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Intelligent Controller for Mobile Robot: Fuzzy Logic Approach

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ABSTRACT: A key issue in the research of an autonomous mobile robot is the design and development of an intelligent controller which can control and enables the robot to navigate in a real world environment, avoiding structured and unstructured obstacles especially in crowded and unpredictably changing environment, whether it is in land, underground, under water, on the air or in space. An intelligent system has the ability to act appropriately in an uncertain environment, where an appropriate action is that which increases the probability of success, and success is the achievement of behavioral sub goals that support the system's ultimate goal. This paper presents the development in the area of intelligent controller for mobile robot in various (known and unknown) environments. A successful way of structuring the navigation task deal with the issues of individual behaviour design and action coordination. The behaviours will be addressed using fuzzy logic in the present research. The inputs to the proposed fuzzy control scheme consist of a heading angle between a robot and a specified target and the distances between the robot and the obstacles to the left, front, and right to its locations, being acquired by an array of sensors. In this paper, we proposed an intelligent controller for mobile robot navigation algorithm employing fuzzy theory in a complex cluttered environment. Simulation results verified the effectiveness of the controllers.

1 Introduction

Current research and development of mobile robot have attracted the attention of researchers in the areas of engineering, computer science, biology, mining and others. This is due to the high potential of mobile robots application. Autonomous mobile robots are robots which can perform desired tasks in unstructured environments without continuous human guidance (Frank and Goswami, 2004; Ibrahim and Fernandes, 2004; Kim and Cho, 2006; Waterman, 1989). Many kinds of robots are *autonomous* to some degree. One important area of current robotics research is to enable the robot to cope with its environment whether this is on land, underwater, in the air, underground or in space. A fully autonomous robot in the real world has the ability to:

- Gain information about the environment.
- Travel from one point to another point, without human navigation assistance.
- Avoid situations that are harmful to people, property or itself.
- Repair itself without outside assistance.

A robot may also be able to learn autonomously. Autonomous learning includes the ability to:

- Learn or gain new capabilities without outside assistance.
- Adjust strategies based on the surroundings.
- Adapt to surroundings without outside assistance.

Navigation for mobile robots can be well-defined in mathematical (geometrical) terms. It also involved many distinct sensory inputs and computational processes. Elementary decisions like turn left, or turn right, or run or stop is made on the basis of thousands of incoming signals (David, 1990; Gallistel, 1990; Parhi, 2005). Thus it is necessary first to define what navigation is and what the function of a navigation system? Navigation is traditionally defined as the process of determining and maintaining a trajectory to a goal location (Gallistel, 1990). Biological navigation behaviours have been an important source of inspiration for robotics in the past decade. According to Levitt and Lawton (1990), navigation consists of answering three questions: (a) “Where am I?” (b) “Where are other places with respect to me?” and (c) “How do I get to other places from here?” However, biological systems do not necessarily require all that knowledge to navigate, but they usually work on a “how do I reach the goal?” basis. Most systems typically deal with different degrees of knowledge depending on the circumstances.

Humans have a remarkable capability to perform a wide variety of physical and mental tasks without any explicit measurements or computations. Examples of everyday tasks are parking a car, driving in city traffic, playing golf, cooking a meal, and summarizing a story. In performing such familiar tasks, humans use perceptions of time, distance, speed, shape, and other attributes of physical and mental objects (Zadeh, 2001). The theory of fuzzy logic systems is inspired by the remarkable human capability to operate on and reason with perception-based information. Rule-based fuzzy logic provides a scientific formalism for reasoning and decision making with uncertain and imprecise information. The main advantages of a fuzzy navigation strategy lie in the ability to extract heuristic rules from human experience, and to obviate the need for an analytical model of the process (Seraji and Howard, 2002).

In this approach, the fuzzy logic system (FLS) is used to produce the control inputs for the robot with inputs from various sensors. Sensor signals are fed to the FLS, and the output provides motor control commands (e.g., turn right or left). The FLS learns the full dynamics of the mobile robot online. Each fuzzy controller for mobile robot has three inputs and two outputs. Both inputs and output have three membership functions. Each membership function is considered as a trapezoidal and triangular membership function. This paper provides a Fuzzy logic framework to be implemented in the mobile robot for behaviour design and coordination. It is verified by the simulated and real world tests, what has been addressed in this paper. The present mobile robot application include automatic freeway driving, guidance of the blind and disabled, explorations of dangerous regions and mechanical parts transfer in flexible assembly system. When we visit an unfamiliar place, like a new building, shopping mall or theme park, we look for guiding information to guide us our destinations in mind. An intelligent controller of autonomous mobile robot that can navigate to a desired location in a known and unknown environment has been exhibited in Figure 1.

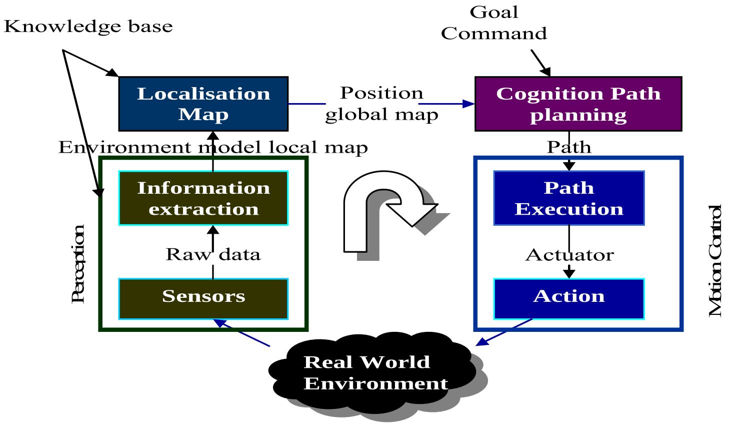


Figure 1. Schematic view of intelligent controller.

2 Fuzzy logic behaviour

Intelligent controller for mobile robot enables the robot to avoid the obstacle and improve target seeking ability. The inputs to the proposed fuzzy control scheme consist of a heading angle between a robot and a specified target and the distances between the robot and the obstacles to the left, front, and right locations, acquired by an array of sensors. The outputs from the control scheme are commands for the speed control unit of two side wheels of the mobile robot. The input signals to fuzzy navigation algorithm are the distances between the robot and obstacles to the left, front, and right locations as well as the heading angle between the robot and a specified target, as shown in Figure 2(a). When the target is located to the left side of the mobile robot, a heading angle *head-ang* is defined as negative; when the target is located to the right side of the mobile robot, a heading angle *head-ang* is defined as positive (Li and Xun, 1994), as shown in Figure 2(b).

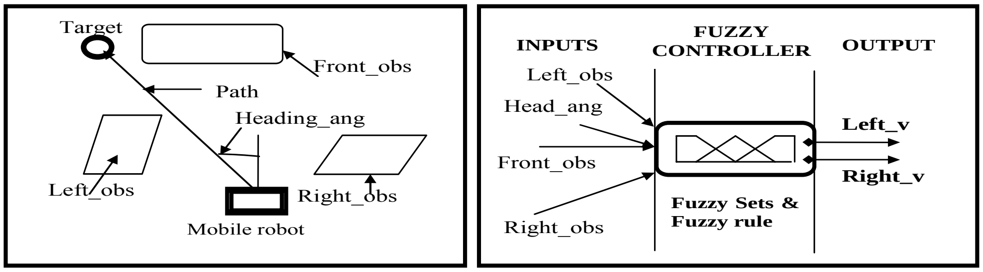


Figure 2(a). Figure 2(b).

Figure 2. Fuzzy logic techniques for behavior based control of mobile robot.

According to acquired range information by sensors, reactive behaviours are weighted by the fuzzy logic algorithm to control the velocities of the two driving wheels of robot. The basic configuration of a fuzzy system consists of four principal elements: *fuzzifier*, *fuzzy rule base*, *fuzzy inference engine*, and *defuzzifier* The *fuzzifier* is a mapping from the observed crisp input space to the fuzzy sets defined in, the fuzzy set defined is characterized by a membership function and is labeled by a linguistic variables *near, medium* and *far* these are chosen to fuzzify *left-obs, right-obs* and *front-obs*. The linguistic variables *P (positive), Z (zero)* and *N (negative)* are used to fuzzify *head-ang,* the linguistic variables *slow, med* and *fast.* These are used to fuzzify the velocities of the *left-v* and *right-v,* respectively (Das and Kar, 2006).

The fuzzy rule base is a set of linguistic rules in the form of "if a set of conditions are satisfied, then a set of consequences are inferred." For three inputs two outputs fuzzy system, the general fuzzy rule base may consist of the following:

If *"matching degree of* x_1 *is* μ(x_1) *and matching degree of* x_2 *is* μ(x_2) *and matching degree of* x_3 *is* μ(x_3) *and matching degree of* x_4 *is* μ(x_4)*"* Then *"matching degree of* v_l *is* μ(y_i)$_l$ *and matching degree of* v_r *is* μ(y_i)$_r$*".*

The matching degree of final output is computed by the following formula:

Matching degree μ(y_i)$_{l,r}$ = min {μ(x_1), μ(x_2), μ(x_3) and μ(x_4)}

Where: i = (1, 2, 3,............n).

x_1, x_2, x_3, x_4 =Sensor inputs of left, right, front obstacle distance and heading angle respectively.

μ(x_1), μ(x_2), μ(x_3), μ(x_4) = Matching degrees of corresponding sensor inputs.

v_l, v_r = Velocity of left and right wheel respectively.

μ(y_i)$_l$, μ(y_i)$_r$ = Inferred input matching degree of corresponding left and right wheel velocity.

When the matching degree is 1 the inferred conclusion is identical to the rule's consequent and if it is 0 no conclusion can be inferred from the rule.

Finally the output firing area of the left wheel velocity and right wheel velocity value can be computed by following formula:

μ_A(y_i)$_{l,r}$ = max {μ(x_1), μ(x_2), μ(x_3) and μ(x_4)}

The final output (crisp value) of the Fuzzy Logic Controller of left wheel velocity and right wheel velocity can be calculated by:

$$\text{Left and right Wheel Velocity} = W_{l,r} = \frac{\sum_{i=1}^{n} \mu_A(y_i) \times (V_i)}{\sum_{i=1}^{n} \mu_A(y_i)}$$

Where:

$\mu_A(y_i)_{l,r}$ = Firing area of left and right wheel velocity for i^{th} rule.

V_i = Centroid distance of the area and

n = Total number of parameter.

In order to reach a specified target in a complex environment, the mobile robot at least needs the following reactive behaviours: 1. Obstacle avoidance and target seeking behaviour, 2.Following edges, 3.Target steer. In this case, a set of fuzzy logic rules is used to describe the reactive behaviours mentioned above. Now, the last part of fuzzy rules from the rule base is to explain, in principle, how these reactive behaviours are realized.

2.1 Robot behaviour

Each robot has four wheels, two front supported wheels which are free and two side middle wheels are powered by separate stepper motors. Each robot has an array of sensors for measuring the distances of obstacles around it, an infrared sensor for detecting the bearing of the target and a radio system for communicating with other robots. According to the information acquired by the robots using their sensors, some of the fuzzy control rules are activated. The outputs of the activated rules are combined by fuzzy logic operations to control the velocities of the driving wheels of the robots. These are denoted by left_v and right_v, for the velocity of the left wheel and the velocity of the right wheel of each robot respectively. these parameters can be used to generate different fuzzy rules. e.g.

*Rule***:** If *(left-obs is far and right-obs is medium and front-obs is near and head-ang is N)* Then *(left-v is slow and right-v is medium).*

By fuzzy reasoning and the centroid defuzzification method, Rule related to the *obstacle avoidance wall-following* and *target seeking* behaviours, are weighted to determine an appropriate control action, i.e., the velocities, *left-v* and *right-v,* of the robot's side wheels as shown in Figure 3, the values of the parameters are decided empirically.

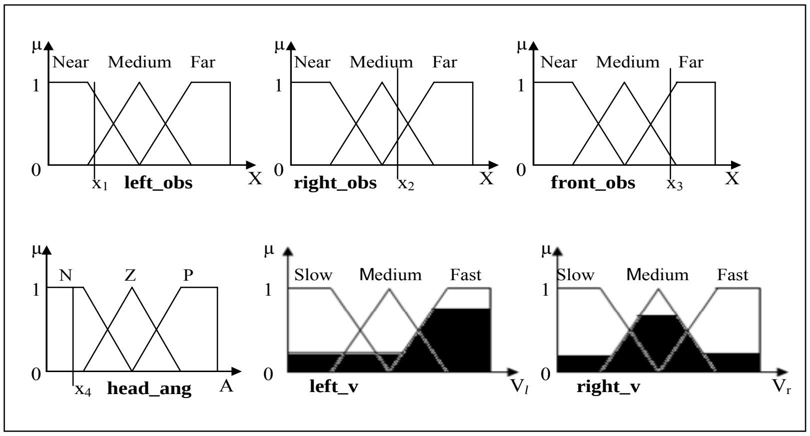


Figure 3. Schematic diagram of the fuzzy logic for navigation of mobile robots.

2.2 Obstacle avoidance

When the acquired information from the sensors shows that there exist obstacles nearby robot, it must reduce its speed to avoid obstacles. When a robot is close to an obstacle, it must change its speed and steering angle to avoid the obstacle. The fuzzy rules used for obstacle avoidance by the robots are listed in Table 1 as rules 1 to 27. All the rules in the table are obtained heuristically.

Table 1. List of rules for obstacle avoidance.

RuleNo	Action	Left_obs	Right_obs	Front_obs	Head_ang	Left_V	Right_V
1.	AO	Near	Near	Near	Any	Slow	Fast
2.	AO	Near	Near	Medium	Any	Slow	Slow
3.	AO	Near	Near	Far	Any	Med	Med
4.	AO	Near	Medium	Near	Any	Med	Slow
5.	AO	Near	Medium	Medium	Any	Med	Slow
6.	AO	Near	Medium	Far	Any	Fast	Med
7.	AO	Near	Far	Near	Any	Fast	Slow
8.	AO	Near	Far	Medium	Any	Med	Slow
9.	AO	Near	Far	Far	Any	Fast	Med
10.	AO	Medium	Medium	Near	Any	Fast	Slow
11.	AO	Medium	Medium	Medium	Any	Slow	Slow
12.	AO	Medium	Medium	Far	Any	Fast	Fast
13.	AO	Medium	Near	Near	Any	Slow	Fast
14.	AO	Medium	Near	Medium	Any	Slow	Med
15.	AO	Medium	Near	Far	Any	Slow	Med
16.	AO	Medium	Far	Near	Any	Med	Slow
17.	AO	Medium	Far	Medium	Any	Med	Fast
18.	AO	Medium	Far	Far	Any	Fast	Med
19.	AO	Far	Near	Near	Any	Slow	Med
20.	AO	Far	Near	Medium	Any	Med	Fast
21.	AO	Far	Near	Far	Any	Med	Fast
22.	AO	Far	Medium	Near	Any	Slow	Fast
23.	AO	Far	Medium	Medium	Any	Slow	Med
24.	AO	Far	Medium	Far	Any	Med	Fast
25.	AO	Far	Far	Near	Any	Fast	Slow
26.	AO	Far	Far	Medium	Any	Fast	Med
27.	AO	Far	Far	Far	Any	Fast	Fast

When the robot sense obstacle near to it or the robot moves at curved and narrow roads, it must reduce its speed to avoid collision with obstacles. In this case, its main reactive behaviour is decelerating for obstacle avoidance.

They give the first and second of fuzzy logic rules for realizing this behaviour as follows:
If *(left-obs is near and right_ obs is near and front-obs is near and head-ang is any)* Then *(left-v is slow and right-v is fast).*
If *(left-obs is near and right_ obs is near and front-obs is medium and head-ang is any)* Then *(left-v is slow and right-v is slow).*

Such fuzzy rules represent that the robot only pays attention to obstacle avoidance as shown in Figure 4 and moves accordingly to listed rule in table 1 when it is close to obstacles or at curved and narrow roads.

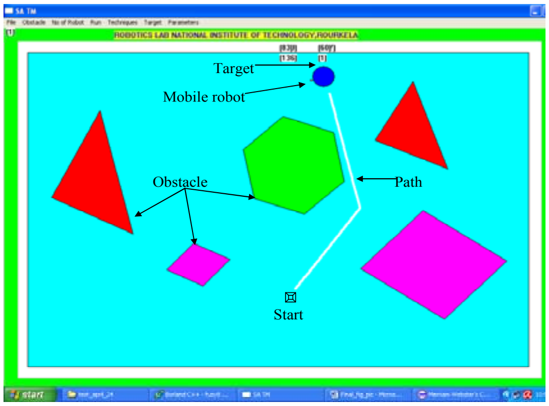


Figure 4. Obstacle avoidance behaviour.

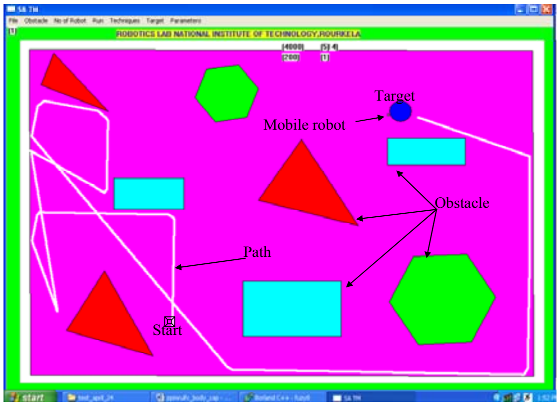


Figure 5. Target seeking behaviour.

2.3 Target seeking behaviour

When the acquired information from the sensors shows that there are no obstacles around robot, its main reactive behaviour is target steer, simulation result shown in Figure 5, by following rule from Table 2.

Table 2. List of some rules for target seeking

RuleNo	Action	Left_obs	Right_obs	Front_obs	Head_ang	Left_V	Right_V
34	TS	Far	Far	Far	P	Fast	Med
35	TS	Far	Far	Med	N	Med	Fast
36	TS	Far	Far	Far	Z	Fast	Fast
37	TS	Far	Far	Med	P	Slow	Med
38	TS	Far	Med	Far	N	Med	Fast
40	TS	Med	Far	Far	Z	Fast	Fast

Here, the 34 and 35 for realizing this behaviour as follows:
If *(left-obs is far and right_obs is far and front-obs is far and head-ang is P)* Then *(left-v is fast and right-v is med).*
If *(left-obs is far and right_obs is far and front-obs is medium and head-ang is N)* Then *(left-v is med and right-v is fast).*

These *fuzzy* logic rules show that the robot mainly adjusts its motion direction and quickly moves to the target if there are no obstacles around the robot. In general, the weights of the behaviours, *obstacle avoidance* and *target steer,* depend largely on the distances between the robot and the obstacles to the left, front, and right locations.

2.4 Wall following behaviour

When robot move in large U shape obstacle, at the initial stage, the robot runs directly toward the target, since the obstacles sensed are far away from the robot. Then, the robot makes a turn to left, in order to avoid the obstacles at the direct front. Since the target is located to the right side of the robot, the behaviour of approaching target tries to make the robot turn to the right. Contrarily, the obstacle-avoidance behaviour makes the robot move away from the obstacles. As a result, the robot moves into the right, and the target orientation is increasing gradually. Consequently, the robot travels along the indefinitely loop in this concave trap as shown in Figure 6. When the robot is moving to a specified target through a narrow channel, or escaping from a U shaped wall specific fuzzy rules for wall following behaviour (Table 3) are activated. In absence of wall following behaviour the robot is incapable of reaching the goal.

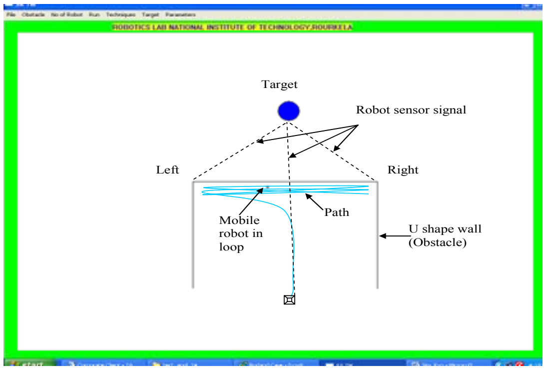


Figure 6. robot in concave trap.

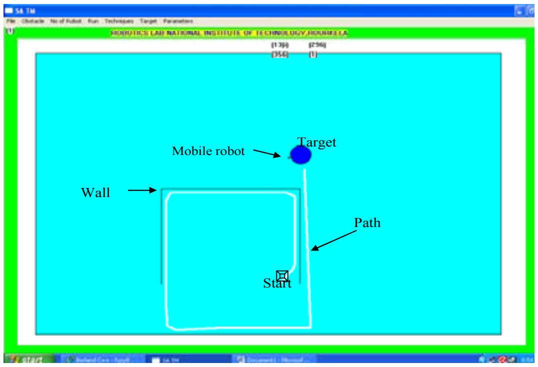


Figure 7. Wall following behaviour.

Table 3. List of some rule for wall following.

RuleNo	Action	Left_obs	Right_obs	Front_obs	Head_ang	Left_V	Right_V
28	FE	Far	Far	Near	Any	Med	Slow
29.	FE	Far	Medium	Near	Any	Slow	Med
30.	FE	Medium	Far	Near	Any	Fast	Med
31.	FE	Near	Far	Medium	Any	Fast	Med
32.	FE	Near	Far	Near	Any	Fast	Med
33.	FE	Near	Medium	Far	Any	Med	Slow

For rule no. 28 and 29 the antecedent and consequent will be:
If *(left-obs is far and right_ obs is far and front-obs is near and head-ang is any)* Then *(left-v is med and right-v is slow).*
If *(left-obs is far and right_obs is medium and front-obs is near and head-ang is any)* Then *(left-v is slow and right_v is med).*

These fuzzy rules show that the robot shall follow an edge of an obstacle when the obstacle is very close to the right or left of the robot, and the target also is located to the right or left. The wall following behaviour depends on a heading angle between the robot and a specified target (simulation result shown in Figure 7).

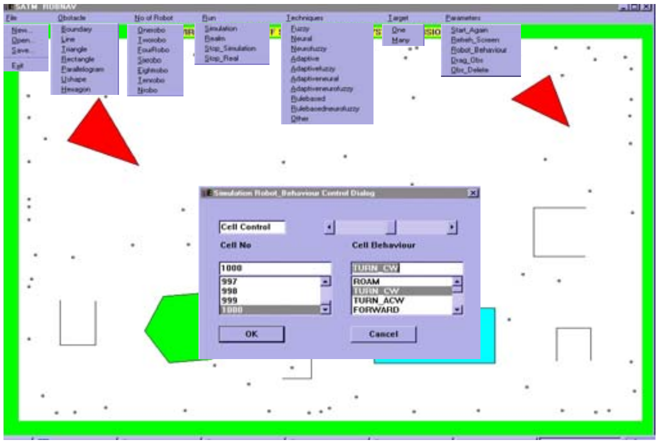
3 Result simulation and discussions

The simulations were conducted with the ROBNAV software being developed in the laboratory using C++ (Parhi, 2000). Figure 8 show a typical screen of the software. It can be noted that, in addition to the fuzzy logic based navigation, the software also allows other navigation control. To demonstrate the effectiveness and the robustness of the proposed method, simulation results on mobile robot navigation in various environments are exhibited.

The obstacle avoidance behaviour is activated when the reading from any sensors are less than the minimum threshold values. This is how the robot determines if an object is close enough for a collision. When an object is detected too close to the robot, it avoids a collision by moving away from it in the opposite direction. Collision avoidance has the highest priority and therefore, it can override other behaviours, in this case, its main reactive behaviour is decelerating for obstacle avoidance as shown in Figure 4.

When the acquired information from the sensors shows that there are no obstacles around robot, its main reactive behaviour is target steer. Intelligent controller mainly adjusts robots motion direction and quickly moves it towards the target if there are no obstacles around the robot as shown in Figure 5. In the proposed control strategy, reactive behaviours are formulated by fuzzy sets and fuzzy rules, and these fuzzy rules are integrated in one rule base.

When robot enters in large U shape or concave shape, based on the preceding analysis, the robot makes turn to the point left and right. In such a situation the robot should keep on heading towards the goal position. But when it moves towards the goal position, the robot also comes closer to the obstacles. Any obstacle-avoidance behaviour except wall following behaviour would make the robot divert from its goal position.



Simulation Robot_Behaviour Control Dialog

Cell Control

Cell No: 1000

Cell Behaviour: TURN_CW

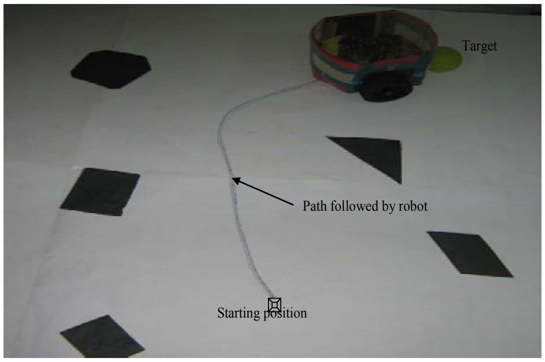
Figure 8. Robot navigation software package (ROBONOV).

To avoid this loop robot must have wall following behaviour, when the robot is moving to a specified target through a U shaped obstacle or narrow channel, it must reflect following edge behaviour so that robot may locate, find and reach the specified target as shown in Figure 7.

4 Experimental result

Figure 9 shows the mobile robot developed by robotics laboratory. The wheels have a radius 3.5cm and are mounted on an axle of length 18.0 cm. The chassis of the robot measures 16×18×15 cm (L×W×H) and contains two DC gear servo motors, two supported free wheels for balance, transmission elements, and 12-V battery. The wheels are driven by motors having rated torque 7 mN.m at 30 rpm and at 12 rated voltage. The assumptions about the mechanical structure and the motion of a mobile robot to which our proposed method is applied are as following:

a) Mobile robot consists of rigid base fitted with DC gear servo motor and wheels are connected to motor shaft.
b) Mobile robot move on a plane surface (on lab specified floor area).
c) The wheel of a mobile robot rolls on the floor without any translational slip.
d) The wheel of a mobile robot makes rotational slip at the contact point between each wheel and the floor.



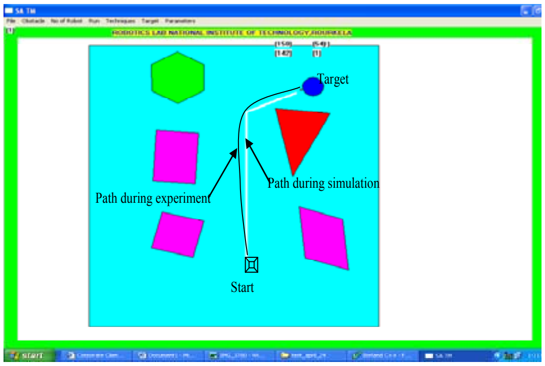


Figure 9. Real mobile robot reaching the goal.   Figure 10.Path traced by simulated and actual real mobile robot.

The experimental paths followed by mobile robots to reach the target are obtained as shown in Figure 9. From the fuzzy controller (inputs: left, front, right obstacle distances and heading angle) after defuzzyfication, robots get the left and right wheel velocities which subsequently give the new steering angles. The paths traced by the robots are marked on the floor by a pen (fixed to the front of the robots) as they move. From these figures, it can be seen that the robots can indeed avoid obstacles and reach the targets. The experimentally obtained paths follow closely those traced by the robots during simulation (shown in Figure 10). From these figures, it can be seen that the robots can indeed avoid obstacles and reach the targets. Table 4 shows the times taken by the robots in simulations and in the experimental tests to find the targets. The figures given are the averages of 12 experiments on each environmental scenario being conducted in the laboratory.

Table 4. Time taken by robots in simulation and experiment to reach targets.

S. No.	Average of 12 experiments in each environment	Time during simulation [seconds]	Time during experiment [seconds]
01.	For 1st environment scenario	28.3	30.25
02.	For 2nd environment scenario	28.4	30.5
03	For 3rd environment scenario	28.3	30.5

5 Conclusions

This paper described the fuzzy logic approach for intelligent navigation control of mobile robots. The proposed intelligent controller for navigation strategy of mobile robots using fuzzy logic rules has major advantages over existing analytical methods. Very good agreement between the simulation and experimental results show the robustness of the fuzzy controller developed. Here the navigational control strategy addresses the question of how to determine a sequence of actions to achieve the goals. The resulting action sequences may be designed to be applied in many ways, such as by mobile robots in different hazardous situations. Planning systems may use a number of techniques to make the planning process practical. In real-world situations, it is seldom possible to generate a complete plan in advance and then execute it without changes. Determining the state of the world and guiding action requires the ability to gather information about the world, though sensors such as sonar or cameras. These sensors data have been used by the fuzzy controller for navigational purpose. The above strategy can be used for other techniques (e.g. neural, neuro-fuzzy) for navigation of mobile robots.

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