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PID CONTROL BASED ON GENETIC ALGORITHM AND ITS APPLICATION IN WATER TANK CONTROL

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Abstract. *The traditional PID controller is simple in principle, easy to use, stable and reliable, and it is still widely used in the control field. However, for many nonlinear and lagging objects, the parameter tuning of PID controller is very important. Genetic algorithm for optimization of PID parameters tuning provides a new way. It uses simple encoding technique and propagating mechanism to represent complex phenomenon, which is not affected by the search space of the restrictive assumption of constraint. In this paper, the global optimization of genetic algorithm is used to optimize the PID parameters, which can improve the control performance and adaptive capability of PID controller. The mathematical model of the dual water tank system is established. The PID controller is used to control the water level. The simulation results verify the effectiveness of the proposed control algorithm.*
Keywords: Genetic algorithm, PID, Dual capacity water tank, Water level

1. **Introduction.** The traditional PID control has strong robustness. Actual operation results and theoretical analysis show that the applications of it in quite a number of industrial processes can get satisfactory results [1,2]. For last decades, the control theory has developed rapidly, but no one can replace the position of PID control in engineering applications. In PID control, tuning PID parameters is the key problem for the reason that industrial practices in many systems are nonlinear and hysteresis, so parameters tuning of PID controller is particularly important [3-5].

Genetic algorithm provides a new way to optimize the parameters of PID. Genetic algorithm is a kind of optimization method, which is widely recognized as a method with global optimal search capability [6]. It only depends on the fitness function, without knowing all the information about the object. In this way, even if in the uncertain object model, it can be used to optimize Kp, Ki and Kd using the output of the object. Genetic algorithm optimization mechanism can offer engineers a global optimal solution [7,8].

Genetic algorithm is very different from the traditional mathematical model. It points out a solution to the problem which is difficult to find the traditional mathematical model. In 1975, Holland firstly proposed genetic algorithm in his work named *Adaptation in Natural and Artificial Systems*. Many of the ideas, the crystallization and detailed description of the theories of genetic algorithm, were shown in this book. Besides, it developed a set of simulations of the biological adaptive system theory [9-11]. De Jong did many serious computational experiments. The famous De Jong five-functions test platform was established. He defined the performance evaluation criteria, and took the optimization function as an example to do detailed experiments and analyze the performance and mechanism of genetic algorithm. In order to overcome the random errors of the random selection operation of De Jong, Brindle studied the doctoral dissertation in 1981 by six replication strategies [12]. Goldberg played an important role in the research of genetic algorithm. In 1983, he firstly used the genetic algorithm for optimizing actual engineering system which was a gas pipeline.

In this paper, genetic algorithm is used as a global optimization algorithm, which is applied to the optimization of the parameters of PID and can improve the performance and adaptive capacity of PID controller [13]. The structure diagram of PID control based on genetic algorithm is presented in the second part. Then, the mathematical model of the dual capacity water tank system is established, and the PID controller based on genetic algorithm is used to control the water level. The simulation results verify the effectiveness of the proposed control algorithm.

2. **Control Algorithm.**

Genetic algorithm is a kind of algorithm based on spatial search. Through natural selection, it mutates operations of Darwinian survival of the fittest theory and simulates natural evolutionary process to find the solution. Simple coding techniques and propagation mechanisms are used to express complex phenomena, which is not restricted by the restriction of the search space. In the genetic algorithm, a number of digital encodings are generated. The fitness function is used to evaluate each individual and eliminate the individuals which have low fitness. Choose individual with high adaptation degree in genetic operation. Individuals after genetic operation are gathered together to form a new group. In the next round of optimization of the new group, the main steps are: (1) initialization group; (2) the fitness value of each individual in the population is calculated; (3) a rule chosen by a decision of the individual fitness to enter the next generation; (4) cross operation with probability Pc; (5) mutation operation with probability Pc; (6) if it does not meet a certain stop condition, then turn to Step (2), or enter the next step; (7) put out the optimal solution.

PID control based on GA (GA-PID) is based on the conventional PID controller, using genetic algorithm to search for the three parameters of PID. First of all, the three parameters Kp, Ki and Kd of PID are combined together as an individual in the group of genetic algorithm. Calculate the fitness value of each set of parameters according to the fitness function. Then, do mutation operation and continuous evolution until the optimal target in the group is found. Get the optimal parameters of PID controller. The PID controller based on genetic algorithm is composed of two parts: ① PID controller: it directly controls the control object, and online optimizes the three parameters Kp, Ki and Kd of PID. ② Genetic algorithm: it is based on the operating state of the system and adjusts the parameters of the PID controller, which is used to achieve the optimization of a certain performance index. The structure of the control system is shown in Figure 1.

3. **Control Object Model.**

Water tank liquid level control system is an open platform based on the physical model of the actual production and industrial process. It can be

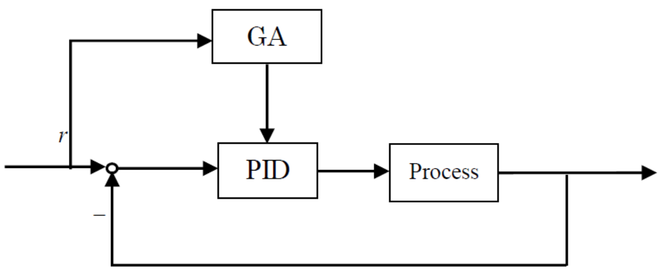

FIGURE 1. PID control system based on genetic algorithm

used to simulate a variety of complex field processes, so it can be carried out to verify advanced complex system control algorithms.

This paper established a multi-tank liquid level control system with various examination components and electrical transactions. The control objects of the system are two solenoid valves which can be adjusted. The electromagnetic valve opening is controlled to regulate the speed of fluid between the water tanks, which can realize the regulation and control of the water tank liquid level height.

The experimental platform of the multi water tank can be used to connect the valve opening and closing of the various water tanks to the different level control system. The principle of this system is shown in Figure 2.

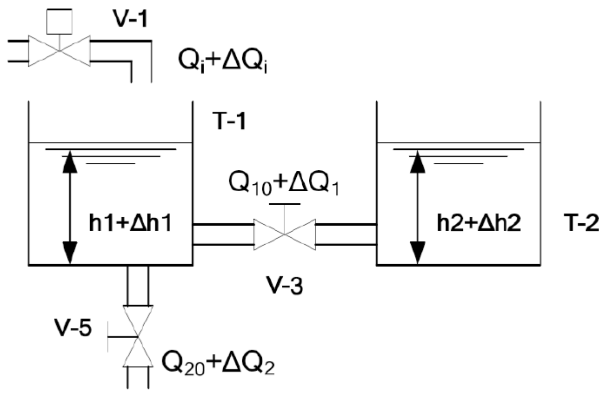

FIGURE 2. Model of double tank water level control system

This is a single tank with two serried in. The input volume ΔQ_i is the increment of the water flow in the left side of the tank. Output volume is liquid level increment Δh_1 in the first tank. The following relationship can be established between the increment of water flow, the increment of liquid level and the liquid resistance of valve:

$$\Delta Q_i - \Delta Q_1 - \Delta Q_2 = A\frac{d\Delta h_1}{dt} \tag{1}$$

$$\Delta Q_1 = A\frac{d\Delta h_2}{dt} \tag{2}$$

$$\Delta Q_1 = A\frac{\Delta h_1 - \Delta h_2}{R_{12}} \tag{3}$$

$$\Delta Q_2 = \frac{\Delta h_1}{R_1} \tag{4}$$

In Formulae (1)-(4), A represents the cross-sectional area of the two water tanks, and R_1 and R_{12} respectively represent two liquid resistances of water tank valve V-3 and V-5. Do the Laplace transform and it can be sorted:

$$\Delta H_1(s) - \Delta H_2(s) = R_{12}As\Delta H_2(s) \tag{5}$$

Then the equations below can be obtained:

$$\Delta H_2(s) = \frac{\Delta H_1(s)}{1 + R_{12}As} \tag{6}$$

$$\Delta Q_i(s) - \frac{\Delta H_1(s)}{R_1} - \frac{As\Delta H_1(s)}{1 + R_{12}As} = As\Delta H_1(s) \tag{7}$$

$$\Delta Q_i(s) = \left(As + \frac{1}{R_1} + \frac{As}{1 + R_{12}As}\right)\Delta H_1(s) \tag{8}$$

$$\frac{\Delta H_1(s)}{\Delta Q_i(s)} = \frac{R_1 + R_1 R_{12} A s}{R_1 R_{12} A^2 s^2 + A(R_1 + R_{12} + R_1)s + 1} \tag{9}$$

The transfer function $G(s)$ can be obtained between the input ΔQ_i and output ΔH_1 of the system, which is as follows:

$$G(s) = \frac{\Delta H_1(s)}{\Delta Q_i(s)} = \frac{b_1 s + b_2}{a_0 s^2 + a_1 s + a_2} \tag{10}$$

in which, $a_0 = R_1 R_{12} A^2$, $a_1 = A(R_1 + R_{12} + R_1)$, $a_2 = 1$, $b_1 = R_1 R_{12} A$, $b_2 = R_1$.

In order to do the step response experiment, the opening degrees of valve V-5 and valve V-3 are fixed, while the water level height change data of tank T-1 and tank T-2 are recorded. The system transfer function can be identified by the system identification function of MATLAB. The system model of this system is shown as Formula (11).

$$G(s) = \frac{0.415s + 0.245}{s^2 + 1.276s + 0.0234} \tag{11}$$

4. **Simulation Results.** In this paper, the mathematical model of the double tank water tank is made by its step response, and the output curve to step response is shown in Figure 3. It can be seen from the diagram that the system is a typical inertia link with the ability of self-balancing. System inertia response time is too long. In this paper, GA-PID is used to control the system, and the control results are as follows.

As can be seen from Figure 4 that both the traditional PID control and GA-PID control can be used to control the system to be stable. However, the response of the GA-PID control is faster than the traditional PID response. At the same time, the overshoot of GA-PID control is less than that of the traditional PID.

In order to verify the robustness of the GA-PID, a simulation experiment is carried out when the control object is mismatched with the practical situation. In this experiment, we

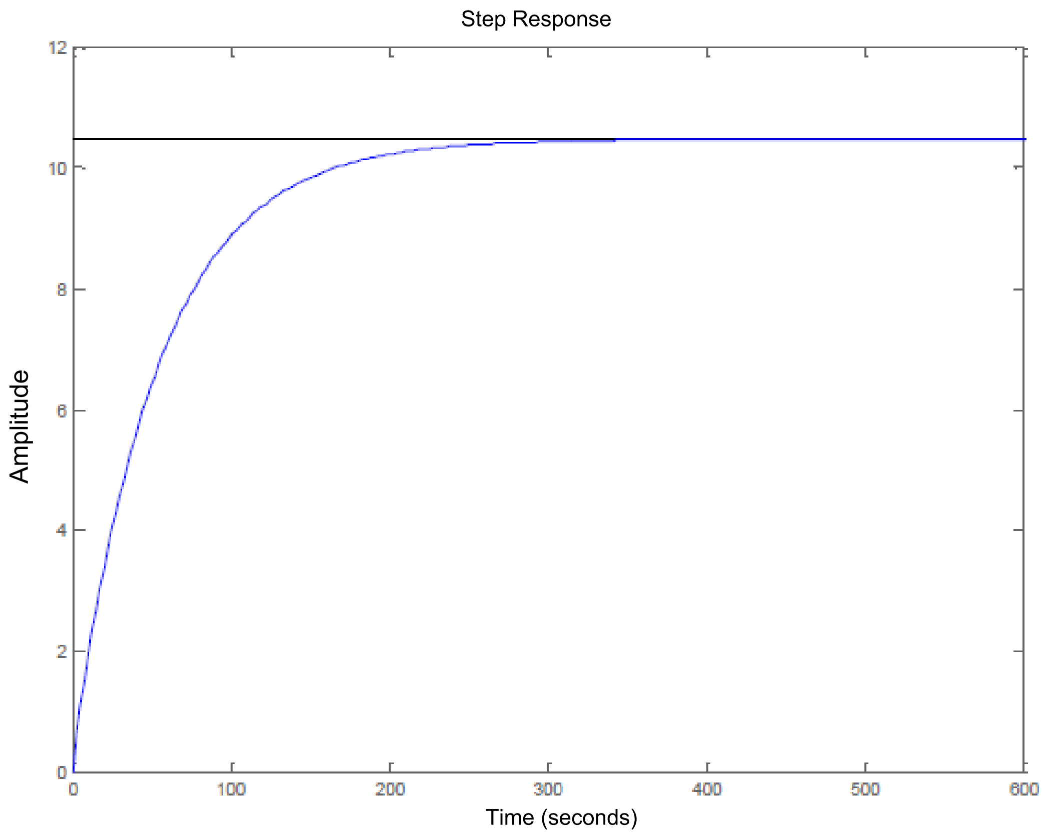

Figure 3. System step response

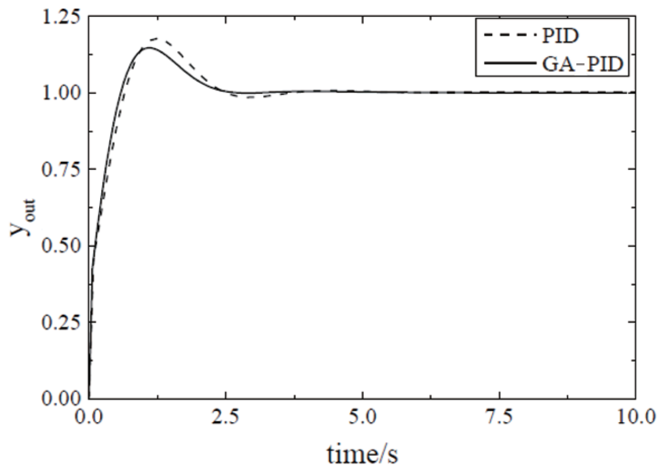

Figure 4. The control results of PID and GA-PID when model is well matched

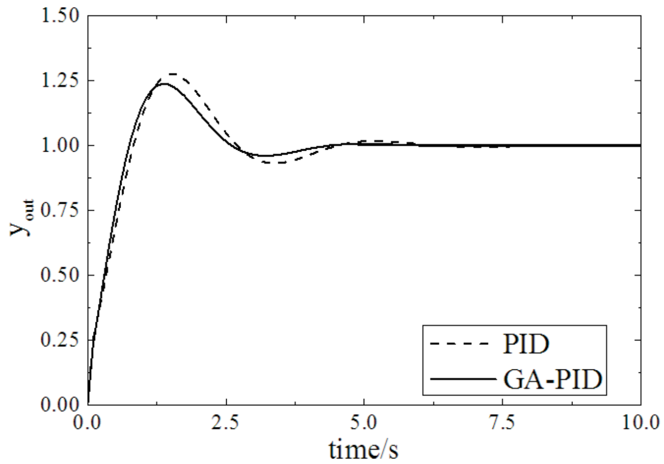

Figure 5. The control results of PID and GA-PID when model is mismatched

use the same control parameters to control the double water tank whose transfer function changes a little. The results are shown as Figure 5.

As it can be seen, the GA-PID has a great robustness than traditional PID. The GA-PID has a less overshoot than PID, and its balanced time is shorter than PID.

5. **Conclusions.** In this paper, the mathematical model of the dual capacity water tank system is established. A GA-PID control is proposed for the system. The parameters of the PID controller can be optimized by using the genetic algorithm. The simulation results show that the control performance of GA-PID is better than that of the traditional PID, which has strong robustness and can shorten the regulation time of the system. For future work, a nonlinear control object should be carried out to verify the robustness of GA-PID.

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