Differential Steering Control System of Lawn Mower Robot

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Abstract. Aiming at the problem of inflexible steering and motion of robot, this paper applies fuzzy adaptive PID control algorithm to the differential steering control system of mowing robot to improve its rapidity and accuracy. In this paper, according to the domestic green environment and the overall parameters of the mowing robot, the overall design of the mowing robot is made, the fuzzy adaptive PID control algorithm of the mowing robot differential steering control system is designed, the mathematical model of the mowing robot differential steering is constructed, and the MATLAB/Simulink is used to simulate the fuzzy adaptive algorithm. The simulation results show that the response speed and overshoot of fuzzy adaptive PID algorithm are 2.42 s and 16.4, respectively, The response speed and overshoot of PID are 7.18 s and 36.3% respectively, so the dynamic performance of the differential steering control system based on Fuzzy Adaptive PID algorithm is better than that based on ordinary PID control.

Keywords: Mowing robot · Fuzzy adaptive PID · Differential steering

1 Introduction

With the acceleration of my country's urbanization process, the construction of urban greening environment has gradually received attention, and lawn mowing has become more and more important. Traditional lawn mowing equipment is mainly hand-push and knapsack lawn mowers [1], with backward technology. In recent years, the advent of intelligent lawn mower robots has greatly changed this phenomenon. Intelligent lawn mowing robot is a kind of intelligent robot that integrates machinery, sensors, intelligent control, human-computer interaction, computer and other disciplines [2]. Zhang Zhigang and Luo Xiwen's team proposed a fuzzy adaptive PID algorithm applied to rice transplanters, which promoted the research on automatic steering of wheeled agricultural machinery [3, 4]. The Hu Lian team of South China Agricultural University used the fuzzy control method to redesign the automatic steering module of the rice transplanter [5], and realized the intelligent control in this respect. The Xiong Ru team of Northwestern Polytechnical University proposed a new type of autonomous driving

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method for smart cars [6]. Zhu Zenghui's team adopted the fuzzy control method and designed a fuzzy controller for braking system [7], which greatly improved the acceleration tracking performance. The Wang Zhenyu team of Kunming University of Science and Technology proposed an AGV differential steering control method and added fuzzy control [8, 9]. Yuan Chaohui's team studied a fuzzy control method of aircraft steering front wheel steering based on an improved immune genetic algorithm optimization [10]. The Zhao Chenyu team of Shanghai University conducted research on modern agricultural automated AGV trolleys, and applied fuzzy control theory to agricultural AGV trolleys [11]. The Wang Maoli team of Qingdao Technological University made a research on the application of fuzzy PID algorithm in agricultural machinery automatic steering system [12]. The Xie Shouyong team of Southwest Agricultural University used a single-chip microcomputer to control and optimized the obstacle avoidance algorithm [13]. The team of Chen Baorui and Yang Lei of Beijing Institute of Technology aimed at the transmission system of high-speed tracked vehicles [14]. The team of Liu Yang and Zhang Wei from Hubei University is based on a large number of control equipment in modern agricultural greenhouses [15]. The team of Li Jun and Yu Fan of Shanghai Jiaotong University proposed a road recognition method based on brake pressure and wheel acceleration [16]. The Chen Zheming team of Chongqing University of Technology proposed a steering control strategy that uses fuzzy control for feedback, which greatly improves vehicle handling and stability [17].

Yang Yang from Jiangsu University proposed an intelligent vehicle tracking control system for corner compensation. The performance improvement of path tracing is more significant [18]. Diao Qinqing proposed a special fuzzy control method for the problem of the steering mechanism of the smart car in the big curve [19]. Jiang Jingping of Zhejiang University proved that fuzzy control has great application value in the field of position servo system [20]. Zhang Kun from South China University of Technology introduced fuzzy control and improved the steering control system [21]. Liao Huali from Hohai University designed a fuzzy controller to improve the line tracking algorithm [22]. Zhang Nan of the Ordnance Engineering College used a fuzzy controller to tune traditional PID parameters [23], which improved the speed and accuracy of the steering control of smart cars. Chen Ming of Hefei University of Technology introduced the Ackerman steering theorem to adjust the angle of the other two wheels to achieve three-wheel full steering [24]. Li Huashi of Beijing Institute of Technology added fuzzy control to optimize it, and the simulation results show that its lateral acceleration can reach the steady-state value at a relatively fast speed [25]. Lan Hua from Beijing Institute of Technology proposed a fuzzy control method with parameter self-tuning [26].

The above studies have used fuzzy control in various fields of control systems, especially motion control and steering control, which shows that fuzzy control has great prospects in the application of steering control systems [27–29]. Both the speed and adaptability have been improved to a large extent. In this paper, fuzzy adaptive PID control is used to optimize the differential steering control system of the lawnmower robot. The PID parameters are adjusted in real time through the fuzzy controller, and then the PID controller calculates the steering deviation of the lawnmower robot. The environmental adaptability of the differential steering control system has been greatly improved.

2 Control System Design Scheme

The control of the lawn mower robot is mainly embodied in two aspects: tool control and motion control. To complete the motion control of the lawn mower robot, the three major modules of the lawn mower robot need to work together. The three major modules are: navigation and positioning module, path planning and avoidance. Barrier module, steering control module.

The mobile function requirements of the lawn mower robot are mainly reflected in: accuracy: need to accurately control the movement of the car body; stability: stable travel without overturning; flexibility: it can complete steering tasks at different angles.

According to the demand analysis of the mobile car body and mobile module of the lawn mower robot, we first need to determine the chassis distribution of the car body. There are three common wheeled robot differential models in Fig. 1.

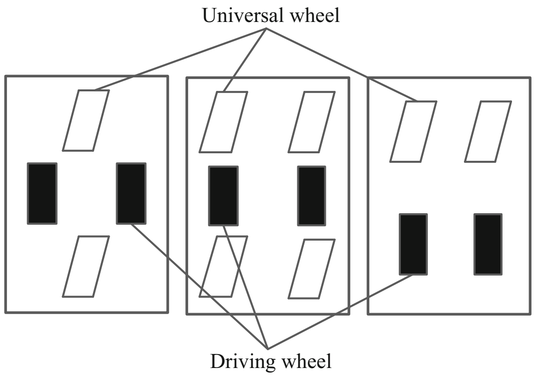

Fig. 1. Three differential models of wheeled robots.

The guidance module is set at the front end of the lawn mower robot and connected with the single-chip microcomputer. The guidance module first obtains the deviation of the lawn mower robot from the original route, and transmits the deviation to the single-chip microcomputer. The single-chip microcomputer transmits the position deviation to the fuzzy adaptive PID control program the speed difference between the two driving wheels is output. At the same time, the speed feedback module installed between the driving wheel and the driving motor feeds back the wheel speed in real time. The actual wheel speed is compared with the wheel speed output by the fuzzy adaptive PID program section, and the error is obtained PID control, and finally output to the motor drive module. The two motor drive modules control the rotation speed of the left wheel motor and the right wheel motor respectively through PWM pulse width modulation and signal amplification, and output the speed difference between the two drive wheels, and finally realize differential steering and reduce Small position deviation. The control diagram of the differential steering control system of the lawn mower robot is shown in Fig. 2.

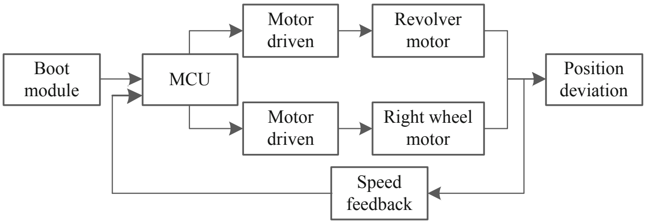

Fig. 2. Control schematic diagram.

3 Design of Fuzzy Adaptive PID Control Algorithm

Fuzzy control system includes four parts: fuzzification, knowledge base, fuzzy reasoning, and defuzzification. Fuzzification is to use language variables to describe the change process of variables, no longer use specific values such as 1cm to express position deviation, but use positive and negative medium fuzzy language to describe it to achieve fuzzification. The knowledge base stores the control rules described by the language. Fuzzy reasoning is to use the rules in the knowledge base to reason and get the fuzzy output. Finally, the accurate output is obtained by defuzzification.

Fuzzy adaptive PID control is an important development direction of fuzzy control. Fuzzy adaptive PID control is self-adaptive and self-learning. It has better control effect for those complex systems with nonlinearity, large time delay, and high order. The schematic diagram of fuzzy adaptive PID control in this article is shown in Fig. 3.

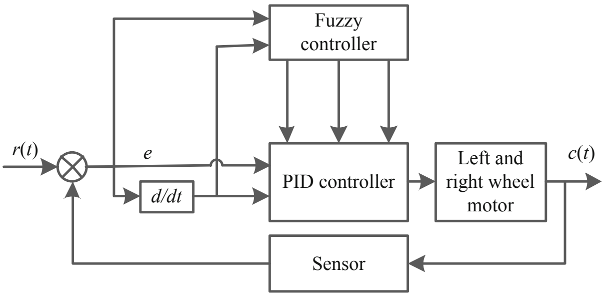

Fig. 3. Fuzzy adaptive PID control principle diagram.

The fuzzy self-adaptive PID control system of this article first takes the angle deviation e and the deviation change rate e_c as the input. After the fuzzy controller's fuzzification, fuzzy inference, and defuzzification, the PID parameter changes ΔK_p, ΔK_i, ΔK_d are output, and then calculated by the PID controller to output the speed difference ΔV between the left and right driving wheels, Realize steering control.

Assuming that the lawn mower robot is on the left side of the predetermined trajectory, the deviation is negative when it needs to turn right, and the basic domain of position deviation e is $[-8, 8]$, and the above basic domain is divided into 7 quantitative levels $\{-6, -4, -2, 0, 2, 4, 6\}$, fuzzy subset {NB, NM, NS, ZO, PS, PM, PB}, respectively representing negative big, negative medium, negative small, zero, positive small, positive middle, positive big. Use these seven fuzzy subsets to describe the magnitude and direction of the angular deviation. The corresponding laws of fuzzy subsets are shown in Table 1.

Table 1. Comparison of steering methods.

Fuzzy subset	NB	NM	NS	ZE	PS	PM	PB
Encoding code	NB	NM	NS	ZE	PS	PM	PB

The membership function is selected in this paper, which is simple in operation and highly sensitive. The membership function is shown in Fig. 4.

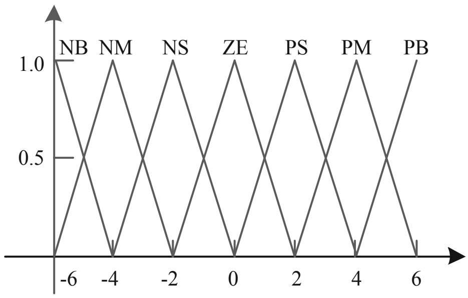

Fig. 4. Membership function.

At present, there are many types of fuzzy inference methods, and the commonly used methods are Mamdani method and Zadeh method. Both methods follow the same fuzzy inference synthesis rules, but the methods for determining fuzzy relations are different. In application, the Mamdani method is commonly used. So this design uses the Mamdani method as the fuzzy reasoning method.

The realization of fuzzy reasoning, in addition to confirming the reasoning method, also needs to improve the knowledge base and adjust the fuzzy rules to achieve the accuracy of control. Since we have three outputs ΔK_p, ΔK_i, ΔK_d, we need to separately analyze how to adjust the PID parameters ΔK_p, ΔK_i, and ΔK_d when facing the corresponding error and error rate of change to enable our control system the most effective.

First, we design the fuzzy rule of ΔK_p. Theoretically, when the error is large, we need a larger K_p to speed up the response speed of the system, and when the error is moderate, we should choose a smaller K_p to ensure The overshoot of the system will not be too large. When the error is small, in order to ensure good steady-state characteristics of the system, a larger K_p is still needed to reduce the static error. Based on the above characteristics of K_p in PID control, we can design a fuzzy control rule of ΔK_p. The fuzzy control rule table of ΔK_p is shown in Table 2:

Table 2. Comparison of steering methods.

K_p		E						
		NB	NM	NS	ZE	PS	PM	PB
E_C	NB	PB	PB	PM	PM	PS	PB	ZE
	NM	PB	PB	PM	PS	PS	ZE	NS
	NS	PM	PM	PM	PS	ZE	NS	NS
	ZE	PM	PM	PS	ZE	NS	NM	NM
	PS	PS	PS	ZE	NS	ZE	NM	NM
	PM	PS	ZE	NS	NM	NM	NM	NB
	PB	ZE	ZE	NB	NM	NM	NB	NB

Next, design the fuzzy rules of ΔK_i. The main function of integral control is to eliminate the steady-state error of the system. However, in the initial stage of adjustment, in order to avoid the instantaneous increase of the error and the integral saturation, the integral link should be restricted, so the error is relatively large. In the large initial stage, $K_i \approx 0$ should be taken. In the middle of adjustment, when the error is moderate, in order to avoid affecting the stability of the system, the value of K_i should be appropriate. At the end of adjustment, when the error is small, K_i needs to be increased appropriately to reduce the static error of the system. The fuzzy control rule table of ΔK_i is shown in Table 3:

Table 3. Comparison of steering methods.

K_i		E						
		NB	NM	NS	ZE	PS	PM	PB
E_C	NB	NB	NB	NM	NM	NS	ZE	ZE
	NM	NB	NB	NM	NS	NS	ZE	ZE
	NS	NB	NM	NS	NS	ZE	PS	PS
	ZE	NM	NM	NS	ZE	PS	PM	PM
	PS	NM	ZE	ZE	PS	PS	PM	PM
	PM	ZE	ZE	PS	PS	PM	PM	PM
	PM	ZE	ZE	PS	PM	PM	PM	PM

Finally, the fuzzy rule of ΔK_d is designed. The function of the differential link is mainly to adjust the dynamic characteristics of the system, reflecting the trend of error changes, leading correction, when the error is large, in order to avoid the differential saturation caused by the instantaneous change of the error, The value of K_d should be relatively small. When the error is moderate, K_d has a greater impact on the system, and the value of K_d needs to be appropriate and remain unchanged. When the error is small, it is generally the later stage of adjustment, and the K_d value should be appropriately reduced to avoid unnecessary oscillations. The fuzzy control rules of ΔK_d are shown in Table 4.

Table 4. Comparison of steering methods.

K_d		E						
		NB	NM	NS	ZE	PS	PM	PB
E_C	NB	PS	NS	NB	NB	NB	NM	PS
	NM	PS	NS	NB	NM	NM	NS	ZE
	NS	ZE	NS	NM	NM	NS	NS	ZE
	ZE	ZE	NS	NS	NS	NS	NS	ZE
	PS	ZE	ZE	ZE	ZE	ZE	ZE	ZE
	PM	PB	NS	PS	PS	PS	PS	PB
	PB	PB	PM	PM	PM	PS	PS	PB

After determining the fuzzy rules, we also need to defuzzify the fuzzy amount after fuzzy inference. The defuzzification usually includes the center of gravity method, the area square method, and the maximum degree of membership method. The design adopts the center of gravity method to realize the defuzzification of the blur amount.

4 Robot Differential Steering Experiment and Simulation

4.1 The Establishment of Differential Steering Model

The lawn mower robot designed in this paper adopts a rear-drive two-wheel differential scheme. For this reason, this article needs to establish a mathematical model of the lawn mower robot steering for further research. Since the mowing robot in this paper only has two rear-drive wheels for driving, in order to simplify the calculation, we abstract the differential model of the mowing robot as a differential model of two rear driving wheels, and the analysis does not consider the difference between the driving wheels and the ground. The relative sliding of and the slight deformation of the driving wheel, in this way, the state of the lawn mower robot can be constructed first, as shown in Fig. 5.

In Fig. 5, the XOY axis is the established grassland coordinate system, the center point of the drive wheel connection at the beginning of point O, D is the distance between the centers of the two drive wheels, R is the turning radius of the lawn mower robot, and V_L is the left The wheel speed of the driving wheel, V_R is the wheel speed of the right driving wheel, V is the overall speed of the lawn mower robot, θ is the turning angle of the lawn mower robot, and e is the position offset of the center position of the lawn mower robot.

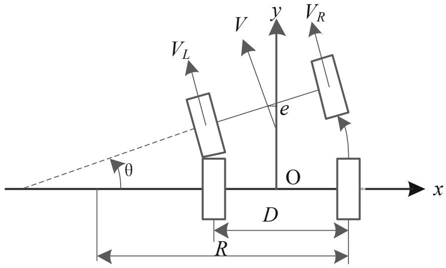

Fig. 5. Motion state diagram of lawn mower robot.

The vehicle speed of the mowing robot is the speed V at the center point, which can be synthesized by the wheel speeds V_L and V_R of the left and right wheels. The relationship is:

$$V = \frac{V_L + V_R}{2} \tag{1}$$

When the lawn mower robot turns, the speed difference between the two driving wheels V_L and V_R results in a speed difference. Because the two driving wheels have a fixed direction, they are regarded as connected rigid bodies, so they turn, and the turning radius is R.

As shown in the situation in Fig. 5, $V_R > V_L$, the lawnmower robot turns left. Since the left and right wheel trajectories should be arcs, according to the circle angle theorem, we can get:

$$\frac{V_R}{R + \frac{D}{2}} = \frac{V_L}{R - \frac{D}{2}} \tag{2}$$

By processing Eq. (2), the relationship between the turning radius of the lawn mower robot and its driving wheel track and wheel speed can be obtained, as shown in Eq. (3):

$$R = \frac{D(V_1 + V_2)}{2(V_1 - V_2)} \tag{3}$$

The angular velocity when turning can be expressed as:

$$\omega = \frac{V_L - V_R}{D} = \frac{V_L + V_R}{2R} \tag{4}$$

The vehicle speed of the mowing robot is the speed V at the center point, which can be synthesized by the wheel speeds V_L and V_R of the left and right wheels. The relationship is:

$$V = \frac{V_L + V_R}{2} \tag{5}$$

Decomposing the speed of the mowing robot to the X axis, we can get:

$$V_X = V \sin\theta \tag{6}$$

Using Eqs. (5), (6) as integral processing, we can get:

$$\theta = \theta_0 + \int_0^t \frac{V_L + V_R}{2R} dt \tag{7}$$

$$x = x_0 \int_0^t \frac{V_L + V_R}{2} \sin\theta dt \tag{8}$$

Among them, θ_0 is the initial offset angle of the lawn mower robot, and x_0 is the initial abscissa offset of the lawn mower robot. By processing Eqs. (7) and (8), we can get the change in the direction angle of the lawn mower robot and the change in the abscissa position in the time of Δt:

$$\Delta\theta = \frac{V_L + V_R}{2R} \Delta t \tag{9}$$

$$\Delta x = \frac{V_L + V_R}{2} \sin\theta \Delta t \tag{10}$$

Differentiate Eqs. (9) and (10) to obtain:

$$d\theta = \frac{V_L + V_R}{2R} dt \tag{11}$$

$$dx = \frac{V_L + V_R}{2} \sin\theta dt \tag{12}$$

The motion of the lawn mower robot is continuous, and the above formula can continue the Laplace transform to obtain:

$$\theta(s) = \frac{V_L + V_R}{2Rs} \tag{13}$$

$$x(s) = \frac{V_L + V_R}{2s} \sin\theta \tag{14}$$

By adjusting the angle and position of the lawn mower robot, the pose of the lawn mower robot can reach the set value.

In order to establish the kinematics model of the lawn mower robot, we also need to add the influence of the motor. According to the principle of the motor, the relationship between the driving wheel and the armature voltage is:

$$V_R(s) = \frac{1}{1 + T_m s} U_{OR}(s) \tag{15}$$

$$V_L(s) = \frac{1}{1 + T_m s} U_{OL}(s) \tag{16}$$

Among them, U_{OR} is the armature voltage of the right-wheel drive motor, U_{OL} is the armature voltage of the left-wheel drive motor, and T_m is the response time constant.

We can establish the dynamic characteristic structure of the lawn mower robot, as shown in Fig. 6.

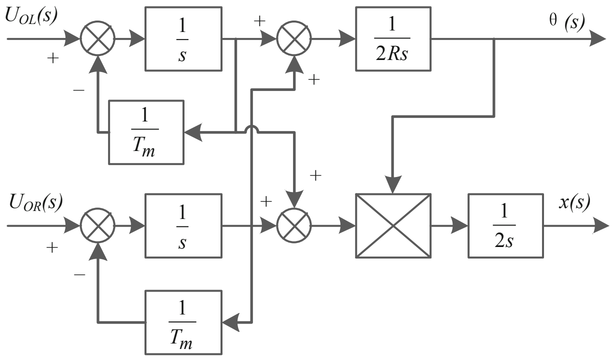

Fig. 6. Structure diagram of dynamic characteristics of lawn mower robot.

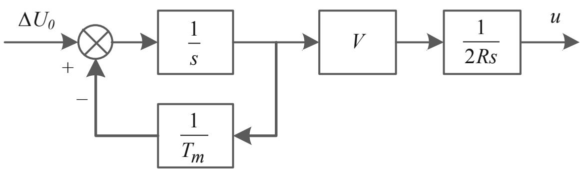

Fig. 7. Block diagram of control variables of lawn mower robot.

Since the lawn mower robot has continuous changes and small deviations during operation, the dynamic characteristic structure diagram of the lawn mower robot in Fig. 6 can be simplified, and the simplified control variable block diagram is shown in Fig. 7.

Among them, ΔU_O is the difference between the armature voltages of the left and right wheel drive motors.

The transfer function of the mowing robot is:

$$d(s) = \frac{T_m s V + 1}{2Rs(T_m s + 1)} \tag{17}$$

4.2 Simulation of Fuzzy Controller

MATLAB is a commercial mathematics software produced by MathWorks in the United States. It is a high-level technical computing language and interactive environment for algorithm development, data analysis and numerical calculation. It mainly includes MATLAB and Simulink. The simulation of the differential steering control system of the lawn mower robot is selected to use MATLAB to complete.

In Simulink, the simulation model of the differential steering control system of the lawn mower robot is established, and the fuzzy controller is put into it for simulation. First, you need to find the required modules in the MATLAB/Simulink toolkit, and drag them into the simulation page, such as Scope module, Gain module, Fuzzy Logic Controller module, etc., and connect them. The differential steering control system of the mowing robot. The simulation model of fuzzy adaptive PID controller is shown in Fig. 8.

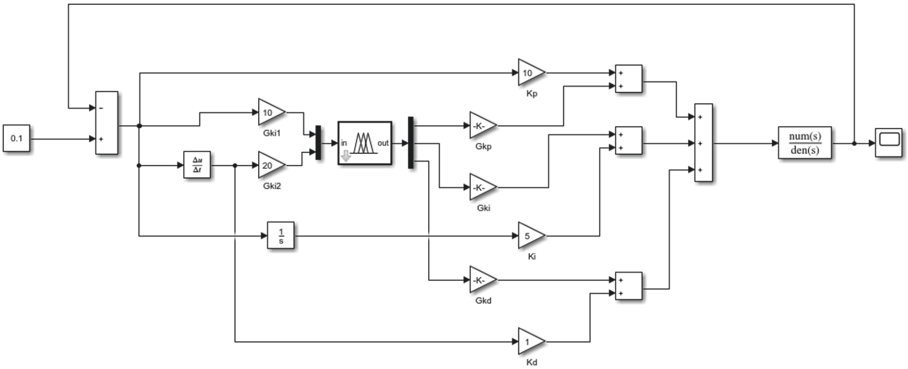

Fig. 8. Fuzzy adaptive PID controller simulation model.

4.3 Simulation Results and Analysis

We also established a conventional PID controller simulation model, and compared with the fuzzy adaptive PID controller, the operating results are shown in Fig. 9:

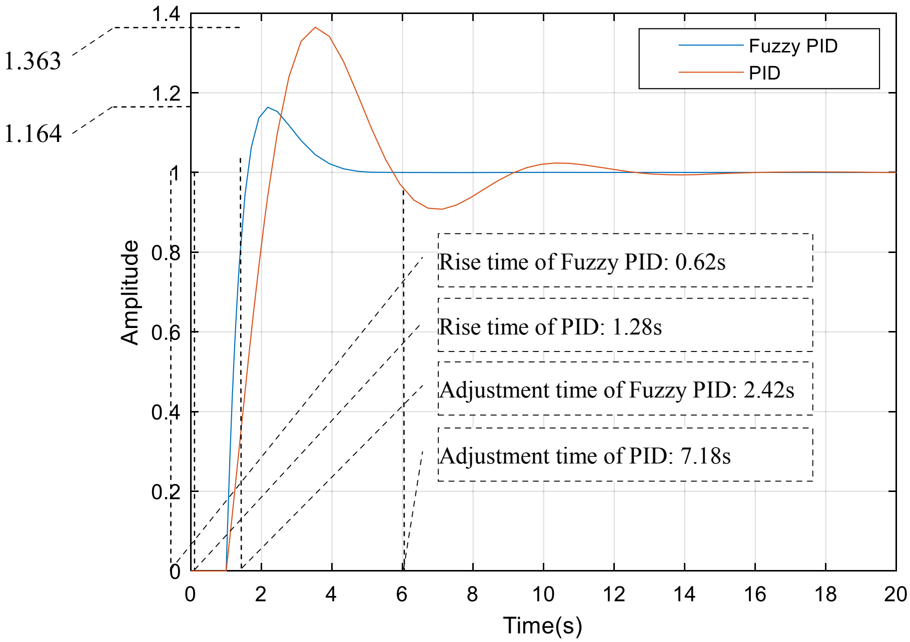

Fig. 9. Comparison chart of simulation results.

In Fig. 9, the blue line is the simulation result of the fuzzy adaptive PID controller, and the black line is the simulation result of the conventional PID controller. Use the scope module to measure the data, and get the data of the two response curves as shown in Table 5.

Table 5. Comparison of steering methods.

Control type	Rise time	Adjustment time	Overshoot
Fuzzy adaptive PID	0.62	2.42	16.4%
Conventional PID	1.28	7.18	36.3%

From the simulation results, it can be seen that when the fuzzy adaptive PID controller controls, the rise time, adjustment time, and overshoot are larger than the conventional PID controller and the number of oscillations is less. The analysis shows that the fuzzy PID controller is correspondingly fast, with small overshoot and short stabilization time. The speed and stability are better than conventional PID controllers.

5 Hardware Circuit for Control System of Mowing Robot

The design core of the differential steering control system of the mowing robot is the controller based on the fuzzy adaptive PID algorithm. The power module of the system supplies power for other modules. The STM32f103c8t6 single chip microcomputer is used as the microprocessor and control core. The electromagnetic guidance module obtains the position deviation and outputs it to the stm32 single chip microcomputer. The drive module controls the rotation of the motor to realize the control of the mowing robot Steering control. The experimental results show that the fuzzy adaptive PID algorithm can effectively control the specific forward, backward, steering and other functions of the mowing robot. The specific control system trajectory is shown in Fig. 10.

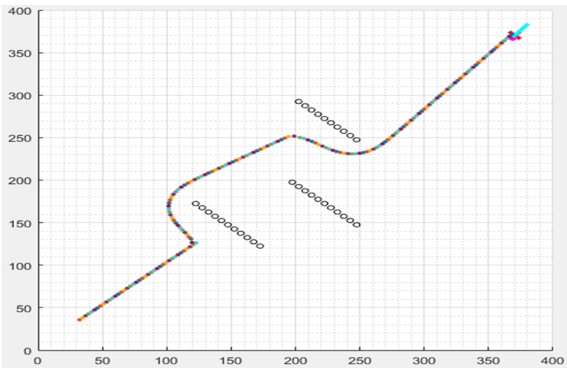

Fig. 10. The control system trajectory of mowing robot.

6 In Conclusion

In this research, through the study of PID control and fuzzy adaptive PID control algorithm, the fuzzy adaptive PID algorithm is applied to the differential steering control system of the lawn mower robot. After establishing a mathematical model and using MATLAB/Simulink to simulate, it is concluded that the use of fuzzy adaptive PID algorithm can improve the response speed and stability of the grass-mower robot's differential steering control system.

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