Study on the deformation control algorithm of brush pruning tool based on fuzzy PID

Kunpeng Liu*, Jingru Li, Longning Wang and Zijie Niu

College of Mechanical and Electronic Engineering, Northwest Agriculture and Forestry University, Xian 712100, Shaanxi Province, China

*Corresponding author e-mail: 1191184569@qq.com

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Abstract: In the process of automatic pruning of bushes with different shapes, the deformation of bushes pruning tools is affected by the dead weight of bushes pruning tools, which leads to the deviation of the actual posture of bushes pruning tools from the set posture. In order to improve the accuracy of the deformation of shrub cutter, based on the analysis of the physical model of shrub cutter and the control principle of steering gear, a fuzzy PID control algorithm is proposed to correct the deformation process of shrub cutter in real time. At the same time, the algorithm has the advantages of flexible control, fast response, small overshoot and strong robustness.

1. Introduction

Based on the multi-degree-of-freedom bush pruning tool can achieve automatic pruning, and can adapt to different sizes of three-dimensional shrubs and according to the needs of the advantages of pruning them into different shapes, in the field of pruning three-dimensional shrubs gradually play a more and more important role[5-6].

Described in this article the shrub trimming cutter model is composed of five joints, is a typical cantilever beam structure, shrub trimming cutter deformation process is easily affected by gravity and other factors, when multiple joint steering Angle deviation of the case, according to the cumulative effect, shrub pruning knives final gesture will happen very big change, lead to deviate from the set of actual stance shrub trimming tools.

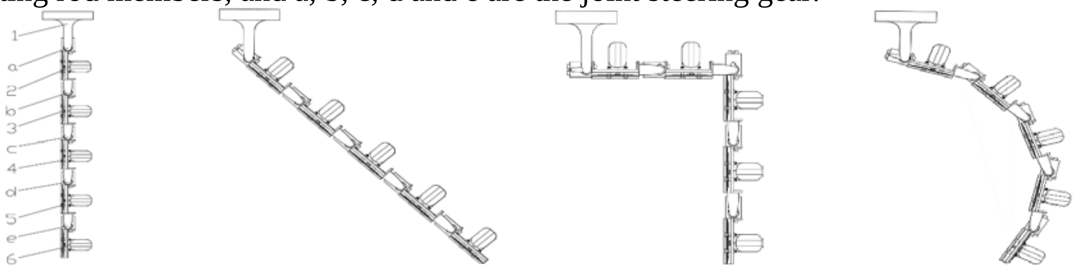
In order to overcome this problem, there are many solutions. The basic idea is to add PID algorithm to the control of the steering gear, so as to adjust the control signal through the change of some parameters in the running process of the system. However, PID algorithm also has many limitations, such as poor control effect on nonlinear and time-varying systems, weak stability and robustness [9], which results in the poor effect of the traditional PID algorithm in the application. In order to improve the effect of traditional PID controller, many scholars focus on the optimization of traditional PID algorithm. Jing Liu et al. proposed an adaptive PID control algorithm based on RBF neural network [3], and conducted simulation analysis. The simulation results show that compared with the traditional PID control, the PID control system based on RBF has higher adaptability and the ability to adjust the network optimization. Chen Lianbo et al. proposed a PID controller for a servo system based on particle swarm optimization algorithm [4], Theoretical analysis and simulation experiments show that this algorithm can effectively improve the tuning performance of the system and is more efficient than the traditional manual parameter setting method. The dynamic performance and steady performance of the motor servo system are improved greatly.

Based on this idea, a fuzzy PID control algorithm is proposed to modify the joint Angle of the bush cutter. The fuzzy adaptive PID controller is formed by adjusting the PID control parameters online using this method. By integrating the simplicity of PID control with the fault-tolerance and robustness of fuzzy control, the advantages of PID control and fuzzy control are brought into full play. Finally, compared with the performance of traditional PID controller, the results verify the superiority of fuzzy PID controller over traditional PID controller.

2. Bush cutter system analysis

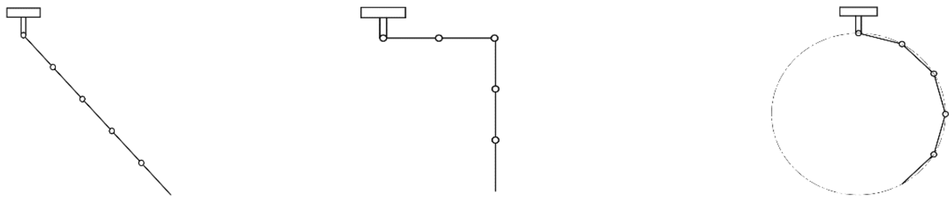
2.1. Brush cutter physical model

The bush cutter model is composed of five joint steering gear connected to six tool assembly members, and an external potentiometer is provided at each joint. FIG. 1(a) shows the initial posture of the bush trimming cutter, while FIG. 1(b), 1(c) and 1(d) respectively represent the target posture. Figure 2(a), 2(b) and 2(c) are the target posture diagrams, respectively. 1, 2, 3, 4, 5 and 6 are the connecting rod members, and a, b, c, d and e are the joint steering gear.



(a) **(b)** **(c)** **(d)**

Fig 1. Solid model of bush cutter



(a) **(b)** **(c)**

Fig 2. Brush trimming tool target posture diagram

2.2. Joint steering gear control scheme

In this paper, the maximum rotation Angle of the joint electric steering gear is selected to be 180 degrees. Through the experiment of the limit parameters of the steering gear, 8us is taken as the unit to control the steering gear's rotation and positioning, so as to achieve the highest control accuracy. We take 1DIV=8us, then the expression of the high level duration of PWM signal is shown in formula (1), where N is the number of pulse dividing parts, and N is 1-250.

$$t = 0.5ms + N \times DIV \tag{1}$$

In the formula, 0ms≤N×DIV≤2ms.

The function of PWM rising edge is shown in figure 3.

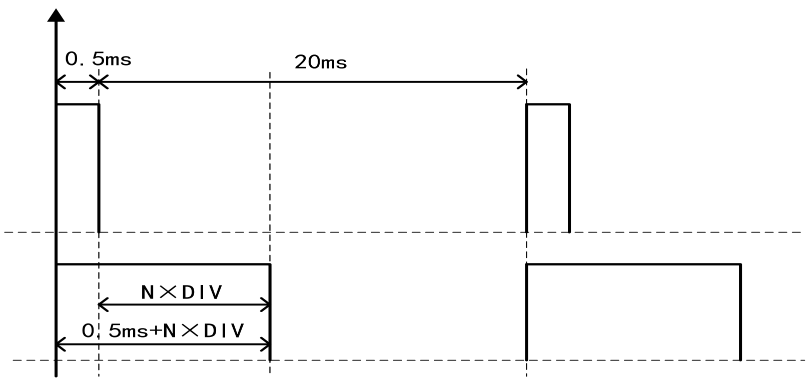


Fig 3. PWM rising edge function

so

$$PWM = 0.5ms + N \times DIV \quad (2)$$

3. The overall structure of the control system

The structure of the control system is shown in figure 4, which is mainly composed of microcontroller, steering engine drive module, electric steering engine, built-in potentiometer, external potentiometer and upper mechanism. The microcontroller ATmega2560 is the core of the control system, which carries out various data calculation and rapid processing of feedback information. Through serial communication with the host computer, the system controls the steering gear drive module to drive the steering gear.

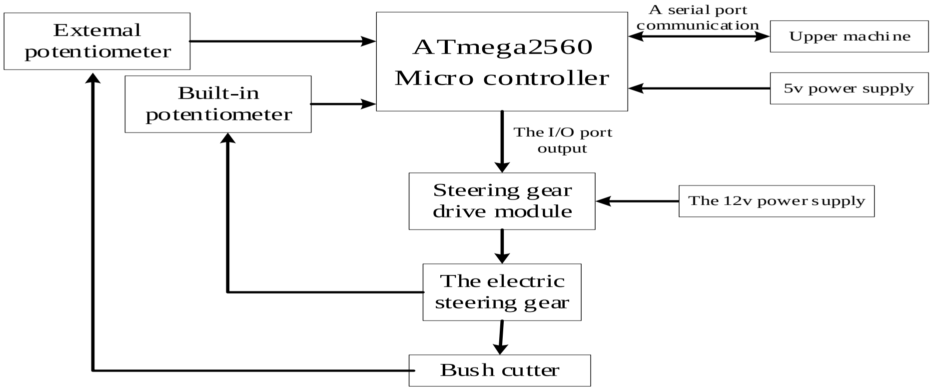


Fig 4. Control system structure diagram

4. Fuzzy PID control algorithm description

4.1. Principle of control system for bush cutting tool

Shrub trimming cutter control system principle as shown in figure 5, with double closed loop control system, using fuzzy PID control algorithm, the external potentiometer voltage - shrub trimming tool joint Angle conversion actual Angle value, and its feedback to control system get the Angle deviation and the Angle deviation increment, sending them to the fuzzy controller, the three parameters of the fuzzy PID control algorithm Kp, Ki, Kd for dynamic adjustment, basic expression for the fuzzy PID control algorithm:

$$\Delta u_n = K_p \times \Delta e_n + K_i \times e_n + K_d \times \left(\Delta e_n - \Delta e_{n-1}\right) \quad (3)$$

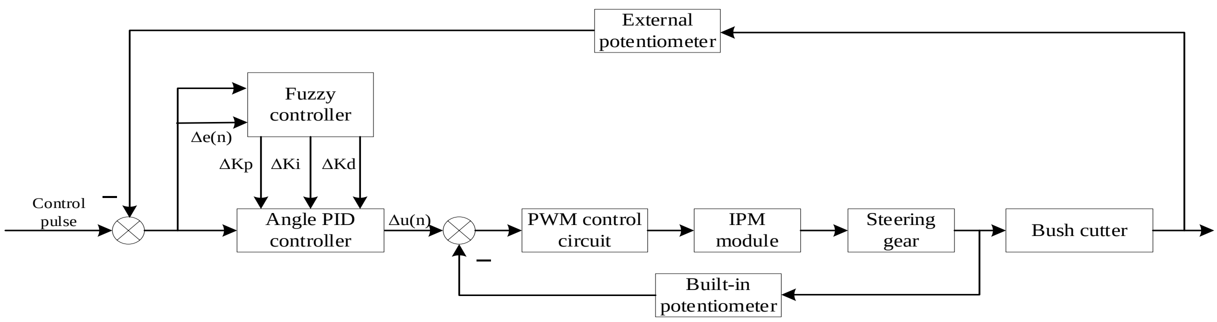


Fig 5. schematic diagram of shrub cutter control system

4.2. Fuzzy PID controller parameters self - tuning

In the control system schematic diagram above, through the perspective of external potentiometer real-time feedback to the Angle of deviation and Angle of deviation increment e de/dt, the results by fuzzy processing after the input of fuzzy controller, fuzzy control rules of Kp, Ki, Kd three parameters on-line modification, so that the controlled object has a good dynamic and static performance.

PID control algorithm parameters have three control effects, its characteristics are as follows: (1) the effect of the proportional coefficient Kp is to speed up the response of the system, improve the system adjustment accuracy. However, if the parameter is adjusted too much, the response will be too fast and overshoot will easily occur, which may even lead to the instability of the original system. If the parameter is too small, the response speed will be slow, thus prolonging the adjustment time and damaging the dynamic and static characteristics of the system. (2) The integral coefficient Ki is used to eliminate the steady-state error of the system. If the parameter is adjusted too large, integral saturation will be generated in the early response, resulting in a large overshoot. If the parameter is adjusted too small, it is difficult to eliminate the static error and affect the system accuracy. (3) the function of the differential action coefficient Kd is to improve the dynamic characteristics of the system, to suppress the variation of deviation in any direction in the response process, and to predict the variation of deviation in advance. However, if the parameter is adjusted too large, the dynamic performance of the system will be affected, and the system will be very sensitive to errors, reducing the anti-interference ability of the system[8].

So under the condition of different e and Δ e, can be controlled object for parameters Kp, Ki, Kd self-tuning principle.

Through fuzzy reasoning and fuzzy, the amount of adjustment of PID controller parameter ΔKp, ΔKi, ΔKd, through the type online self-tuning of controller parameters, the type of Kp0, Ki0, Kd0 for initial value.

$$K_p = K_{p0} + \Delta K_p \tag{4}$$

$$K_i = K_{i0} + \Delta K_i \tag{5}$$

$$K_d = K_{d0} + \Delta K_d \tag{6}$$

4.3. The design of fuzzy controller

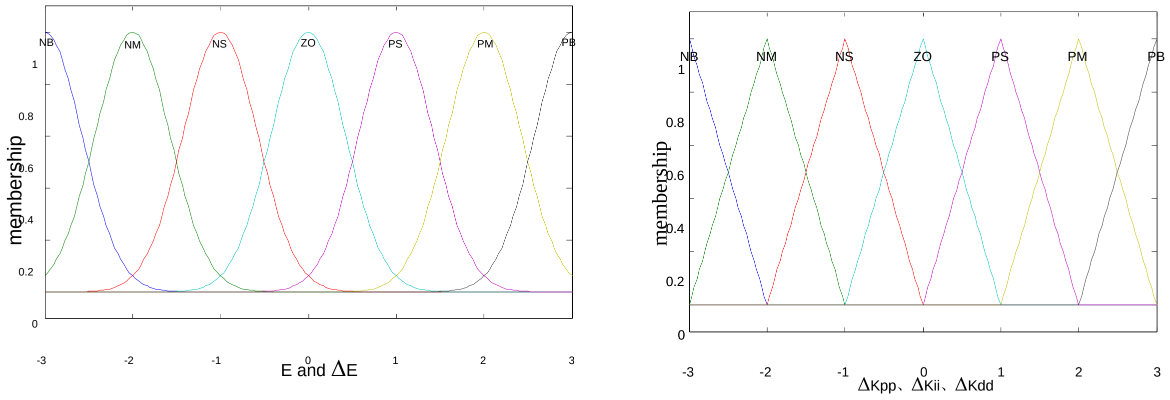
The key of fuzzy PID control algorithm is the design of fuzzy controller. The design process of fuzzy controller proposed in this paper can be divided into three steps: fuzzification, fuzzy reasoning and defuzzification.

(1) The blurring of input and output

Fuzzification refers to the mapping of the actual values of input and output to the corresponding fuzzy domain, which can be used to describe the state of input and output variables of the fuzzy controller in terms of "large, medium and small". Select E to represent the fuzzy language variable of deviation E, whose domain is {-3, -2, -1, 0, 1, 2, 3}; The language value of the fuzzy variable E is {negative large, negative medium, negative small, zero, positive small, median, super brand}, and the fuzzy subset is expressed as: {NB, NM, NS, ZO, PS, PM, PB}. Select the fuzzy language variable of deviation increment Δe as ΔE, whose theoretical domain is also {-3, -2, -1, 0, 1, 2, 3}, the fuzzy variable Δe language value is {negative large, negative medium, negative small, zero, positive small, middle, super brand}, and the fuzzy subset is expressed as: {NB, NM, NS, ZO, PS, PM, PB}. Select the fuzzy language variables of ΔKpp, ΔKii and ΔKdd to represent the output values of the fuzzy controller, ΔKp, ΔKi and ΔKd respectively, the theory of domain are {3, 2, 1,0,1,2,3}, the language values of the fuzzy variables ΔKpp, ΔKii, ΔKdd are {small negative, negative, negative, zero, is small, middle, zhengda}, represented as a fuzzy subset {NB, NM, NS, ZO, PS, PM, PB}.

In practical measurement, deviation e of basic theory of domain for [to 10, 10], deviation increment Δ e of basic theory of domain for [2.0, 2.0], and e, Δe are accurate input, through the quantitative makes the dispersed quantities. Deviation quantization factor ke=0.3, deviation rate quantization factor kΔe=1.5.

In this paper, in the design of input variables e and Δe of the membership function of fuzzy subset by gauss curve membership, output variable ΔKp, ΔKi, ΔKd membership function adopts triangle membership degree, their membership functions are shown in figure 6.



(a) e and Δe (b) ΔKp、ΔKi、ΔKd

Fig 6. e, Δe, ΔKp, ΔKi, ΔKd membership functions

(2) Fuzzy reasoning

The core task of the fuzzy controller is to determine the fuzzy rules and deduce the fuzzy results. Based on the long-term accumulation of predecessors, the fuzzy rules determine the range of parameter values through experiments. The form of fuzzy reasoning is: if(E is Ai) and (ΔE is Bi), then (Kp is Ci1) and (Ki is Ci2) and (Kd is Ci3). According to the principle of PID parameter adjustment for the output variable ΔKp, ΔKi, ΔKd fuzzy control rule table, as shown in table 1.

Table.1. ΔKp, ΔKi, ΔKd control rules

	Δe						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB NB PS	PB NB NS	PM NM NB	PM NM NB	PS NS NB	ZO ZO NM	ZO ZO PS
NM	PB NB PS	PB NB NS	PM NM NB	PS NS NM	PS NS NM	ZO ZO NS	NS ZO ZO
NS	PM NB ZO	PM NM NS	PM NS NM	PS NS NM	ZO ZO NS	NS PS NS	NS PS ZO
ZO	PM NM ZO	PM NM NS	PS NS NS	ZO ZO NS	NS PS NS	NM PM NS	NM PM ZO
PS	PS NM ZO	PS NS ZO	ZO ZO ZO	NS PS ZO	NS PS ZO	NM PM ZO	NM PB ZO
PM	PS ZO PB	ZO ZO NS	NS PS PS	NM PS PS	NM PM PS	NM PB PS	NB PB PB
PB	ZO ZO PB	ZO ZO PM	NM PS PM	NM PM PM	NM PM PS	NB PB PS	NB PB PB

(3) To blur

The fuzzy output value obtained by fuzzy inference is a fuzzy subset in the output domain, which cannot be directly used for control, and can only be applied to the object by transforming it into a precise control quantity through defuzzification. In this paper, gravity method is selected to defuzzize, and its mathematical expression is shown in formula (7).

$$U^* = \left\langle \frac{\sum_{i=0}^{n} U_i \mu_{C^*}(U_i)}{\sum_{i=0}^{n} \mu_{C^*}(U_i)} \right\rangle \tag{7}$$

In the formula, <> represents rounding operation, U^* is the exact output, U_i is the fuzzy variable, $\mu_{C^*}(U_i)$ is the membership value.

5. Experiment and data analysis

Aiming at the problem of deformation deviation of shrub pruning tool, this paper uses the Simulink simulation tool in Matlab to design the traditional PID controller and the fuzzy PID controller according to the fuzzy control and classical PID control principle, and builds the system simulation model as shown in figure 7.

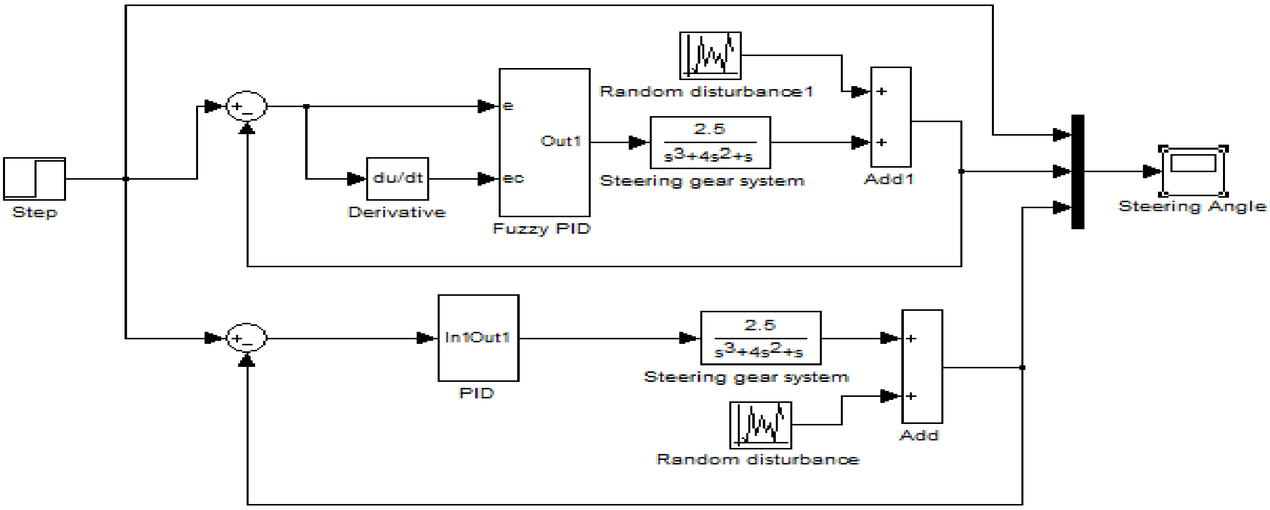


Fig 7. Simulink control simulation model

Considering the influence of the uncertain factors in the real environment, the traditional PID control step response curve and the fuzzy PID control step response curve are obtained through simulation with the addition of random disturbance, as shown in figure 8.The blue curve is the traditional PID control response curve, and the red curve is the fuzzy PID control response curve.

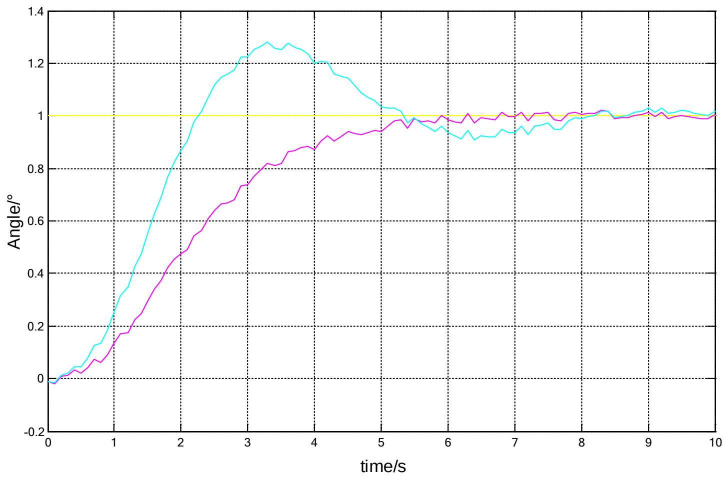


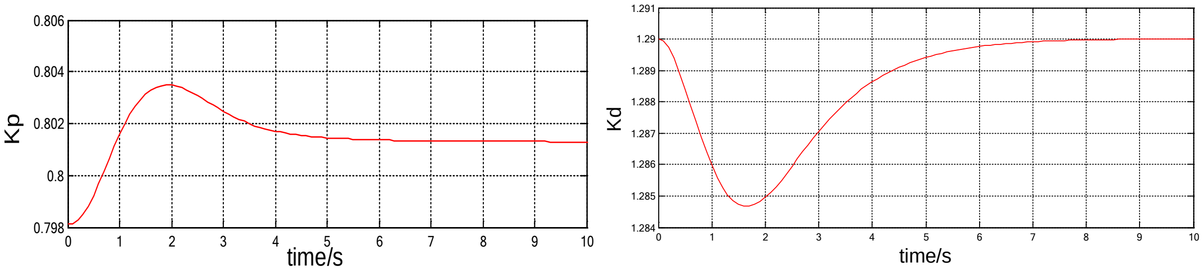
Fig 8. Comparison of PID and fuzzy PID control simulation

According to the output waveform of the control system, the control performance parameters are shown in table 2. It can be seen from the table that compared with the classical PID controller, the fuzzy PID controller has less adjustment time, less overruns, fewer oscillations, and the system has better dynamic characteristics and stability.

Table.2. Comparison of control performance parameters

Control performance / Control scheme	The transition process	Overshoot amount	Adjust time	Oscillation frequency
Fuzzy PID control	Strictly monotone	None	7s	0
Traditional PID control	Attenuation of oscillation	Yes	9s	1

For the fuzzy PID controller, the random disturbance is removed, and the self-tuning process of fuzzy controller parameters, namely Kp and Kd, is further observed, as shown in figure 9.



(a) (b)

Fig 9. PID parameter self-tuning curve

6. Conclusion

Aiming at the problem that the actual shape of the cutter is deviated from the theoretical shape after the cutter is deformed due to the influence of the dead weight, a fuzzy PID control algorithm is proposed to correct the deformation of the cutter by using the feedback Angle value of the external potentiometer as a parameter.

1) The fuzzy PID control on the deformation process of shrub pruning tool is realized, and the problem of inaccurate deformation caused by the tool's dead weight in the deformation process of shrub pruning tool is solved, so as to improve the accuracy of shrub pruning.

2) Through the experiment in the Matlab Simulink simulation tool, compared with the traditional PID control and fuzzy PID control of the experimental curves, the results show that fuzzy PID control algorithm is amount of the adjusting time and overshoot of the system have been improved obviously.

References

[1] Haibo Zhou,Rui Chen,Shun Zhou,Zhenzhong Liu. Design and Analysis of a Drive System for a Series Manipulator Based on Orthogonal-Fuzzy PID Control [J]. Electronics, 2019, 8(9).

[2] Song yongjie. Research on the drive and adaptive control of small steering g ear based on brushless dc motor [D]. Nanjing university of science and technology, 2016.

[3] Jing Liu,Guo Xin Wang. The Optimization of Adaptive PID Control Algorithm Based on RBF Neural Network[J]. Advanced Materials Research,2014,3349.

[4] Chen Lianbo, Xiong Xinhong, Zheng Yousheng, et al. Parameter Tuning of PID Controller of Servo System Based on Particle Swarm Optimization Algorithm. 2019, 533(1).

[5] Gu zhengping, shen ruizhen. Current situation and development trend of landscape machinery at home and abroad [J]. Forestry machinery and woodworking equipment, 2004 (02) : 4-7.

[6] Duan chongqun, zhang jian, niu dexue, wang haipeng, zhang xian, zhao zhengyang, wang mingyuan. Design of a deformable green pruning machine [J]. Modern manufacturing technology and equipment, 2019 (04) : 19-20 + 24.

[7] Wenbin Yan,Dada Wang,Pengfei Jia,Weiguo Li. The PWM speed regulation of DC motor based on intelligent control[J]. Systems Engineering Procedia,2012,3.

[8] He zhiqiang. PID controller parameter setting method and its application [D]. Zhejiang university, 2005.

[9] Haibo Liang,Jialing Zou,Kai Zuo,Muhammad Junaid Khan. An improved genetic algorithm optimization fuzzy controller applied to the wellhead back pressure control system[J]. Mechanical Systems and Signal Processing,2020,142.