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Application of fuzzy neural network based on T-S model for mobile robot to avoid obstacles

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Abstract **– The problem of avoiding obstacles for mobile robot is quite difficulty, because work circumstance of the mobile robot is usually unknown. It was against this background that a study was undertaken with the specific aim of mobile robots reaching the destination without collision. A fuzzy neural network method based on Takagi-Sugeno(T-S) model was proposed to be used in the study. It not only has the advantage of fuzzy logic and neural network, but also has good self-study ability. The data collected by 8 ultrasonic sensors were classified firstly. Then the navigation algorithm based on T-S model was carried out. The test results show that the mobile robot using this fuzzy neural network can recognize the obstacles in all environment types, decide its action, and then arrive at destination after 231 seconds averagely. It is faster than the mobile robot using BP neural network which takes 239 seconds averagely.**

Key words - Mobile robot; Fuzzy neural network; Avoiding obstacles; Multi-sensor

I. INTRODUCTION

Multi-sensor information fusion in allusion to the system which uses many congeneric sensors or many different types of sensors is developing. It is a new research direction of the information processing. The information detected by many sensors is redundant and complementary, and the information fusion of these data improves the reliability of the system. In recent years, multi-sensor information fusion is widely used in many intelligent systems[1]. Mobile robot is an important field for the application of the multi-sensor fusion. The mobile robot's automatic navigation includes edge-detection[2], wall-following[3], avoiding obstacles[4][5], and so on. Because work circumstance of the mobile robot is usually unknown, the robot should perceive the changing environment so as to avoid obstacles and navigate automatically. There are normally two kinds of perceptual sensor systems mounted on the mobile robot: single or multiple sensors perceptual system. A perceptual system based on a single sensor has an inherent weakness: they generally can not reduce uncertainties. One knowledge source is not able to provide all information necessary for detection and manipulation tasks. To overcome this problem, some researchers have proposed turning to another type of perceptual system, which relies on multiple general-purpose sensors, and it has become a tendency in the research of mobile robot navigation.

In the navigation system of the mobile robot, the information detected by many sensors has a certain uncertainty. The fuzzy fusion is a process of this uncertainty reasoning. Moreover, the fuzzy neural network combines the knowledge configuration of fuzzy logic and the self-study ability of neural network, so it has the ability of uncertainty reasoning and the self-study. In this paper, the fuzzy neural network based on the Takagi-Sugeno information fusion arithmetic was used in avoiding obstacles of mobile robots whose detecting device had been designed. Through the experiment with the information method put forward, the mobile robot can recognize the obstacles and environment type, decide its action, and then realize its movement without collision.

II. THE DETECTING DEVICE OF MOBILE ROBOT

Generally, ultrasonic range sensors were employed for obstacles detection in our mobile robot. This type of sensor is simple, low-cost and efficient to measure distances to obstacles. Eight ultrasonic range sensors are installed at different places, and could detect information in different directions. The use of multi-sensor endows the system with the merit of redundant and complementary information, and decreases the uncertainty degree of the system. Even if one sensor is invalid, the redundant information can make up the lost information, and then improve the robust of the system.

Automatic navigation is a process that the robot according to the optimization or sub-optimization path can move to the destination which is decided in advance without collision, though the system has no information about the circumstance. Our mobile robot who can navigate automatically has an orientation system and eight ultrasonic sensors, and can change the wheel's velocity. The velocity is controlled by the voltage supplied by direct current electromotor.

The eight sensors are mounted in a circle on the front of mobile robot by 22.5° apart, as shown in Fig.1. They are used to detect the eight directions' obstacles information. The range of the sensors' detection is from 30 to 300cm. And the detected information is used as the fusion initial value.

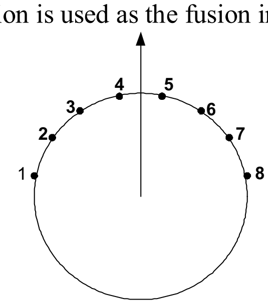


Fig. 1 Grouping of ultrasonic sensors

There is an orientation system which can detect the current position and moving direction. The target direction is defined relatively to the heading of the mobile robot, and taken into account during the active navigation. It is divided into 5 levels as shown in Fig.2. The details of this division are as follows:

$$t = \begin{cases} 1 & 180^\circ < \phi \le 270^\circ \\ 2 & 120^\circ < \phi \le 180^\circ \\ 3 & 60^\circ < \phi \le 120^\circ \\ 4 & 0^\circ < \phi \le 60^\circ \\ 5 & otherwise \end{cases} \tag{1}$$

Where ϕ is the direction of the target with respect to the current heading of the mobile robot.

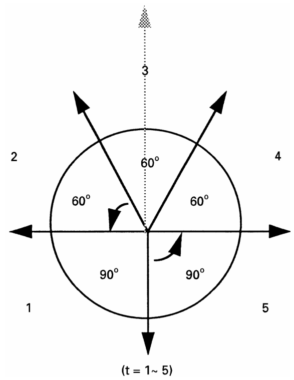


Fig. 2 Quantization of target direction

Nine typical obstacles-configuration classes were considered as depicted in fig.3

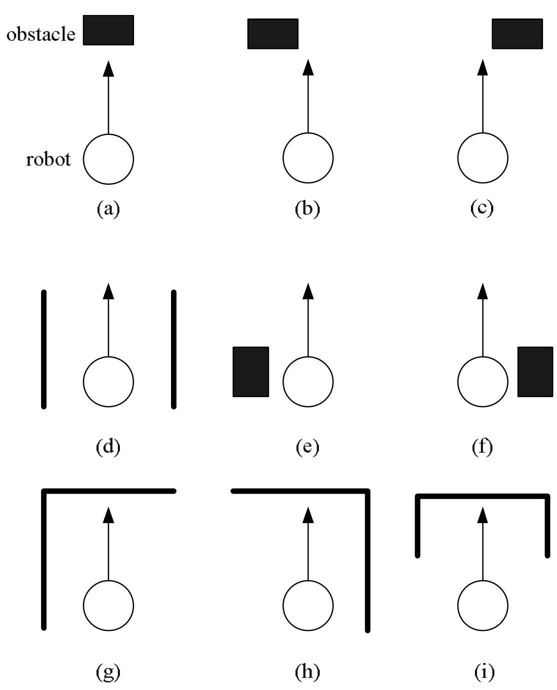


Fig. 3 Environment types perceived by the robot

The mobile robot detects the circumstance per second. The detected information is quantized firstly, and the results are used as the inputs of the fuzzy neural network; the outputs of the fuzzy neural network are the value of the action control estimate for the left wheel's velocity and the right one's velocity.

III. THE METHODS OF INFORMATION FUSION

Using the ultrasonic sensors and the orientation system, the robot can obtain the information about the position of the obstacles. The simulation circumstance of the robot is a two dimensions field where a group of obstacles are placed. The position and the shape are unknown to the robot. The following method is used to process the information.

With the ultrasonic sensors, the robot can obtain eight detected data $d_1, d_2, \cdots, d_8$ respectively. These eight sensors are divided into five groups, and the quantization formulas for groups are as follows.

$$t = \begin{cases} x_1 = d_1 \\ x_2 = \min(d_2, d_3) \\ x_3 = \min(d_4, d_5) \\ x_4 = \min(d_6, d_7) \\ x_5 = d_8 \end{cases} \tag{2}$$

Where x_1 is the distance to the left obstacles from the robot, x_2 is the distance to the left and front obstacles, x_3 is the distance to the front ones, x_4 is the distance to the right and front ones, x_5 is the distance to the right ones.

The fused distance is classified as follows:

if $x_i < 2$, the distance in this direction is considered as x_i and there is an obstacle in this direction;

if $x_i \ge 2$, the distance in this direction is considered as 4 and there is no obstacle in this direction.

$x_1 \sim x_5$ and t are used as the inputs of fuzzy neural network.

IV. THE FUZZY NEURAL NETWORK USED IN AVOIDING OBSTACLES OF MOBILE ROBOT

The fuzzy neural network based on the T-S model can easily expresses the complex system, and approach to the nonlinear system with high precision. The fuzzy neural network has the reasoning ability of fuzzy logic and the self-study ability of neural network, which make the fuzzy neural network have a better ability to approach to the destination. So, the fuzzy neural network arithmetic based on T-S was used in avoiding obstacles in the mobile robot.

The network configuration is shown in Fig.4. $x_1 \sim x_5$ are the distances in five directions, t is the direction layer to the object, The neuron function of every layer is shown as follows:

(1)The first layer:

$$f_i^{(1)} = x_i^{(0)} = x_i; x_i^{(1)} = g_i^{(1)} = f_i^{(1)}, i = 1, 2, \ldots 5 \tag{3}$$

Where f is the input of neuron node, $x_i^{(j)} = g_i^{(j)}(f^{(j)})$ is the output of neuron node, $g_i^{(j)}$ is the non-linear function, superscript is the layer of the neuron node.

(2)second:

$$f_{is_i}^{(2)} = -\frac{(x_i^{(1)} - c_{is_i})^2}{\sigma_{is_i}^2} \tag{4}$$
$$x_{is_i}^{(2)} = \mu_i^{s_i} = g_{is_i}^{(2)} = e^{f_{is_i}^{(2)}} = e^{-(x_i - c_{is_i})^2/\sigma_{is_i}^2}$$

where $\mu_i^{s_i}$ is the membership function, $i = 1,2,...5$; $s_i = 1,2$.

(3)third:

$$\min\{\mu_1^{s_{1j}}, \mu_2^{s_{2j}}, \cdots, \mu_5^{s_{5j}}\}, x_j^{(3)} = \alpha_j = g_j^{(3)} = f_j^{(3)} \tag{5}$$

where $s_{1j} \in \{1,2\}$, $s_{2j} \in \{1,2\}$, $\cdots$, $s_{5j} \in \{1,2\}$, α_j is the applicable degree of every rule; $j = 0,1,\cdots,8$.

(4)forth:

$$f_j^{(4)} = x_j^{(3)} / \sum_{i=1}^{m} x_j^{(3)} = \alpha_j / \sum_{i=1}^{m} \alpha_j \tag{6}$$
$$x_j^{(4)} = \overline{\alpha_j} = g_j^{(4)} = f_j^{(4)}$$

where $\overline{\alpha_j}$ is the normally applicable degree of every rule; $j = 0,1,\cdots,8$.

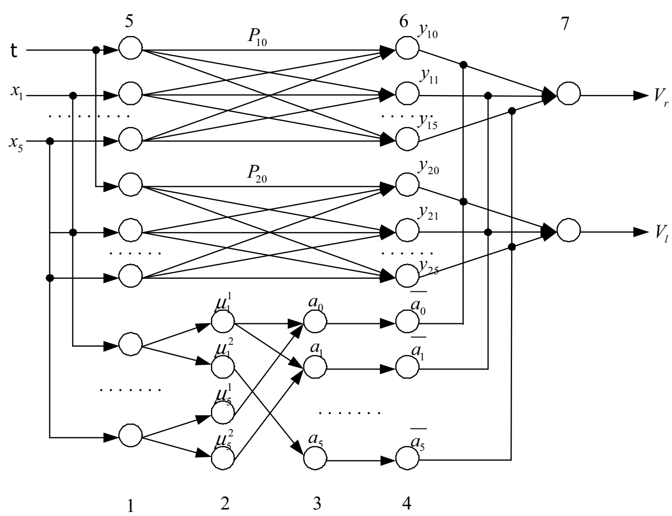


Fig. 4 T-S fuzzy neural network used in avoiding obstacles of robot

(5)fifth:

$$f_i^{(5)} = x_i^{(0)} = x_i, i = 1,2,\cdots,5$$
$$f_0^{(5)} = x_0^{(0)} = t \tag{7}$$
$$x_i^{(5)} = g_i^{(5)} = f_i^{(5)}, i = 0,1,\cdots,5$$

(6)sixth:

$$f_i^{(6)} = \sum_{j=0}^{5} P_{ij}^k x_j^{(5)} \tag{8}$$
$$x_i^{(6)} = y_{ki} = g_i^{(6)} = f_i^{(6)}, k = 1,2; i = 0,1,\cdots,8$$

where P_{ij}^k is the weight of the network, y_{ki} is the output value of every rule.

(7)seventh :

$$f_k^{(7)} = \sum_{i=0}^{8} y_{ki} x_i^{(4)} = \sum_{i=0}^{8} y_{ki} \overline{\alpha_i} \tag{9}$$
$$x_1^{(7)} = V_r = f_1^{(7)}; x_2^{(7)} = V_l = f_2^{(7)}; k = 1,2$$

where V_r and V_l are the value of the action control estimate for the left and the right wheels' velocities of mobile robot respectively.

V. SIMULATION

The mobile robot uses eight ultrasonic sensors to detect the environment, and the information is fused by the fuzzy neural network based on T-S arithmetic; sequentially the control decision is obtained. After the network has been trained, the fuzzy neural network is used in avoiding obstacles. The expected result is that the mobile could avoid the obstacles in unknown environment and reach the object with lower consumption. The start point is（14，8），unit is centimeter, and the destination is（14，18）. The robot should set out at the start point, and arrive at the destination without collision. The fuzzy neural network based on T-S can easily express the fuzzy self-study, which improves the real time of the mobile robot. The simulation process is shown in Fig.5 and Fig.6.

According to Fig.5 and Fig.6, the BP neural network and fuzzy neural network were separately used in mobile robot to avoid obstacles. The mobile robot could avoid obstacles and reach the destination without collision. Fig.7 records wheels' velocities of avoiding obstacles using BP neural network navigation algorithm. Fig.8 records wheels' velocities of avoiding obstacles using fuzzy neural network.

As shown in the figures, the mobile robot uses the fuzzy neural network takes 231 seconds to the goal, whereas it takes 239 seconds to the goal when the mobile uses BP neural network, and the switch time of the latter is longer. Comparing the time cost of the robot to reach the destination in the two methods respectively, we find the prior is better.

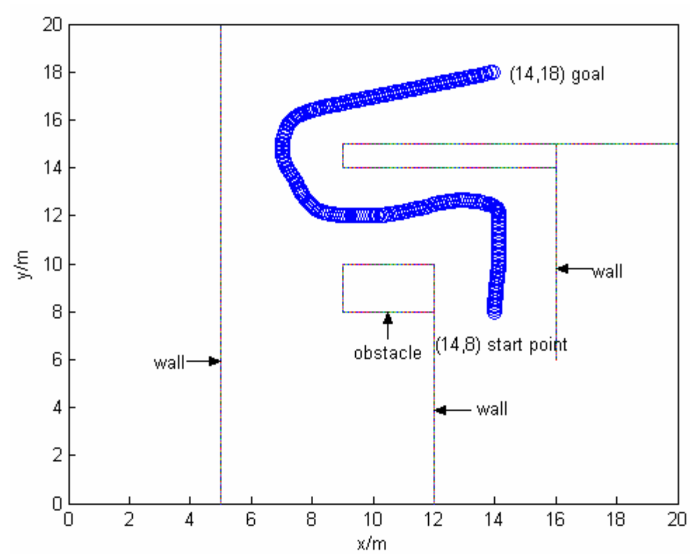


Fig. 5 The recorded robot's track of avoiding obstacles using BP model

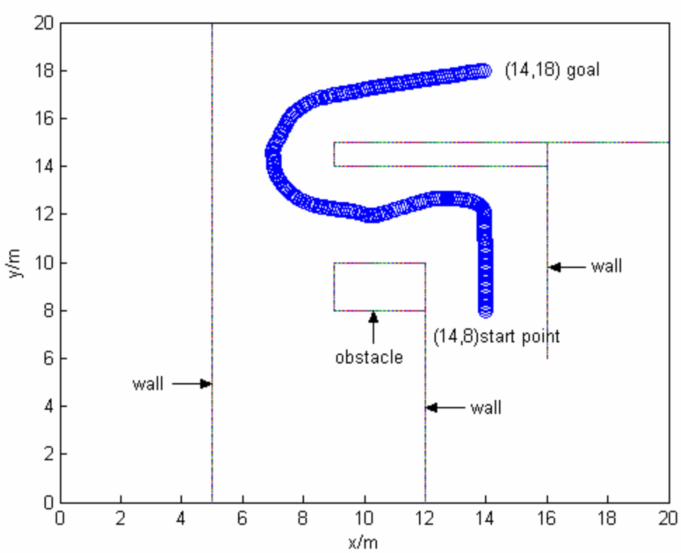


Fig. 6 The recorded robot's track calculated by using T-S model

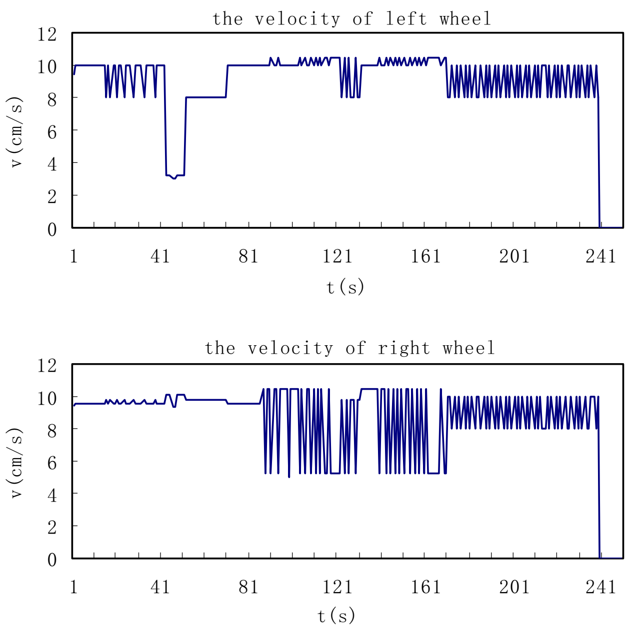
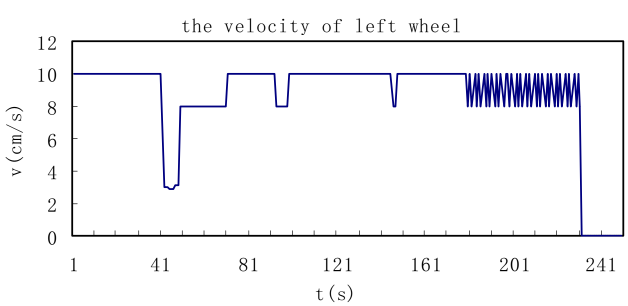


Fig. 7 The Recorded wheel velocities of avoiding obstacles using BP model



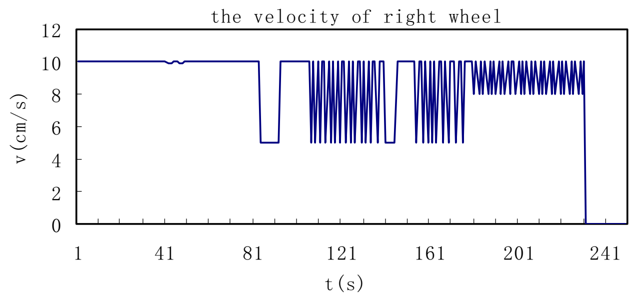


Fig. 8 The Recorded wheel velocities of avoiding obstacles T-S model

VI. Conclusion

Automatic navigation of robots in unknown environment is quite a difficult matter. The main reason is that it is uncertain to sense unknown environment for robots. In this paper, fuzzy neural network based on T-S model was used in avoiding obstacles. The information detected by the ultrasonic sensors was classified and fused. Then the fused results and direction level were the inputs of the fuzzy neural network. The outputs of the fuzzy neural network were the values of the action control estimate for the left and the right wheels' velocities of mobile robot.

This navigation algorithm had been implemented by using computer simulation, and obtained satisfactory results. It proves that the fuzzy neural network based on T-S model is doable. Furthermore, we compare the test results between BP model and T-S model used in avoiding obstacles. Simulation results show that the T-S method can make the mobile robot arrive to the destination with a lower consumption and more effectively.

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