits to define

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systems that handle imprecise information about the system model [2]. The knowledge of the human operator would be presenting in the form of a set of fuzzy linguistic rules. These rules produce an approximate decision in the same manner as an expert would do [2][3].
Behavior based navigation systems (Arkin, 1989 [4]), (Brooks, 1986 [5]), (Fatmi et al. 2006 [6]) and (Seraji H, 2002 [12]) have been developed as an alternative to the more traditional strategies of constructing representation of the world and then reasoning prior to acting. The main idea of behavior based navigation is to identify different responses (behaviors) to sensory inputs. A variety of behavior-based control schemes have been inspired by the success of Brooks [5] with his architecture which is known by the subsumption architecture. Many works used fuzzy logic system to mobile robot navigation and representing behaviors [3][6][8][9].
The aim of this paper is to show how fuzzy logic approach can be used to guide an autonomous mobile robot in an unknown environment. Fuzzy logic control (FLC) is an interesting tool to be applied to the problem of path planning since the output varies smoothly as the input changes. In this paper, we will discuss a fuzzy navigation controller design based on expert experience and knowledge that was applied to a tricycle mobile robot. The paper is organized as follows: Section 2 gives the necessary background of behavior based navigation approach. The proposed controllers are introduced and explained in section 3. Section 4 shows simulation results for examples of mobile robot navigation in unknown environment. Section 5 concludes the paper.

BEHAVIOR BASED NAVIGATION

One of the long standing challenging aspect in mobile robotics is the ability to navigate autonomously, avoiding modeled and unmodeled obstacles especially in crowded and unpredictably changing environment. A successful way of structuring the navigation task in order to deal with the problem is within behavior based navigation approaches (Arkin, 1989 [4]), (Brooks, 1986 [5]), (Saffiotti, 1997[3]) (Fatmi et al. 2006 [6]), (Yang et al. 2005 [7]), (Mataric, 1997 [10]) and (Rosenblatt et al. 1989, [11]). The basic idea in behavior based navigation is to subdivide the navigation task into small easy to manage, program and debug behaviors (simpler well defined actions) that focus on execution of specific subtasks. For example, basic behaviors may be "avoid obstacles" or "reaching a desired goal" as shown in figure 2. This divide approach has turned out to be a successful approach, for it makes the system modular, which both simplifies the navigation solution as well as offers a possibility to add new behaviors to the system without causing any major increase in complexity. The suggested outputs from each concurrently active behavior are then blended together according to some action coordination rule. The task then reduces to that of coupling actuators to sensory inputs, with desired robot behaviors. Each behavior can take inputs from the robot’s sensors (camera, ultrasound, infrared, tactile…) and/or from other behaviors in the system, and send outputs to the robot’s actuators (wheels, grippers, arm…) and/or to other behaviors. A variety of behavior-based control schemes have been inspired by the success of (Brooks [5]), with his architecture which is known by the subsumption architecture. In this architecture behaviors are arranged in levels of priority where triggering a higher level behavior suppresses all lower level behaviors. (Arkin [4]) has described the use of reactive behaviors called motor schemas. In this method, potential field is used to define the output of each schema. Then, all the outputs are combined by weighted summation. Rosenblatt et al. [11] presented DAMN architecture in which a centralized arbitration of votes provided by independent behaviors combines into a voted output. Others as in [3][7][8][12] used fuzzy logic system to represent and coordinate behaviors.

A. Fuzzy behavior based navigation

In the fuzzy logic control inputs are processed in three steps: Fuzzification, Inference and Deffuzification, as seen in Fig. 1. Each behavior is considered as a controller composed of a set of fuzzy rule statements aimed at achieving a defined objectives [3][6]. In the fuzzification block, when we define for example fuzzy set A in a universe of discourse X defined by its membership function $\mu_A(x)$ for each x representing the degree of membership of x in X. In fuzzy logic control, membership functions assigned with linguistic variables are used to fuzzify physical quantities. Next, in the inference block, fuzzified inputs are inferred to a fuzzy rules base. This rules base is used to characterize the relationship between fuzzy inputs and fuzzy outputs as follows:

$$IF\ x_1 \text{ is } A_1^i \text{ and ... and } x_n \text{ is } A_n^i \text{ THEN } y \text{ is } B^i \quad (1)$$

Where $i=1...N$, and N is the number of rules in a given fuzzy rule base, x_1 ... x_n are the input variables which are the sensor data of the mobile robot, $A^i{}_1...A^i{}_2$ are the input fuzzy sets, B^i is the output fuzzy set and y is the output variable. The response of each fuzzy rule is weighted according to the degree of membership of its input conditions. The inference engine provides a set of control actions according to fuzzified inputs. Since the control actions are in fuzzy sense. Hence, a deffuzification method is required to transform fuzzy control actions into a crisp value of the fuzzy logic controller.

In fuzzy logic behavior based navigation systems the problem is decomposed into simpler tasks (independent behaviors). Each behavior is composed of a set of fuzzy logic rule statements aimed at achieving a well defined set of objectives, for example the rules could be:

If Goal is Far THEN the Speed is High
If Obstacle is on Right THEN Turn to Left

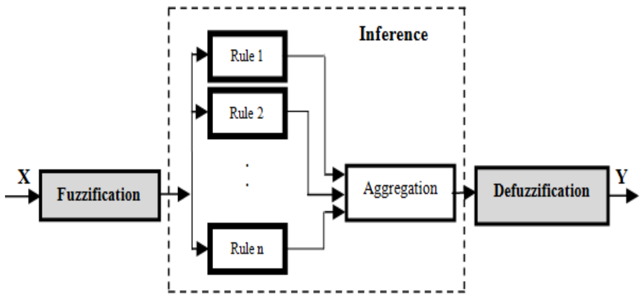

Figure 1 The structure of Fuzzy Logic Controller

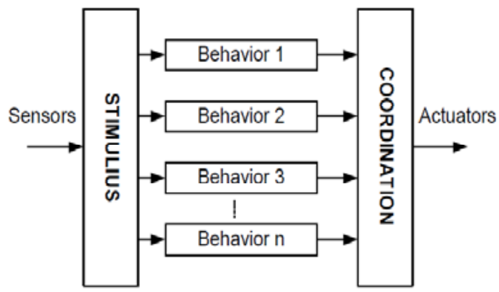

Figure 2 Behavior based navigation architecture

B. The Model of used Mobile Robot

The robot used in this study is a tricycle mobile robot with non-holonomic property that restricts its mobility in the sideways direction and with limitation of angle. The kinematic model of the mobile robot has two rear driving wheels and a passive front wheel. The inputs of this system are the steering angle α and the velocity v_r. The outputs are: (x_r, y_r, θ_r) as depicted in Fig.3. In perfect adhesion conditions, this kinematic model can be described by the following equations 2.

$$\dot{x}_r = v_r \cos(\theta_r)$$
$$\dot{y}_r = v_r \sin(\theta_r) \qquad (2)$$
$$\dot{\theta}_r = \frac{v_r}{l} tg(\alpha)$$

Where: (x_r, y_r) are the position coordinates and θ_r is the orientation angle of the robot. l is the robot length.

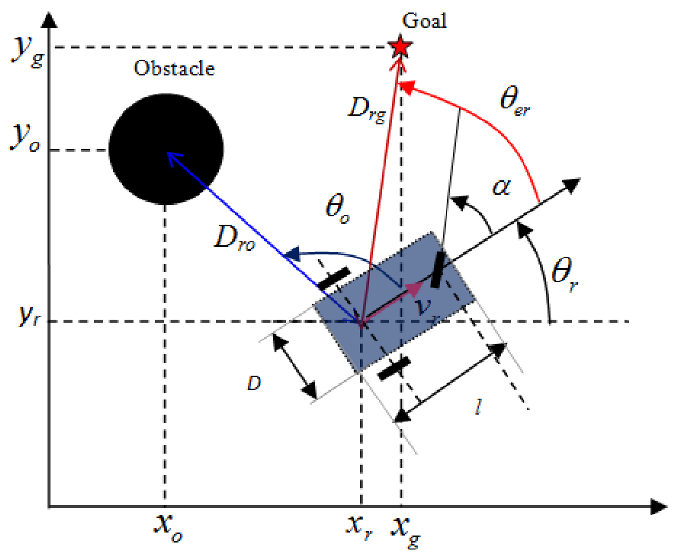

Fig. 3 The parameters of the mobile robot

PROPOSED CONTROLLERS

To provide the robot with ability to navigate autonomously by avoiding obstacles in crowded and unpredictably environment; the following behaviors are designed: Goal reaching, Obstacle avoidance. Each behavior was represented using fuzzy *IF-THEN* rule base as presented in eq.3. We have chosen a Takagi-Sugeno Fuzzy Inference Systems with two inputs and two outputs for each behavior.

$$IF\ x_1\ is\ A^i_1\ and\ x_2\ is\ A^i_2\ THEN\ \alpha\ is\ B_1^i\ and\ V_r\ is\ B_2^i \qquad (3)$$

The values of α and V_r in the consequent part of the rules are fuzzy labels reduced to a singleton. The two outputs of the fuzzy controller are calculated by:

$$\alpha = \sum_{i=1}^{N} w_i \alpha_i \quad \text{AND} \quad V_r = \sum_{i=1}^{N} w_i V_{ri} \qquad (4)$$

Where w_i is the truth value rule i for a given input vector. N is the number of fuzzy rules. If we consider the previous rule, the truth value can be given by:

$$w_i = \mu_{A_{i1}}(x_1) \times \mu_{A_2}(x_2) \qquad (5)$$

A^i_1 and A^i_2 are the membership functions of the inputs.

A. Goal Reaching behavior

The goal reaching behavior tends to drive the mobile robot from a given initial position to a stationary or moving target goal. This behavior drives the robot to the left, to the right or forward depending on the two input variables: the distance between the robot and the goal (D_{rg}) and the angle error θ_{er}; it is the difference between the desired heading (the heading required to reach the goal noted θ_d and the actual current orientation θ_r which are given by Equations (6)-(8), respectively. Fig.4 gives the block diagram of the goal reaching

behavior. From this figure we can notice that the designed fuzzy controller uses these two values to generate the appropriate actions to reach the target (u_1 is the steering angle α and u_2 is the robot speed v_r). The inputs variables (angle error and the distance robot-target) are fuzzified using the membership functions depicted in Fig.5 and Fig.6. Therefore the rule base used for this behavior is shown in table. 1.
The outputs variables are represented by the fuzzy sets reduced to singletons as shown in Fig.7 and Fig.8. With the following linguistic labels for all input-output variables: **Z**: Zero, **PS**: Positive Small, **PB**: Positive Big, **NB**: Negative Big, **NS**: Negative Small, **NM**: Negative Medium, **PM**: Positive Medium, **F**: Fast, **SL**: Slow, **MD**: Medium, **VF**: Very Fast.

$$D_{rg} = \sqrt{(x_g - x_r)^2 + (y_g - y_r)^2} \tag{6}$$

$$\theta_d = arctg(\frac{y_g - y_r}{x_g - x_r}) \tag{7}$$

$$\theta_{er} = \theta_d - \theta_r \tag{8}$$

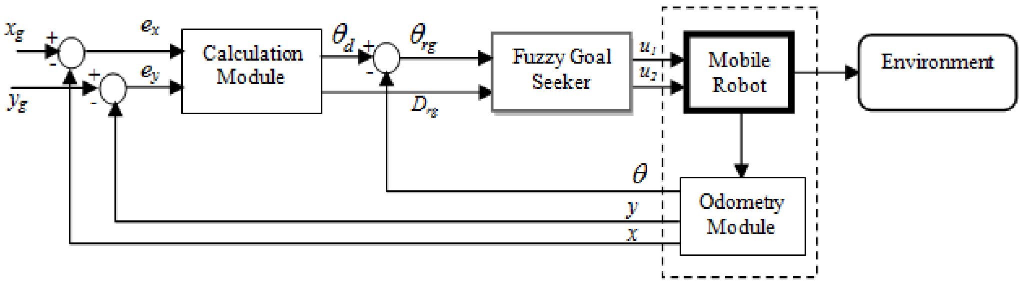

Figure 4 The functional bloc of Fuzzy goal seeker

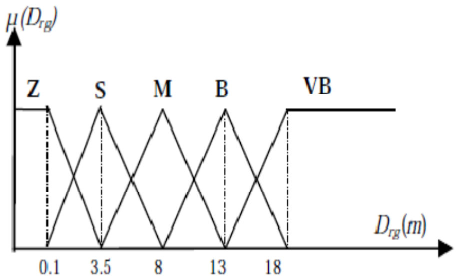

Figure 5 The fuzzy sets of the distance D_{rg}

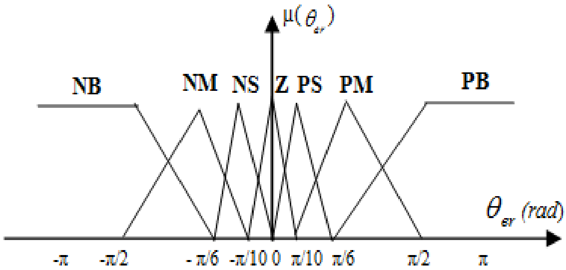

Figure 6 The fuzzy sets of the angle error θ_{er}

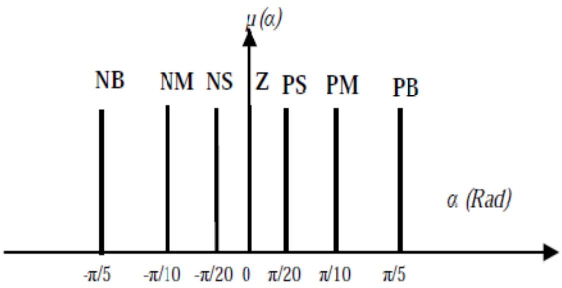

Figure 7 The fuzzy sets of the steering angle

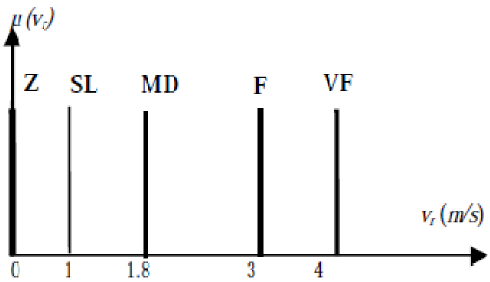

Figure 8 The fuzzy sets of the linear velocity

TABLE I. FUZZY RULES FOR GOAL REACHING BEHAVIOR

Outputs			Angle Error (θ_{er})						
			NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
Distance (D_{rg})	**Z**	α	*PM*	*PS*	*Z*	*Z*	*Z*	*NS*	*NM*
		V_r	*Z*	*Z*	*Z*	*Z*	*Z*	*Z*	*Z*
	S	α	*PB*	*PB*	*PM*	*Z*	*NM*	*NB*	*NB*
		V_r	*SL*	*SL*	*SL*	*SL*	*SL*	*SL*	*SL*
	M	α	*PM*	*PM*	*PS*	*Z*	*NM*	*NB*	*NB*
		V_r	*SL*	*SL*	*MD*	*MD*	*MD*	*SL*	*SL*
	B	α	*PM*	*PS*	*PS*	*Z*	*NS*	*NS*	*NM*
		V_r	*SL*	*MD*	*F*	*F*	*F*	*MD*	*SL*
	VB	α	*PM*	*PM*	*PS*	*Z*	*NS*	*NM*	*NM*
		V_r	*SL*	*MD*	*F*	*VF*	*F*	*MD*	*SL*

B. Obstacle Avoidance behavior

For obstacle avoidance behavior, the robot needs to acquire information about the environment. This task tends to steer the robot in such a way as to avoid collision with objects that happens to be in the vicinity of the robot. This behavior is elaborated using Takagi-Sugeno fuzzy controller. Where the navigation task can be achieved by the behaviors: obstacle avoidance and goal seeking and a controller for reducing the velocity when the robot avoids obstacles. In this study, we assume that the environment of mobile robot navigation contains uniform shapes of obstacles. The inputs of this behavior are the distance D_{ro} and the error angle to an obstacle θ_o. Each distance is fuzzified using the membership functions described in Fig.9 and Fig.10. Where SM: Small, MD: Medium and BG: Big. The strategy used for designing this behavior is expressed symbolically by the fuzzy rules presented at table 2 in order to calculate the control values transmitted to the robot actuators.

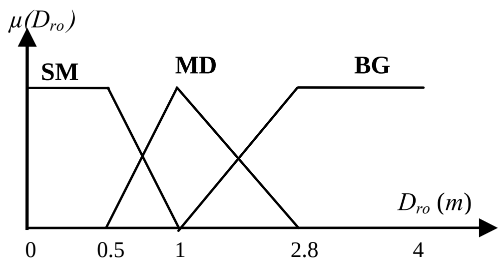

Figure 9 The fuzzy sets of D_{ro}

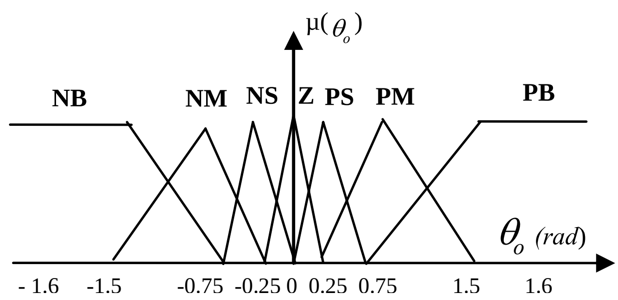

Figure 10 The fuzzy sets of the distance robot-obstacle

TABLE II. FUZZY RULES FOR OBSTACLE AVOIDANCE BEHAVIOR

			Angle θ_o						
	Outputs		**NG**	**NM**	**NP**	**Z**	**PP**	**PM**	**PG**
Distance D_{ro}	**SM**	α	*NM*	*NM*	*NB*	*NB*	*PB*	*PM*	*PM*
		V_r	*SL*	*SL*	*Z*	*Z*	*Z*	*SL*	*SL*
	MD	α	*NS*	*NM*	*NB*	*NB*	*PB*	*PB*	*PS*
		V_r	*MD*	*MD*	*SL*	*SL*	*SL*	*MD*	*MD*
	BG	α	*Z*	*Z*	*NM*	*NM*	*PM*	*Z*	*Z*
		V_r	*MD*	*MD*	*MD*	*MD*	*MD*	*MD*	*MD*

SIMULATION RESULTS

In this section, examples of mobile robot navigation in indoor environment are presented to verify the validity of the proposed schemes. The designed environment takes into account several situations such as: free space and an area with many circular shapes as obstacles. These typical cases in which the robot task is to move from a given current position to a desired goal position in obstacle free environment and in the presence of obstacles.

A. Goal seeking behavior

By choosing different start points, Fig. 11 shows that in simulation the robot reaches the desired goal based on the minimization of the path to be taken. As depicted, in all cases the robot moves from its initial positions (*Si*) toward the goal (*Gi*) where (*i=1 to 5*). The elaborating fuzzy controller is well performed to accomplish this task. The linear velocity of the mobile robot decreases when it approaches the target. The results show the effectiveness of the elaborated behavior to accomplish this task.

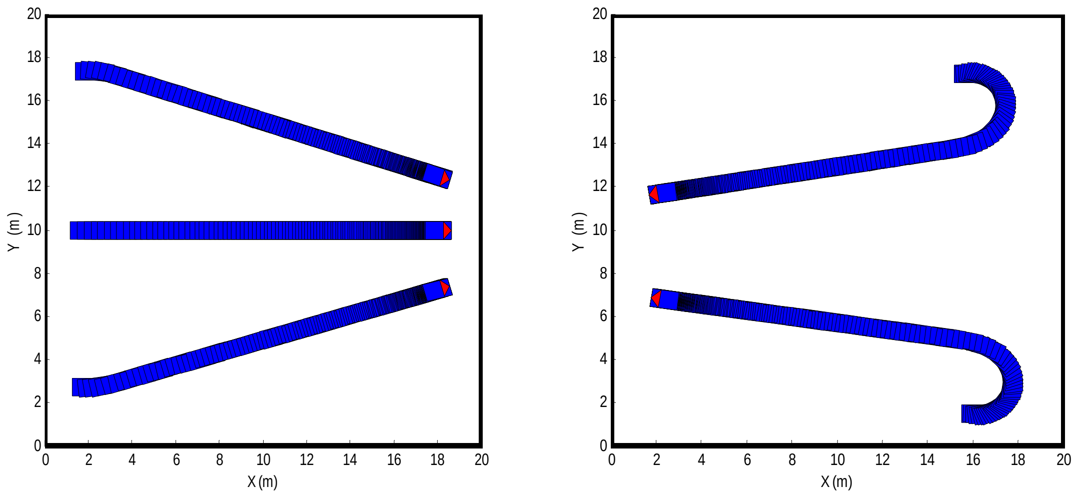

Figure 11 Goal seeking using TS fuzzy controller

B. Navigation with Obstacle Avoidance

If the environment of the robot contains one or more obstacles, the robot must be able to avoid collisions. The robot uses the obstacle avoidance controller in order to reach the final destination safely without collision with the objects. Fig.12 shows examples of mobile navigation with multiple obstacles in the environment. The robot moves toward the goal, when an obstacle is detected in one of the three sides (front, right and left); the obstacle avoidance behavior is activated to generate the appropriate actions for avoiding these collisions. In example (1) Fig.12; the robot has to reach the Goal (G_1) for the start point (S_1). The robot begins to execute the behavior according to the rule base depending on the current context. First, the robot moves toward the goal by activating the goal reaching behavior with maximum velocity until it senses obstacle 1 (Obs 1) on its right side, then it changes its behavior to obstacle avoidance at point A up to point B during which the robot is in free space and it goes ahead to the goal until point C. At this moment the robot detects the obstacle 2 (Obs 2) in its front; the robot executes the obstacle avoidance behavior until point D by turning to the right. The same work is done at points E, F, G and H. Finally, the goal reaching behavior is activated to reach the goal by decreasing the velocity when it approaches the goal. As depicted, in all cases the robot is able to navigate autonomously and can reach the goal by avoiding obstacles successfully. The smoothness and the stability of the robot movements show that fuzzy logic based controller could be a good level of performances.

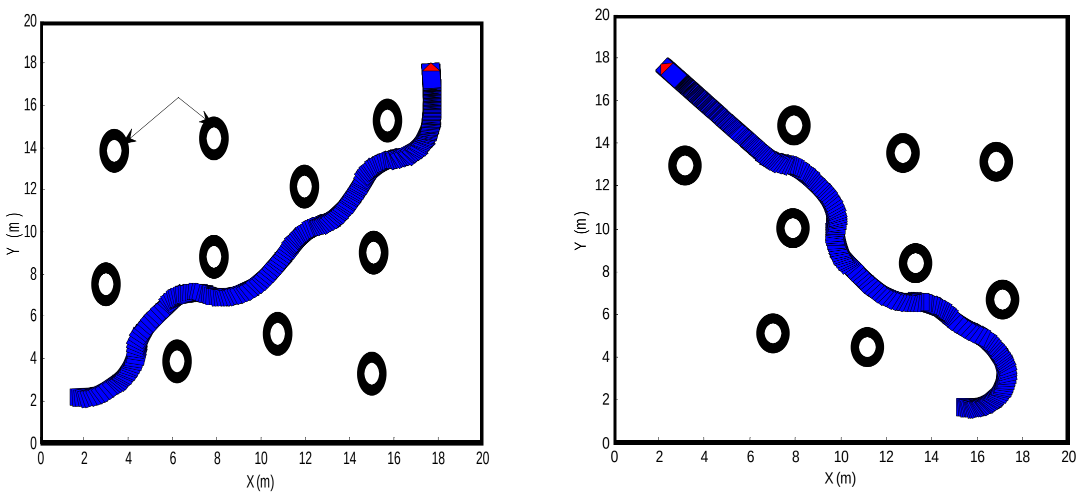

Figure 12 Navigation of robot in unknown environment with obstacles

CONCLUSION

In this paper, we have shown how fuzzy logic approach can be used in a successful way of structuring the navigation task in order to deal with the problem of mobile robot navigation. The fuzzy logic can be effectively used to design behaviors based navigation system. Fuzzy logic controller is well suited for controlling a mobile robot because it is capable of making inference even under uncertainty. A simple coordination method is used to switch between navigation actions according to outputs of each behavior. The obtained results show the efficiency of the proposed control method. In all cases, the robot is able to reach the goal in different configuration of the environment by avoiding obstacles. The interest will be given to the development of a complete navigation system including other behaviors like wall following and avoiding moving obstacles.

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