Design of Obstacle Avoidance System for Mobile Robot using Fuzzy Logic Systems

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Abstract

There were many reports about an obstacle avoidance of a mobile robot. In this paper, we design a fuzzy logic system and propose an obstacle avoidance algorithm for a path planning in unknown environment for a mobile robot. The ultrasonic sensors are employed for detecting the distance to obstacles and their positions. An angular velocity control for left and right wheels is implemented by a fuzzy logic system. We here propose another new rule table that is induced from the consideration of the distance to obstacles and the angle between the robot and the goal. Some simulation results show that the proposed method generates a good path with avoiding obstacles and has faster travelling time.

Keywords: *fuzzy logic system, mobile robot, obstacle avoidance, path planning, ultrasonic sensor*

1. Introduction

There were many research results about obstacle avoidance and path tracking of a mobile robot. The fuzzy logic system has widely used for one of effective means in unknown and complex industrial environments. In many research results, a fuzzy logic system has usually implemented for improving the efficiency of obstacle avoidance and path planning of mobile robot at unknown environments. The fuzzy logic system has well suited for implementing controllers due to its capabilities of inference and approximate reasoning under uncertainty. Most fuzzy logic systems have a complex rule table for achieving different control objectives. And the size of complete rule-bases increases exponentially with the number of input variables. Many algorithms were addressed in related journals for obstacle avoidance and path planning of a mobile robot [1-9]. In [1], a hierarchical behavior-based control architecture was introduced. This structure was motivated by the hierarchical nature of behavior as hypothesized in ethological models. He proposed a new approach to design a fuzzy controller for increasing the ability of mobile robot to react to dynamic environment. A simple structured fuzzy logic system was implemented in [2]. Its main concept was introduced in [10].

In this paper we propose a fuzzy logic based control system for path tracking of an indoor mobile robot. The ultrasonic sensor is used for positioning and identifying the recognition of an obstacle. Here the left and right wheels' angular velocities are controlled by a fuzzy logic system. The methods for fuzzification and reasoning are singleton and Mamdani's method, respectively. In the case of the conventional fuzzy logic system, the number of control rules is forty nine for each wheel [2]. So, we analyze the fuzzy control rules of the conventional system and then induce another control rules from eight conditions of positions of obstacles and three parts of the angle between the robot and the target position. The organization of this paper is as follows: In next section we introduce the controlled process of an indoor mobile robot. We describe the design process of fuzzy logic based obstacle avoidance algorithm for an indoor mobile robot in Section 3. Simulation examples are shown in Section 4. We here use the Matlab/Simulink as a simulation tool. We show that good performance could be obtained at several simulation results. Finally, we present some concluding remarks.

2. Architecture of Mobile Robot System

A kinematics model of a mobile robot used in this paper is shown in Figure 1.

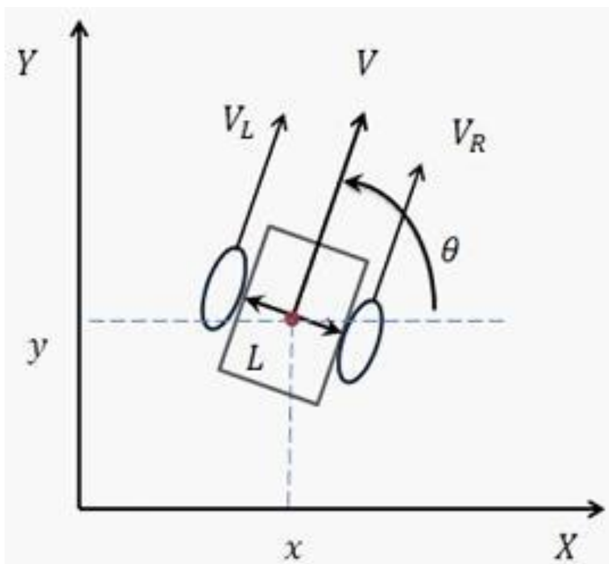

Figure 1. Kinematics Model of the Robot

Accelerations of left and right wheels are ω_L and ω_R, respectively. We assume that the contact between the wheels and the ground is pure rolling and non-slipping [5]. The relationship between left and right wheels of velocity and acceleration is as follows:

$$V_L = r\omega_L \text{ and } V_R = r\omega_R \ , \tag{1}$$

where r is a radius of the wheel. The linear velocity of the mobile robot is V. Linear velocities for the left and right wheels are V_L and V_R, respectively. The relationship between ω_L, ω_R, V_L and V_R is as follows:

$$V = \frac{V_R + V_L}{2} = r\frac{\omega_R + \omega_L}{2} \qquad \omega = \frac{V_R - V_L}{L} = r\frac{\omega_R - \omega_L}{L} \tag{2}$$

Now we can summarize a dynamic model for the mobile robot as follows:

$$x' = V\cos\theta,\ y' = V\sin\theta,\ \theta' = \omega, \tag{3}$$

$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} V \\ \omega \end{bmatrix}$$

3. Design of Fuzzy Logic Systems

The conventional fuzzy logic system mainly includes fuzzification, knowledge base, fuzzy reasoning and defuzzification. The fuzzification converts the accurate input variables into input grades named as fuzzy variables. The knowledge base is used to store relevant data and control rules. The fuzzy reasoning generates fuzzy results from inferencing of the knowledge base and the inference engine. The defuzzification converts fuzzy variables to accurate output variables. Its typical architecture is shown in Figure 2.

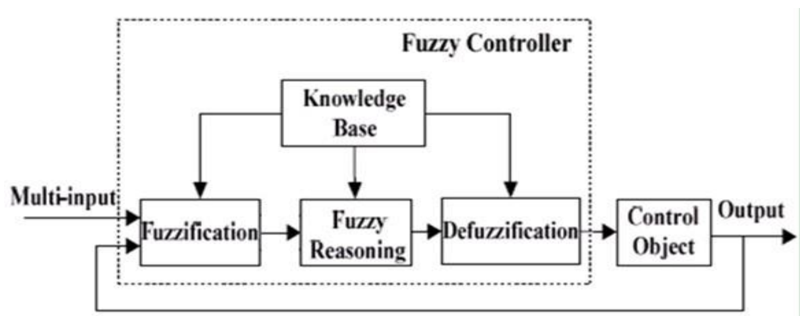

Figure 2. Typical structure of a fuzzy logic system

3.1. Determination of Input and Output Variables

The inputs for the proposed fuzzy logic system are distances measured from the obstacle to the sensors and the angle between the robot and the goal. The sensors are located at left, right, and front sides of the robot. The angle means an angle between robot's orientation and target position. The output variables are velocities of the left and right wheels.

3.2. Fuzzification

Linguistic variables "near" and "far" are taken for the distance from the obstacle to the sensor. Eight conditions are defined by the location of the obstacles like Table 1. The domain for the angle between the robot and the target position is constructed with {left, front, right}. Here "left" means that the goal is located at the left side of the robot. The domain for velocities of the left and right wheels is constructed with {slow, L-slow, mid, L-fast, fast}, where L and mid stand for "Little" and "middle", respectively. The membership functions are shown in Figure 3.

Table 1. Eight conditions according to the detection of obstacles

	left-obstacle	front-obstacle	right-obstacle
D1	near	near	near
D2	near	near	far
D3	near	far	near
D4	near	far	far
D5	far	near	near
D6	far	near	far
D7	far	far	near
D8	far	far	far

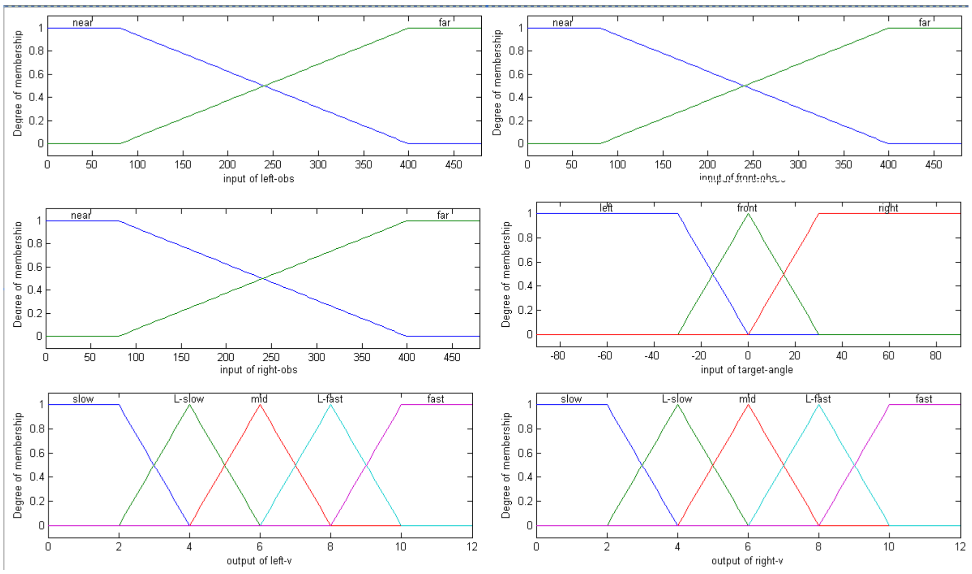

Figure 3. Membership functions for fuzzy logic system

Input and out membership functions were defined as Table 2 and 3, respectively. Values in the tables present values of *x*-axis in a kind of singular points. That is, “0 : 80 : 400 : 480” is values of *x*-axis in singular points for a fuzzy membership function “near” of input fuzzy variables and “0 : 6 : 8 : 10 : 12” is values of *x*-axis in singular points for a fuzzy membership function “L-Fast” of output fuzzy variables.

Table 2. Definition of input membership functions

Terms	Meaning	Range of Membership Function
Near	Near	0 : 80 : 400 : 480
Far	Far	0 : 80 : 400 : 480
Left	Left	-90 : -30 : 0 : 30 : 90
Front	Front	-90 : -30 : 0 : 30 : 90
Right	Right	-90 : -30 : 0 : 30 : 90

Table 3. Definition of output membership functions

Terms	Meaning	Range of Membership Function
Slow	Slow	0 : 2 : 4 : 12
L-Slow	Little Slow	0 : 2 : 4 : 6 : 12
Mid	Middle	0 : 4 : 6 : 8 : 12
L-Fast	Little Fast	0 : 6 : 8 : 10 : 12
Fast	Fast	0 : 8 : 10 : 12

3.3. Generation of Control Rules

The control rules could be induced by empirical knowledge. They are shown in Table 4 and Table 5 for left and right wheel, respectively. The rules were basically generated by eight conditions from D1 to D8. For example, the condition D1 means that obstacles are located at near to the front, left, and right sides. The angle "Right" means that the goal is located at the right side of the robot.

Rule base is composed of many fuzzy implication relations, which are obtained based on lots of experiments, observation and operation experience. Furthermore the actual number of fuzzy rules should be taken depends on many factors. The general principle is on the completeness of the premise. In order to simplify the design process of the fuzzy logic system, a smaller number of rules are better. In [2], the conventional fuzzy logic system had 98 rules, that is, 49 rules were required for each wheel of left and right.

Table 4. Fuzzy control rules for the left wheel

Angle	D1	D2	D3	D4	D5	D6	D7	D8
Left	Slow	L-Slow	Mid	L-Slow	Slow	Slow	Mid	L-Fast
Front	L-Slow	L-Slow	L-Fast	Mid	Slow	L-Slow	L-Slow	Fast
Right	L-Slow	L-Slow	Mid	L-Fast	Slow	L-Slow	Slow	Fast

Table 5. Fuzzy control rules for the right wheel

Angle	D1	D2	D3	D4	D5	D6	D7	D8
Left	L-Slow	Slow	Mid	Slow	L-Slow	L-Slow	L-Fast	Fast
Front	Slow	Slow	L-Fast	L-Slow	L-Slow	Slow	Mid	Fast
Right	Slow	Slow	Mid	Mid	L-Slow	Slow	L-Slow	L-Fast

The meaning of several rules of Table 4 and 5 is as follows:

R01:

IF the condition is D1 and the angle is Left,

THEN the left wheel is Slow(V_L =Slow) and the right wheel is Little Slow(V_R =L-Slow).

R08:

IF the condition is D3 and the angle is Front,

THEN the left wheel is Little Fast(V_L =L-Fast) and the right wheel is Little Fast (V_R =L-Fast).

R16:

IF the condition is D6 and the angle is Left,

THEN the left wheel is Slow(V_L =Slow) and the right wheel is Little Slow(V_R =L-Slow).

R24:

IF the condition is D8 and the angle is Right,

THEN the left wheel is Fast(V_L =Fast) and the right wheel is Little Fast (V_R =L-Fast).

3.4. Defuzzification

Many defuzzification algorithms have been reported. There are several common methods, such as maximum membership grade, median clustering, average maximum membership grade and weighted average method, and *etc.* We here use the center of gravity, where $\mu_c(z)$ is degree of membership, *z* is steering angle, and z_a is a crisp value.

$$Z_a = \frac{\int \mu_c(z) \cdot zdz}{\int \mu_c(z) dz} \quad (4)$$

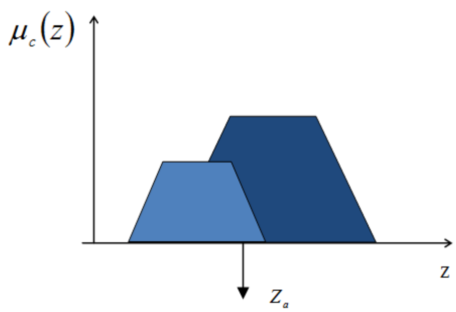

Figure 4. Center of gravity method for defuzzification

4. Simulation Study

The simulation environment is like Figure 4. It has three obstacles and is the same environment in [2]. The starting position of the robot and its goal are (0, 0) and (25, 25), respectively. Then the robot moved along the bold path and line path by the proposed fuzzy logic system and Ref. [2], respectively. However the conventional fuzzy logic system of [2] used 49 control rules and the proposed system used only 24 rules.

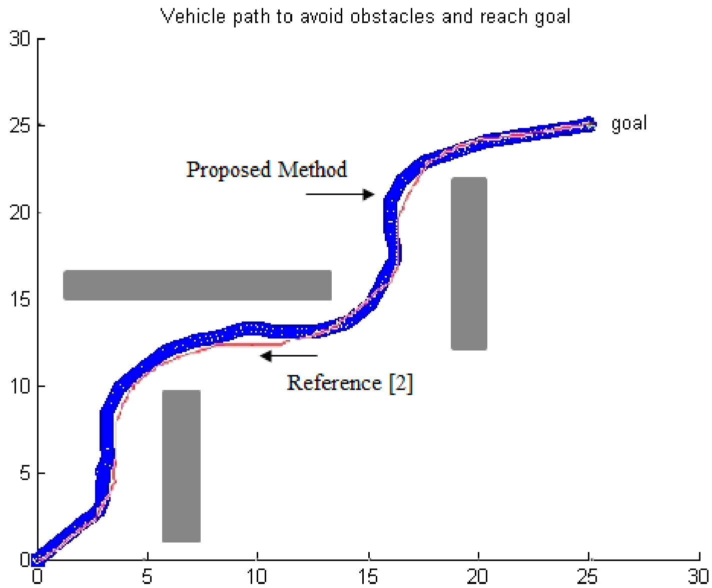

Figure 5. Simulation results of obstacle avoidance

The mobile robot could safely avoid some obstacles. The comparison with the conventional fuzzy logic control system of [2] and the proposed system was shown in Table 6. From the table, the performance of the conventional fuzzy logic system is better than that of the proposed system in the case of the travelled length. However the performance of the proposed fuzzy logic system is better than that of the conventional system in the case of the travelled time. The proposed system has smaller control rules, then the computational time is also more fast.

Table 6. Numerical comparison of two methods

Method	Traveled Path Length (m)	Traveled Path Time (sec)
Proposed Method	45.6	50.2
Ref.[2]	43.8	55.6

5. Concluding Remarks

We here described the design process of fuzzy logic based obstacle avoidance algorithm for a mobile robot, and studied an obstacle avoidance system of mobile robot by using fuzzy logic control systems.

The velocities of the two wheels were independently controlled. Their outputs for the fuzzy control system were the velocities of the left and right wheels. And their input variables were positions of obstacles and the angle between the robot and the target position. Here positions of obstacles were categorized by eight conditions. The angle of input variable was divided by three part of front, left, and right. Therefore, the number of total control rules was only 24 compared to the case of 49 in [2] for each wheel of the robot. The proposed fuzzy logic system showed a good performance with small control rules and fast travelling time. The simulation results demonstrated the effectiveness of the obstacle avoidance capability with fast time in an unknown environment.

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