Control Method Based On Long Time-delay System

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Abstract. In today's industrial control field, the control system often has long time-delay property, which makes the sensor unable to acquire real-time information and the control system difficult to control. A control method is proposed here, on the one hand, which uses Fuzzy-PID control to adjust control parameters in real time, improves control accuracy and strengthens the robustness of the control system; On the other hand, this method uses particle swarm algorithm to calculate the optimal fuzzy control parameters to make the system in the optimal control state, and at the same time, uses Smith algorithm to overcome the system delay. Finally, through the simulation, this control strategy has higher precision than traditional PID control, and has a shorter reflection time, which achieves precise control of systems for long time-delay system.

1. Introduction

In the process of industrial control, the time-delay of the system is common, and the degree of delay varies. In the control system, if the controlled object has a pure delay, the control of the system will become more difficult, the quality of the control will deteriorate, and the stability of the system will also decrease, which will cause the controlled quantity to not reflect the system’s encountered or endured disturbances, even if a signal is detected, it will take some time to act on system. This system will inevitably go through timeless adjustment times and produce significant overshoot. Controlled system control’s difficulty increases with the degree of delay increases, and therefore controlling delay system is a big problem in the industry urgent to be solved.

Generally, the ratio of the pure delay time and the dynamic time constant of the system is used to reflect the degree of delay. When the ratio is greater than or equal to 0.5, the controlled system is a long time-delay system. For long time-delay systems, the control parameters must be updated in real time. The control strategy introduced here uses fuzzy PID control to adjust the control parameters in real time. At the same time, the fixed control parameters in the system are in the best state by particle swarm optimization. Finally, Smith algorithm overcomes the interference caused by long time-delay systems. The control block diagram is shown in Figure 1:
2. The establishment of fuzzy-PID control system

Select the transfer function as:

\[ G(s) = \frac{0.233}{10s + 1} e^{-20s} \]

Taking this model as the research object, this model has a time constant of 10 and a pure delay time of 20, which is a typical long-time-delay system. The design of fuzzy PID control model also needs to determine the input and output fuzzy domain, scale factor (Factor 1), fuzzy subset and membership function, fuzzy rules, deblurring method and quantization factor (Factor 2). Among these, the optimal values of scale factor and quantization factor are obtained by particle swarm optimization. Next, this paper will analyze other parameters:

Input and output fuzzy domain: In this fuzzy control model, error (e) and rate of error change (ec) are used as inputs, and ΔKp, ΔKi, and ΔKd are used as outputs. The fuzzy domain of error and rate of error change is [-3, 3]. The range of ΔKp, ΔKi, and ΔKd fuzzy domains is also [-3, 3].

Fuzzy subset and membership function: the characteristic of fuzzy control is that it can make full use of artificial experience to control the control object, and the fuzzy subset fully reflects this feature. In this fuzzy control model, the fuzzy universe is divided into seven fuzzy Subset, the scope and membership function of error (e) are explained in detail as follows (the rest are similar, do not repeat).

Error (e): the range of fuzzy domain is [-3,3], divided into seven fuzzy subsets {NB, NM, NS, ZO, PS, PM, PB}. The definition domain is shown in the table below:

| Subset | Membership Function | Domain         | Subset  | Membership Function | Domain         |
|--------|---------------------|----------------|--------|---------------------|----------------|
| NB     | gaussmf            | [0.4248 -3]    | PS     | trimf               | [0 1 1.999]    |
| NM     | trimf              | [-3 -1.999 -1] | PM     | trimf               | [1 1.999 3]   |
| NS     | trimf              | [-1.999 -1 0]  | PB     | gaussmf             | [0.4254 3]    |
| ZO     | gaussmf            | [0.03183 0]    |        |                     |                |

The form of fuzzy rules is: if x is A and y is B, then z is C, where x and y are input quantities, z is output quantity, A and B are input fuzzy quantities, and C is output fuzzy quantity. This rule is determined by experiment.
Deblurring method: in order to obtain accurate control quantity, it is required that the deblurring method can well express the calculation result of the membership function. The invention adopts the area center of gravity method. The area center of gravity method takes the center of gravity of the area enclosed by the membership function curve and the abscissa as the final output value of fuzzy inference. The formula is as follows:

\[
v_o = \frac{\int v \mu(v) dv}{\int \mu(v) dv}
\]

\(\mu(v)\) - membership function

\(v\) - variable

3. Establish Smith Algorithm

The control system with a pure delay link will reduce the stability of the system because it contains a delay function in the characteristic equation. If the delay time is too long, it will make the system unstable. So this paper calculate the error caused by the system delay into the total error, the stability of the system can be greatly improved. The specific method is to use the difference between the expected value and the actual output value as error 1, the error generated by the delay as error 2. Record the difference between error 1 and error 2 as the total error, and thus the Smith algorithm model is established, as shown in the Figure 2:

![Figure 2 Fuzzy-PID-Smith diagram](image)

4. Establish Particle Swarm Optimization

So far, the control system model is built, but in this model, the scale factor and quantization factor are in an unknown state. Therefore, this paper uses particle swarm optimization to find the optimal value of the scale factor and quantization factor. The specific process is as follows:

Initialization: Set the motion range of the parameters, set the learning factors \(c_1\), \(c_2\), the maximum evolutionary generation \(G\), \(k_g\) represents the current evolutionary generation. In a 5-dimensional parameter search solution space, the size of the population composed of particles is \(\text{Size}\), and each particle represents a candidate solution in the solution space, where the position of the \(i\)-th particle in the entire solution space is expressed as \(X_i\), the speed is expressed as \(V_i\). The optimal solution generated by the search for the \(i\)-th particle from the initial to the current iteration number is the individual extremum \(f_{gbest}\), and the current optimal solution of the entire population is \(f_{zbest}\). Randomly generate the position matrix and velocity matrix of the initial population.

Fitness evaluation: taking the initial position of each particle as an individual extreme value, the fitness function is used:

\[
f(x) = \int (t \cdot |e(t)|) \ dt
\]
Calculate the initial fitness value \( f(X_i) \) of each particle in the population, and find the optimal position of the population.

Update the speed and position of particles, generate new populations, and check the speed and position of particles beyond boundaries. In order to avoid the algorithm falling into local optimum, a local adaptive mutation operator is added for adjustment. The update formula is as follows:

\[
V_{i}^{kg+1} = w(t) \cdot V_{i}^{kg} + c_1 \cdot r_1 \cdot (fgbest_i^{kg} - X_i^{kg}) + c_2 \cdot r_2 \cdot (fzbest_i^{kg} - X_i^{kg})
\]

\[
X_{i}^{kg+1} = X_i^{kg} + V_i^{kg+1}
\]

Among these, \( kg = 1, 2, ..., G \), \( i = 1, 2, ..., Siz \). \( r_1 \) and \( r_2 \) are random numbers from 0 to 1, \( c_1 \) is the local learning factor, and \( c_2 \) is the global learning factor.

Compare the particle's current fitness value \( f(X_i) \) with its own historical optimal value \( fgbest \), if \( f(X_i) \) is better than \( fgbest \), then set \( fgbest \) to the current \( f(X_i) \), and update the particle position.

Compare the particle's current fitness value \( f(X_i) \) with the population optimal value \( fzbest \). If \( f(X_i) \) is better than \( fzbest \), then set \( fzbest \) to the current \( f(X_i) \), and update the population global optimal value.

Check the end condition, if it is satisfied, then end the optimization, otherwise \( kg = kg + 1 \), go to (3). The end condition is that the optimal search reaches the maximum evolution algebra, or the evaluation value is less than the given accuracy.

The matlab/simulink diagram is shown in Figure 3:

![Algorithm diagram](image)

**Figure 3** Algorithm diagram

5. **Simulation results and comparison**

Simulate in Simulink the traditional PID and the control method described in this paper. The results are shown in Figure 4 and Figure 5:
The experimental results prove that the problem of low control accuracy of the traditional control method is effectively solved, and the problem of system instability caused by delay is solved.

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