Fuzzy-based Reactive Controllers for a Simple Goal Seeking and Obstacle Avoidance by a Mobile Robot in unknown Environment

Lakhmissi Cherroun and Mohamed Boumehraz

Abstract -- **This paper deals with the reactive control of an autonomous mobile robot which should move safely in a crowded unknown environment to reach 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 study, issues of individual behavior design will be addressed using fuzzy logic approach. Simulation results show that the designed fuzzy controllers achieve effectively any movement control of the robot from its current position to its end motion and without any collision.**

***Index Terms*-- mobile robot, behavior based navigation, intelligent navigation, fuzzy controller.**

I. Introduction

TERE is a growing interest in service robots and this is due to the fact that robots are finding their way out of sealed working stations in factories to our homes and to populated places such as museum halls, office buildings, railway stations, department stores and hospitals [1]. 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 unmodeled obstacles especially in crowded and unpredictably changing environment [2].

Navigation and obstacle avoidance are very important issues for the successful use of an autonomous mobile robot. When computing the configuration sequence, we allow the robot to move from one position to another. 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 within the surrounding environment [1][2].

A successful way of structuring the navigation task in order to deal with the problem is within behavior based navigation approaches (Brooks [3]) saffiotti [4]). Behavior based navigation systems have been developed as an alternative to the more traditional strategy of constructing representation of the world and then reasoning prior to acting. 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 could be "avoiding obstacles" or "goal seeking". This divide and conquer 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 [3][4]. The suggested outputs from each concurrently active behavior are then "blended" together according to some action coordination rule. A variety of behavior-based control schemes have been inspired by the success of Brooks [3] 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 [12] has described the use of reactive behaviors called motor schemes. In this method, potential field is used to define the output of each schema. Then, all the outputs are combined by weighted summation. Many works used fuzzy logic system to mobile robot navigation and representing behaviors [10][11].

Fuzzy logic controller is well suited for controlling a mobile robot because it is capable of making inference even under uncertainty [5]-[7]. Fuzzy logic is a mathematical tool that can manipulate human reasoning, concepts and linguistic terms. It suits to define systems that handle imprecise information about the system model [8]. A fuzzy controller system is commonly defined as a system that emulates a human expert. 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 [8]-[10].

The objective of this paper is to show how to guide an autonomous mobile robot in an unknown environment using a fuzzy logic approach. 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 work, we will discuss a fuzzy path planning controller design based on expert experience and knowledge that was applied to a tricycle mobile robot. The fuzzy inference system is based on

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a human driver like reasoning in an indoor environment that is free or contains obstacles or other mobile robots.

This paper is organized as follows: Section 2 gives the necessary background of fuzzy logic technique. In section 3, we present the model of the used mobile robot. The proposed controllers are introduced and explained in section 4. Section 5 shows simulation results for examples of movement of the mobile robot in unknown environment. Section 6 concludes the paper.

I. FUZZY LOGIC CONTROL

The theory of fuzzy logic systems is inspired by the remarkable human capacity to reason with perception-based information. Rule-based fuzzy logic provides a formal methodology for linguistic rules resulting from reasoning and decision making with uncertain and imprecise information [8]. The bloc diagram of a fuzzy control system is shown in Fig. 1.

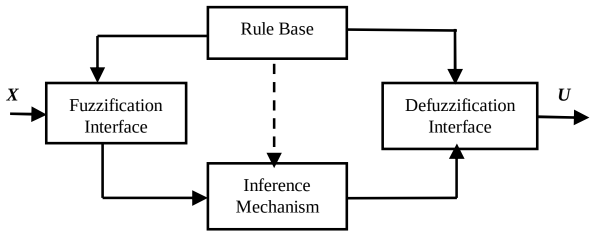


Fig. 1. The structure of fuzzy logic Controller

The fuzzy controller is composed of the following elements [8][9]:

- *A fuzzification interface:* converts controller inputs into information that the inference mechanism can easily use to activate and apply rules.
- *A rule-base:* a set of *If-Then* rules which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve good control.
- *An inference mechanism:* or *"fuzzy inference module"*. It emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.
- *A defuzzification interface:* converts the conclusions of the inference mechanism into actual inputs for the process. There are two types of FLC; Mamdani model and that of Takagi-Sugeno [8]. The structure of fuzzy controller presented in Fig. 1 will be invested for the design of the robot controllers.

II. MOBILE ROBOT KINEMATICS

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) (see Fig.2). In perfect adhesion conditions (movement without sliding), this kinematic model can be described by the following equations [1]:

$$\begin{aligned} \dot{x}_r &= v_r \cos(\theta_r) \\ \dot{y}_r &= v_r \sin(\theta_r) \\ \dot{\theta}_r &= \frac{v_r}{l} tg(\alpha) \end{aligned} \qquad (1)$$

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

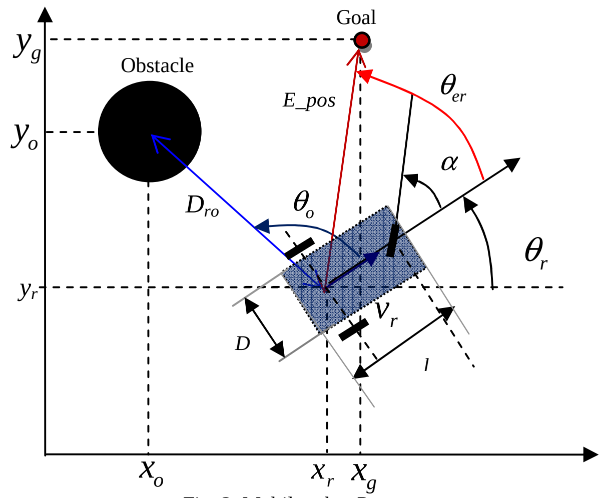


Fig. 2. Mobile robot Parameters

III. PROPOSED CONTROLLERS

In this section, the developed approach is discussed. This design method motivated by the efficiency and the simplicity of making the controller more suitable for real time implementation.

A. *Goal Seeking controller*

The task of the robot is to reach a desired point in the environment called a goal. The bloc diagram of the robot controller is shown in Fig. 3. The calculation module compares the actual robot coordinates with the coordinates of the target. The outputs are the angle noted β and the distance between the robot and the goal (position error) noted *E_pos.* The angle value is compared with the orientation of the robot delivered by the odometry module in order to compute the angle error θ_{er}. 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) .

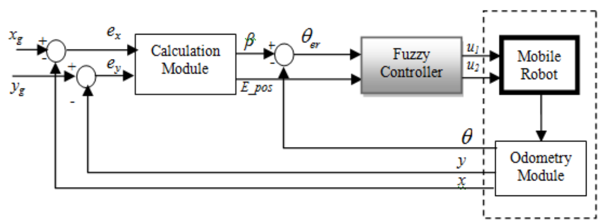


Fig. 3. Fuzzy controller

The inputs variables (angle error and the distance robot-target) are fuzzified using the membership functions depicted in Fig.4 and Fig.5.

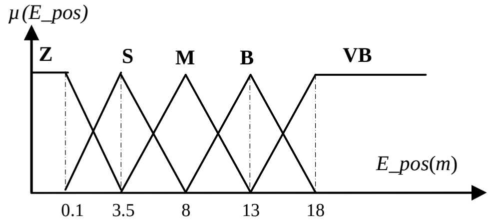


Fig.4. The membership functions for the Error of position

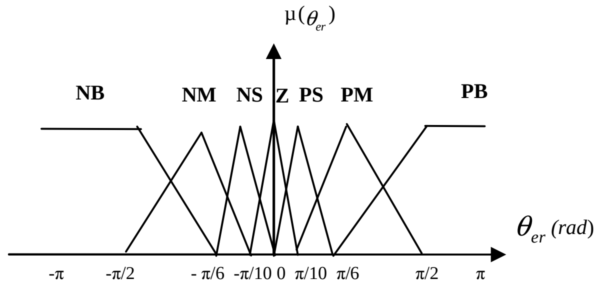


Fig.5. The membership functions of θ_{er}

The outputs variables are represented by the fuzzy sets shown in Fig.6 and Fig.7. With the following linguistic values for all input-output variables: **Z**: Zero, **S**: Small**, M**: Medium, **B**: Big, **VB**: Very, Big **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.

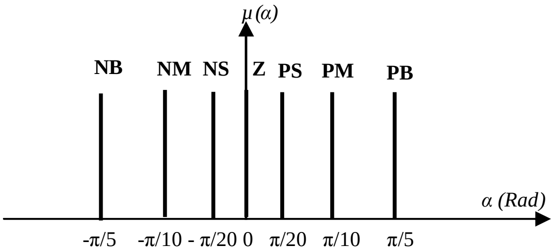


Fig.6. The membership functions of the steering angle command

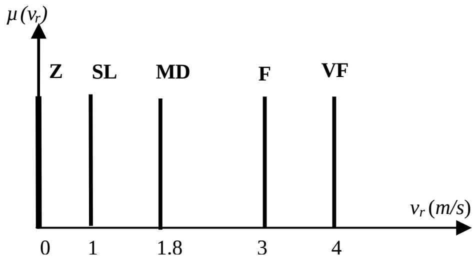


Fig.7. The fuzzy sets of the linear velocity

The Goal seeking task is expected to align the robot's heading with the direction of the goal. We have chosen a Takagi-Sugeno Fuzzy Inference System (FIS) with two inputs and two outputs. Therefore the rule base used for this behavior is shown in table. 1. For example the following rule can be read from the table:

If E_pos is M and θ_{er} *is NM then α is PM and* V_r *is SL*

The values of α and V_r in the consequent part of the rules (see previous rule) are fuzzy labels reduced to a singleton (e.g. ZR(Zero), PS(Positive Small),…). The two outputs of the fuzzy controller are calculated by:

$$\alpha = \sum_{i=1}^{N} w_i \alpha_i \quad \text{AND} \quad V_r = \sum_{i=1}^{N} w_i V_{ri} \tag{2}$$

Where w_i is the truth value of the 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:

$$w_i = \mu_{A_n}(E\_pos) \times \mu_{Bm}(\theta_{er}) \tag{3}$$

A_n and B_m are the membership functions of the position error and the angle error respectively.

TABLE I
FUZZY RULES FOR GOAL SEEKING BEHAVIOR

α/Vr			Angular Error (θ_{er})						
			NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
Position Error (E_pos)	**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 controller

The obstacle avoidance is one of the basic missions of a mobile robot. It is a significant task that must have all the robots, because it permits this machine to move in an unknown environment without collisions [2]. The obstacle avoidance tends to steer the robot in such a way as to avoid collision with obstacles that happens to be in the vicinity of the robot. In the present work, this behavior is realized using another Takagi-Sugeno fuzzy controller. Where the navigation task can be achieved by the two behaviors: obstacle avoidance and goal seeking. The former behavior is inherently *nearsighted* as it only considers how to avoid obstacles and ignores whether it causes the robot to deviate from the goal; whereas the latter behavior is inherently *farsighted* as it enables the vehicle moves toward the goal and neglects if it causes a collision.

Firstly, we consider that the environment where navigate the robot contains uniform shapes of obstacles. So the inputs of the controller are the distance D_{ro} and the error angle to an obstacle θ_o. The inferred actions are the steering angle and the velocity of the robot. The fuzzy sets used for the distance input are depicted in Fig.8. The angle error and the outputs variables have the same membership functions used in the previous section (goal seeking behavior). The fuzzy labels are: SM: Small, MD: Medium and BG: Big.

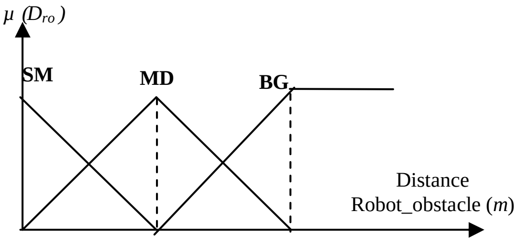


Fig.8. The fuzzy sets of the distance robot-obstacle

The strategy used for this behavior is expressed symbolically by the fuzzy rules presented in table 2.

TABLE II
FUZZY RULES FOR THE OBSTACLE AVOIDANCE BEHAVIOR

α/V_r			Angle θ_o						
			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*

IV. SIMULATION RESULTS

In this section, examples of mobile robot navigation in indoor environment are presented to verify the validity of the proposed schemes. These typical cases were simulated in which a robot is to move from a given current position to a desired goal position in both environment types (obstacle free environment and in the presence of obstacles).

The figures 9.(a-b-c-d) present the robot trajectories for different initial positions of the robot and the goal. As depicted, in all cases the robot moves toward the target from its initial position by delevering continous actions (steering angle and linear velocity). 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 generated control values can be mesured at time of movement as depicted in Fig.10.

The results show the effectiveness of the elaborated behavior. The smoothness and the stability of the robot movements show that fuzzy logic based controller could be a good level of performances.

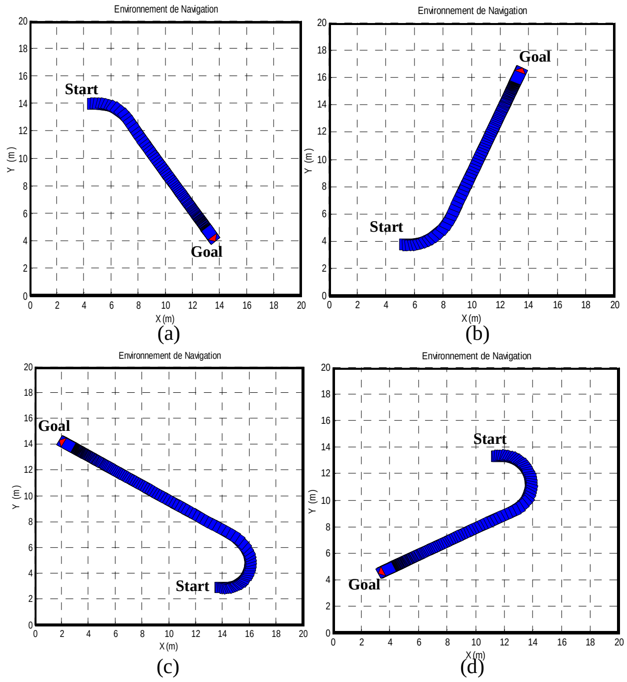


Fig.9. Goal seeking using fuzzy controller

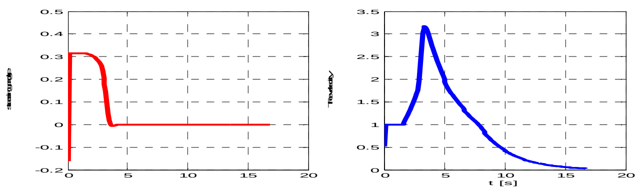


Fig.10. The control values

If the navigation environment contains one or more obstacles, the robot must use the obstacle avoidance controller in order to reach the final destination safely without collision with these objects. Fig.11 shows the robot path in cluttered environment. The robot moves toward the goal, and 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.

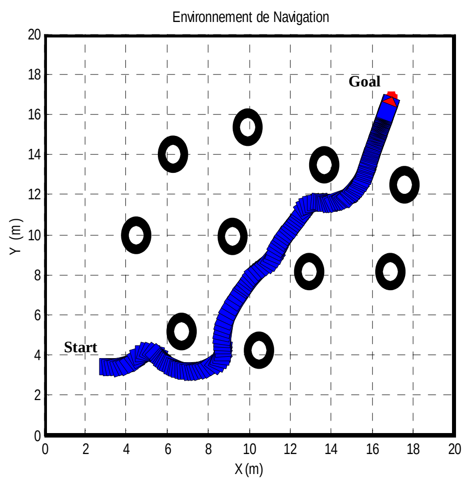
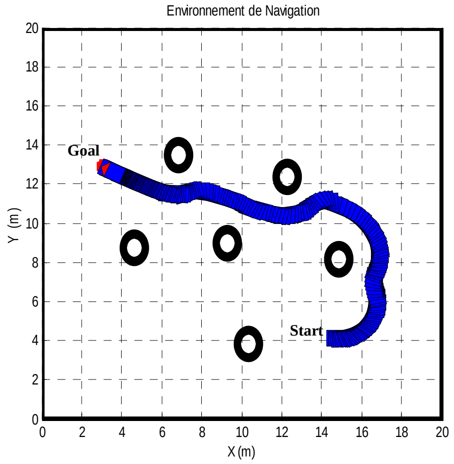
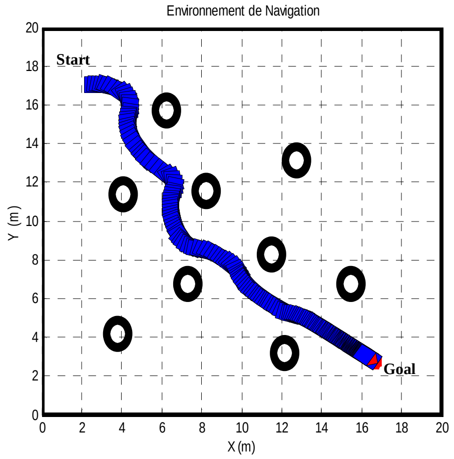


Fig. 11. Navigation of robot in an unknown environment with obstacles

Other examples with multiple obstacles in the environment are shown in Fig. 12 (a-b). The robot in all cases is able to navigate autonomously and can reach the goal by avoiding obstacles successfully.



(a)



(b)

Fig. 12. Examples of navigation in an unknown environment

In the case when the environment of navigation contains obstacles with different shapes, the robot needs to acquire correct information about the environment and it must be able to navigate correctly corresponding to the form of these obstacles. To simplify the studied strategy of navigation, Fig. 13 illustrates the fuzzy sets used to fuzzify the readings of sensors directed in different directions around the robot, where: **N**: near **F**: far. We define d_m as the minimum distance to an obstacle and d_s as a security distance (the robot can move freely).

The elaborated fuzzy controller uses as variables:

- The distances between the robot and the obstacle in the three directions (opposite, on the right and on the left).
- The actions are the steering angle and the velocity of the robot.

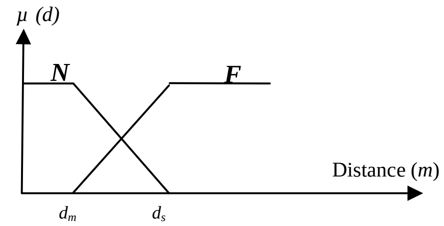


Fig.13. Membership functions for distance to obstacle

The used fuzzy controller gives acceptable results to achieve the mobile robot navigation task. In figures 14, 15 different examples of navigation are presented in various unknown environments. During displacement, the basic mission of the robot is to go toward the goal. When the robot encounters an obstacle which obstructs the goal, the robot must have a capacity of obstacle avoidance. It is observed that the robot is able to move (navigate) in its environment without collision with the obstacles and can reach its target effectively. In figure 16; the robot task is to reach a goal inside a u shaped walls. During movement, the robot goes parallel to the right side wall until the orientation error enters in the limits of a predefined interval of vision. The robot begins to head for the goal to reach it.

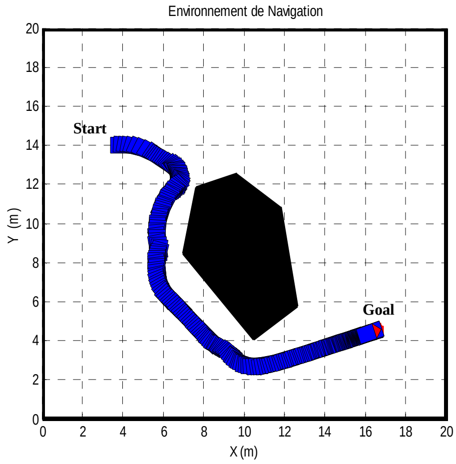


Fig. 14. Navigation in an unknown environment with one obstacle

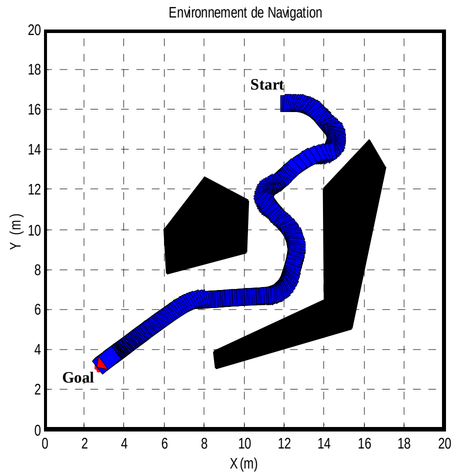


Fig. 15. Robot path in an unknown environment with different forms of obstacles

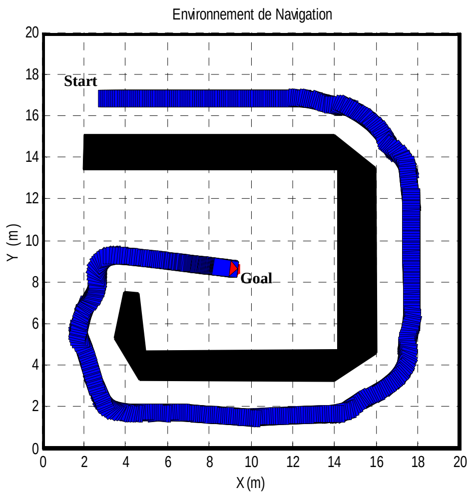


Fig. 16. Reaching a goal inside U shaped walls.

V. CONCLUSION

In this work, we presented an intelligent technique for the mobile robot navigation based on fuzzy logic approach. The fuzzy controllers can be effectively used to design behaviors based navigation system. 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. It is of a great importance to emphasize on the obtained smoothness of the robot movements.

In future works, 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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