Fuzzy Logic Based Control for Autonomous Mobile Robot Navigation and Obstacles Avoidance

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Abstract— **This study proposes two fuzzy logic controllers for path planning and obstacle avoidance for mobile robots operating in hostile environments. This paper's major goal is to demonstrate how to use a fuzzy controller with a minimum of eight rules to steer an autonomous mobile robot in a confusing environment. The proposed approach aims to change the movements, guidelines and displacements of the mobile robot to achieve the objectives with an obstacle avoidance strategy. When the robot approaches the obstacle, the collision avoidance behavior is proactive, otherwise else, goal-finding behavior continues. We employed V-REP and MATLAB tools to check the viability and efficiency of the suggested model. The simulation results demonstrated that the performance of our two intelligent controllers allowed the mobile robot to successfully navigate in an uncharted terrain.**

Keywords--Path planning, obstacle avoidance, Fuzzy logic controller, mobile robot

I. INTRODUCTION

The ability to autonomously navigate in an unfamiliar environment is one of the most difficult components of mobile robotics. Finding local impediments, navigating past them, and arriving at a destination are the main challenges. Path planning and reactive navigation are the two categories into which mobile robot navigation can be divided. Potential fields, genetic algorithms, neural networks, vision, and fuzzy logic are just a few of the techniques that have been developed in recent years to address the navigation issues that arise with mobile robots. It has been established that fuzzy logic is a useful tool for handling incomplete information including measurement, process, model and implementation uncertainties in robot navigation [1]-[3]. It is real that the fuzzy logic method needs practice and testing because the best function can only be determined through trial and error, which can take some time. However, fuzzy logic is still the approach most frequently used approach in autonomous mobile robots to avoid obstacles for various reasons. [4]–[6]: it is easy to model reasoning, it can handle uncertainty and nonlinearity, it can be easily implemented and used with linguistic variables, it mimics human control logic, uses imprecise language and is inherently stable, it's adaptable and can be modified, and it can be combined with traditional control techniques [7].

For path planning and obstacle avoidance for mobile robots working in different environments, we propose two fuzzy controllers in this paper. We want to use a simple inference system to show that this strategy is feasible. For the autonomous mobile robot's best navigation, we divided the navigation system into two simple-to-manage controllers: a free navigation fuzzy controller and an obstacle avoidance controller.

The organization of this article is as follows. The introduction is presented in Section I. In Section II, the suggested working context is provided. The approach is described in Section III. Results from the simulation are displayed in Section IV, and conclusions are offered in Section V.

II. PROPOSED WORKING CONTEXT

This work was created for a wheeled unicycle mobile robot. The robot's front wheels are connected to independent motors that govern steering, while its rear wheel serves as a caster wheel for equilibrium. The direction (motor speed) of the front wheels dictated how the mobile robot moved. Figure 1 depicts the robot's kinematic modeling. In Figure 1, VR and VL stand for the mobile robot's right wheel and left wheel speeds, respectively. Between the drive wheel axes' centers is where the point P is situated. The field navigation environment is coupled to the reference point (O, X, Y). The center point (Xc, Yc) is the center of the two steered front wheels and θ is the steering angle (O, X) around the axle. The following kinematic equation describes the motion and direction of the robot in a terrain navigation environment:

$$[i+1] = X[i] + V cos\theta \quad (1)$$

$$[i+1] = Y[i] + V sin\theta \quad (2)$$

$$\theta = \tan^{-1}\frac{[G_y - y[i]]}{[G_x - x[i]]} \qquad (3)$$

where i = 0, 1, 2,…, n.

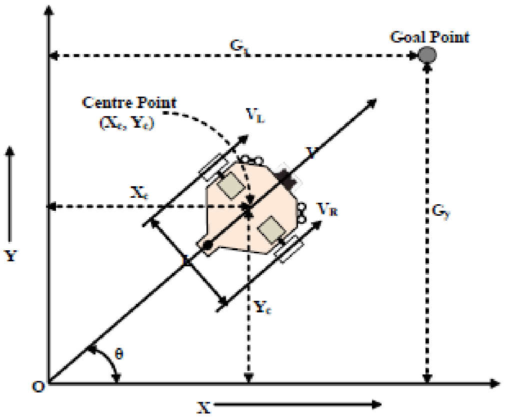


Fig. 1. The kinematic modeling of a robot

where X [i] is the actual position of the moving robot on the X axis and X [i] is the updated position of the robot as it moves forward using Equation 1. Y [i] is the actual position of the mobile on the Y axis of the robot and Y [i 1] is the updated position of the robot as it moves forward using equation 2. The angle θ is the directional angle of the moving robot and that directional angle changes (or is updated) depending on the location of the target in the environment. Gx and Gy are the points of the target (or object) on the X and Y axes respectively. V is the average speed in meters per second (m / s); VL means left linear speed and VR means right linear speed.

PROPOSED APPROACH

The principal goal of this research must be allowed a mobile robot to navigate independently from the starting point to the end in an unknown hostile environment. For this purpose, two zero-order Takagi-Sugeno fuzzy logic controllers with minimal rules are used:

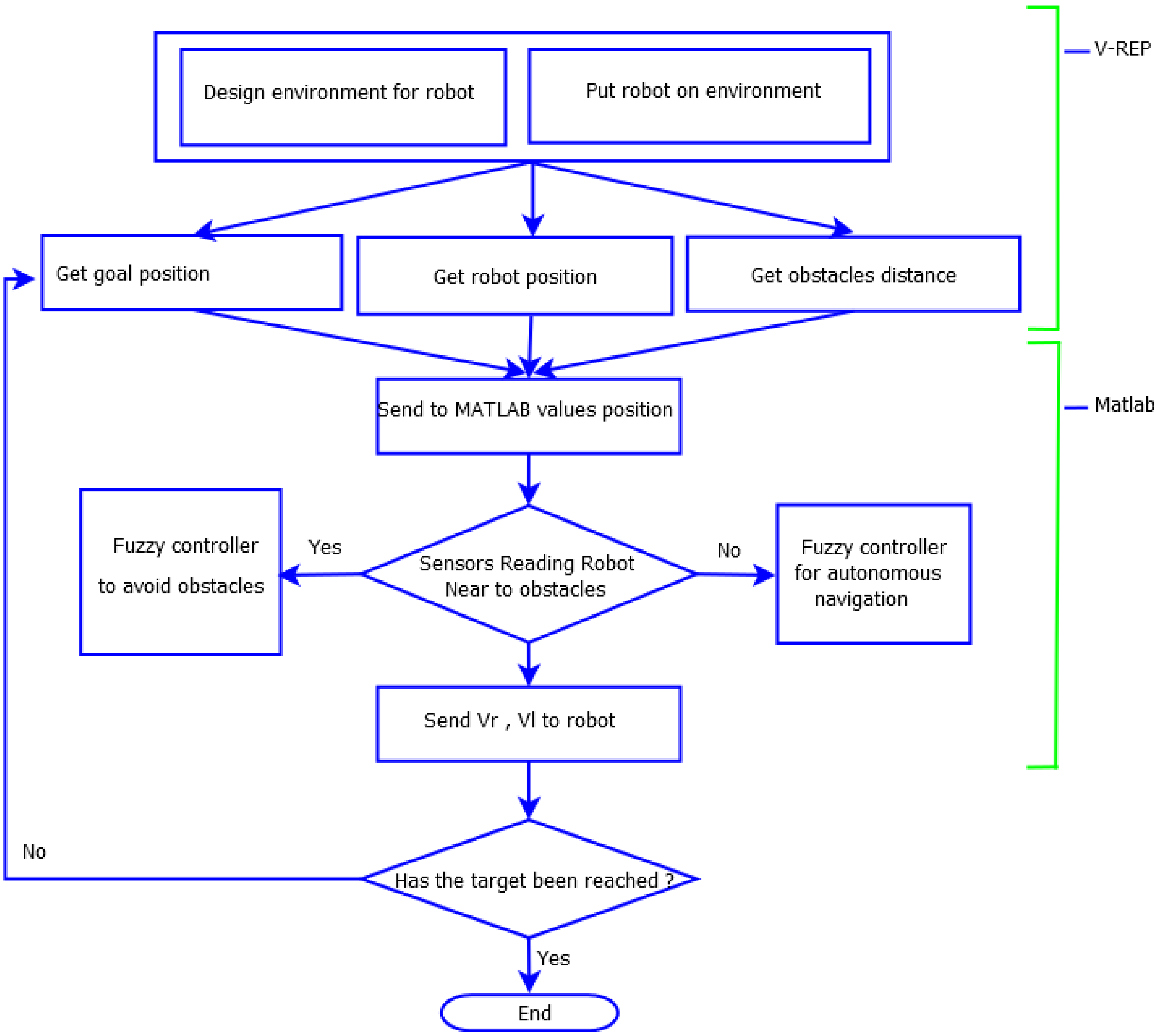


Fig. 2. The functional architecture of the proposed system

The first fuzzy controller is responsible for generating adequate movements to ensure robot navigation from start point to the target, and the second controller is responsible for obstacle avoidance. The Figure 2 presents the functional architecture of the proposed system.

A. *Fuzzy controller for autonomous navigation*

This controller allows the mobile robot to perform the action "convergence towards the goal" from the knowledge of its current position and the definition of a relative position to reach in the navigation environment (it makes the robot toward the goal direction).

The calculation module compares the actual robot coordinates with the goal coordinates to calculate the robot-to-goal distance and the desired angle θ to reach it. Then compare this angle value with the robot's current orientation θr to calculate the angle between the robot's axis and the target θ` using the following formula:

$$D = \sqrt{(G_x - x)^2 + (G_y - y)^2} \qquad (4)$$

$$\theta = \tan^{-1}\frac{(G_y - y)}{(G_x - x)} \qquad (5)$$

$$\theta' = \theta - \theta r \qquad (6)$$

The fuzzy controller developed for the navigation task receives the angle θ' between the object and the robot as input. Figure 3 shows the angular error E_ang defined by seven membership functions: negative large (NG), negative medium (NM), negative small (NP), zero (Z), positive small (PP), positive medium (PM) and positive large (PG) in the universe of discourse [−pi/2 pi/2] rad. The outputs of the controller are the speed of the right wheel □□ and the speed of the left wheel □□ as shown in Figure 3. The maximum and minimum speed of the mobile robot used for navigation is 1.2 m/s and 0.1 m . /s.

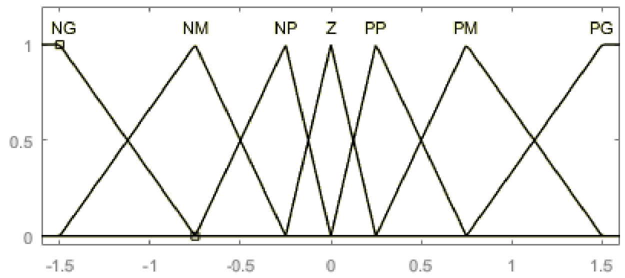


Fig. 3. Fuzzy membership function for the input variable Angular error.

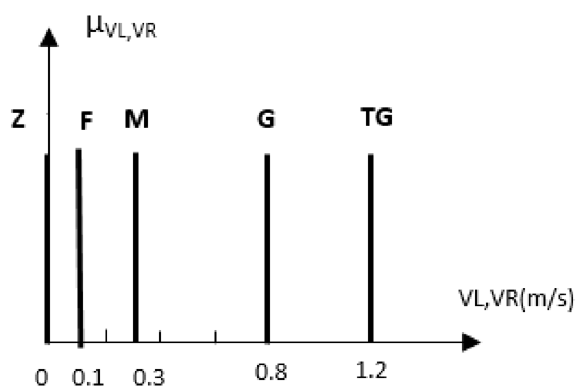


Fig. 4. Sugeno type fuzzy membership function for the output variables VL,VR

TABLE I. FUZZY RULES DESIGNED IN THE FIRST PROPOSED CONTROLLER.

Fuzzy rules number	Angular Error E_ang	Left motor speed	Right motor speed
1	NG	TG	F
2	NM	G	F
3	NP	G	M
4	Z	G	G
5	PP	M	G
6	PM	M	TG
7	PG	F	TG

B. *Fuzzy obstacle avoidance controller*

To navigate safely without human intervention,mobile robots must use a series of sensors to acquire information about their surroundings.

The propose fuzzy controller has three inputs and two outputs. The three inputs are the distances of the obstacles, which are obtained from the front, left and right sensors of the pioneer p3dx robot.

These sensors detect obstacles within a range of approximately 0.3 to 1 meter. As shown in Figure 5, the combined readings from the two frontmost ultrasonic sensors (3, 4) are used for the forward distance, sensor 0 is used to display the left distance, and the right distance selects sensor 7.

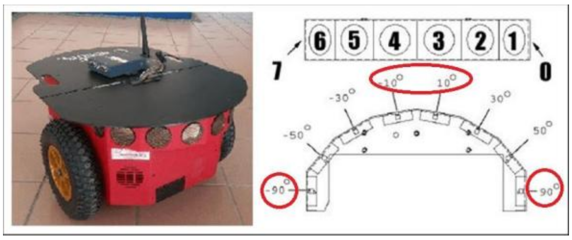


Fig. 5. Sensor assemblies used in our FLC obstacle avoidance design.

The controller outputs are denoted by the Left Motor adjustment Speed (VL) and the Right Motor adjustment Speed(VR) respectively, and are distributed by five constants singletons as presented on figure 4.The meanings of the labels of output are: DI (Significant Decrease), D (Decrease), AC (No Change), A (Increase) and AI (Significant Increase). Using this distribution, the table of inference from speed variation includes only 8 fuzzy rules (Table II).

TABLE II. FUZZY RULES DESIGNED IN THE PROPOSED CONTROLLER

Fuzzy rules number	Front obstacle distance	Left obstacle distance	Right obstacle distance	Left motor speed	Right motor speed
1	Far	Far	Far	AC	AC
2	Far	Near	Far	AC	D
3	Far	Near	Near	D	D
4	Far	Far	Near	DI	AC
5	Near	Near	Near	AI	D
6	Near	Near	Far	AI	DI
7	Near	Far	Far	DI	AC
8	Near	Far	Near	DI	AI

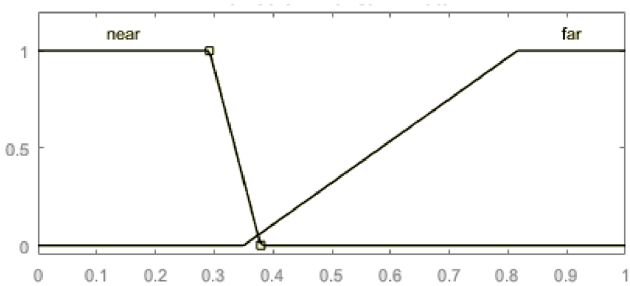


Fig. 6. Fuzzy membership function for the input variable Distance from the front obstacle

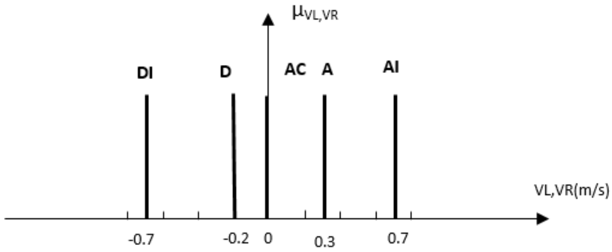


Fig. 7. Sugeno fuzzy membership function for output variables

III. Simulations Results

In this work, a navigation application for the pioneer robot p3dx was developed using VREP and the MATLAB platform. Simulate this designed application on VREP to observe the comportment of the mobile robot. The application developed in this researcher is simulated on a computer with Intel Core i7, 8 GB RAM and Windows 10 operating system. VREP V3.6.2 and MATLAB 2016b software were used. The figures below show some navigation cases:

In the first scenario shown in Figure 8, the navigation is smooth towards the target without the presence of obstacles.

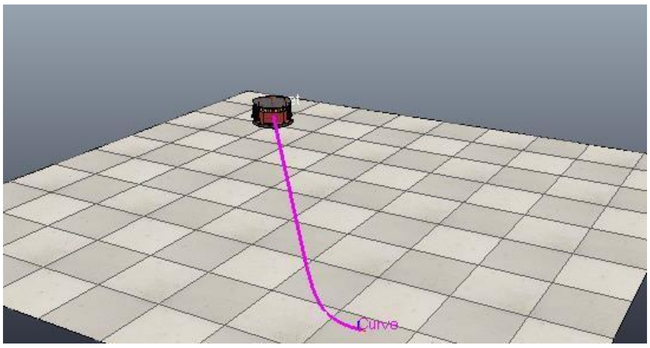
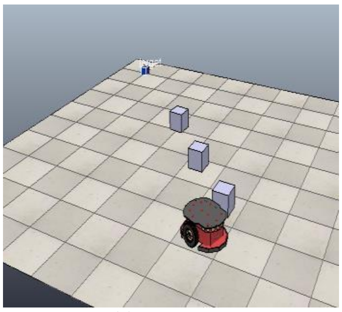
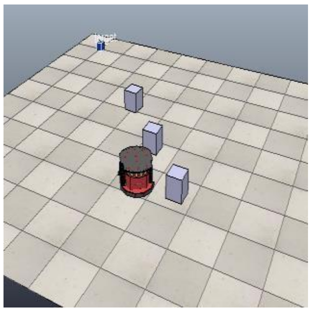


Fig. 8. Navigation in environment without obstacles

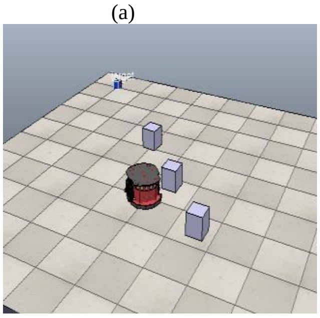
The second navigation scenario is a simple environment with only three obstacles: If the robot encounters an obstacle,it is required to make a small turn to avoid collision with theobstacle as illustrated in the Figure 9 (a), (b), (c), (d) and(e).



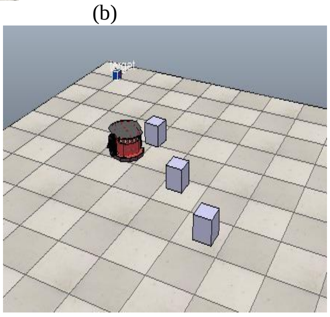
(a)



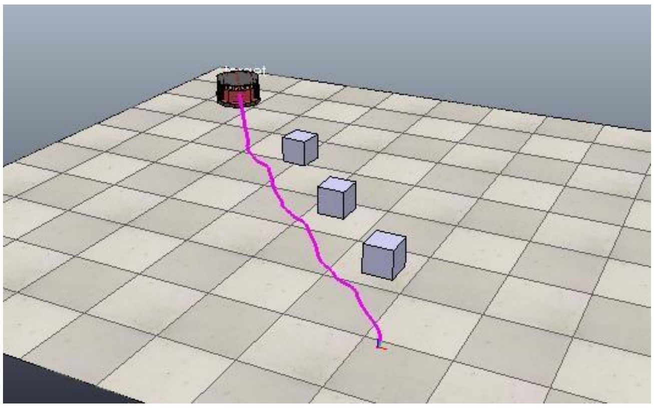
(b)



(c)



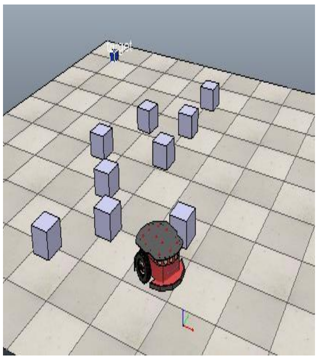
(d)



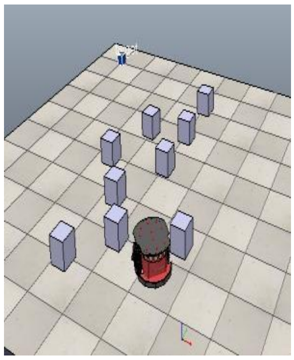
(e)

Fig. 9. Navigation in environment with 3 obstacles

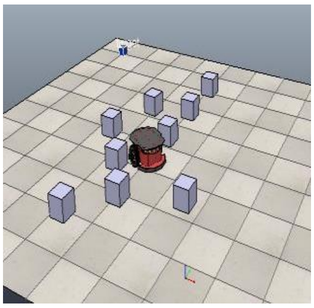
The third navigation scenario presented in the Figure 10 (a), (b), (c), (d) and (e) is a complex environment with nine cuboid obstacles. The robot is forced to make a small turn between the obstacles to avoid collision.



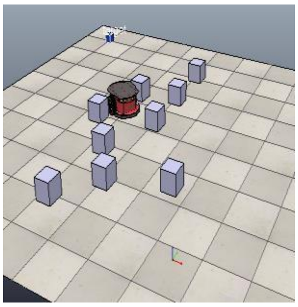
(a)



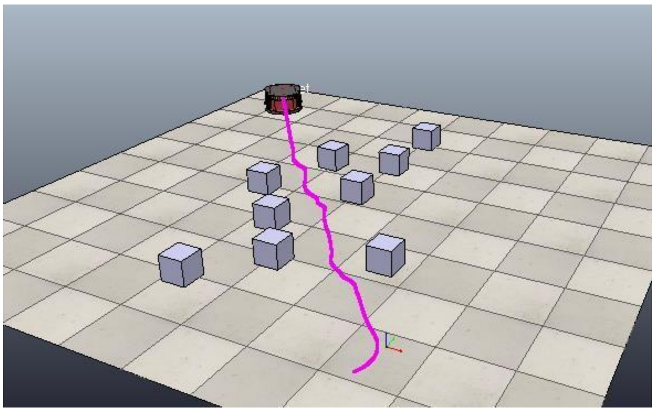
(b)



(c)



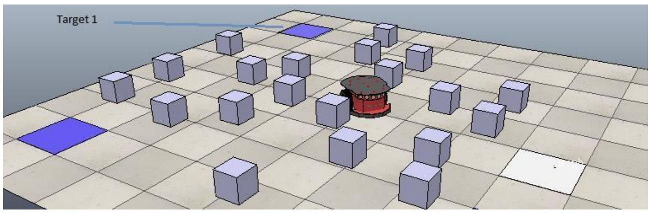
(d)



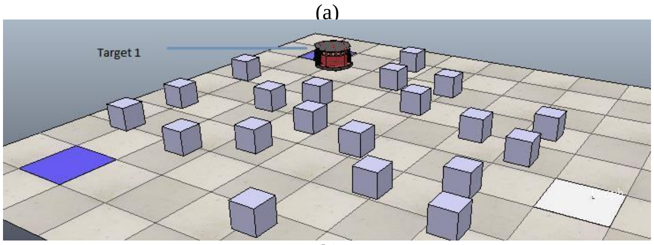
(e)

Fig. 10. Navigation in complex environment

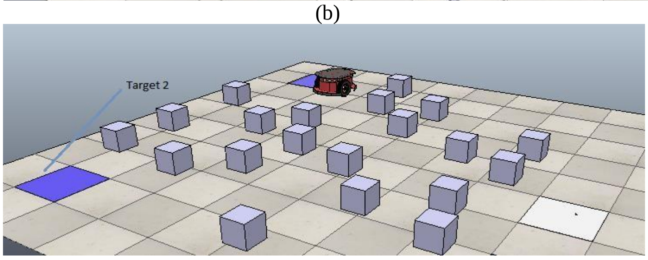
The fourth case considers a more complex environment in the presence of a large number of obstacles with two targets to reach as demonstrated in the Figure 11.



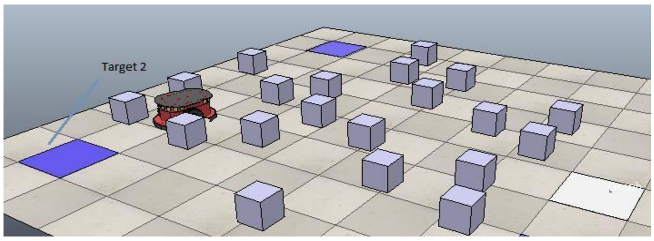
(a)



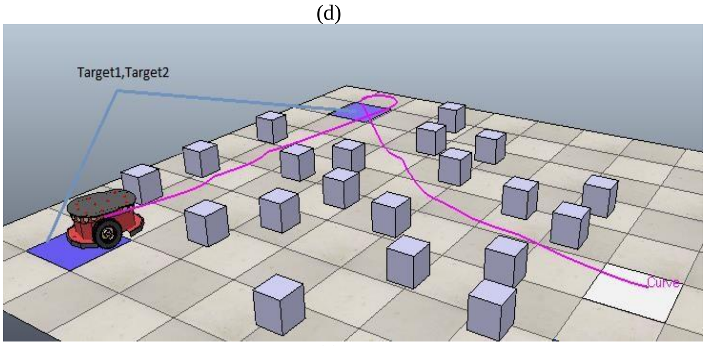
(b)



(c)



(d)



(e)

Fig. 11. Navigation in complex environment toward two goals

As can be seen from Figures 8, 9, 10 and 11:

- The pioneer robot is reaching the target safely in different scenarios.
- The paths of movement which are marked with purple color are close to the optimal.
- The system constantly produces the right path around obstacles.

IV. Conclusion

We have created a control system based on the fuzzy logic for obstacle avoidance. This method is oriented to solve the problem of difficulty and sometimes lack of a mathematical model for modeling and control of nonlinear systems. We have also developed two fuzzy controllers with minimum rules helping the robot for the generation of trajectories which allow reach a goal with the ability to get around obstacles cluttering the mobile robot environment. The effectiveness and efficiency for the suggested method is proven through a simulation-based design approach in which, the robot successfully reached the target without colliding with obstacles in all cases.

Prospects emerged during the realization of this work as improving the system for that it is suitable for dynamic environments. We hope that extending this article will motivate the reader to join other scientific themes around robotics mobile with the exploitation of the intrinsic properties of fuzzy logic.

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