Mobile Robots Navigation in Unknown Environments by Using Fuzzy Logic and Learning Automata

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Autonomously navigation of mobile robots in unknown environments is a basic challenge in robotics. We can use behavior based approach in navigation of mobile robots in environments with obstacles. If actions of robot be taken as behavior, we can design them by fuzzy logic. It decreases the problem states, make the navigation easier and also can be used as initial knowledge for reinforcement learning. In this paper we used learning automata for coordinating behaviors which caused robot to choose the best action in any situation. Using Pioneer robot in V-rep simulator environment showed that fuzzy logic and learning automata for robot navigation had a better performance in convergence and learning speed rather than fuzzy logic and Q-algorithm.

Keywords—behavior based navigation, fuzzy logic, learning automata, Pioneer robot, V-rep Simulator

I. INTRODUCTION

Recently autonomously navigation of mobile robots with many applications in industries, hospitals etc., have been identified as one the most important fields of research. As many environments are unknown and not modeled for robots, we have to installsome sensors on robot to get environment information, analyze them and decide [1]. Many researchers have worked on navigation of mobile robots by using intellectual techniques but because of complexity and uncertainty of navigations, methods like observe graph [2], Veronoi diagram [3], grids [4], cellular decomposition [5], and artificial potential [6] are not suitable for unknown environments. One the most used and researched approaches is behavior based approach. For the first time Brook [7] in 1985 stated initial idea of designing control, based on behavior. In this architecture, control system contains of layers which everyone, based on worthyness, does a special action. In 1987, Arkin proposed using reacting behaviors under the name of schema motor in which for defining every output of schema uses a potential field and then all the outputs related to schemas are composed with weighed total [8]. Rosenblat et al in 1994 used DAMN architecture in which has an intensive judgment and put together all units of behavior votes, compose them and produce the final output [9]. Althaus, P. et al in 2001 proposed a plot based on in linear dynamic system which had a problem on interference of behavior in spontaneously active output behaviors [10]. Seraji et al in 2002 by dividing big goals in some sub goals and focus on performing them, based on weight of every behavior, combined output of them and get the final output [11]. In 2002 Parasurman et al proposed dividing navigation action into some smaller actions or behaviors in which, in every position, based on output data from robot sensors, a suitable behavior is defined [12].

Fatmi et al in 2008 used fuzzy behavior based navigation with layered approach. One of the layers is supervision layer which by using if then fuzzy logic take the output for four behaviors of wall following, obstacle avoidance, go to goal, and emergency situation and chooses suitable behavior [13].

Behhmed et al in 2011had a new approach which was defining four main types of behavior for robot and using fuzzy logic for implementing them, also employing reinforcement learning of Q for robot to choose the best behavior and coordination between behaviors [14]. In this work behavior based approach for navigation of mobile robot is used. The main idea of behavior based navigation is decomposing of navigation into some smaller and easier actions to manage programming and performing behaviors and also focus is on sub-actions [15].

In this article four types of behaviors are defined for robot to do in navigation environment and get to the goal:

Obstacle avoidance, Wall following, Emergency situation, Go to goal

Which are designed based on fuzzy logic, gives initial information to the robot and decrease number of states in environment. Here the main issue is coordinating between behaviors, means in any situation for prioritizing behaviors robot have to choose the best of them. Learning automata is employed for coordinating behaviors and performance of proposed approach which is done in MATLAB and V-rep simulator environment. In section 2 approaches used in this article are presented and 3rd section is about robot

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introduction, 4th proposed method, and 5th is describing results.

II. Approaches Used in This Article:

A. *Fuzzy logic*

Fuzzy logic concept was presented by Lotfizad (1965) for the first time to complete the fuzzy sets theory. This concept is a multi-valued logic and is based on fuzzy sets which, in contrast with certain sets that just accept one and zero quantities, can take any quantity between one and zero [16]. In this article, fuzzy logic is used for implementing of behaviors.

B. *Learning automata*

Learning automata is a machine which can do some finite actions. Every selected action is evaluated by a random environment and the result is shown as a positive or negative signal which affect the selecting of the next action. Here final goal is to automata afford to choose the best action, the action which has the highest probability of getting reward from the environment [17].

In using learning automata in updating probability of actions, if we take "a" as probability of reward and "b" as penalty probability, equations are like below:

a- desirable respond from environment:

$$p_i(n+1) = p_i(n) + a[1 - p_i(n)]$$
$$p_j(n+1) = (1-a)p_j(n) \;\; \forall j, j \neq i$$

b- Undesirable respond from environment:

$$p_i(n+1) = (1-b)p_i(n)$$
$$p_j(n+1) = \frac{b}{r-1} + (1-b)p_j(n) \quad \forall j, j \neq i$$

Depend on the quantity of a and b, there are three state: if a and b are equal, if b is zero, and if b<<a , learning automata is L_{RP}, L_{RI} and $L_{R\varepsilon P}$, respectively.

III. Robot Introduction

In this article, Pioneer p_3dx in V-rep is used. This robot have 16 sonar sensors which for making the learning and simulation easier, these sensors are divided into six sets (figure1). Sensor measures destination depend on the shortest destination between the nearest set of the sensor from the obstacle, which is taken as the destination of this set from obstacle (table1).

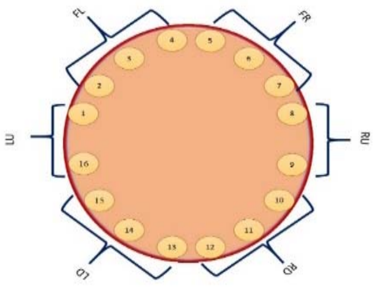

Figure 1: Sets of sensors

IV. Proposed Approach

A. *Designing behaviors by fuzzy logic*

Fuzzy logic have the main role in forming robot behaviors, which they are implemented by fuzzy logic and all of them are recognizable in this logic [18].

Table 1: Sets of sensors

Right Down=min(D10,D11,D12)	Right Up=min(D8,D9)
Front Right=min(D5,D6,D7)	Front Left=min(D2,D3,D4)
Left Down=min(D13,D14,D15)	Left Up=min(D16,d1)
Di is the distance calculated by i'th sensor. i=1,2,3,…,16	

Destinations show the input of fuzzy behavior, which these destinations are not calculated for "go to goal" behavior. Every destination is fuzzy made depend on the membership function in figure2.

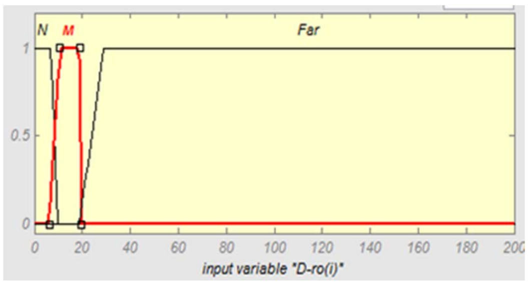

Figure 2: D_ro(i) membership function

In figure2, N: near, M: medium, and F: far. Also D_ro(i) is the distance between robot and obstacle and i is the number of obstacles i=1,2,3,…,6.

Every behavior gets 2 outputs: velocity and steering, which membership function for these 2 outputs are in figure 3 and figure 4.

Steering (degree) is the direction which robot should go in the next level.

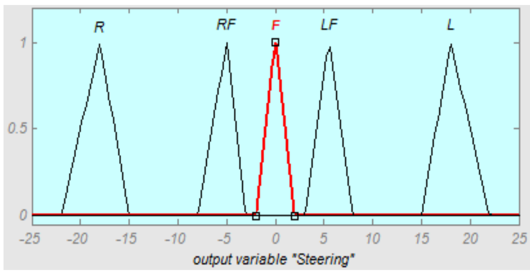

Figure 3: Membership function of "steering"

Velocity (mm/s): second output for fuzzy behavior is velocity. The velocity which robot have to get after destination and the difference between direction of robot head and direction of goal. Membership function of velocity is shown in figure 4.

In figure 4, Z: zero, SP: small positive, P: Positive.

And here we have details of designing behaviors:

1) go to goal

This behavior aims at leading robot to a pre-defined item, goal, in navigation environment. This behaviors' inputs are:

Distance (mm): spacing between robot's position at present state and next state that have to go.

Membership function for distance input is shown in figure5, in which N: near, M: medium, and B: big.

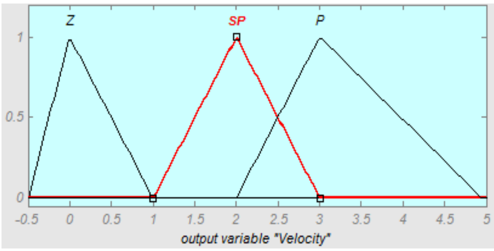

Figure 4: Membership function of "velocity"

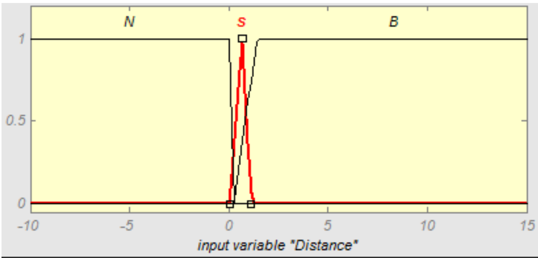

Figure 5: Membership function of "distance"

Angle difference (degree): it is the angle difference between head direction of robot and direction of goal. Membership for angle difference is imagined in figure6.

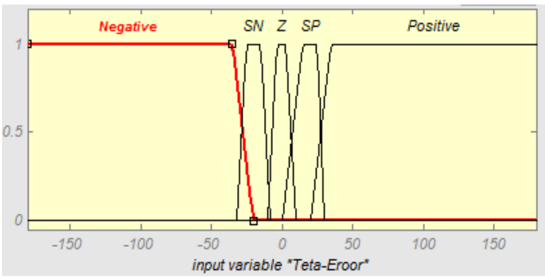

Figure 6: Membership function of "angle difference"

In figure 6, N: negative, SN: small negative, Z: zero, SP: small positive, and P: positive. Inference rules for this behavior are in table2.

2) Obstacle avoidance

This behavior allows robot to move in environment without striking to obstacles, which is one of the most interesting behaviors for robot and many researches have been done under this title. Inputs for obstacle avoidance are derived from sensors (RU, RD, FR, FL, LU, LD). Some examples of fuzzy rules for this behavior is shown in table3.

3) Wall following

this behavior aims at robot to not recognize wall as obstacle and follow that to get to the goal, so wall following saves energy and time for getting to goal. Rules for this behavior are in table 4.

Table 2: Fuzzy rules for "go to goal" behavior

Input		Output	
Distance	Tetha-error	Steering	Velocity
Big	Zero	Front	Positive
	Small Negative	Front Right	Small Positive
	Negative	Right	Small Positive
	Small Positive	Front Left	Small Positive
	Positive	Left	Small Positive
Small	Zero	Front	Small Positive
	Small Negative	Front Right	Small Positive
	Negative	Right	Small Positive
	Small Positive	Front Left	Small Positive
	Positive	Left	Small Positive
Near	Zero	Front	Zero
	Small Negative	Front Right	Zero
	Negative	Right	Zero
	Small Positive	Front Left	Zero
	Positive	Left	Zero

Table 3: Fuzzy rules for "obstacle avoidance" behavior

		Inputs						outputs	
Rows		Right Down	Right Up	Front Right	Front Left	Left Up	Left Down	Steering	Velocity
1				F	N			R	Z
				F	M			R	SP
2				N	F			L	Z
				M	F			L	SP
3			N					L	Z
			M					L	SP
4						N		R	Z
						M		FR	P
5							N	R	Z
6		N						L	Z
7			N	N	F			L	Z
			M	M	F			L	SP
8				F	N	N		R	Z
				F	M	M		R	SP
9				N	N	F		L	Z
				M	M	F		L	SP
				F	F			F	P
10			N	F	F	N		F	SP
			N		M	N		F	SP
			N	M		N		F	SP

4) Emergency situation

This behavior allows robot to do obstacle avoidance in emergency situations so that choose the optimized movement. Usually emergency happens when robot enter in a place which is surrounded with obstacles and here, the best action is to steer with a big degree and exit from entrance path. Fuzzy rules for this behavior are in table5.

Table 4: Fuzzy rules for “wall following” behavior

	Inputs							Outputs	
Rows	Right Down	Right Up	Front Right	Front Left	Left Up	Left Down		Steering	Velocity
	M	M	F	F				F	P
	M	M	M	F				F	P
			F	F	M	M		F	P
			F	M	M	M		F	P

Table 5: Fuzzy rules for “emergency situation” behavior

	Inputs							Outputs	
Rows	Right Down	Right Up	Front Right	Front Left	Left Up	Left Down		Steering	Velocity
		F	M	M	M			R	SP
		M	M	M	F			L	SP
		M		F	M			L	Z
		M	F		M			L	Z
		M	M	M	M			R	Z

B. Coordination between behaviors by learning automata

After designing main behaviors of robot by fuzzy logic, for robot to choose the best behavior in any situation, learning automata is used. In using learning automata to coordinate fuzzy behaviors, ε-greedy approach is used, which in the beginning ε is taken 0.5 and in this state probability of choosing random action and choosing action by experience are equal, but in the following states, ε is multiplied in a regressive factor for decreasing error and increasing probability of choosing action by experience:

Epsilon (k+1) = epsilon (k) *0.99

Here is algorithm for choosing action, reward, and updating probability:

```
If random (0…1) <epsilon then action=random(1,2,3,4)
Elseif action= index(max_a= behaviorProbability)
```

Algorithm 1: Algorithm for choosing actions in learning automata

```
If distance is near && D_ro(i) is far and abs(tetha-error) is small then r = 0.999
Elseif
If the best action is chose then r = 0.5
Elseif r = -0.5
Else r = 0
End.
```

Algorithm 2: Reward algorithm in learning automata

C. Results of simulating in MATLAB and V-rep simulator

Test environment is shown in figure7. This environment is designed in a way that robot be in all situations and for better navigation, it can use four behaviors of wall following, go to goal, emergency situation, and obstacle avoidance. 100 episodes of tests was done for 3 types of standard learning automata with different quantities of a and b. Tests were done 3 times and results was averaged. In 100 episodes, 50 episodes were for robot learning phase and the rest for test phase.

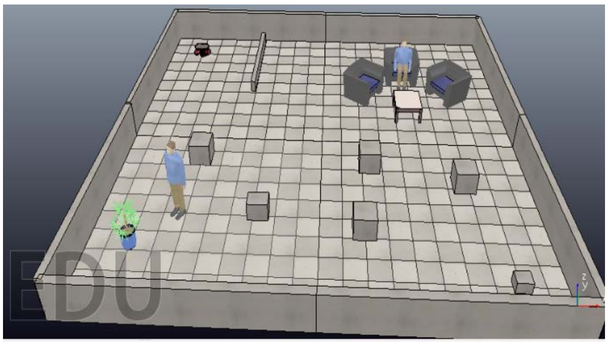

Figure 7: Simulation environment designed in V-rep.

In every steps of learning, depend on the situation of the robot, decisions are made and are implied on environment by robot. In all the tests, learning parameter was taken 0.2 and regressive parameter was 0.8. Results shows that standard automata of LRI with a=0.5 and standard automata LRεP with a=0.5 and a=0.2 (figure8) have the best output in number of selected behaviors and speed of convergence.

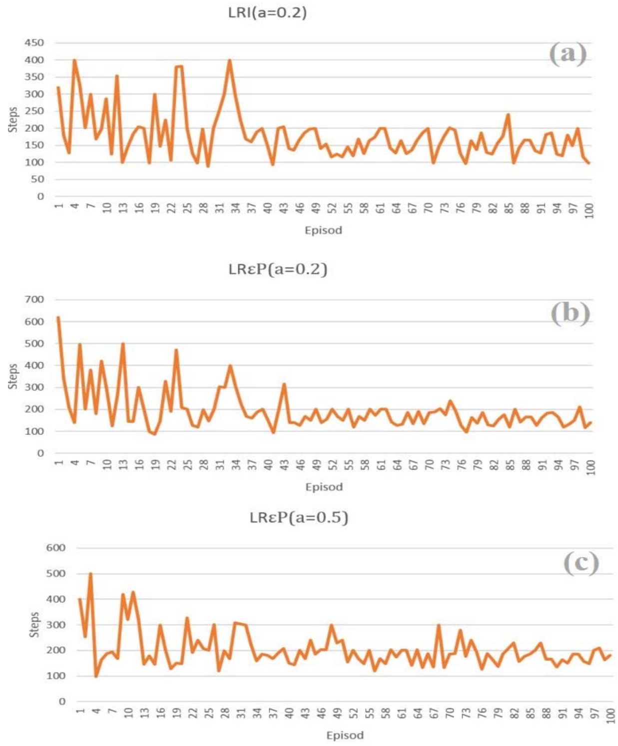

Figure 8: Conclusions of standard automata for a) LRI=0.2, b) LRεP=0.2 and c) LRεP=0.5, respectively.

```
Beta=nextReward;
If Beta>0 then   %Reward
behaviorsProb(chosenBehavior)=
behaviorsProb(chosenBehavior)+a*(1-behaviorsProb (chosenBehavior));
behaviorsProb(unchosenBehaviors)=
(1-a)*(behaviorsProb(unchosenBehaviors));
else Beta<=0   % Penalty
behaviorsProb(chosenBehavior)=(1-b)*behaviorsProb(chosenBehavior);
behaviorsProb(unchosenBehaviors)=
(b/3)+(1-b)*behaviorsProb(unchosenBehaviors);
```

Algorithm 3: Updating probability algorithm in learning automata

Figure 9: Benhmed's work results by using Q-learning [14]

For a better presentation of results, they are compared with results of Benhmed's work (figure9) [14].

In figure10 navigation of robot, before and after learning is imaged.

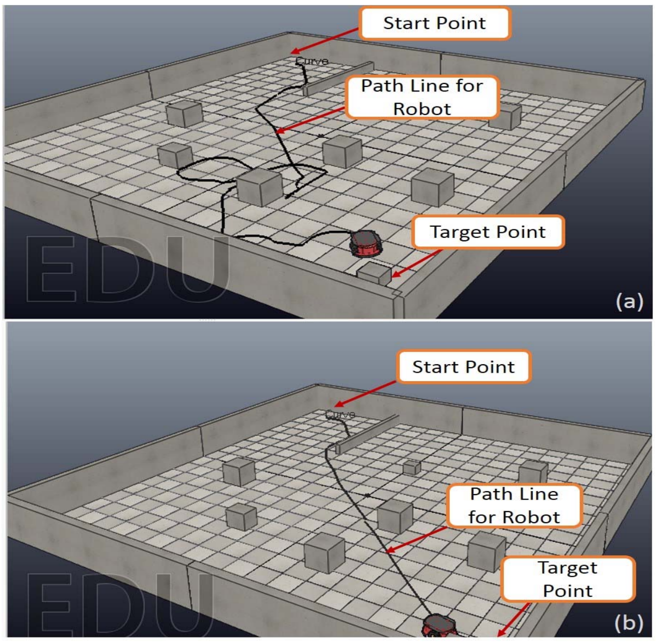

Figure 10:Navigation of robot a) before learning and b) after learning

V. Conclusion

Navigation of robot is one the most important issues in mobile robot fields, which aims at finding the shortest path between an initial situation to a final goal. Here, main challenge is on finding a path without strike and optimized or semi optimized. In this article, purpose was to develop an approach for controlling mobile robot by using artificial intelligence techniques, which guarantee learning of navigation in unknown environments. Behavior based navigation by dividing actions into some executable actions, makes it easier. Fuzzy logic techniques (wall following, go to goal, obstacle avoidance, emergency situation) are employed for designing behaviors, and also used for elimination of ambiguities and errors of measurements. These techniques allow robot to choose the best action, in any situation, to get to the goal. Comparing the results of this article and prior works shows that here, number of robot' behaviors in every episode, for getting to goal, decreased in all the episodes, robot find a way to goal and there is no error in implementing algorithm or getting in local minima. Also the most important result is considerably increase of convergence speed.

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