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Research on intelligent algorithm of electro - hydraulic servo control system

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Abstract. In order to adapt the nonlinear characteristics of the electro-hydraulic servo control system and the influence of complex interference in the industrial field, using a fuzzy PID switching learning algorithm is proposed and a fuzzy PID switching learning controller is designed and applied in the electro-hydraulic servo controller. The designed controller not only combines the advantages of the fuzzy control and PID control, but also introduces the learning algorithm into the switching function, which makes the learning of the three parameters in the switching function can avoid the instability of the system during the switching between the fuzzy control and PID control algorithms. It also makes the switch between these two control algorithm more smoother than that of the conventional fuzzy PID.

1 Introduction

Electro-hydraulic servo system is a large control system of implementing agencies. Its working principle is that the command signal of the control system via the electro-hydraulic servo controller controls the opening of the electro-hydraulic servo valve, the cylinder piston position and then drives the implementation mechanism[1]. In a real control system, electro-hydraulic servo control system , a typical nonlinear uncertain system is difficult to establish accurate mathematical model. In recent years, more and more electro-hydraulic servo control systems are applied in the occasions with high precision and fast response. Its controlled objects need higher and higher requirements for the system accuracy, response speed and stability. Although the traditional PID algorithm can eliminate the steady-state error of the system, with its poor adaptive ability in the fast charges of the controlled object that it is difficult to meet requirements of the high standard to a certain extent. The fuzzy control can ensure that the system responses quickly while maintain a small overshoot, and has a strong ability to adapt the changes of the control parameters. However, the drawback of the fuzzy control is the existence of the steady-state errors in the control process. Therefore, since a single control algorithm obviously cannot meet the requirements of the system, an improved fuzzy PID switching learning algorithm which combines PID algorithm with the fuzzy control is proposed in this paper.

The proposed algorithm uses a sub-control strategy. When a deviation is large, the utilization of the fuzzy control makes the system obtain a good dynamic performance. When the deviation is small, using PID control, the system can eliminate the steady-state error. Due to a transition area between the switching point of traditional PID and that of the fuzzy PID is established, the parameters of the switching function are learned in the learning algorithm. According to the actual situation of the industrial site, the parameter values which suit to the system at that time are generated. Thus, selecting a switching function that matches the switch at that time can make the switch between those two algorithms more smoother.

2 The Conventional Fuzzy PID Switching Algorithm

The traditional fuzzy PID switching algorithm is based on a threshold switching, in which deviations are divided into large deviations and small deviations according to the characteristics of the whole system. These two deviations use different control strategies. Its structure shown in Figure 1.

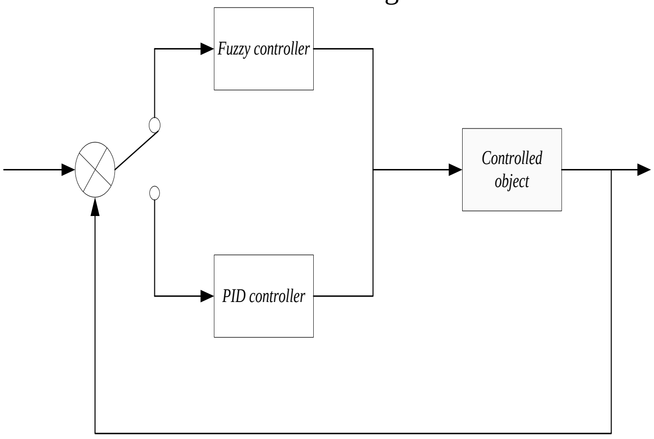

Figure 1 A block diagram of conventional fuzzy PID switching

However, this threshold-based fuzzy PID handover algorithm has following drawbacks:

Because the switching procedure is according to a given deviation range, the selection of the switching point becomes a key influencer of the servo control system. An early switch cannot reflect the advantages of fuzzy control and leads to on the increase of the overshoot. A late switch may lead the system cannot enter the PID control. Therefore, relying only on the experience whithout the actual situation of the industrial site cannot solve the the contradictions between system speeds and overshoots.

When the two control algorithms are switched, in order to ensure the continuity of the control output, the derivatives of the two controllers at the switching point cannot be equal. However, it must ensure that the output control of the two controllers at that point be equal to prevent the output from jumping[2]. When the closed-loop control system is switched from one control mode to another, it is difficult to make the output of the two controllers equal which ensures the continuous output of the system control. Therefore, the existence of perturbations cannot be avoid in the switching process between the fuzzy control and PID control. Because a simply setting of the switching point cannot meet the requirements of the servo control system, a smart switch is designed, in which the output of the control system is completed during a smooth switching process.

3 The fuzzy PID switching learning algorithm

The conventional fuzzy PID switching as a mutated switching mode, causes an unstableof the system near the switching point. In order to solve this problem, a fuzzy PID switching[3] learning algorithm is designed. After learning the parameters in the switching function,suitable parameters,which are obtained according to the actual situation of the industrial field, can provide a smoother switching and a better dynamic performance.

3.1 The fuzzy PID switching process

With a good dynamic performance and a strong robustness, the fuzzy control has a better ability to adapt the interference of the outside. However, its disadvantage is that it is easy to produce oscillation near the operating point because of its poor steady-state accuracy. For PID control, its characteristic that the static performance is better than the dynamic performance leads to a strong control near the working point[4]. Firstly, the error value is calculated according to the difference between a given value and a feedback value. Then the switching control decision module is selected. After compareing the size of the calculated error value with the threshold value, the switching control decision module selects an appropriate control mode to control objects. The flowchart of the fuzzy PID[5] switching is shown in Figure2.

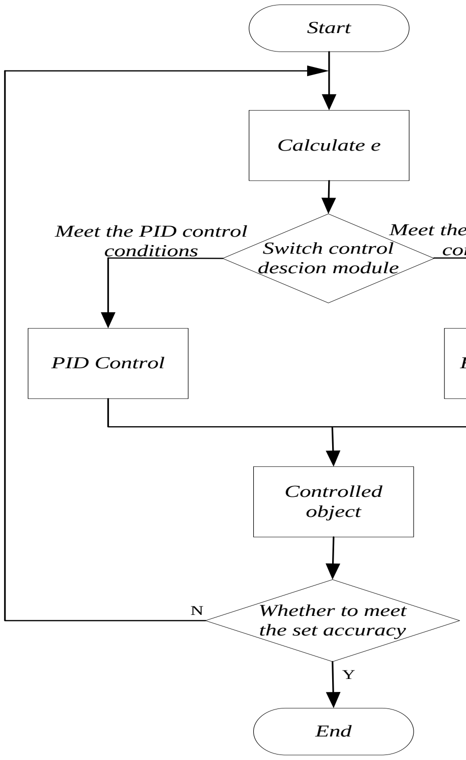

Figure 2 A flowchart of the fuzzy PID switching algorithm

3.2 A controller using the fuzzy PID switching learning algorithm

By learning the three parameters in the switching function, the fuzzy PID switching learning algorithm can apply to the actual situation of the industrial site. It also makes the switch of the two control mode more smooth. The system uses deviations and deviation rates as inputs. The fuzzy control is used when the deviation is larger than a certain threshold. When the deviation is lower than the threshold, PID control is selected[6].

This mutational switching method causes an unstable of the system at the switching point. Therefore, a smoothing switch function b is introduced. Figure 3 illustrates the structure of the fuzzy PID switching learning algorithm.

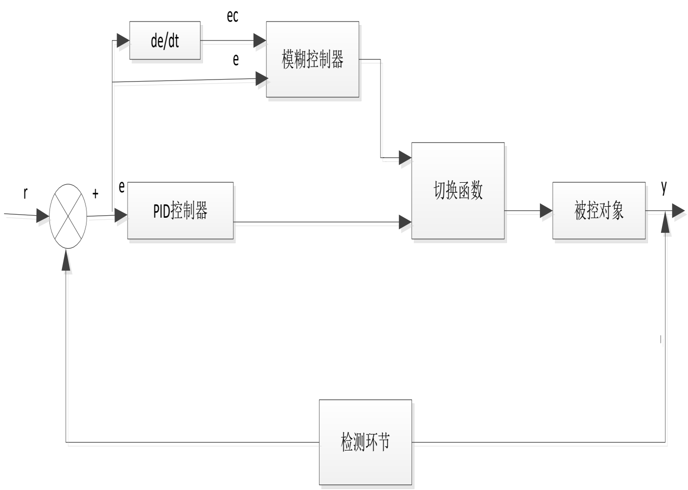

Figure 3 The fuzzy PID Switching Learning Algorithm

The fuzzy PID switching control algorithm is expressed as:

$$u = \beta u_{FZ} + [1 - \beta] u_{PID} \tag{1}$$

Where, the larger of β value is, the greater the effect of fuzzy control is and the smaller PID control is.

Then the expression of the switching function $\beta(|e|)$ can be obtained:

$$\beta(|e|) = \begin{cases} 0 & , \quad |e| < e_a \\ \dfrac{|e|^\rho - |e_a|^\rho}{|e_b|^\rho - |e_a|^\rho} & , \quad e_a \le |e| \le e_b \\ 1 & , \quad |e| > e_b \end{cases} \tag{2}$$

Where e_a, e_b are two demarcation points of fuzzy control. when $|e| < e_a$, the deviation of PID control is small, which leads to a high accuracy of the system. When $|e| > e_b$, the deviation of the fuzzy control is large, which makes the system has a faster response speed. When $e_a < |e| < e_b$, the fuzzy control and PID control woke at the same time. As the coefficient that changes the shape of the switching function β, the value of ρ affects the switching function of the fuzzy control and PID control, which determines whether the switch is smooth or not. According to the industrial field, the switching function using equations is designed to calculate a minimal fitting error as follow:

$$f = \frac{1}{2}\left[\beta|e_0| - y_0\right]^2 \tag{3}$$

Where, $|e_0|$ is a given input error, y_0 is a given output error, $\beta|e_0|$ is the output of the designed switching function with the given the input error. When f has the minimum value, the parameters e_a, e_b and r can be determined. To calculate the minimum value of these parameters, the partial derivative of these parameters need to obtained :

$$\frac{\partial f}{\partial e_a} = \frac{\rho|e_a|^{\rho-1}(\beta(e_0) - y_0)\left[(|e_0|^\rho - |e_a|^\rho) - (|e_b|^\rho - |e_a|^\rho)\right]}{(|e_b|^\rho - |e_a|^\rho)^2} \tag{4}$$

$$\frac{\partial f}{\partial e_b} = -\frac{\left(\rho|e_b|^{\rho-1}\right)(|e_0|^\rho - |e_a|^\rho)(\beta(e_0) - y_0)}{(|e_b|^\rho - |e_a|^\rho)^2} \tag{5}$$

$$\frac{\partial f}{\partial \rho} = \frac{(\beta(e_0) - y_0)(|e_0|^\rho In|e_0| - |e_a|^\rho In|e_a|)(|e_b|^\rho - |e_a|^\rho)}{(|e_b|^\rho - |e_a|^\rho)^2} - \frac{(\beta(e_0) - y_0)\left[(|e_0|^\rho - |e_a|^\rho)(|e_b|^\rho In|e_b|) - (|e_a|^\rho In|e_a|)\right]}{(|e_b|^\rho - |e_a|^\rho)^2} \tag{6}$$

To optimize parameters e_a, e_b and r, the learning algorithm is represented as:

$$e_a(q+1) = e_a(q) - \alpha\frac{\partial e}{\partial e_a} \tag{7}$$

$$e_b(q+1) = e_b(q) - \alpha \frac{\partial e}{\partial e_b} \tag{8}$$

$$\rho(q+1) = \rho(q) - \alpha \frac{\partial e}{\partial \rho} \tag{9}$$

where, q is the number of learning, α is a step length.

4 Simulation and Analysis

This paper uses the electro-hydraulic servo[7] valve in the electro-hydraulic servo control system as a research object, in which the electro-hydraulic servo valve[8] is approximated as a second-order oscillation link with the transfer function $G_S = \frac{1}{s^2 + 0.6s + 1}$. A Matlab simulation is applied to the control algorithm of the conventional fuzzy PID switching and the learning algorithm of the fuzzy PID switching, respectively.The simulation results are shown in Figure. 4 and Figure.5.

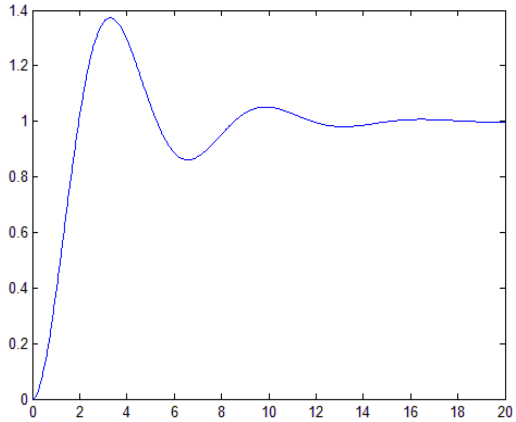

Figure 4 Simulation Results of the Conventional Fuzzy PID Switching Algorithm

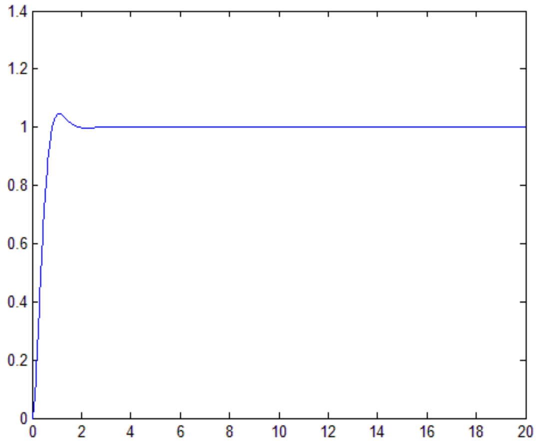

Figure 5 Simulation results of the fuzzy PID switching learning algorithm

In Figure 4 and Figure 5 , the switching algorithm of the conventional fuzzy PID and the switching learning algorithmof the fuzzy PID can achieve the switching between those two algorithms. However, compared with the curve in figure 4,the curve in figure 5 shows a shorter switching time, a smaller overshoot and a faster switching rate, which means that the fuzzy PID switching learning algorithm has a more smaller oversizes, more faster response speeds and more stronger anti-interference abilities than the conventional fuzzy PID switching algorithm.

5 Conclusionss

The controller using the learning algorithm of the fuzzy PID switching,which combines the advantages of the fuzzy control and PID control,can improve the dynamic performance of the electro-hydraulic servo control system. PID control is used to ensure the steady-state performance of the system. The introduction of switching function makes the switching between the fuzzy control and PID the control more smoother than the conventional fuzzy PID switch. This strategy can effectively avoid the instability of the system during the switching of these two control algorithms. An introduction of the learning algorithm makes the three parameters in the switch function can be learned. According to the specific environment of the industrial control site, the optimized switching function provides a higher accuracy, a faster response and a greater stability of the electro-hydraulic servo control system.

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