Research on the Simulation of Time-Delay System

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Abstract

Most of modern industrial processes is continuous, large-scale and complex. Large time-delay system is increasingly common in the process of industrial production. It is difficult to make the system satisfy the performance specification requirements by traditional Proportional-Integral-Derivative (PID) control. Aiming at time-delay phenomenon, the paper discusses the Smith and Fuzzy control algorithm of time-delay system in order to improve dynamic performance of the system.

Keywords: Time-delay system, Smith predictive compensation, Fuzzy control

1. Introduction

Large time-delay system is very typical in those complex processes such as petrochemical, brewery, and papermaking or metallurgical, and this kind of system is hard to control. The system cannot meet the requirements of performance specifications when the time-delay is very large and even worse the system will become unstable (Wang, 2009). As the conventional PID algorithm cannot make the system satisfy performance specification requirements, therefore, many scholars are studying on the problem and many improved algorithms have been proposed. In addition to traditional strategies, several advanced control algorithms such as predictive control or robust control are also adopted in this field (Ting & Chang, 2011; Xia, Zhu, Li, Yang & Zhu, 2009; Wei, 2010).

2. Smith Predictive Compensation of Time-Delay System

The mathematical model of time-delay system is given as:

$$G(s) = \frac{15.2}{1200s+1} e^{-40s} \tag{1}$$

This is a pure time-delay and large inertia system. Generally, PID control can make the system stable, but it cannot satisfy the performance specification requirements (Hang, Ho, & Cao, 1994). In the process of industrial production, when it is difficult for PID controller to obtain satisfactory performance, generally, according to the requirements of the system's dynamic characteristics, a compensation device is designed, and then the controlled process and the compensation device can be seen as an equivalent controlled process to control. The process after compensation can feedback the controlled variables to controller in advance, which makes controller operate in advance and thus overcomes the influence of the large delay, reduces overshoot and settling time and improves the system's dynamic performance (Wang, 2006).

The fundamental theory of Smith compensation is: connect a compensation device with PID controller in parallel and the device is Smith compensator. The transfer function of Smith compensator which is designed based on pure delay phenomenon in this paper is:

$$G(s) = (1 - e^{-40s}) \frac{15.2}{1200s+1} \tag{2}$$

The diagram of control system that adopted Smith compensator is shown in Figure 1. In Figure 1, the delay time is 40S, three parameters of PID controller are: $K_P = 80, T_I = 4, T_D = 0.1$, the step response curve after compensation is shown in Figure 2.

From Figure 2 it can be known that adopted Smith compensator, the control performance of the system has been improved greatly. The overshoot is 10%, the settling time is 20S. But the response speed of the system is very slow.

3. Smith and Fuzzy Controller Design of Pure Delay System

In order to improve the performance of the system, this paper designs Smith and two-dimensional Fuzzy controller for pure delay system, and fuzzy sets of error (E), error change rate (EC), control variable U are defined as: (Chang, Huang, Chang, & Ku, 2001; Jang & Chen, 2007)

{nb, ns, z, ps, pb }

The universe of error (E) and error change rate (EC) is:

{-2, -1, 0, 1, 2}

The universe of control variable U is:

{-8, -4, 0, 4, 8}

The membership functions of error (E) and error change rate (EC) is shown in Figure 3 and Figure 4. The control rule table of Fuzzy controller is shown in Table 1. The principle of selecting control variable includes two aspects. When the error is large or larger, stress should be put on eliminating error. When the error is small, stress should be put on reducing overshoot.

After defining the fuzzy sets, the universe, the membership functions and the control rule, the FIS (Fuzzy Inference System) is established. The Fuzzy controller is shown in Figure 5.

The diagram of control system that adopted Smith and Fuzzy controller is shown in Figure 6. The Smith compensator and Fuzzy controller are integrated in Figure 6. The simulation curve adopted Smith and Fuzzy controller system is shown in Figure 7, the overshoot is 10%, the settling time is 15S. Compared with Figure 2, we can see that adopting Smith and Fuzzy control algorithm reduces overshoot and settling time and improves the dynamic performance of pure delay system. (Wu & Lin, 2002)

4. Conclusions

Aiming at large time-delay controlled process, Smith compensation controller and Fuzzy controller are designed in this paper respectively. By simulation analysis we can see that comparing with Smith compensation controller; Fuzzy control algorithm can improve dynamic performance of the time-delay system and enhance its robustness.

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Table 1. The control rule table of fuzzy controller

U \ EC / E	nb	ns	z	ps	pb
nb	nb	nb	nb	ns	z
ns	nb	nb	ns	z	ps
z	nb	ns	z	ps	pb
ps	ns	z	ps	pb	pb
pb	z	ps	pb	pb	pb

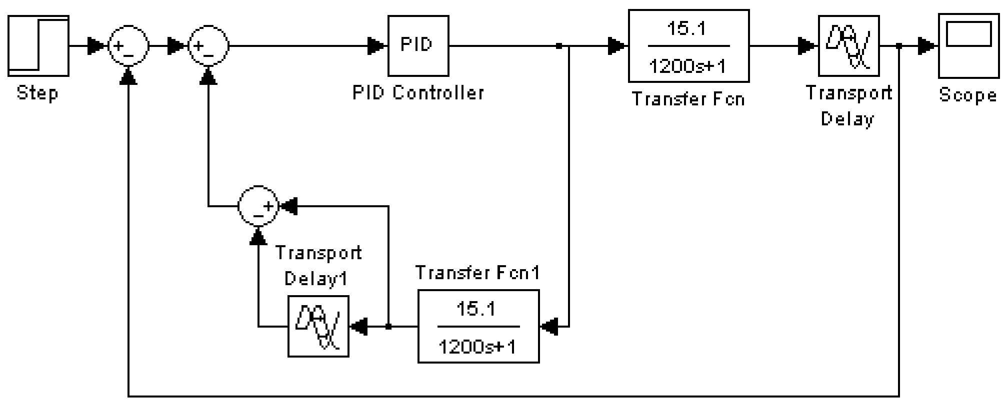

Figure 1. PID control with Smith predicative compensation

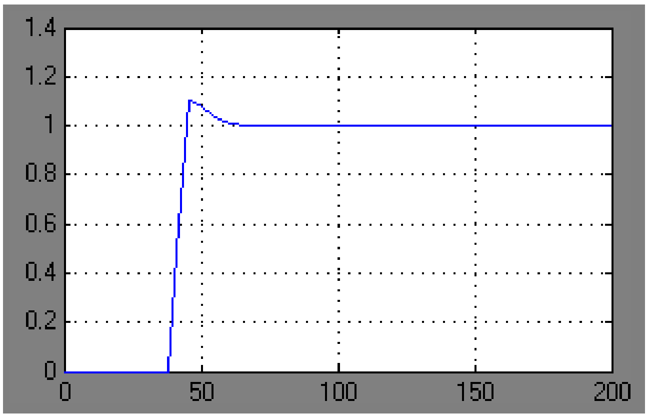

Figure 2. Step response curve after Smith compensation

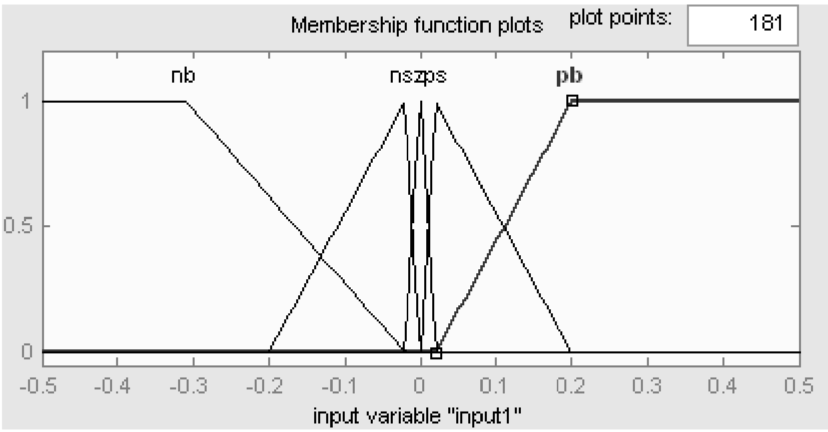

Figure 3. The membership functions of error (E)

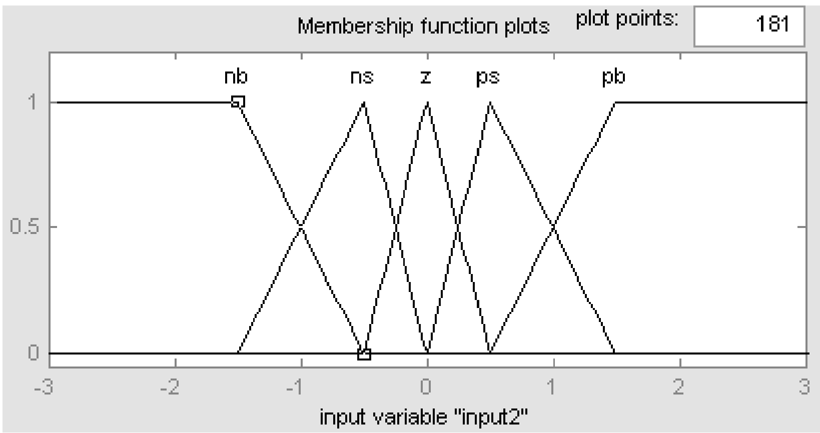

Figure 4. The membership functions of error change rate (EC)

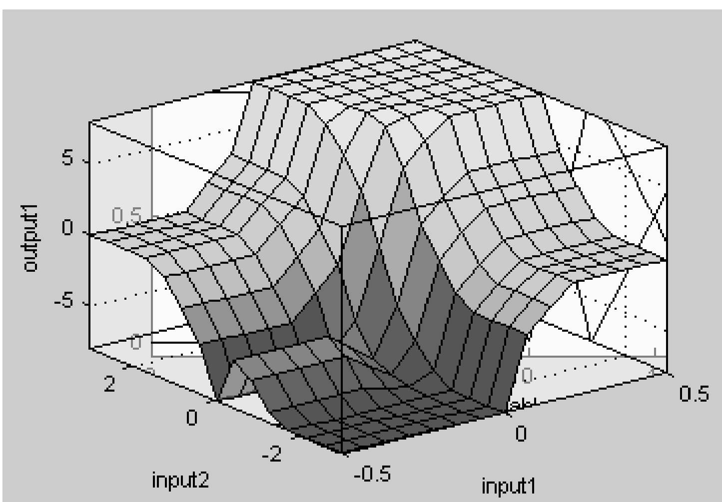

Figure 5. The fuzzy controller

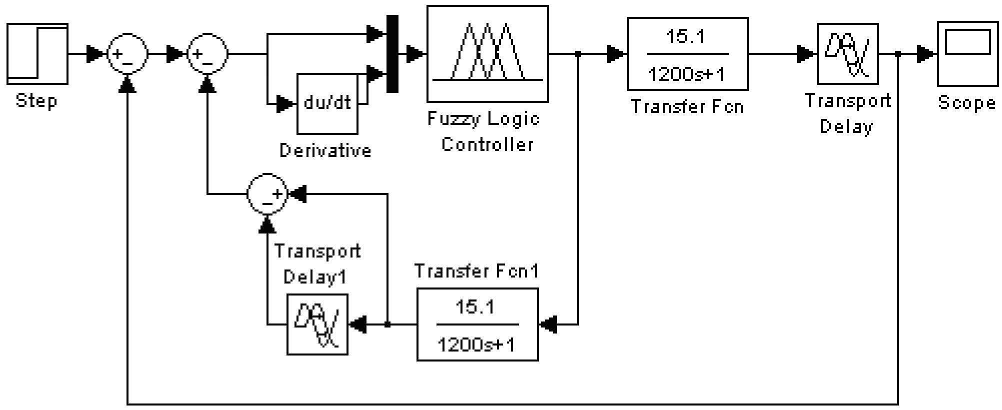

Figure 6. Diagram of control system that has introduced smith and fuzzy controller

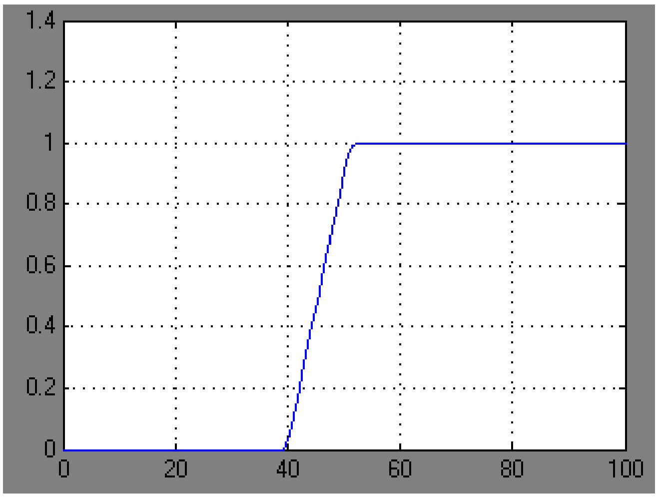

Figure 7. Simulation curve that adoptssmith and fuzzy controller system