An Improved Method for PID Control of Time-Delay Systems

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Abstract. The industrial systems has became more complex, because of the rapid development of industrial production. Large time-delay, time variation, and highly nonlinear have placed higher requirements on industrial control systems. Smith predicting controller is a controller specifically used for time-delay systems. It estimates the dynamic characteristics of the system's basic disturbances in advance, and designs an estimator for compensation control, which can effectively improve the system response. But Smith predicting controller depends too much on the mathematical model of the controlled object. This paper proposed a control system based on Smith-PIDNN, which combines Smith controller with neural network PID (PIDNN), uses the neural network's ability to simulate non-linear systems and self-learning ability, and adjusts control parameters online. And it was simulated by MATLAB software, the effectiveness of this combination method was proved.

1. Introduction
There are widely Time-varying processes with large time delay in the industrial production, that is the parameters of the system change with time and the environment, including retardation time, inertia time, and forward amplification factor etc. In addition to the volume delay, the controlled object usually has different degrees of pure delay. For example, in a heat exchanger, the controlled variable is the outlet temperature of the material being heated, and the operating variable is the flow rate of the heat transfer medium. When the flow rate of the heat transfer medium is changed, the effect on the outlet temperature of the material must retardation behind for a period of time, that is the time required for the medium to pass through the pipe.

The characteristic of this type of control process is that the controlled parameter has no corresponding response at all, so the system cannot adjust with the controlled quantity in time to overcome the disturbance to the system within the retardation time range after the control effect is generated. Therefore, the process will inevitably produce a relatively large amount of overshoot and a long transient time.

Actually, in the actual production process, even explosions, coking and other accidents may occur due to severe overshoot. In addition, a large retardation will reduce the stability of the entire control system. Therefore, processes with pure delay are considered to be more difficult to control, and the degree of difficult control increases as the ratio of pure retardation time to the dynamic time parameter of the entire process increases.
2. Application status of PID control in retardation systems

There are a lot of methods to solve the effects of hysteresis. The simplest way is to use the features of conventional PID regulators such as highly adaptable and easy to adjust. However, along with the development of modern industry, conventional PID control is difficult to meet the increasingly severe production environment. In order to realize the automatic control of such retardation systems, the modern industrial control field mainly has the following methods:

2.1. Derivative forward pid control

The characteristic of derivative forward pid control is that it only differentiates the output amount \( y(k) \), and does not differentiate the given value \( r(k) \). In this way, when the set value is changed, the output will not change, and the change of the controlled quantity is usually relatively mild. This kind of output value differential control can effectively avoid the situation where the given value rises and falls frequently. The system oscillation caused by the rise and fall, the application of derivative forward pid control in industrial process control can significantly improve the dynamic characteristics of the system, as shown in Figure 1. For the differential first control scheme.

It can be seen from the derivative forward pid control scheme that the output signal of the differential link includes the controlled parameter and its changing speed value, and inputs it as a measured value to the proportional integral regulator, so that the system's effect of overshooting is strengthened.

2.2. Smith predictive control

In order to improve the control quality of the large retardation system, in 1957, O.J.M. Smith proposed a process control method based on large retardation estimation compensation. Smith predictived compensation control is to design a model (such as adding links or adding control branches) to the feedback control system according to the characteristics of the object, and estimated the dynamic response of the object under disturbance, and made early compensation to make the controller Act early to reduce overshoot and speed up the transient process. Figure 2 is a block diagram of the Smith predictive control system.

As shown in the figure above, it is the transfer function of the Smith predictive compensator. The controller estimates the dynamic characteristics of the process under the influence of interference in advance, and then is compensated by the estimator, try to make the controlled amount of the retardation time forward to the input of the controller, so that the controller acts in advance, Eliminates the impact of pure retardation on system control quality.
2.3. Advanced process control technology

As the process industry becomes larger and more complex, the quality of control of the production process is becoming higher and higher, and many production systems with very complicated processes, structures, environments, and controls have emerged. Under the urgent need of new process control theory and technology, Advanced Process Control (APC) has appeared. The use of advanced process control with better dynamic characteristics, faster convergence speed, and adaptive ability can effectively reduce the effect of retardation time on system control effects. Such as sampling control, internal model control, Dehlin algorithm, etc. have been applied in engineering.

3. Control system based Smith-PIDNN

This section simulates the engineering implementation of the Smith predictive control, analyze the limitations of Smith's control advantage, and further proposes a BP neural network control based on the actual situation of the system. The full use of the Smith estimator to compensate for the pure retardation link and the learning ability of the BP neural network effectively optimize the system response.

3.1. Engineering Implementation of Smith Predictive Control

The Smith predictor is applied to the liquid level control process of a storage tank. The liquid passes through the valve 1 and the one-meter pipeline to flow into the storage tank in a delayed manner, and also continuously flows out. Liquid outflow $Q_2$ is controlled by the opening degree of valve 2. The controlled volume is liquid level $h$, which needs to be stable to 0.8m. Among them: the liquid inflow rate $Q_1=0.0083$ $m^3/s$, Maximum liquid outflow rate $Q_2$ is 0.02 $m^3/s$, Tank cross-sectional area $A=0.5m^2$. The transfer function between the change of the liquid level in the storage tank and the opening of valve 2 is Formula (1).

$$G(s) = \frac{2}{10s+1}e^{-s}$$  \hspace{1cm} (1)

The simulation software in MATLAB / Simulink Smith tank control is used to control the liquid level of this storage tank. The structural block diagram control method of Figure 2.2 is used for simulation. For convenience of observation, the comparison with the conventional PID control scheme, the step response curve is shown in Figure 3. As shown.

![Figure 3. Response curve of Smith predictive control applied to the liquid level control of a storage tank.](image-url)
According to the response curve in Figure 3, Smith's estimated control has a good compensation ability for the system's retardation time, optimizes the system's transient time, and reduces the overshoot amount, but for more severe industrial control sites, the control ability is not enough, and the Smith controller is too dependent on the mathematical model of the controlled object. If the model estimation is not accurate, it will seriously affect the control effect. Therefore, Smith predictive control + BP neural network control strategy is proposed.

3.2. Smith predictive control + BP neural network control strategy

BP neural network has the ability to approximate nonlinear functions with arbitrary precision, and the structure and learning algorithm are simple and clear. Find the PID controller parameters under a certain optimal control rate through neural network. The design block diagram of the Smith predictive PID controller based on BP neural network is shown in Figure 4.

With the quadratic function \( E(k) = \frac{1}{2} (r(k) - y(k))^2 \) as the performance index, the parameters \( K_P, K_I, K_D \) of the PID controller are adjusted online by the BP neural network to achieve an optimal non-linear combination.

![Figure 4. Block diagram of Smith predictive PID controller based on BP neural network.](image)

The Smith prediction PID control based on the BP neural network was applied to the liquid level control of a storage tank constructed in Section 3.1, and compared with the Smith prediction control at the same coordinates. In order to further compare the anti-interference ability of the system, \( t = 50s \), the same interference is applied to the controller output of the two control models, so as to obtain the step response curves of the respective systems, as shown in Figure 5. The parameters of the Smith predictive PID control system based on BP neural network are adjusted during the control the curve is shown in Figure 6.

![Figure 5. Comparison of simulation curves of two control schemes (controller output adds interference).](image)
According to Figure 5 and Figure 6, it can be seen that the transient time, overshoot, and anti-interference ability of the Smith-estimated PID control system based on BP neural network are far stronger than the control system with only Smith-estimated control. The water level control process Medium, it can reach the set value quickly without steady-state error, which meets the requirements of industrial control well.

4. Conclusion
Based on the time-delay system in industrial production, this paper analyzes the application of conventional control schemes—differential advance control, Smith predictive control, and advanced control technology—in the time-delay system. The Smith predictive control is applied to the liquid level control of a storage tank, and the control performance and response speed are stronger than the conventional PID control. But the dynamic performance of Smith's predictive control is slightly worse for demanding industrial production, and it relies too much on models.

Therefore, the controller is improved on the basis of Smith predictive control. The Smith predictive PID control system of BP neural network is designed. It can be seen through simulation that the system can quickly reach the set value and run smoothly. The system transient time, overshoot and anti-interference have shown strong advantages.

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