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Simulation Design of Controller for Networked Control System

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Abstract

Aiming at the problem of time delay in the networked control system, by using the nonlinear approximation of the fuzzy control algorithm， and Smith forecast compensation. A kind of controller based on fuzzy adaptive PID with new Smith predictor is presented. This controller is easy to be implemented. Then using Matlab/simulink simulation software, the simulation research on a DC motor is done, and the simulation result shows, compared with the traditional PID control and PID control with Smith predictor, the control algorithm based on the fuzzy adaptive PID with new Smith predictor can effectively improve the robustness and adaptability of the system.

Keywords*: Networked Control System, Time delay, Fuzzy adaptive PID, Smith predictor*

1. Introduction

The networked control system is one of the new technologies in the field of computer control, it has the advantage of information resources sharing, easy to extend and maintenance, high reliability and flexibility, and it becomes a development trend of complex control system and remote control system [1]. In the networked control system, data and information is transmitted through the networked, this will lead to time delay of networked. Time delay can reduce the performance of the system, even cause system instability.

At present, research results of the networked control system mainly include two aspects of control and networked. In the control aspect, the research content mainly includes the design of the controller, the design of control algorithm and stability of the system. Nilsson researched the system of independent random time delay which is less than a sampling period, and discussed design problem based on the stochastic optimal controller [2]. Lunk and Ray put forward a method of building a buffer whose length is greater than the maximum period number of time delay in the controller and actuator nodes [3]. Thus, the random delay is transformed into a deterministic system. Ma and Fang proposed a networked control algorithm of model predictive compensation [4]. Yi puts forward a kind of method using least square support vector machine to forecast the networked time delay [5]. Fan et al. study how the different forms of compensator affect the characteristic of networked control system, and design an appropriate form of compensator [6]. Chen et al. propose a Fuzzy-Smith compensator based on the modeling error for the time delay compensation of networked control system. When the controlled plant is a nonlinear time-varying system, the identification model error of Smith predictor will change as well, which will lead to a poor control performance. For this problem, the fuzzy control method based on identification model gain self-tuning is introduced to improve the robustness of the compensator [7].

In this paper, a kind of control algorithm based on fuzzy adaptive PID with new Smith predictor is proposed. Because of the existence of forward delay and feedback delay, a new Smith predictor is adopted. In addition, Fuzzy controller is used so as to solve the

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problem that is generated by the inaccuracy of model controlled object. Fuzzy controller uses experience of human expert control. It can automatically adjust the PID parameters, and achieve the optimal control of networked control system, the performance is better than traditional PID controller. Furthermore, it shows excellent adaptability in the control of the nonlinear and complex object.

2. The Structure of Networked Control System

Networked Control System is also known as control system based on networked. Networked control system is a fully networked and distributed control system, and is also a closed-loop feedback control system through the networked connection [8]. Specifically, networked control system achieves information exchange among sensors, controllers and actuators using the networked as a transmission medium, and realizes resource sharing, remote monitoring and controlling. Networked control system generally consists of controller, controlled object and communication networks.

A kind of typical block diagram of networked control system is shown in Figure 1. Data is transmitted among the controller, actuator and sensor over the networked, so there exist three kinds of time delay in the system. One is communication delay τ_{sc} between the sensor and the controller; the other is computational delay τ_c in the controller and the third is communication delay τ_{ca} between the controller and the actuator. Because τ_c is very small, usually it is considered to merge into τ_{ca}, so the system delay is expressed as $\tau = \tau_{sc} + \tau_{ca}$.

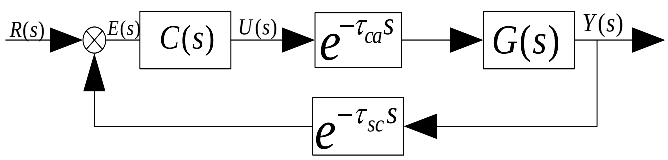


Figure 1. A Typical Block Diagram of Networked Control Systems

In Figure 1, R(s), U(s), Y(s) and E(s) are respectively Laplace transforms of the reference signal, the control signal, the output signal and error signal. $C(s)$ Is transfer function of the controller, $G(s)$ is the transfer function of the controlled object, τ_{sc} is time delay between the sensor and the controller and τ_{ca} is time delay between the controller and the actuator [9].

Because time delay appears in the control loop and it has uncertainty with the change of the controlled object, the timing of data sampling is changed, and the signal of the forward and feedback channel generates random time delay. The random time delay makes the system has slow response, great overshoot, long adjustment time, and when the time delay is too large, the stability of the system will be affected.

3. Design of New Smith Predictor

In the process of industrial control, many of the controlled objects have the nature of the pure lag. Smith proposed a pure lag compensation model. Its principle is that a compensation link is in parallel with PID controller, the compensation link called Smith estimates

Smith predictor is characterized by predicting the dynamic characteristic of system under the system with time delay. The delay controlled quantity can be received by the controller in advance through using the predictor, so that the controller is able to take action early, which reduces overshoot and accelerates adjustment process. But in the networked control system, due to time varying and uncertainty of time delay, it is almost impossible traditional Smith predictor to build a precise prediction model of time delay. And when the signal is transmitted, the “empty sampling” or “more sampling” is produced by the existence of time delay, the compensation error is produced and the stability of the system will be affected only using the traditional Smith predictor. Therefore, a new Smith predictor is presented [10]. It can realize Smith dynamic compensation control. The structure of networked control system with new Smith predictor is shown in Figure 2.

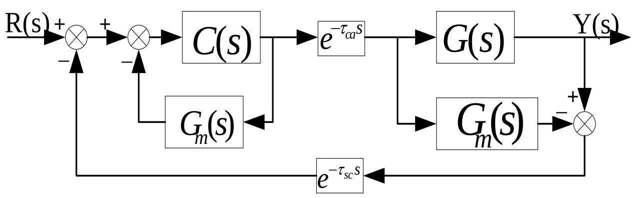


Figure 2. The Structure of Networked Control System with New Smith Predictor

As seen in Figure 2, which is based on the new Smith predictor in the structure of networked control systems, as long as the process of signal transmission can be used with random, time-varying， uncertainty, or certain time delay (including the time delay value is 0) , and constitute a closed-loop feedback control system with controlled object, we can consider to adopt new Smith predictor, Doing so can avoid the delay in the transmission process of measurement, estimation, or identify, implementing all time delay exponential terms of affecting stability are removed from closed-loop control system, so that the quality of the control system will be improved [11].

Because the networked time delay is time-varying and uncertain, so system just only with new Smith predictor can not achieve a satisfied result. It is necessary to introduce effective method of control to overcome the adverse effect which is caused by network delay.

4. Fuzzy Control Algorithm

Fuzzy control is computer intelligent control system. It is composed of fuzzy set theory, fuzzy language variables and fuzzy logic reasoning. The basic concept was first proposed by the famous professor L. A. Zadeh of the California University. After more than 20 years of development, the Fuzzy control has achieved great success in terms of theory and application.

4.1. Fuzzy Control Description

The composition of the fuzzy controller block diagram is shown in Figure 3. Fuzzy controller is the core of fuzzy control. Fuzzy controller is mainly composed of fuzzy interface, knowledge base, reasoning machine and Defuzzy Interface. The major difference between Fuzzy control system and usual computer digital control system is that fuzzy control system uses fuzzy controller. A fuzzy control system performance depends on agencies of controller, the fuzzy rules adopted by the fuzzy controller, synthesis reasoning algorithm, and the method of fuzzy decision and other factors.

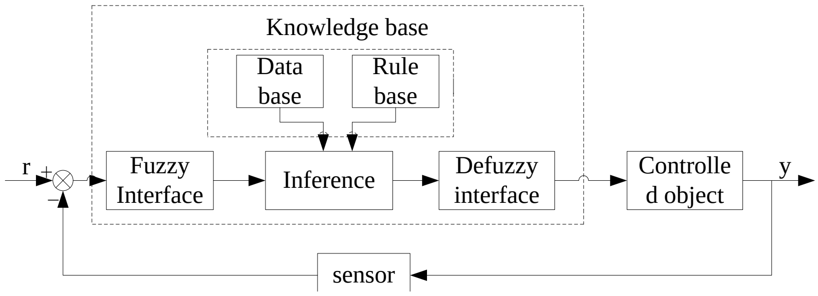


Figure 3. The Block Diagram of the Fuzzy Controller

The simplest realization of the fuzzy controller method is to set a series of fuzzy control rules of offline into a lookup table (also called control table). The fuzzy control rules are Stored in the computer for using online. This structure of fuzzy controller is simple and easy to be used. It is one of the most basic intelligent control algorithms.

4.2. Fuzzy Adaptive PID Control

Fuzzy adaptive PID is based on traditional PID, its control rules are expressed by fuzzy sets, and these rules and relevant information will be stored in the knowledge base. Furthermore, it can achieve the optimal control by using error and error rate as the input, and using fuzzy rules to modify the PID parameters online. The principle diagram of the fuzzy adaptive PID controller is shown in Figure 4.

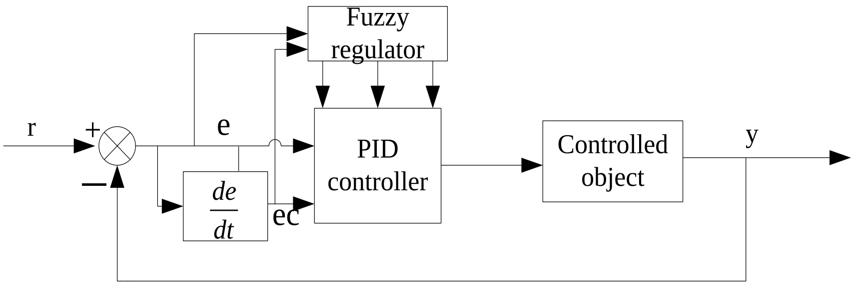


Figure 4. The Principle Diagram of the Fuzzy Adaptive PID

4.3. Fuzzy Rules

Fuzzy control uses error e and error rate ec as input linguistic variables, uses $\Delta k_p, \Delta k_i, \Delta k_d$ as output linguistic variables. In this paper, fuzzy controller uses two inputs and three outputs [12]. The input and output variables are divided into seven sets, named as {NB, NM, NS, ZO, PS, PM, PB}. Then the control table of fuzzy rules is built according to stability, response and overshoot. The domain of $\Delta k_p, \Delta k_i, \Delta k_d$ are respectively set at [-0.3 0.3], [-0.06 0.06] and [-3 3]. The domain of fuzzy sets is [-6 6]. Fuzzy rules table of $\Delta k_p, \Delta k_i, \Delta k_d$ are shown in the Tables 1, 2 and 3.

Table 1. Fuzzy Rule of Δk_P

Δk_P	*ec*						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS

NS	PM	PM	PM	PS	ZO	NS	NS
e ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. Fuzzy Rule of Δk_i

Δk_i	*ec*						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
e ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3. Fuzzy Rule of Δk_d

Δk_d	*ec*						
	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
e ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

According to control rules of $\Delta k_p, \Delta k_i, \Delta k_d$, fuzzy control quantity of $\Delta k_p, \Delta k_i, \Delta k_d$ can be obtained through fuzzy calculation. At last, the accurate output is obtained by center of gravity method [13]. The equation is described as follows.

$$U = \frac{\sum_{i=1}^{N} \mu_{i(e,ec)} Z_i}{\sum_{i=1}^{N} \mu_{i(e,ec)}} \quad (1)$$

Where, U is accurate output of fuzzy decision, $\mu_{i(e,ec)}$ is membership function of *ith* elements, Z_i is *ith* elements of domain, N is the number of elements.

u is control quantity of controlled object. It is obtained in the equation (2).

$$u = K_u U \quad (2)$$

Where, K_u is scale factor of real output quantity. Its size affects the output of the controller, and affects the performance of the control system. If K_u is too small, it may make dynamic response of system become longer; if K_u is too large, it causes the oscillation of system. Therefore, appropriate K_u should be selected according to actual situation. There are different response characteristics of system for different K_u .

Correctional parameters are shown in the equation (3).

$$\begin{aligned} \Delta k_P &= U \cdot K_{u(\Delta k_P)} \\ \Delta k_i &= U \cdot K_{u(\Delta k_i)} \\ \Delta k_d &= U \cdot K_{u(\Delta k_d)} \end{aligned} \tag{3}$$

Therefore, three parameters of fuzzy adaptive PID controller are described using the following equation (4).

$$\begin{aligned} k_p &= k_{p0} + \Delta k_P \\ k_i &= k_{i0} + \Delta k_i \\ k_d &= k_{d0} + \Delta k_d \end{aligned} \tag{4}$$

In the process of control, PID parameters achieve correction online through the operation of fuzzy controller. Ultimately parameters achieve the self-tuning [14].

New Smith predictor can remove the influence of time delay in the process of networked control system; fuzzy adaptive PID controller can adjust three parameters of PID online by using experts experience so as to make the controlled object get better stability performance. Hence the combination of fuzzy adaptive PID with new Smith predictor not only has excellent adaptability and strong controllability, but also has great dynamic characteristics. The structure of networked control system with new smith predictor and fuzzy adaptive PID is shown in Figure 5.

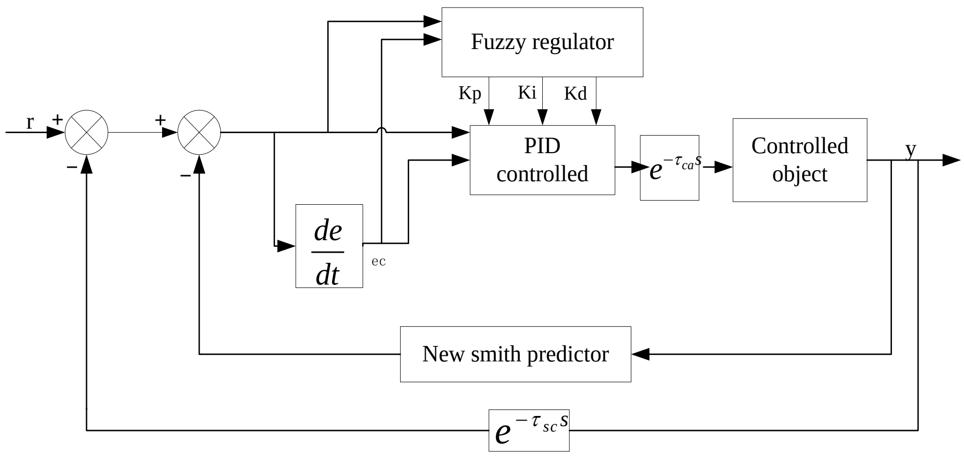


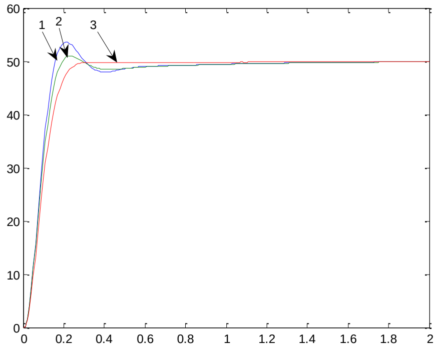
Figure 5. The Structure of Networked Control System with New Smith Predictor and Fuzzy Adaptive PID

5. Simulation Results

In order to prove the effectiveness of the method, in the Matlab/simulink environment, a DC motor is taken as the controlled object to do simulation [15]. The transfer function of the DC motor is described as follows.

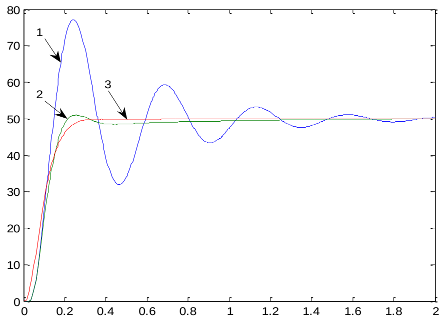
$$G(s) = \frac{2029.826}{(s+26.29)(s+2.296)} \tag{5}$$

The sampling period T=10ms, the reference input R=50rad/s, the time delay in forward and feedback channel is produced by gauss random generator in Simulink toolbox. The initial value of fuzzy adaptive PID parameters k_{p0} =0.118, k_{i0} =0.268, k_{d0} =0.0001. Using simple PID method, PID control with Smith predictor method and fuzzy adaptive PID with new Smith predictor method respectively, the step responses are observed under random delay $\tau < 10ms$ and $\tau > 10ms$. The results are shown in Figure 6 and Figure 7.



1-PID; 2-PID Control with Smith Predictor; 3-Fuzzy Adaptive PID with New Smith Predictor

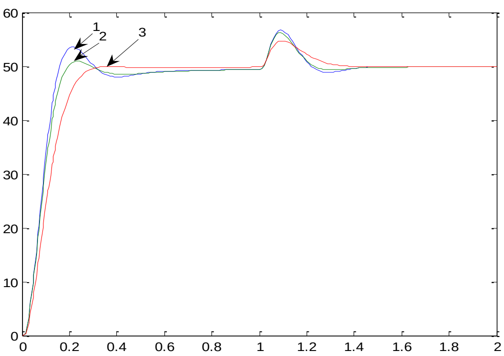
Figure 6. The Response When the Time Delay $\tau < 10ms$



1-PID; 2-PID Control with Smith Predictor; 3-Fuzzy Adaptive PID with New Smith Predictor

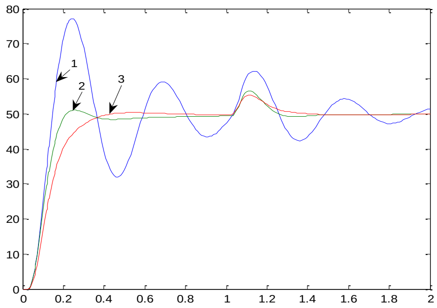
Figure 7. The Response When the Time Delay $\tau > 10ms$

During the simulation, the interference is added to the controller output at 1s. The pulse generator is chosen from the sources module library as interference, and parameters of pulse generator are: the pulse height is 20, the pulse period is 20 seconds, and the pulse width is 0.2 seconds. The system simulation diagram with disturbance is shown in Figure 8 to Figure 9.



1-PID; 2-PID Control with Smith Predictor; 3- Fuzzy Adaptive PID with New Smith Predictor

Figure 8. The Response with Disturbance When the Time Delay $\tau < 10ms$



1-PID; 2-PID Control with Smith Predictor; 3- Fuzzy Adaptive PID with New Smith Predictor

Figure 9. The Response with Disturbance When the Time Delay $\tau > 10ms$

The simulation results show that the fuzzy adaptive PID with new Smith predictor possesses high control accuracy, small overshoot, short adjusting time and strong anti-disturbance ability compared with the other two methods. It can be seen that the fuzzy adaptive PID realizes the automatic adjustment of control parameters, the new Smith predictor realizes that the delay of forward channel from controller to actuator is removed to closed circuit outside, and the delay of feedback channel from sensor to controller is completely eliminated in the control system, so the performance of the whole control system is improved. Therefore, the control method based on fuzzy adaptive PID with new Smith predictor is able to effectively meet the requirements of networked control system.

6. Conclusion

In this paper, the simulation model of networked control system is established by matlab/simulink, and the simulation research is made using the control algorithm of fuzzy adaptive PID with new smith predictor. The simulation result shows that this control algorithm possesses stable output, short adjustment time and strong robustness, and can meet the requirements of networked control system.

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