# Mobile Robot Navigation Using Fuzzy logic Controller

S.M.Raguraman, D.Tamilselvi and N.Shivakumar

**Abstract**— The proposed System assists the sensor based mobile robot navigation in an indoor environment using Fuzzy logic controller. Fuzzy logic control is well suited for controlling a mobile robot because it is capable of making inferences even under uncertainty. It assists rules generation and decision-making. It uses set of linguistic Fuzzy rules to implement expert knowledge under various situations. A Fuzzy logic system is designed with two basic behaviors- obstacle avoidance and a target seeking behavior. The inputs to the Fuzzy logic controller are the desired direction of motion and the readings from the sensors. The outputs from the Fuzzy logic controller are the accelerations of robot wheels. Under the proposed Fuzzy model, a mobile robot avoids the obstacles and generates the path towards the target.

**Index Terms**— Fuzzy logic, fuzzy controller, mobile robot navigation, obstacle avoidance, robot.

## 1 INTRODUCTION

THERE 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. 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 obstacles especially in crowded environment.

Fuzzy logic control is well suited for controlling a mobile robot because it is capable of making inferences even under uncertainty [1]. For mobile robot navigation, several researchers have investigated fuzzy logic approaches. Li and Yang [2] proposed an obstacle avoidance approach using fuzzy logic, but the input sensors are separately inferred. Saffiotti proposed some fuzzy logic methods for robot navigation [3, 4]. However, these methods cannot guarantee that the robot will not be trapped on local minima or infinite loops. The process of tuning the parameters of fuzzy rules may be rather difficult. Vadakkepat [5] proposed a fuzzy behavior based model to control a team of three soccer robots to finish a simple task in a court environment. Four rules, 12 behaviors, and a set of actions were designed.

Neural network-based approaches have been employed for robot motion planning. In these approaches, the robot is treated as a point moving under the influence of an artificial neural potential field. The attractive potential force attracts the robot toward the target configuration, while repulsive potential forces push it away from obstacles. Godjevac [6] proposed a neurofuzzy model for a mobile robot to avoid obstacles. More than 600 rules are formulated, where many of them are redundant and there are no methods suppress the useless rules. Rusu [7] proposed a neurofuzzy controller for mobile robot navigation in indoor environments. Infrared and contact sensors are used for detecting target and avoiding collisions. Two levels with several behaviors are designed for the controller. Fuzzy inference is used in every behavior. A neural network is used to tune the system parameters. A switching coordination technique is used to select the appropriate behavior. Command fusion is used to combine the output of several neurofuzzy subsystems. Anmin Zhu [8] proposed Neurofuzzy based approach to mobile robot navigation in unknown environments.

In this paper, a fuzzy logic-based model is presented for navigation of mobile robots in indoor environments. The inputs of the fuzzy controller are the outputs from the sensor system, including the obstacle distances obtained from the left, front, and right sensor groups, the target direction, and the current robot speed. A set of linguistic fuzzy rules are developed to implement expert knowledge under various situations. The output signals from the fuzzy controller are the accelerations of left and right wheels, respectively. Under the control of the proposed fuzzy logic-based model, the mobile robot can generate reasonable trajectories towards the target.

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## 2 MOBILE ROBOT

The circular shaped mobile robot has a differential steering system shown in Fig. 1. Two DC motors independently control two wheels on a common axis. A third wheel is provided for support. The distance between the wheels is set as 0.18m, wheel diameter is 0.07m, and wheel width is 0.02m.

The sensor system consists of three IR range sensors and one target sensor. The three IR range sensors are equipped on left, right and middle of the front part of the robot to measure the distance between the robot and the obstacles. The target sensor is equipped on front side of the robot in order to find the target direction. A speed odometer is equipped on the robot to measure the current robot speed.

## 3 PROPOSED APPROACH

The structure of the proposed fuzzy logic approach is shown in Fig. 2. The inputs of the fuzzy controller are the outputs from the sensors: the obstacle distances $d_l$, $d_f$ , $d_r$ obtained from the left, front, and right sensor groups, the target direction $t_d$ (that is, the angle between the robot moving direction and line connecting the robot with the target), and the cur-

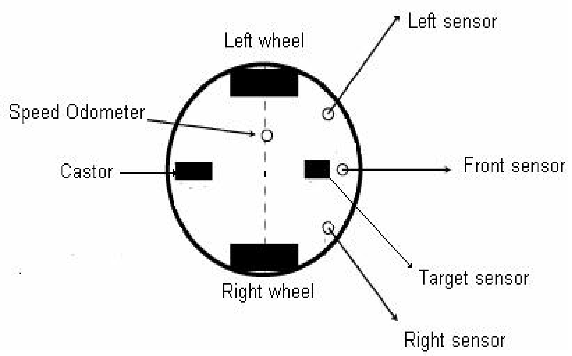


Fig. 1 Mobile robot with sensors

rent speed $r_s$. The output signals from the fuzzy controller are the accelerations of left and right wheels, $a_l$ and $a_r$, respectively
The proposed fuzzy logic method is simple, easy to understand, has human-like intelligence, and quick reaction capability. Fuzzification, inference mechanism, and defuzzification are considered to create the fuzzy logic controller.

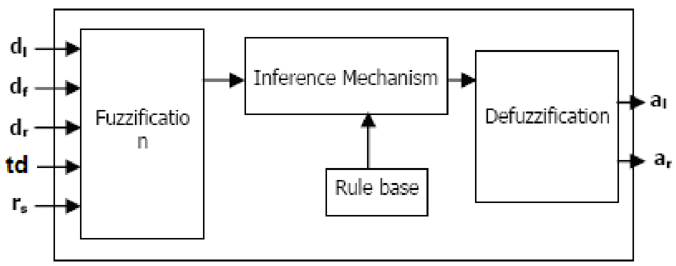


Fig. 2. Fuzzy logic controller

### 3.1 Fuzzification

The fuzzification procedure maps the crisp input values to the linguistic fuzzy terms with membership values between zero and one. In most fuzzy logic systems, nonfuzzy input data are mapped to fuzzy sets by treating them as Gaussian, triangle, trapezoid, sharp peak membership functions, etc. In this paper, triangle functions, S-type and Z-type functions will be chosen to represent fuzzy membership functions. Membership functions for the terms of the input and output variables in this controller are shown in Fig. 3.The outputs of the fuzzification procedure are given as follows, for a triangle function:

$$p_{ij} = \begin{cases} 1 - \dfrac{2|u_i - m_{ij}|}{\sigma_{ij}}, & if\ m_{ij} - \dfrac{\sigma_{ij}}{2} < u_i < m_{ij} + \dfrac{\sigma_{ij}}{2} \\ 0, & otherwise \end{cases} \quad (1)$$

For an S-type function:

$$p_{ij} = \begin{cases} 0, & if\ \ u_i > m_{ij} + \dfrac{\sigma_{ij}}{2} \\ 1, & if\ \ u_i < m_{ij} \\ 1 - \dfrac{2|u_i - m_{ij}|}{\sigma_{ij}}, & otherwise \end{cases} \quad (2)$$

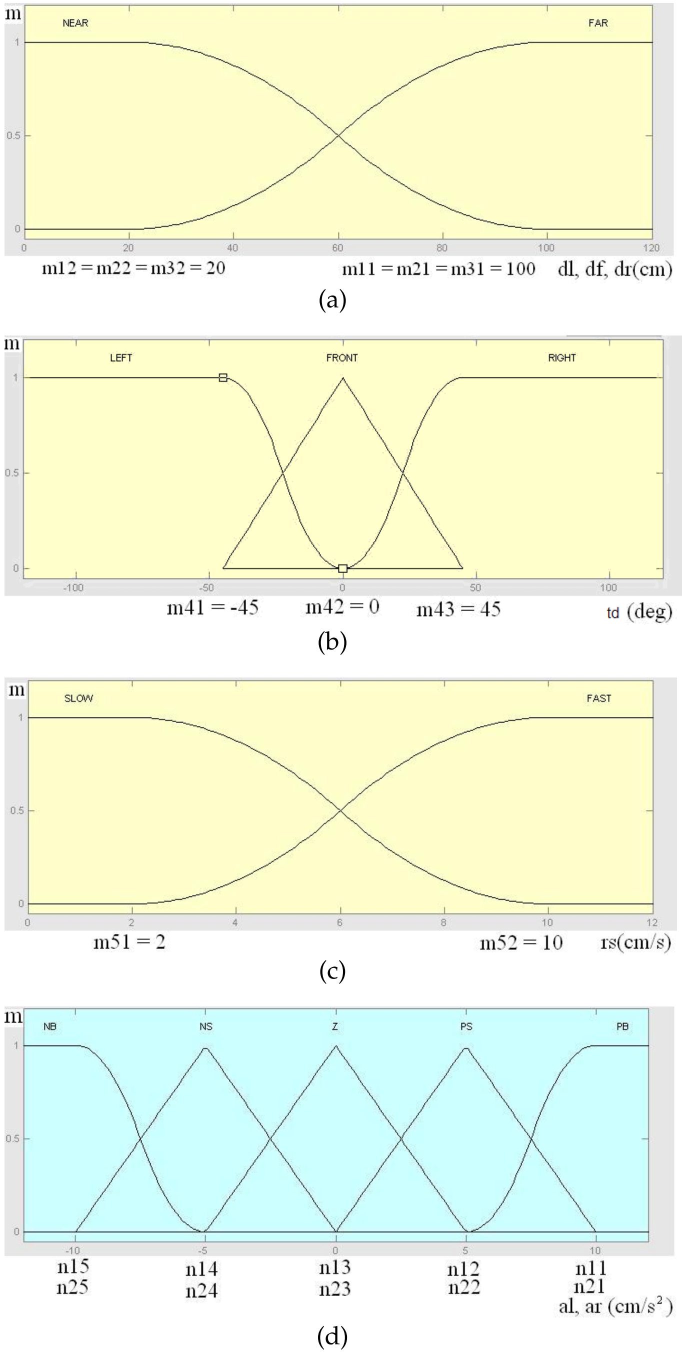


Fig.3. Membership functions of the input and output variables.$m_{ij}$ , $n_{ls}$, the centers of membership functions; m., membership; meanings of NB,NS,Z,PS,PB.,are negative big, negative small,zero,positive small, positive big respectively (a) of obstacle distances, (b) of the target direction, (c) of the current robot speed, (d) of accelerations

for a Z-type function:

$$p_{ij} = \begin{cases} 0, & if\ \ u_i > m_{ij} + \dfrac{\sigma_{ij}}{2} \\ 1, & if\ \ u_i < m_{ij} \\ 1 - \dfrac{2|u_i - m_{ij}|}{\sigma_{ij}}, & otherwise \end{cases} \quad (3)$$

where $i = 1, 2, \ldots, 5$, represents the number of input signals; $j = 1, 2, \ldots, 5$, is the number of terms of the input variables; $p_{ij}$ is the degree of membership for the $i$th input corresponding to the $j$th term of the input variable; $u_i$ is the $i$th input signal to the fuzzy controller, $\{u_1, u_2, u_3, u_4, u_5\} = \{d_l, d_f, d_r, t_d,$

IF
Obstacle distance on left ($d_l$) is Near and
Obstacle distance on front ($d_f$) is Far and
Obstacle distance on right ($d_r$) is Far and
Target direction ($t_d$) is Right and
Current robot speed ($r_s$) is Slow

THEN
Acceleration of left wheel ($a_l$) is PB
Acceleration of right wheel ($a_r$) is PS

Fig. 4. Example of the inference rules. $d_l$ = NEAR, {FAR}, $d_f$ = {NEAR, FAR}, $d_r$ = {NEAR, FAR}, $t_d$ = {LEFT, CENTER, RIGHT}, $r_s$ = {SLOW, FAST}, $a_l$ = {PB, PS, Z, NS, NB}, $a_r$ = {PB, PS, Z, NS, NB}.

$r_s$}; $m_{ij}$ is the center of the membership function corresponding to the $i$th input and the $j$th term of the input variable; and $_{ij}$ is the width of the membership function corresponding to the $i$th input and the $j$th term of the input variable. For example, $u_4 = t_d$, represents the input value about the target direction; $m_{42} = 0$ means the value of the membership function center related to the second term ("Center") of the fourth input variable ($u_4$ or $t_d$) is 0; and $_{42} = 90$ is the width of the membership function.

### 3.2 Inference Mechanism

The inference mechanism is responsible for decision-making in the fuzzy controller using approximate reasoning. The rule base is essential for the controller, which stores the rules governing the input and output relationship of the proposed controller. The inferences rules are in the general form in Fig. 4.

Forty-eight rules are formulated for the proposed controller given in Table 1 and 2. There are two basic behaviors in the rule base: target seeking behavior (Table 1), and obstacle avoidance behavior (Table 2). In general, the target seeking behavior is used to change the direction of the robot toward the target when there are no obstacles blocking the robot. The obstacle avoidance behavior is used to turn away from the obstacles disregarding the direction of the target when obstacles are close to the robot.

TABLE 1
RULE BASE FOR TARGET SEEKING BEHAVIOR

| Rule no | Input | | | | | Output | |
|---|---|---|---|---|---|---|---|
| | $d_l$ | $d_f$ | $d_r$ | $t_d$ | $r_s$ | $a_l$ | $a_r$ |
| 1 | F | F | F | L | SL | PS | PB |
| 2 | F | F | F | L | FS | NS | Z |
| 3 | F | F | F | C | SL | PB | PB |
| 4 | F | F | F | C | FS | Z | Z |
| 5 | F | F | F | R | SL | PB | PS |
| 6 | F | F | F | R | FS | Z | NS |
| 7 | F | F | N | L | SL | Z | PS |
| 8 | F | F | N | L | FS | NS | Z |
| 9 | N | F | N | C | SL | PS | PS |
| 10 | N | F | N | C | FS | NS | NS |
| 11 | N | F | F | R | SL | PS | Z |
| 12 | N | F | F | R | FS | Z | NS |

*N-Near, F-Far, L-Left, C-Center, R-Right, SL-Slow, FS-Fast*

TABLE 2
RULE BASE FOR OBSTACLE AVOIDANCE BEHAVIOR

| Rule no | Input | | | | | Output | |
|---|---|---|---|---|---|---|---|
| | $d_l$ | $d_f$ | $d_r$ | $t_d$ | $r_s$ | $a_l$ | $a_r$ |
| 1 | F | F | N | C | SL | Z | PS |
| 2 | F | F | N | C | FS | NS | Z |
| 3 | F | F | N | R | SL | NS | Z |
| 4 | F | F | N | R | FS | NB | NS |
| 5 | F | N | N | L | SL | NS | Z |
| 6 | F | N | N | L | FS | NB | NS |
| 7 | F | N | N | C | SL | NS | Z |
| 8 | F | N | N | C | FS | NB | NS |
| 9 | F | N | N | R | SL | NS | Z |
| 10 | F | N | N | R | FS | NB | NS |
| 11 | N | N | N | L | SL | NS | Z |
| 12 | N | N | N | L | FS | NB | NS |
| 13 | N | N | N | C | SL | NS | Z |
| 14 | N | N | N | C | FS | NB | NS |
| 15 | N | N | N | R | SL | Z | NS |
| 16 | N | N | N | R | FS | NS | NB |
| 17 | N | F | N | L | SL | Z | Z |
| 18 | N | F | N | L | FS | NS | NS |
| 19 | N | F | N | R | SL | Z | Z |
| 20 | N | F | N | R | FS | NS | NS |
| 21 | N | F | F | L | SL | Z | NS |
| 22 | N | F | F | L | FS | NS | NB |
| 23 | N | F | F | C | SL | PS | Z |
| 24 | N | F | F | C | FS | Z | NS |
| 25 | N | N | F | L | SL | Z | NS |
| 26 | N | N | F | L | FS | NS | NB |
| 27 | N | N | F | C | SL | Z | NB |
| 28 | N | N | F | C | FS | NS | NB |
| 29 | N | N | F | R | SL | Z | NS |
| 30 | N | N | F | R | FS | NS | NB |
| 31 | F | N | F | L | SL | NS | Z |
| 32 | F | N | F | L | FS | NB | NS |
| 33 | F | N | F | C | SL | NS | Z |
| 34 | F | N | F | C | FS | NB | NS |
| 35 | F | N | F | R | SL | Z | NS |
| 36 | F | N | F | R | FS | NS | NB |

*N-Near, F-Far, L-Left, C-Center, R-Right, SL-Slow, FS-Fast*

### 3.3 Defuzzification

The defuzzification procedure maps the fuzzy output from the inference mechanism to a crisp signal. Many methods can be used to convert the conclusion of the inference mechanism into the actual output of the fuzzy controller. The "center of gravity (CoG)" method is used in the proposed controller, which combines the output represented by the implied fuzzy sets from all rules to generate the gravity centroid of the possibility distribution for a control action. The value of the output variables $a_l$ and $a_r$ are given in equation (4) and (5). Where $v_{k,1}$ and $v_{k,2}$ denote the estimated values of the outputs provided by the $k$th rule, which are related to the center of membership functions of the output variables, $q_k$ is the conjunction degree of the IF part of the $k$th rule, $k$ is the number of rules, $p_{ik1}$ is the degree of the membership for the $i$th input contributing to the $k$th rule, and $i$ is the number of input values.

$$a_l = \frac{\sum_{k=1}^{48} v_{k,1} q_k}{\sum_{k=1}^{48} q_k} \tag{4}$$

$$a_r = \frac{\sum_{k=1}^{48} v_{k,2} q_k}{\sum_{k=1}^{48} q_k} \tag{5}$$

$$q_k = \min\{p_{1k_1}, p_{2k_2}, p_{3k_3}, p_{4k_4}, p_{5k_5}\} \tag{6}$$

## 4 Simulation Results

To verify the validity of the proposed scheme, some typical cases were simulated in which a robot is to move from a given current position to a desired goal position in various environments. For demonstrations of the effectiveness of the proposed fuzzy logic based controller, simulations using a mobile robot simulator (Rossum's Playhouse simulation environment based on a 2-D robot simulator developed by Lucas [9]) are performed.

### 4.1 Building Suitable Indoor Environment

The first step in the simulation of the mobile robot is to create the suitable environment. Using Rossum playhouse simulator we have created environment with static obstacles, home and target. This has been tested in four simulated maze-like indoor environments; one of the test environments is shown in Fig.5

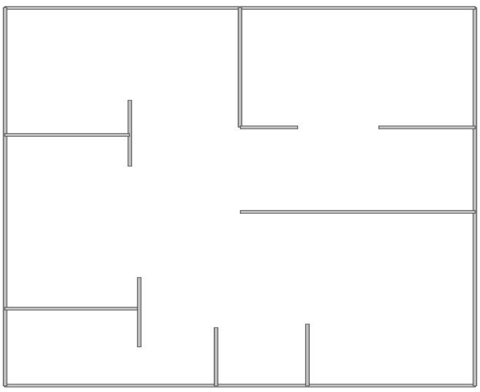

Fig. 5 Shape of the test setting

### 4.2 Designing Robot

After creating the environment, we have designed the robot.The robot is designed as shown in Fig. 1. The circular shaped mobile robot has a differential steering system. Two DC motors independently control two wheels on a common axis. A third wheel is provided for support. The distance between the wheels is set as 0.18m, wheel diameter is 0.07m, and wheel width is 0.02m. The sensor system consists of three IR range sensors and one target sensor. The three IR range sensors are equipped on left, right and middle of the front part of the robot to measure the distance between the robot and the obstacles. The target sensor is equipped on front side of the robot in order to find the target direction. A speed odometer is equipped on the robot to measure the current robot speed.

### 4.3 Applying Fuzzy Logic

Using Rossum playhouse simulator we have created a fuzzy controller by defining fuzzy variable, fuzzy membership function and fuzzy rules. There are 48 fuzzy rules are developed based on the obstacles distances and robot direction. In that fuzzy rule, there are five inputs and two outputs. The five inputs are distances between the obstacles and robot from left, front and right sides and target direction from robot and robot speed. These inputs are given to the fuzzy logic controller. The two outputs are accelerations of left and right wheels. Inputs are called Antecedent and outputs are called Conclusions.

The results of the test run are as shown in Fig. 6(a-d) demonstrating the validity of the proposed approach.

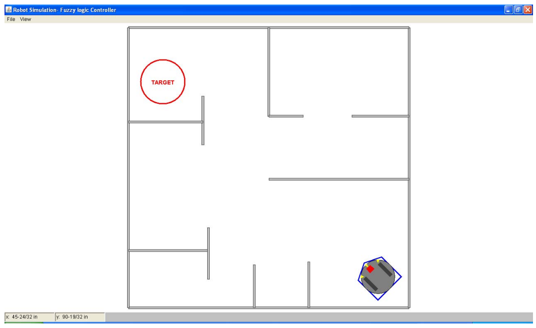


Fig. 6(a) Mobile robot in starting position

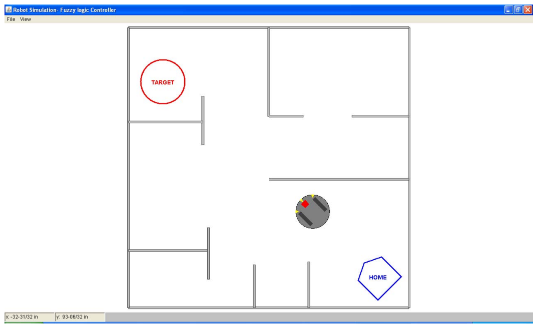


Fig. 6(b) Mobile robot moves with fuzzy rules

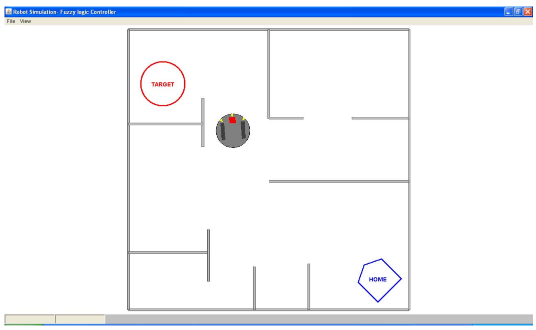


Fig. 6(c) Mobile robot moves with fuzzy rules

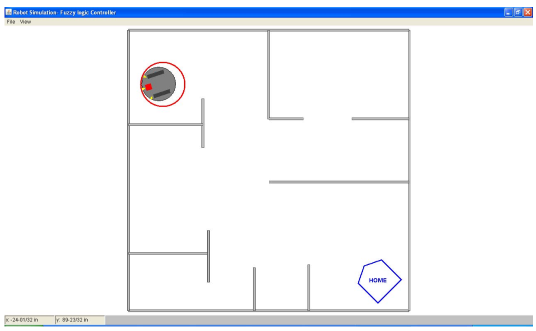


Fig. 6(d) Mobile robot attains the target

## 5 CONCLUSION AND FUTURE WORK

The Mobile robot navigates using Fuzzy rules by means of applying fuzzy logic controller. A successful way of robot navigation is demonstrated. A novel fuzzy logic based control system is proposed for real time reactive navigation of a mobile robot. Forty-eight fuzzy rules and two behaviors are designed in the proposed model, much fewer than conventional approaches that use hundreds of rules. Fuzzy logic was used to implement individual behaviors, to coordinate the various behaviors, to select roles for each robot, and for robot perception, decision-making, and speed control. Fuzzy logic is used in different parts of the perceptual model. Under the control of the proposed fuzzy logic-based model, the mobile robot can autonomously reach the target along a smooth trajectory with obstacle avoidance.

In Future, the Neuro-fuzzy approach will be proposed to this problem. To improve the performance, neuro-fuzzy methods will be used. Neuro-fuzzy is the combinations of neural networks and fuzzy logic. A neural network assists learning and adaptation and Fuzzy logic assists Rules generation and decision-making. A learning algorithm based on neural network techniques will be developed, which smoothes the trajectory generated by the fuzzy logic system.

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