

FUZZY BEHAVIOR BASED NAVIGATION APPROACH FOR MOBILE ROBOT IN UNKNOWN ENVIRONMENT

Lakhmissi CHERROUN Mohamed BOUMEHRAZ

Sciences and Technology Department, University of Djelfa-17000, Algeria

Sciences and Technology Department, University of Biskra-07000, Algeria

E-mail: cherroun_lakh@yahoo.fr, medboumehraz@netcourrier.com

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 without any collision.*

Key words: *Mobile Robot, Behavior-Based Navigation, Goal Seeker, Obstacle Avoider, TS-Fuzzy Controller.*

1. Introduction

There is growing interest in applications of mobile robots. This is due to the fact that the 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][3]. 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 with the surrounding environment [1][3].

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", "goal seeking" or "wall following". 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 [5][6]. 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 [7] 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. Fuzzy logic controller is well suited for controlling a mobile robot because it is capable of making inference even under uncertainty [5][8]-[11]. 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 [12]. 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 [13].

The objective of this paper is to show how to guide an autonomous mobile robot in an unknown environment using 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 a human driver like reasoning in an indoor environment that is free or contains obstacles or other mobile robots.

The paper is organized as follows: Section 2 gives the necessary background of fuzzy logic technique and a brief of fuzzy behavior based navigation. 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 robot in unknown environment. Section 6 concludes the paper.

2. Fuzzy logic control

A. Fuzzy Controller Structure

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 [12]. The block diagram of a fuzzy control system is shown in Fig. 1.

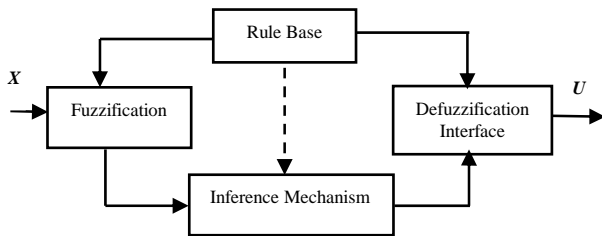


Fig. 1 The structure of fuzzy logic Controller

The fuzzy controller is composed of the following elements [12]:

- *Fuzzification interface*: converts the real controller inputs (X) 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*: It emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.
- *Defuzzification interface*: converts the conclusions of the inference mechanism into actual inputs (U) for the guided process. There are two popular types of FLC; Mamdani and Takagi-Sugeno model. The structure of

fuzzy controller presented in Fig. 1 will be invested for the design of the robot behaviors using zero order TS model due to its simplicity of effectiveness to the process control.

B. Fuzzy Behavior Based Navigation

In fuzzy behavior based navigation approach, the problem is decomposed into simpler tasks (behaviors). The control level contains primitive behaviors to perform special task, which is in this configuration as depicted in figure. 2, each behavior is considered as a controller composed of a set of fuzzy logic rule statements aimed at achieving a defined objective. The behaviors are supervised using a coordination system for generating the appropriate action transmitted to the actuators. 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 modify or add new behaviors to the system without causing any major increase in complexity [3][5].

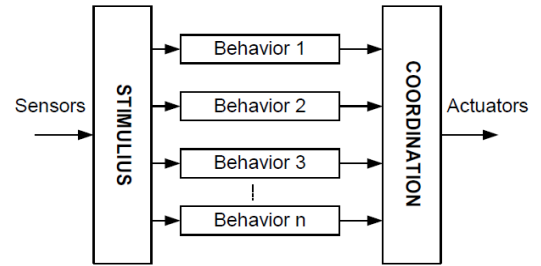


Fig. 2 The structure of behavior based navigation

3. 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 of the front wheel and the linear velocity v_r . The outputs are the coordinates of the robot: (x_r, y_r, θ_r) . In perfect adhesion conditions (movement without sliding), this kinematic model can be described by the following equations:

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

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

In our work, we suppose that the simulated mobile robot is able to detect the coordinates of the final goal and it is equipped by sensors for perceiving its environment. Fig.3 shows the mobile robot parameters and the used variables.

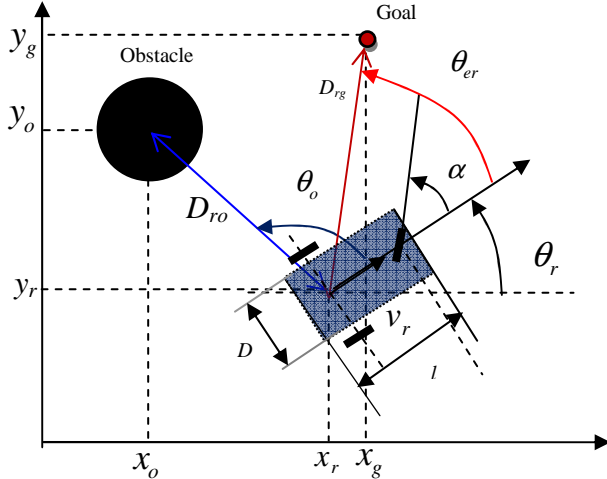


Fig. 3 The parameters of the mobile robot

4. Designing of Fuzzy 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 behavior (GSB)

The task of the robot is to reach a desired point in the environment called a goal. This goal seeking behavior is expected to align the robot's heading with the direction of the goal coordinates. The block diagram of the robot controller is shown in Fig. 4. The calculation module compares the actual robot coordinates with the coordinates of the target using mathematical equations. The outputs are the angle noted θ_d and the distance between the robot and the goal (position error) noted D_{rg} . 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} between the robot axis and the goal vector. We have chosen a zero order Takagi-Sugeno Fuzzy Inference System (FIS) with two inputs and two outputs. The designed fuzzy controller uses these two values D_{rg} and θ_{er} as depicted in the figure to generate the appropriate actions to reach the target where u is a vector containing two values (u_1 is the steering angle α and u_2 is the robot speed v_r). 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 D_{rg} 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 the following equations:

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

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:

$$w_i = \mu_{A_n}(D_{rg}) \times \mu_{B_m}(\theta_{er}) \quad (3)$$

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

The inputs variables are fuzzified using the membership functions depicted in Fig.5 and Fig.6. The type and the positions of the fuzzy sets are based on the designer experience about the studied task. Optimization methods can be used for tuning the premise parameters and the conclusion parts [14][15].

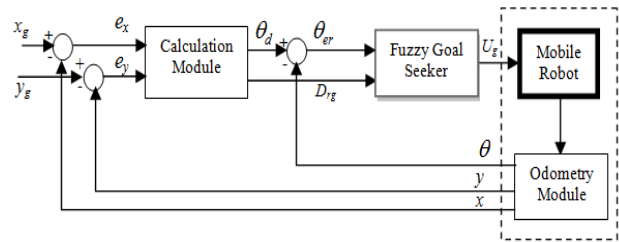


Fig. 4 Fuzzy goal seeker

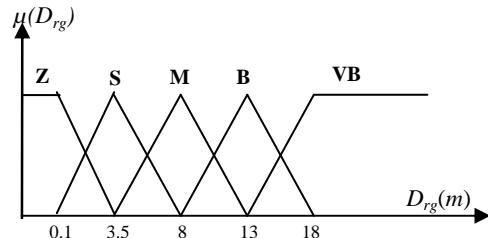


Fig.5. The membership functions for the distance robot-goal

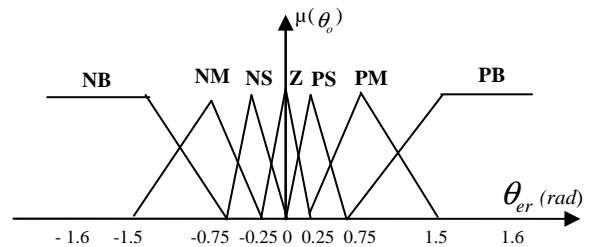


Fig.6 The membership functions of θ_{er}

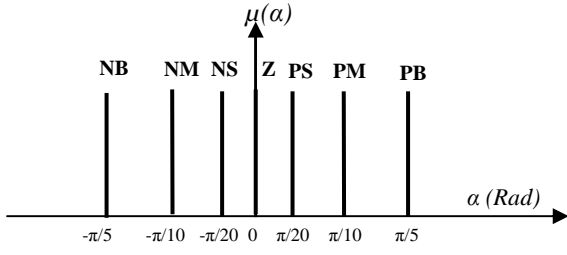


Fig.7 The membership functions of the output steering angle

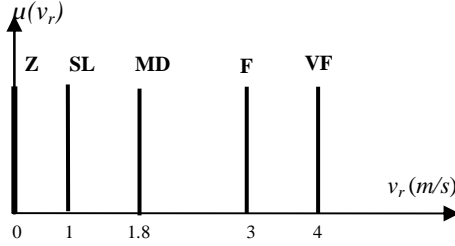


Fig.8 The fuzzy sets of the linear velocity

The outputs variables are represented by the fuzzy sets shown in Fig.7 and Fig.8 using the following linguistic terms 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.

TABLE I
FUZZY RULES FOR GOAL SEEKING BEHAVIOR

a/V_r		Angular Error (θ_{er})							
		NB	NM	NS	Z	PS	PM	PB	
Distance robot-goal (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
	V	α	PM	PM	PS	Z	NS	NM	NM
		V_r	SL	MD	F	VF	F	MD	SL

B. Obstacle Avoidance behavior (OAB)

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.

Our contribution presented here is based on two applications, the first using navigator with two behaviors (GSB) and (OAB) for generating the two outputs control. But the second focuses to implement five fuzzy behaviors (GSB, FOA, ROA, LOA and VRB) to accomplish the navigation task.

1. Using the distance and angle error:

In the first application, we consider that the environment where navigate the robot contains uniform shapes of obstacles as presented in Fig. 3. 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 defined by the vector U_o . The fuzzy sets used to fuzzify the distance input are depicted in Fig.9 with three fuzzy labels: **SM**: Small, **MD**: Medium and **BG**: Big. The angle error and the outputs variables have the same membership functions used in the previous section (goal seeking behavior in figures 6-8). The architecture of the proposed robot navigator is shown in Fig. 10. The navigation task is realized by switching between the two main behaviors (goal seeking and obstacle avoidance). Using sensor readings about the target position (x_g, y_g) and the nearest obstacle (x_o, y_o) to activate the corresponding behavior for mobile robot movement.

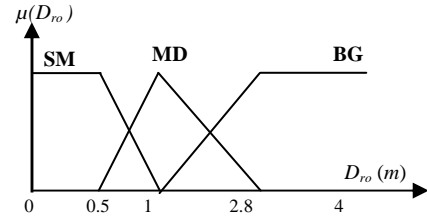


Fig.9 The fuzzy sets of the distance robot-obstacle

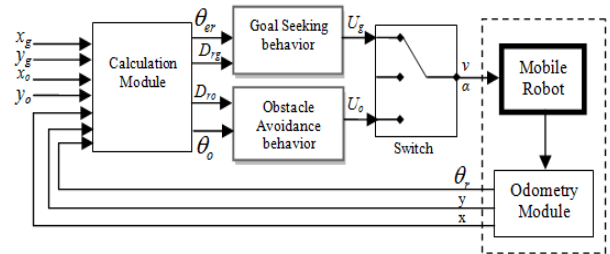


Fig. 10 Fuzzy Navigator

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

TABLE II
FUZZY RULES FOR OBSTACLE AVOIDANCE BEHAVIOR

		Angle θ_o							
		α/V_r	NG	NM	NP	Z	PP	PM	PG
Distance D_o	SM	α	NM	NM	NB	NB	PB	PM	PM
		V_r	SL	SL	Z	Z	Z	SL	SL
MD	BG	α	NS	NM	NB	NB	PB	PB	PS
		V_r	MD	MD	SL	SL	SL	MD	MD
BG	MD	α	Z	Z	NM	NM	PM	Z	Z
		V_r	MD	MD	MD	MD	MD	MD	MD

2. Using the distances in the three sides:

In the second application, the environment of mobile robot navigation contains obstacles with different shapes (ellipses, polygons, walls...), 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. The architecture of proposed navigator is depicted in the Fig. 11. It consists of 5 main behaviors: a goal seeking behavior (GSB), front obstacle avoidance (FAO), right obstacle avoider (RAO), left obstacle avoider (LAO) and velocity reducing behavior (VRB). These behaviors are connected with a simple supervisor for switching the appropriate action that will be transmitted to the robot actuators.

For designing the proposed behaviors, the sensors around the robot are collected in three groups (*modules*). Each module uses three reading sensors as inputs to generate the appropriate steering angle α for avoiding the nearest obstacles. The sensor i detects the nearest distance to an obstacle d_i where $i = 1, \dots, 7$. Figure. 12 shows the clustered sensors around the robot. The membership functions of the control output (the steering angle) are the same used in the previous behaviors (with singleton forms).

- The module 1 for front obstacle avoidance. Their inputs are d_1, d_2, d_3 .
- The module 2 for right obstacle avoidance. Their inputs are d_2, d_4, d_6 .
- The module 3 for left obstacle avoidance. The inputs are the distances d_3, d_5, d_7 .

Fig. 13 illustrates the fuzzy sets used to fuzzify the readings of sensors directed in different directions around the robot, where: **NR**: near **FR**: far, and d_m is the minimum permitted distance to an obstacle, and d_s is the safety distance beyond which the robot can move at high speed. The fuzzy rules of the three behaviors are presented in tables 3, 4 and 5.

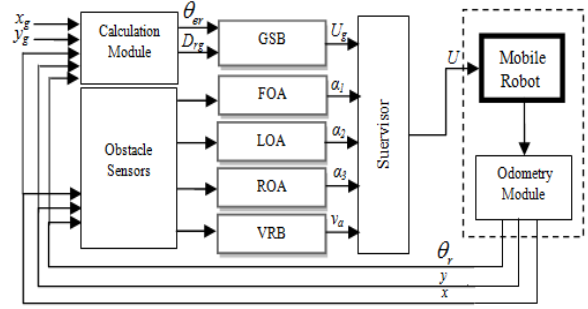


Fig. 11 Fuzzy Behavior Navigator

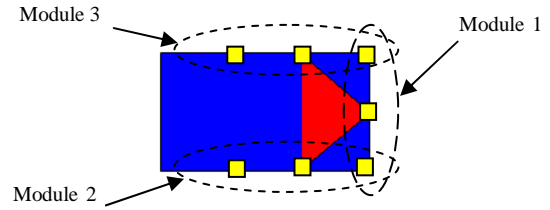


Fig.12 Clustered sensors

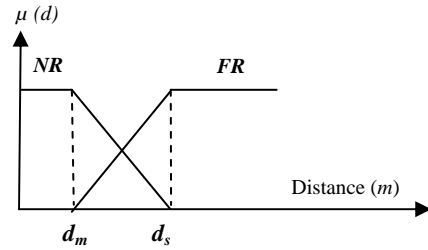


Fig.13 Membership functions for the distance to an obstacle

TABLE III
FUZZY RULES FOR THE FRONT OBSTACLE AVOIDANCE BEHAVIOR (MODULE1)

Steering angle α			Distance d_3			
			NR		FR	
			Distance d_1			
			NR	FR	NR	FR
d_2	F	α	PB	PM	PB	Z
	Z	α	PB	PM	PB	NB

TABLE IV
FUZZY RULES FOR THE RIGHT OBSTACLE AVOIDANCE BEHAVIOR (MODULE 2)

Steering angle α			Distance d_6			
			NR		FR	
			Distance d_4			
			NR	FR	NR	FR
d_2	F	α	NM	Z	NM	Z
	Z	α	NB	NM	NB	NM

TABLE V
FUZZY RULES FOR THE LEFT OBSTACLE AVOIDANCE BEHAVIOR (MODULE 3)

Steering angle α			Distance d_7			
			NR		FR	
			Distance d_5			
			NR	FR	NR	FR
d_3	F	α	PM	PM	PM	Z
	Z	α	PB	PM	PB	PM

In the case of obstacle avoidance behavior; the robot must reduce its velocity. For this purpose, the global architecture of the navigator is modified using an additional TS fuzzy controller (VRB: velocity reducing behavior) for generating the adjusted velocity added to the current executed speed. This action is noted (V_{adjust}). The inputs of this behavior are the actual linear velocity (V_r) and the minimum distance to an obstacle in the three sides noted (D_{min}) with the two membership functions (NR and FR) depicted in Fig. 14. The Figures 15 and 16 show the fuzzy sets of the actual and the generated robot speed where; **SL**: slow, **F**: Fast, **VF**: Very Fast), (**NC**: No Changed, **I**: Increase, **D**: Decrease, **IB**: Increase Big, **DB**: Decrease Big). The rule base is defined in table.6.

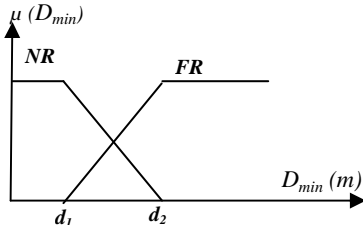


Figure 14 Fuzzy sets for D_{min}

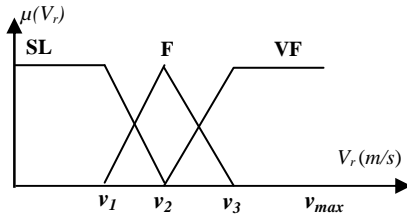


Fig.15 Membership functions for the distance to an obstacle

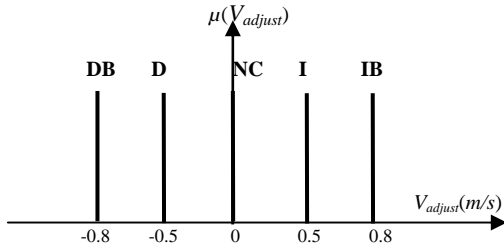


Fig.16 Membership functions of the adjusted velocity

TABLE VI
FUZZY RULES FOR THE VELOCITY

Robot velocity		Distance D_{min}	
		NR	FR
Velocity	SL	V_r	NC
	F	V_r	D
	VF	V_r	DB

5. Simulation Results

A. Results of Goal seeking behavior

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 the robot task 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 simulation is done using Matlab software by modeling all parts of the robot navigation task (mobile robot, target, walls, obstacles, and the studied approaches Takagi Fuzzy Logic Controllers.

The figures 17.(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 generating continuous actions (steering angle and linear velocity). The elaborating fuzzy controller is well performed to accomplish this task and it has an advantage to equip the robot with a certain degree of intelligence. The generated control values can be measured at time of movement as depicted in Fig.18. We observed that after some time steps of steering, this control value is equal zero illustrates the orientation of the robot to the direction of the goal. The linear velocity of the mobile robot decreases when it approaches the target. 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.

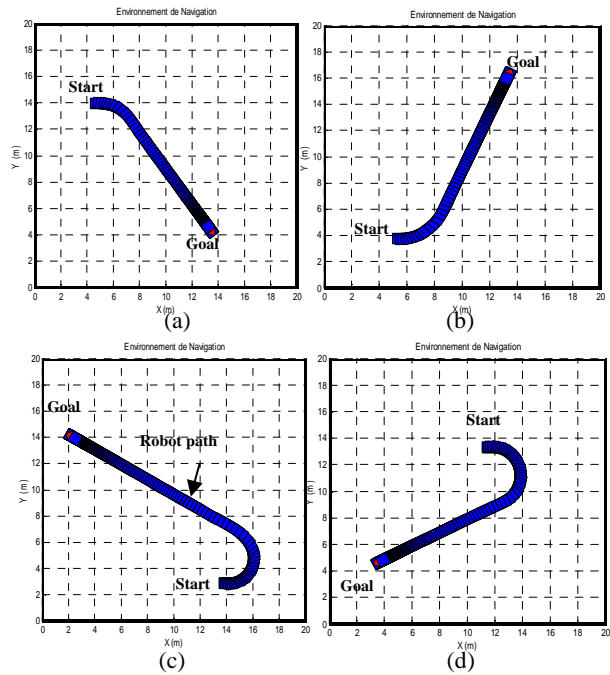


Fig.17 Goal seeking using TS fuzzy controller

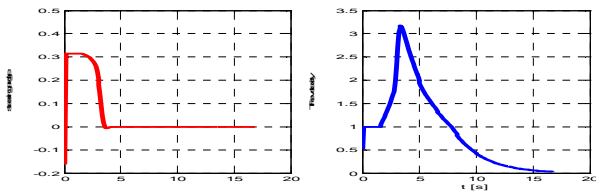


Fig.18 The output controls (steering angle and velocity)

B. Navigation with Obstacle Avoidance

If the navigation of environment 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 these objects. Figures 19-20 present the robot paths in examples of cluttered environments. 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. With multiple obstacles in the environment, the robot in all cases is able to navigate autonomously and can reach the goal by avoiding obstacles successfully.

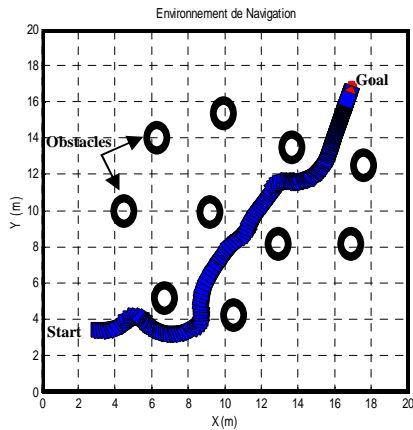


Fig.19 Navigation of robot in unknown environment with multiple obstacles

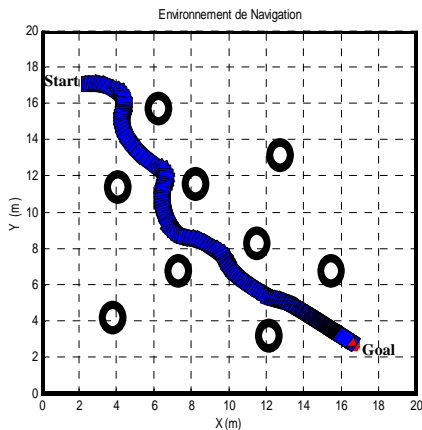


Fig. 20 Mobile robot navigation in unknown environment

C. Navigation with Obstacle Avoidance (2nd application)

The used fuzzy controller gives acceptable results to achieve the mobile robot navigation task. In figures 21, 22 different examples of navigation are presented in various unknown environments. During movement, 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 23; the robot task is to reach a goal inside a u shaped walls. During the sequence of the displacement, the robot goes parallel to the left 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.

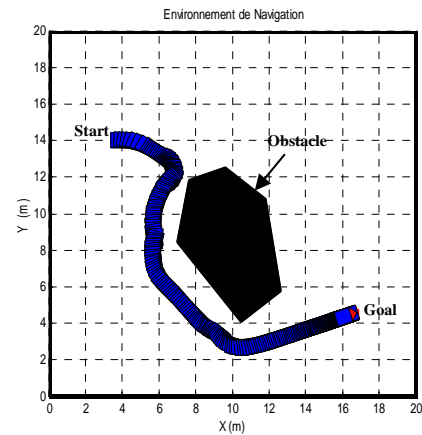


Fig.21 Navigation in unknown environment with one obstacle

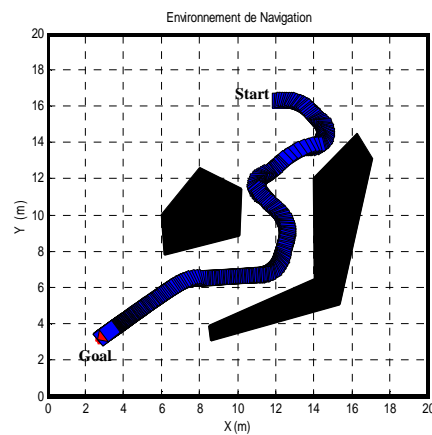


Fig.22 Robot path in unknown environment with different forms of obstacles

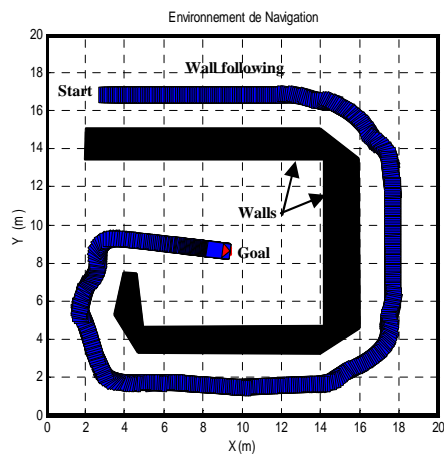


Fig.23 Reaching a goal inside U shaped walls

6. Conclusion

In this paper, we have presented an intelligent technique for the mobile robot navigation based on fuzzy behavior based navigation 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 configurations 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. The optimization of fuzzy controller parameters is an interesting approach to be studied.

References

1. S. G. Shuzhi, F. L. Lewis, "Autonomous Mobile Robots, Sensing, Control, Decision, Making and Applications", CRC, Taylor and Francis Group, 2006.
2. J. C. Latombe, "Robot Motion Planning", Norwell, MA: Kluwer, 1991.
3. R. Brooks, "A Robust Layered Control System for a Mobile Robot", IEEE Journal on Robotics and Automation, Vol. 2, No. 1, pp.4-23, 1986.
4. A. Saffiotti, "The Uses of Fuzzy Logic for Autonomous Robot Navigation", Soft Computing, Vol. 1, No. 4, pp. 180-197, 1997.
5. A. Fatmi, A. S. Al Yahmedi, L. Khriji and N. Masmoudi, "A Fuzzy Logic based Navigation of a Mobile robot", World academy of science, Engineering and Technology, Vol. 22, pp. 169-174, 2006.
6. C. Ye, N. H.C. Yung and D. Wang, "A Fuzzy Controller with Supervised Learning Assisted Reinforcement Learning Algorithm for Obstacle Avoidance". IEEE Trans. Syst., Man, and Cybern. B, vol. 33, no.1, pp.17-27, 2003.
7. R. C. Arkin, "Motor schema-based mobile robot navigation ", International Journal of Robotic Research, Vol 8, pp. 92-112, 1989.
8. F. Abdessemed, K. Benmahammed and E. Monacelli, "A Fuzzy-based Reactive Controller for Non-holonomic Mobile Robot", Robotics and Autonomous Systems, vol. no. 47, pp. 31-46, 2004.
9. H. Seraji and A. Howard. "Behavior-based Robot Navigation on Challenging Terrain: A Fuzzy Logic Approach", IEEE Trans. Rob. Autom. Vol. 18, No. 3, pp. 308-321, 2002.
10. L. Cherroun and M. Boumehraz, "Designing of Goal Seeking and Obstacle Avoidance Behaviors for a Mobile Robot Using Fuzzy Techniques", Journal of Automation and Systems Engineering (JASE), Vol no 6, Issue 4, pp. 164-171, 2012.
11. I. Ayari and A. Chatti, " Reactive Control using Behavior Modeling of a Mobile Robot", International Journal of Computers, Communications & Control, Vol. 2, No. 3, pp. 217-228, 2007.
12. K. M. Passino and S. Yurkovich, "Fuzzy Control", Menlo Park: Addison Wesley, 1998.
13. X. Yang et al, "A Layered Goal-Oriented Fuzzy Motion Planning Strategy for Mobile Robot Navigation". IEEE Trans. Syst., Man, and Cybern. B, vol. 35, No.6, pp.1214-1224, 2005.
14. J.-S.R Jang, "ANFIS: Adaptive-Network-based Fuzzy Inference System", IEEE Trans. on Systems, Man, and Cybernetics, Vol 23, pp. 665-685, 1993.
15. L. Cherroun and M. Boumehraz, "Tuning Fuzzy Controllers by Q-learning for Mobile Robot Navigation". In Proceeding of the International Conference on Electrical Engineering, Electronics and Automatics ICEEA'10, November 2010, University of Bejaia, Algeria.