Tuning of PID parameters based on particle swarm optimization

Deqing Yang
Industrial Technology Research Institute, Zhengzhou University, Zhengzhou 450001, China

Abstract. PID controller has the advantages of simple algorithm, easy realization, easy adjustment and good robustness, and is widely used in various industries. Engineers have accumulated a wealth of experience in the long-term practice of PID controller parameter tuning, but the traditional experience-based PID parameter tuning method has been unable to meet the control needs of modern nonlinear complex objects. In this paper, the PID parameter tuning algorithm of basic particle swarm optimization (PSO) is designed. Establish the second-order system, select the experience trial and error method to tune the PID parameters, this method cannot quickly calculate the PID parameters, the staff need to rely on experience to constantly try and error, inefficient. However, the optimal solution of PID parameters can be obtained quickly by using PSO, and the control effect is good.

1. Introduction
Kendrick and Eberhard proposed the PSO algorithm together in 1955. Particle swarm optimization (PSO) is widely used because of its simplicity, ease of implementation, high efficiency and few parameters to be adjusted.

PID control law has been playing an important role in the control system because of its simple algorithm, good robustness, strong stability, high reliability and easy realization. The greatest advantage of PID control is that the control mechanism does not depend on the mathematical model of the object, but only uses the error of the actual behaviour of the control object and the controlled object to generate a control method to reduce the error. The PID controller accounts for more than 90% of the industrial controller, which should be very mature and widely used. Many control systems work on the basis of PID controller. However, the control object has the characteristics of time-varying and non-linear, so it is not easy to create a model. The traditional tuning methods (such as the most commonly used critical proportion method, ZN empirical method, ISTE optimal setting method, etc.) cannot achieve the optimal control effect. Therefore, we need better algorithm to adjust the PID parameters. With the rapid development of computer technology, particle swarm optimization (PSO) with better control performance has solved this problem well.

2. PID controller

2.1. The basic principle of PID controller
PID controllers are widely used in control systems. The PID controller is a linear controller based on the difference between reference value R (T) and output value Y (T):
\[ e(t) = r(t) - y(t). \tag{1} \]

The discretization formula of PID controller is as follows:
\[ \Delta u(k) = K_p[e(k) - e(k-1)] + K_i e(k) + K_d[e(k) - e(k-1)]. \tag{2} \]

The parameter tuning of PID controller is to adjust the parameters of the controller when the controller is already PID, so that the control loop can achieve the dynamic and static characteristics and control objectives required by the system. Parameter tuning is very important, and the quality of the parameters directly affects the quality of the control.

2.2. Step response example
A two level control system is established. Its transfer function expression is:
\[ G(s) = \frac{1.05s + 1}{s^2 - 5s + 1}. \tag{3} \]

Under the action of unit step response input, the output response of the system diverges and the system is unstable when the time \( t \) increases gradually. After joining PID, the step response matlab generation of the system is shown in Figure 1. \( K_p = 10, K_i = 0.1, K_d = 15 \)

![Figure 1. Step response of system after PID entry](image)

After joining the PID, the system just started to shake, and then tended to be stable, with an overshoot of 69.43%. The rise time is 0.0897s. Assuming that the allowable range of the deviation between the output and the final value corresponding to the input is 5%, the adjustment time is 1.435s. The parameters of this method are not good, the overshoot is large, the rise time is large, and the adjustment time is large.

According to the step response of the control system, we will further test and set up the control system. \( K_p = 50, K_i = 0.1, K_d = 15 \)
The ordinate is 1
Step response curve

\[ K_p = 50, K_i = 0.1, K_d = 15 \]

The control effect of the system has been greatly improved, but the overshoot, mediation time and rise time of the system response are still relatively large.

2.3. Critical proportionality method
At this time, according to the period of equal amplitude oscillation, three parameters of PID are finally obtained. \( K_p = 8.16, K_i = 0.769, K_d = 2.96 \)

Using MATLAB to generate step response curve of the system

At this time, the system's step response overshoot and adjustment time are large, and the control effect is poor.

In summary, for the experiential trial-and-error method, in order to get better response effect, we need to further adjust the parameters, the amount of calculation is large, in order to overcome this shortcoming, we use the PSO algorithm to tune the PID parameters.

3. PID parameter tuning based on PSO algorithm

3.1. Search algorithm design
Suppose that an \( m \) particle forms a population of target search space with dimension \( D \). The position of the first particle is the \( d \)-dimensional vector of the second particle, that is, the position of the second particle in the \( d \)-dimensional search space is the velocity vector of the second particle. The position and velocity of each particle are updated according to the following updated formula. Eq. (4) explains the relationship between the velocity and position of the particle at the next moment and the velocity and position at the current moment. Particles in the search for feasible solutions take into account their own flight experience and the flight experience of other particles.
\[ v_{id}^{i+1} = w \cdot v_{id}^{i} + c_{1}r_{1}(p_{id}^{i} - x_{id}^{i}) + c_{2}r_{2}(p_{sd}^{i} - x_{id}^{i}) \]
\[ x_{id}^{i+1} = x_{id}^{i} + v_{id}^{i+1}. \]

3.2. Selection of objective function

The PID controller has three parameters, \( K_p, K_i, K_d \). Form a matrix \([K_p, K_i, K_d] \), the main purpose of PID parameter control is to get better control effect, I choose time absolute value product (ITAE) as part of the objective function. In this way, the expression of the optimal parameter can be obtained.

\[ J = \int_{0}^{\infty} (w_1 |e(t)| + w_2 u(t)^2) dt + w_3 t_u. \]

Among them: \( e(T) \) system error, \( t \) time, \( t_u \) Rise time, \( w_1, w_2, w_3 \) Inertia weight

4. Simulation results

The control object is the two order system mentioned above, and the transfer function is:

\[ G(s) = \frac{1.05s + 1}{s^2 - 5s + 1} \]

The reference input is step signal, and the sampling period TS is 0.001 seconds. assigned to the three parameters of the PID controller, and the speed and position of the particle swarm are constantly updated in the iterative process to find the optimal solution, and the fitness function and the variation of the three parameters and the order of the system can be generated. Jump response curve. After running the program, the values of the three parameters can be obtained. \( K_p = 104.4, K_i = 0, K_d = 0.7853 \)

![Figure 4. System step response curve (Kp)](image-url)
As can be seen from figs. 6, 7, and 8, the fitness function saturates and does not change at the number of iterations in the 20th generation. At the same time, the three parameters do not change, indicating that the system is basically stable at this time; in the system step response diagram, it can be seen that the time to reach stability is about 0.1, and the overshoot is very small.

5. validation results
Through simulation, the waveform is shown in Figure 7, and the step response is convergent. Calculated by particle swarm optimization algorithm, $K_p = 104.4, K_i = 0, K_d = 0.7853$ Then the step response of the system is calculated by using the given PID parameters and transfer functions. As shown in Figure 8.

Figure 5. System step response curve (Ki)

Figure 6. System step response curve (Kd)

Figure 7. Step response diagram
The system is stable at this time. The rise time is 0.025s and the overshoot is 5.5%. Assuming that the allowable range of the deviation between the output and the final value corresponding to the input is 5%, the adjustment time is 0.125s. Compared with the conventional PID parameters, the PSO algorithm has shorter rise time, smaller overshoot and shorter adjustment time. The system is stable.

6. Conclusion

PID parameter tuning based on PSO optimization algorithm can quickly find the optimal solution of the three parameters, which satisfies the performance optimization index well. The overshoot is small, the response time is fast, the robustness is good, and the control effect is very good. Moreover, the algorithm is simple and easy to understand, easy to understand, easy to implement, not only can be applied to the tuning of PID parameters can also be applied to other complex control systems. It is more accurate and faster than the experience trial method.

References

[1] Chen Liwei. Gas detection and gas source localization technology [M]. Beijing: Publishing House of electronics industry, 2017.6.
[2] Tang Tieying. Artificial Immune Algorithm and Its Application in Power System Planning [D].
[3] Niu Jumei. Design of Ball and Rod System Controller Based on Adaptive Genetic Algorithm [D]. Master's Degree Dissertation of Northeast University, 2010.
[4] Ji Zhen, Liao Huilian et al. Particle swarm optimization algorithm and its application [M]. Beijing: Science Press, 2009, 30 (3): 41 - 50.
[5] ho Yi. Research and implementation of fuzzy genetic algorithm [D]. [D]. master's thesis, 2005.
[6] Xu Junjun, Huang Yonghong et al. Reactive power optimization of distribution network with DG access based on natural selection particle swarm optimization [J]. Electrical measurement and instrumentation, 2014, 10 (3) 33 - 38.
[7] Shen Yong. Research on fuzzy methods of dynamic systems [D]. [D]. master's thesis, 2009.