The Autonomous Performance Improvement of Mobile Robot using Type-2 Fuzzy Self-Tuning PID Controller

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Abstract. Autonomous driving of mobile robot is important in various working environment. For its autonomous driving, mobile robot utilized ultrasonic sensor to detect obstacles and avoid them. Also, there has been researched on supplementing function of avoiding crash by using control methods based on adoption of intellectual system. This research has designed type-2 fuzzy self-tuning PID controller which can enhance autonomous driving function of mobile robot under fixed obstacle environment. The fuzzy controller has utilized type-2 with multiple values and the fuzzy self-tuning PID controller adjusting gain value of PID controller is applied. In terms of function of type-2 fuzzy controller with 5 rules, it was confirmed through improvement in function of autonomous driving of mobile robot using Matlab/Simulink.

Keywords: Matlab/Simulink, Mobile robot, PID controller, Self-tuning controller, Type-2 fuzzy controller.

1 Introduction

The mobile robots have been researched to detect the obstacles and to avoid conflicts. The obstacle avoidance using artificial intelligence techniques is based on model, fuzzy logic, neural networks, genetic algorithms [1-3].

The PID controller is also used in a lot of simple designs of the control method. A control performance can be stable by using the PID controller. But it is not easy and intelligent to set appropriated parameters. In this paper, the fuzzy controller was used to improve the performance of autonomous mobile robots and complement the shortcomings of PID controller [4].
2 Mobile robot system

The kinematic model of a mobile robot can be described as Fig. 1. The reference coordinate system ($I$) of the mobile robot ($I_p$) position can be expressed by position ($[x \ y]^T$) and tracking direction ($\theta$)[2].

Fig. 1. The robot kinematics model

A position and a tracking direction of the robot are expressed as $I_p = [x \ y \ \theta]^T$. The velocity of the robot is as following equation (1).

$$\dot{I_p} = [\dot{x} \ \dot{y} \ \dot{\theta}]$$

In general, an attitude of the robot in reference coordinate system is expressed by an orthogonal rotation matrix. In the case of a mobile robot, driving on a plane is a rotation axis $z$. Based on the moving coordinate system ($M$), the rotation matrix in the reference coordinate system ($I$) is as the following equation (2)[6].

$$R_{MI} = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

A wheels angular velocity and the linear velocity of the mobile robot are shown in Fig.3. $v$ is linear velocity and $v_R$, $v_L$ are velocity of both wheels and $L$ is distance of between both wheels

Fig. 2. Angular speed and linear velocity of mobile robot
The angular velocity in both wheels is expressed by $\omega_L$ and $\omega_R$. Under non-slipping conditions, velocity at the junction of two wheels and grounds is equation (3)[3].

$$
\begin{align*}
    v_R &= r \omega_R \\
    v_L &= r \omega_L
\end{align*}
$$

Velocity ($v(t)$) is as follows.

$$
v(t) = \frac{1}{2} (v_R + v_L)
$$

Angular speed ($\omega(t)$) is as follows.

$$
\omega(t) = \frac{1}{L} (v_R - v_L)
$$

3 Type-2 Fuzzy Self-Tuning PID Controller Design

Type-1 fuzzy logic has a crisp output as input a scalar value. Type-1 fuzzy logic includes fuzzifier rules, inference engine, and defuzzifier. Type-2 fuzzy logic is a type-1 fuzzy logic added to type-reducer. So type-2 fuzzy logic output is membership grade and crisp value.

Fig. 3. Structure of fuzzy self-tuning PID controller
As shown in Fig. 3, fuzzy self-tuning PID controller receives input error \( e \) and error rate \( e' \) to the input of the fuzzy controller [5]. Gain value of a PID controller is determined by the obtained output through the fuzzy controller [4].

A variables input of the fuzzy controller is the angular speed error \( e \) and angular error rate \( e' \). The variable output of the fuzzy controller is the gain value a PID controller. A structure of type-2 fuzzy control logic is shown in Fig. 4. The proposed controller is designed with Matlab/Simulink [4].

Table 1. Fuzzy rule table

<table>
<thead>
<tr>
<th>( K_p/K_i/K_d )</th>
<th>( e )</th>
<th>( e' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>VB/S/S</td>
<td>VB/B/S</td>
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<tr>
<td>NS</td>
<td>B/B/S</td>
<td>B/B/S</td>
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<tr>
<td>ZE</td>
<td>M/B/M</td>
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<td>PS</td>
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<td>PB</td>
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</table>

A fuzzy rule base is used in order to obtain the optimized PID gain value. We use the 25 general rules in this paper.

4 Simulation

We performed the simulation with Matlab/Simulink and Solidworks. A Pioneer 3DX mobile robot was built using Solidworks. As shown in Fig. 5, (a) is a part that implements the hardware of Pioneer 3DX using Matlab/Simulink. (b) is a control unit which controls the angular velocity of the mobile robot. (c) is a section for outputting the results of the simulation visually. Matlab/Simulink and Solidworks are linked so that we can check the movement of the mobile robot.
Fig. 5. Pioneer 3DX Simulink Model

(a) Only Ultrasonic sensor  (b) Type-2 Fuzzy Self-Tuning PID Controller

Fig. 6. Autonomous of Mobile Robot

Fig. 7. Type-2 Fuzzy Self-Tuning PID Controller heading

As shown in Fig. 7, it indicates the direction of the mobile robot.
5 Conclusion

In this paper, we propose a type-2 fuzzy self-tuning PID controller to improve the performance of autonomous mobile robots. The angular error and the error rate are the output PID gain through the fuzzy controller. An autonomous mobile robot using only ultrasonic sensors could not escape the minimum point easily. Type-2 fuzzy self-tuning PID controller has complemented the shortcomings and improves the autonomous performance. We confirmed the proposed controller through MATLAB/Simulink simulations.

References