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PID parameter tuning of multi-capacity system based on differential evolution algorithm

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Abstract

Aiming at the characteristics of large, time-varying, and nonlinear PID control of the multi-capacity system, the differential evolution algorithm of modern intelligent algorithm is used to simulate the high-order system by selecting the first-order time-delay system, and then use the correlation of the first-order time-delay system The parameters k, t, τ are brought into the tuning rules to calculate the PID of the higher-order system. Finally, the third-order system and the first-order time-delay system are simulated by matlab. The final result shows that there is not much difference between the two. It also greatly improves the response rate and speed, and can also be used in other high-end systems.

Keywords

Multi-capacity system; large lag; time-varying; nonlinear; differential evolution algorithm; first-order time-delay system.

1. Introduction

Due to the coupling of the multi-capacity system, PID control has defects such as large time delay, nonlinearity and multiple disturbances. It is difficult for ordinary PID to accurately control it. For multi-capacity system control, scholars at home and abroad have conducted in-depth research, literature [1] The fuzzy control method is used to adjust the control parameters, and the combination of advanced control and iterative PID learning law effectively improves the accuracy of control and improves the quality of control. Literature [2] proposed a phase plane analysis method, which can directly calculate the required control amount based on the error, and has strong anti-interference performance, and a differential feedback link is added to the multi-capacity water tank, which greatly reduces the control error. . Literature [3] proposed an approximate dynamic programming predictive control algorithm based on the large lag and nonlinear characteristics of the dual-capacity water tank system. The algorithm uses the BP neural network approximation, which has a better control effect than the traditional PID. In reference to the problem of four-capacity water tank, literature [4] proposed an adaptive spatial predictive controller with variable forgetting factor, which improved the identification sensitivity and adaptability of the controller. Reference [5] proposed a multi-variable constrained predictive control algorithm for the coupled dual-capacity water tank system, which introduced the expected attenuation factor of the control increment, and reduced the amount of calculation for the prediction of the multi-variable coupling problem. Literature [6] aims at the four-capacity water tank multi-variable system with dual input and dual output. It is identified and decoupled by the PSO method and the dynamic feedforward compensation decoupling method. Finally, a more precise control effect is achieved through PI control. Literature [7] is based on the standard transfer function of multi-capacity inertia to set PID parameters. Through simulink simulation, the overshoot becomes smaller and the robustness becomes stronger than that of ordinary PID control. Literature [8] proposed a nonlinear Hebbian algorithm with terminal constraints, and

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used it with a water tank system. The simulation proved that it has a faster convergence rate and higher accuracy than the traditional NHL algorithm. Literature [9] used PID level control algorithm and simulink simulation to model and simulate a three-tank water tank control system. The results show that the mathematical model can reflect the characteristics of the controlled object. Literature [10] analyzed the four-capacity water tank system and used the improved BP learning algorithm to predict, and finally achieved the stable control of the four-capacity water tank system. Literature [11] designed a two-input two-output system controller, which reduced the order of diagonal matrix elements through a first-order time-delay model, and introduced the reduced-order model into the inner membrane control for PID parameter tuning, and used it in the laboratory. The control effect of the water tank control system is good. Literature [12] designed a first-order predictive control optimization algorithm, which decomposes the large-scale parameter optimization problem into independent small-scale parameter optimization problems through time decomposition, and obtains an explicit optimization solution. It is proved by Matlab simulation to obtain a better solution. The control effect. Literature [13] achieved a better control effect by discretizing the three-tank liquid level control system, combined with adaptive predictive control than adaptive control and traditional PID control, and improved accuracy and response speed. Literature [14] improved the traditional PID control algorithm and fuzzy control algorithm, and designed a fuzzy immune adaptive control to control the three-tank water tank system. The simulation was verified by simulink, and the results showed that the control effect was improved. Literature [15] uses genetic algorithm to model the three-capacity water tank system, and finally calculates the mathematical model of the three-capacity water tank system. Literature [16] used the improved DMDE algorithm in optimal PID control, and improved the stability and rapidity of the system through sensitivity analysis. Literature [17] introduced an optimal control strategy based on PID, using an improved version of the hill-climbing algorithm and Firefly algorithm to achieve a comparative analysis between the four controllers in terms of performance and robustness, and simulation proved that even if In the presence of interference, good performance can still be maintained. Literature [18] proposed a predictive automatic coupling PID (PAC-PID) control algorithm to be used to design tobacco temperature and moisture content control, and the simulation results show that this method can track the target signal smoothly, quickly and with high precision. . Literature [19] proposed a discrete-time fractional-order PID control. Through evaluation on a real three-order single-input single-output system, the proposed implementation of the fractional-order PID is compared with the classical integer-order PID, which can get better The final response.

This paper takes the three-capacity water tank system as an example to analyze the PID control parameters of the multi-capacity system. Through the establishment of the mathematical model of the three-capacity water tank, the parameter setting of the differential algorithm, the simulink simulation, and finally the first-order lag model is fitted to the three-capacity water tank by the differential evolution algorithm. The first-order model finally realizes the control of the multi-capacity system.

2. Optimal Modeling of the Liquid Level Control System of Three-Capacity Water Tank

2.1 Three-capacity water tank system structure

The structure of the three-capacity water tank system is shown in the figure. The main structure of the three-capacity water tank system includes 3 chain water tanks, 4 valves, a frequency conversion pump, a water tank and interconnected pipes and other components. The system structure diagram is shown in Figure 1. As a typical nonlinear and time-delay system, the three-tank level control system has strong industrial representativeness. Many models in the industry can also be abstracted into a three-tank level control system, so the research on the three-tank system is important The theoretical significance and practical application value.

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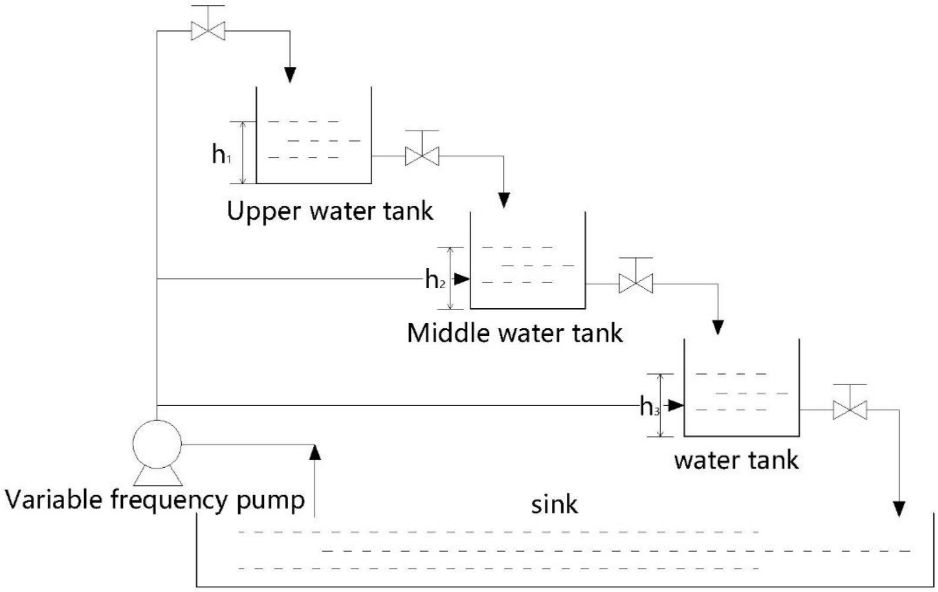

Figure.1 Three-capacity water tank structure diagram

2.2 Three-capacity water tank system control principle

The main principle of the three-capacity water tank level control system is to directly control the flow rate and inlet and outlet water pressure of the upper water tank, and then directly control the water level of the lower water tank through the middle water tank liquid level system. The liquid object to be detected is composed of three liquid parts connected in series with the liquid tank, so we call it the three capacity. The product of the mathematical model between the three tanks is the numerical product of the mathematical model between the three tanks. The upper and lower water tanks are divided into two small water tanks with different displacements, and the difference between them can be combined into different time constants. The water in the upper water storage tank is automatically controlled by an automatic solenoid valve, and then directly flows into the lower middle water tank, which is connected in series to form a water tank with two to three capacities.

2.3 Modeling of Three-Capacity Water Tank System

The three-capacity water tank is the controlled object. If the water in and out is the same, the level of the water tank will not change. After balance, when the valve on the inflow side is opened, the inflow is greater than the outflow, causing the liquid level to rise. At the same time, the outflow volume increases as the outlet pressure increases. The trend is to re-establish the balance relationship between inflow and outflow, that is, when the liquid level rises to a certain height, the outflow volume increases to equal to the inflow, and the balance relationship is re-established, and the liquid level finally stabilizes at a certain level. Height; instead, the liquid level will drop and eventually stabilize at another height. Since the inlet water volume of the water tank can be adjusted, and the water outlet volume changes with the change of the liquid level, the mathematical model of the water tank can be established only by establishing the mathematical relationship between the water inlet volume and the liquid level.

Upper water tank:

$$\frac{dh_1}{dt}=\frac{1}{A_1}(Q_{in}-Q_1) \tag{1}$$

Middle water tank:

$$\frac{dh_2}{dt}=\frac{1}{A_2}(Q_1-Q_2) \tag{2}$$

Water tank:

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$$\frac{dh_3}{dt} = \frac{1}{A_3}(Q_2 - Q_3) \tag{3}$$

Among them, Q_{in} is the water intake, A_1, A_2, and A_3 are the cross-sectional areas of the upper, middle, and lower tanks respectively. If there is no water in the water tank at the beginning, you can get

Upper water tank:

$$h_1 = (Q_{in} - Q_1)/A \tag{4}$$

Middle water tank:

$$h_2 = (Q_1 - Q_2)/A \tag{5}$$

Water tank:

$$h_3 = (Q_2 - Q_3)/A \tag{6}$$

Where $Q_i=h_i/R_i$

Finally, a third-order transfer function can be obtained through differential and integral calculation and finishing.

3. Tuning of the Optimal PID Parameters for the Liquid Level System of the Three-Capacity Water Tank

3.1 PID parameter tuning algorithm

Evaluating whether the performance of a system is qualified and whether it is optimal is definitely inseparable from performance indicators. The error performance index can reflect the size of the error produced by the system in the response process. In fact, it is the integration of the deviation of the actual response curve of the system from the steady-state final value and the time axis during the response process. In the system control process, the error integral is more The smaller the better, the length of the adjustment time and the magnitude of the error have an impact on the value of the error integral.

Error integral (IE) performance index:

$$IE = \int_0^\infty e(t)dt \tag{7}$$

Absolute integral error (IAE) performance index:

$$IAE = \int_0^\infty |e(t)|dt \tag{8}$$

Squared Error Integral (ISE) performance index:

$$ISE = \int_0^\infty e^2(t)dt \tag{9}$$

Time and error absolute product integral (ITAE) performance index:

$$ITAE = \int_0^\infty t|e(t)|dt \tag{10}$$

Time and error square product integral (ITSE) performance index:

$$ITSE = \int_0^\infty te^2(t)dt \tag{11}$$

In this paper, the differential evolution algorithm is adopted, the evaluation function is set to the ITAE value, and the optimal PID parameters are found through continuous iterative evolution. The algorithm flow is as follows:

Step 1 Initialization parameters: genetic generation 50, population size 30, mutation rate 0.8, hybridization rate 0.5;

Step 2 Set the upper and lower bounds of the parameters, and randomly generate 30 individuals;

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Step 3 To assign a value to each population, use the evaluation function to evaluate, and sort by the evaluation value from small to large;

Step 4 Randomly select 3 different individuals, perform mutation and crossover, and perform cross-border processing;

Step 5: Evaluate, select and reorganize the mutant population, and leave the excellent genetic individuals for the next iteration.

Step 6 The termination condition is reached, the iteration is completed, and the optimal individual is output.

The transfer function of the selected three-tank system model is:

$$G(s) = e^{-4s} \frac{1.716}{1.575s^3 + 4.95s^2 + 4.1s + 1} \tag{12}$$

3.2 Result analysis

After running 30 times, the optimal PID parameters are shown in Table 1 below:

Table 1 Optimal tuning results of PID parameters of three-capacity water tank

Number of runs （n）	Kp	Ki	Kd
30	0.4	0.089	0.89

4. Simulink simulation of three-tank liquid level system

If the ordinary closed-loop PID control is used for the three-capacity system, the control system block diagram is shown in Figure 3.

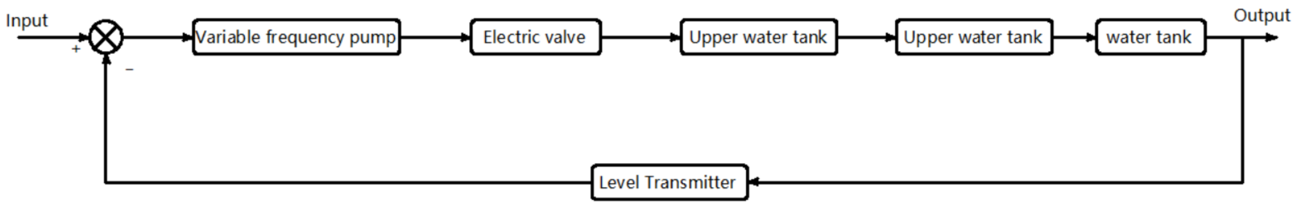

Figure 3 Single closed-loop control diagram of three-capacity water tank

Carry on Simulink simulation in Matlab, adopt traditional pid control, its simulation structure diagram is shown in Fig. 4. The simulink simulation results are shown in Figure 5, where kp=0.4, ki=0.089, kd=0.89:

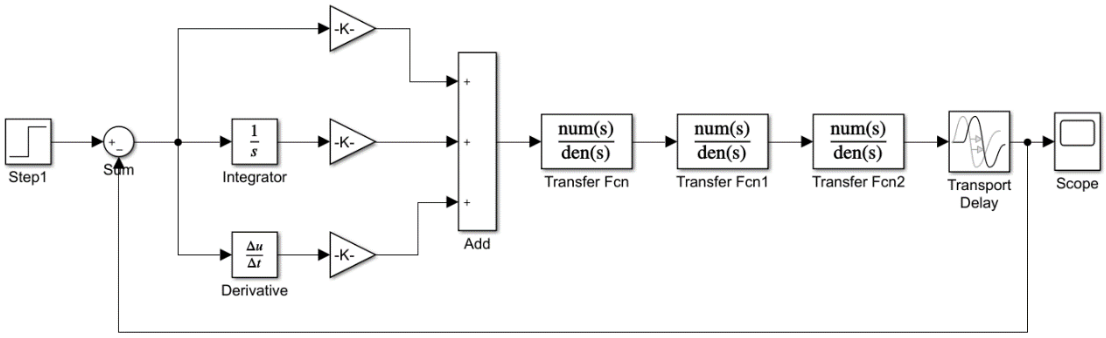

Figure 4 Simulink simulation structure diagram of three-capacity water tank system

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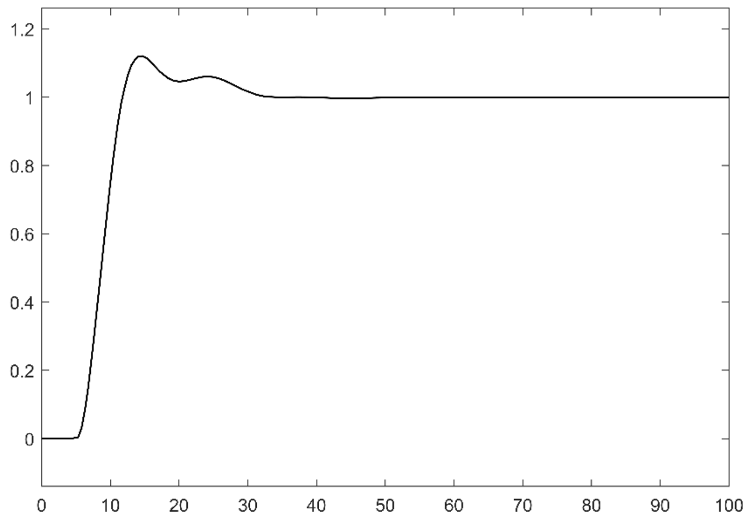

Figure 5 Simulation results of three-capacity water tank

5. The level system of a three-tank tank is approximated by a first-order time-delay system

5.1 Higher-order system reduction

In system analysis, design and simulation, some complex high-order multivariable systems are often encountered. For example, energy systems and economic systems have as many as hundreds of state variables, and it is very troublesome to simulate or design high-end systems. From a simulation perspective, the simulation of high-end systems takes up more memory and machine time. From the perspective of system design, the controllers of high-end systems are often very complex, and some are even impossible to implement. Therefore, it is necessary to simplify and reduce the order of the high-order system to make it easier for engineering calculations and implementation, and at the same time to show the characteristics of the original system within a certain accuracy range. The so-called model simplification is the establishment of low-order approximate models for high-order complex systems. It is simpler in calculation and analysis than the original high-level system model, and it can provide enough original system information.

5.2 Differential evolution algorithm implementation

By setting the time series, calculating the output data of the original system model, using the differential evolution algorithm to simulate a first-order time delay model, by continuously modifying k, t, τ to approximate the output value of the objective function, the objective function value is the approximate model and The step response output of the actual object is the sum of squares of errors. After continuous evolutionary iterations, the optimal individual is finally found, which is an approximate low-order model. The procedure steps are as follows:

Step 1 Set the time series, determine the end time, the parameters of the difference algorithm, and the objective function.

Step 2 Initialize the population, calculate the fitness value of each individual, and arrange the fitness value from small to large.

Step 3 Randomly select 3 individuals, select the best, perform differential mutation operation, and perform cross-border processing for the cross-border individuals (generated by random update). The specific expression of differential mutation is as follows,

$$V_i^{G+1} = x_{r3}^G + rand(1, CodeL).*(x_{r1}^G - x_{r2}^G) \tag{13}$$

In the formula, V_i^{G+1} is a variant individual of the G+1 generation, r1, r2, and r3 are 3 individuals randomly selected from the population respectively, CodeL is the length of each individual's

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chromosome, and rand (1, CodeL) produces a 1*CodeL The column vector of 0~1 can ensure the diversity of the population and reduce the probability of obtaining the local optimal solution.

Step 4 Perform crossover processing according to crossover probability, cross the mutation individual in the previous step with the individual currently operating in the loop, and calculate the fitness value. If the fitness of the mutation parameter is better than the fitness of the current operating individual in the population, replace the current operating individual.

Step 5 Sort the new individuals generated from small to large in terms of evaluation value, select the first 50 individuals, and perform the next iteration until the iteration is completed, and output the optimal individual and approximate models and images represented by the optimal individual.

The running results are shown in Figure 6, Figure 7, Figure 8.

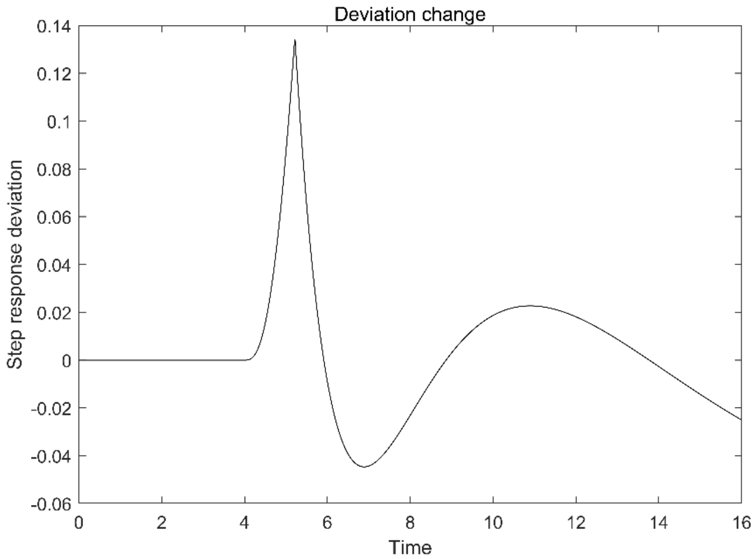

Figure 6 Step response deviation diagram

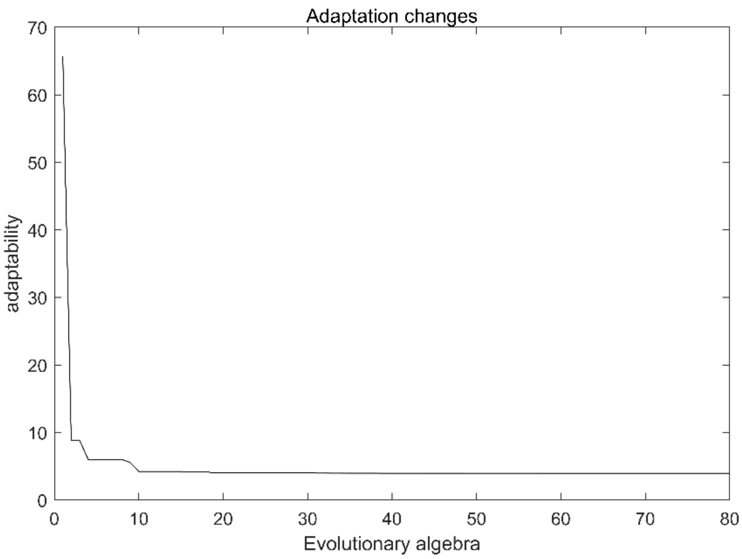

Figure 7 Adaptation change graph

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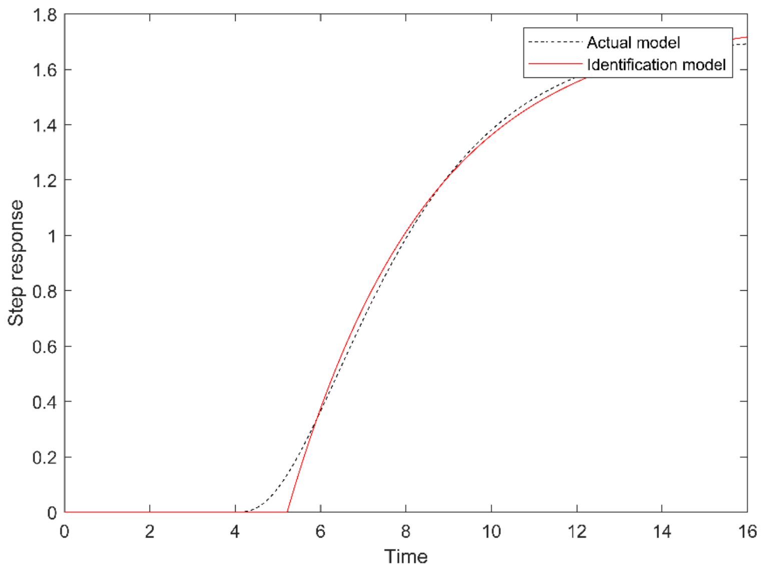

Figure 8 Comparison between the output of the identification model and the actual output

Draw an approximate model:

$$G(s) = e^{-5.22s} \frac{1.786}{3.321s+1} \tag{14}$$

It can be seen that the program finds the optimal value after 20 generations, the deviation of the step response is also within 0.03, with a small deviation, and then through the PID parameter tuning based on the differential evolution algorithm, the optimal PID parameter Kp=0.51 is obtained. , Ki=0.1, Kd=0.73, through simulink simulation, the simulation structure diagram is shown in Figure 9, and the running result is shown in Figure 10.

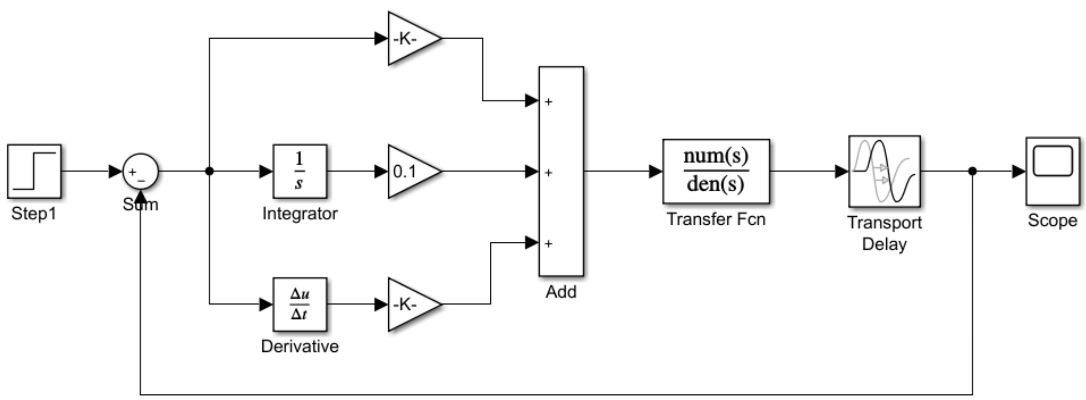

Figure 9 Simulink simulation structure diagram of a first-order time-delay system

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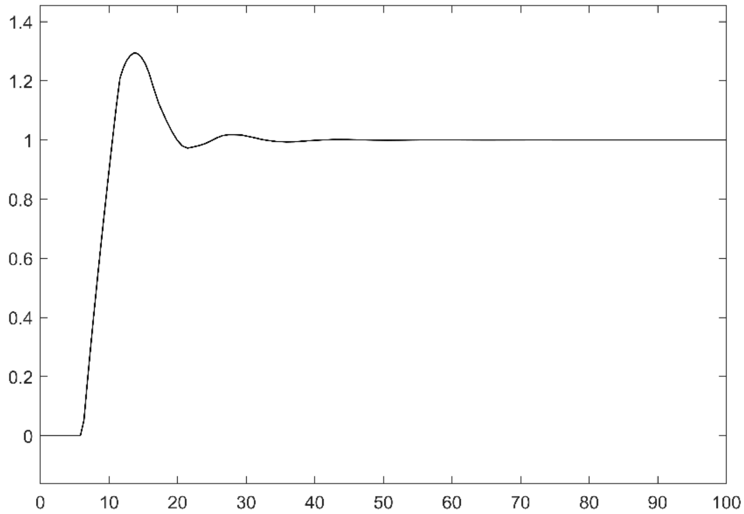

Figure 10 The simulation results of the first-order time-delay system

It can be seen that it has a faster response time and a smaller steady-state error, which can still meet the control requirements.

6. Concluding remarks

This paper uses the differential evolution algorithm in the intelligent optimization algorithm, and uses ITAE (time and error absolute value product integral performance index) as the evaluation function to set the PID parameters of the third-order system to obtain the optimal PID parameters of the third-order system, and then use the difference The evolutionary algorithm approximates the third-order model to the first-order time-delay model, which is verified by establishing a simulink model, and both have achieved better control effects.

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Sichuan Science and Technology Plan (2018JY0197, 19ZDZX0037, 2019YFSY0045, 2016SZ0074) .

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