Chaos Optimization Strategy on Fuzzy Adaptive PID Control of Boiler Drum Water Level

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Abstract: Fuzzy adaptive PID control algorithm based on chaos optimization which combines fuzzy adaptive PID control with chaos optimization is designed. The proposed algorithm is used to control the drum water level. Simulation results show that the method can effectively enhance the searching efficiency and greatly improve the searching quality.

Keywords: fuzzy adaptive PID; chaos optimization; drum water level

1 Introduction

PID control is the most common method of industrial process control. Most of the feedback loops are used PID control as the control method. When the controlled object has a non-linear characteristics, traditional PID control is sensitive to parameter tuning. Traditional PID control is easy to produce oscillations or loss of stability. Fuzzy control [1] can easily deal with uncertainty, time-varying features, nonlinear. It can change its control strategy at any time. Combining fuzzy control with Adaptive control is a good way for complex systems. This Algorithm can improve control precision and anti-jamming capability [2].

Boiler Drum Water Level always includes the delay, inertia, interference, dead zone, saturation and other non-linear link. Chaotic motion has features of ergodicity, randomness and regularity. Choas can traverse all of the state within a certain range. Chaos optimization algorithm is easy to jump out of local optimal solution and to achieve the best control effect [3].

In this paper, a new algorithm which combines fuzzy adaptive PID control with chaos optimization is designed. It is used controlling the system of boiler drum water level.

2 Three Impulse Control Scheme for Boiler Drum Water Level

2.1 General System Structure

The general system structure [4] of the three impulse control system for boiler drum water level is shown in Figure 1. H is drum water level, V_0 is signal of given water level, D is steam flow, W is water flow, $G_d(s)$ is the transfer function of steam flow relative to drum water level, $G_W(s)$ is the transfer function of water flow relative to drum water level and $G_c(s)$ is the transfer function of water level regulator.

$$G_W(s) = \frac{\varepsilon}{s(T_1 s + 1)} \qquad G_d(s) = \frac{K_d}{T_2 s + 1} - \frac{\varepsilon}{s}$$

γ_D is the transfer coefficient for Measuring transducer of steam flow D, γ_W is the transfer coefficient for Measuring transducer of water flow W and γ_H is the transfer coefficient for Measuring transducer of drum water level H.

α_D is the partial pressure coefficient of steam flow and α_W is the partial pressure coefficient of water flow. K_z is the feature coefficient of implementing agencies and K_p is the feature coefficient of valves.

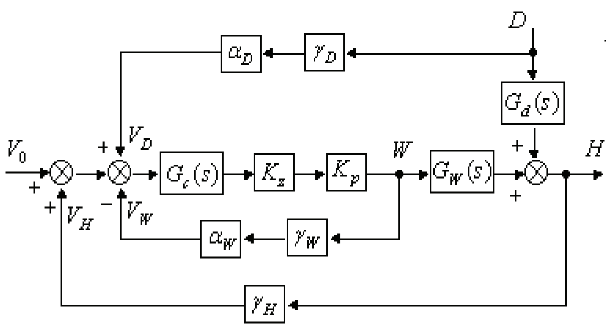

Figure 1. Control structure for boiler drum water level

2.2 Simplified System Structure

The simplified system structure is shown in Figure 2. To facilitate the research, the parameters are chosen as follows. $\varepsilon = 0.037$, $K_d = 3.6$, $T_1 = 30$, $T_2 = 15$, $\gamma_D = \gamma_W = 0.083$, $\gamma_H = 0.033$, $\alpha_D = \alpha_W = 0.21$, $K_z = 10$, $K_p = 2$. The regulator $G_c(s)$ is chosen as proportion controller. $G_c(s) = K_c = 0.4648$. The simpli-

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fied transfer functions are $G_{mW}(s)$ and $G_{md}(s)$.

$$G_{mW}(s)=\frac{30.303}{80s+1}e^{-25s}, \quad G_{md}(s)=\frac{-3.25}{60s+1}e^{-100s}.$$

By comparing the step response curves before and after the simplification, the error is very little [5].

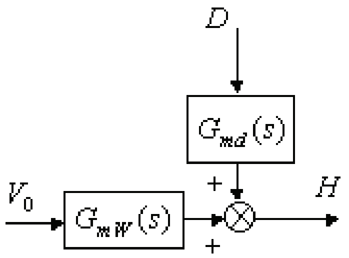

Figure 2. Simplified system structure for boiler drum water level

3 Principle of Fuzzy Adaptive PID Control

Adaptive control detects characteristic parameters of the object with modern control theory. It can change its control strategy at any time. Optimization target can be kept within the optimum range, but its control results depend on the accuracy of identification model which is difficult for complex systems. The most important feature of fuzzy control does not depend on the precise model of controlled object. Less control rules can be applied to control object. Fuzzy control has strong robustness. Therefore, combining fuzzy control with adaptive control is a good way for complex systems.

3.1 Design of Fuzzy Adaptive PID Controller

Error e and error variation ec are inputs of the fuzzy adaptive PID controller. Real-time data including k_p, k_i and k_d are changed according to the value of e and ec. The structure of fuzzy adaptive PID controller is shown in Figure 3. In this way, the controlled object has a good dynamic and static characteristic.

The core of fuzzy control design is creation of an appropriate fuzzy table according to the technical knowledge

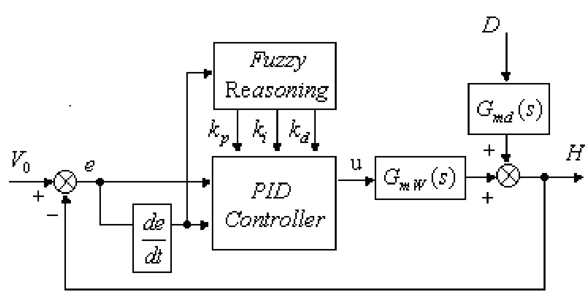

Figure 3. Structure of fuzzy adaptive PID controller

and practical experience of engineers. The range of error e and error variation ec is defined as the universe of fuzzy set. e,ec={-3,-2,-1,0,1,2,3}. Its fuzzy subset is defined as follows. e,ec={NB,NM,NS,ZO,PS,PM,PB}. Elements of the subset are respectively negative big, negative moderate, negative small, zero, positive small, positive moderate and positive big.

The fuzzy control tables[6] of k_p, k_i and k_d are respectively shown in table 1, table 2 and table 3.

Table 1. The fuzzy control table of k_p

Δk_p		ec						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	PB	PB	PM	PM	PS	ZO	ZO
	NM	PB	PB	PM	PS	PS	ZO	NS
	NS	PM	PM	PM	PS	ZO	NS	NS
	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. The fuzzy control table of k_i

Δk_i		ec						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	NB	NB	NM	NM	NS	ZO	ZO
	NM	NB	NB	NM	NS	NS	ZO	ZO
	NS	NB	NM	NS	NS	ZO	PS	PS
	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. The fuzzy control table of k_d

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

3.2 Fuzzy Adaptive PID Control Algorithm

Discrete PID control method is defined by

$$u(k) = k_p error(k) + k_i \sum_{j=0}^{k} error(j)T + k_d \frac{error(k) - error(k-1)}{T}$$

e, ec, kp, ki and kd are set to obey normal distribution. Then, the membership degree of fuzzy set is get. By searching the fuzzy control table, the revised formula of kp, ki and kd are defined by the following equation.

$$k_p = k_p' + \Delta k_p$$

$$k_i = k_i' + \Delta k_i$$

$$k_d = k_d' + \Delta k_d$$

k_p', k_i' and k_d' are the initial value.

4 Chaos Optimization Algorithm

4.1 Control Structure Based on Chaos Optimization

Structure of fuzzy adaptive PID control based on chaos optimization is shown in Figure 4. The basic idea is using fuzzy adaptive PID control system and chaotic state variable is introduced to control the domain of the fuzzy adaptive PID controller. PID parameters are optimized by chaotic ergodicity.

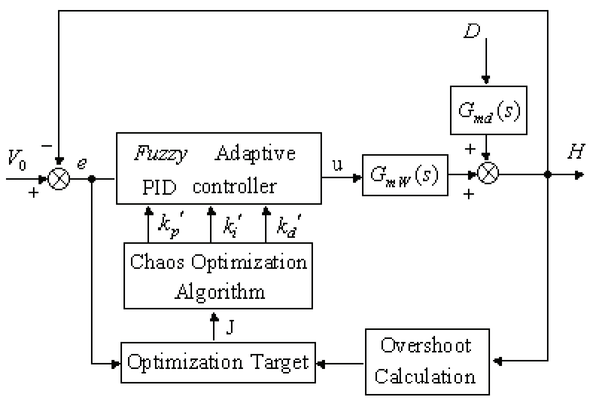

Figure 4. Structure of fuzzy adaptive PID controller based on chaos optimization

4.2 Chaotic Optimization Steps

Logistic map is used to produce chaotic variable. This map is defined by[7]

$$x_{n+1} = \lambda x_n (1 - x_n) \quad for\ 0 < \lambda \le 4 .$$

The form of chaotic track depends on growth rate parameter λ. If λ is equal to 4, the form of chaotic track is completely at the state of chaos. The track is covered by interval [0,1].

Optimization target is defined by the following equation.

$$J = \int_0^{\infty} (\omega_1 |e(t)| + \omega_2 u^2(t)dt + \omega_3 \cdot t_u$$

$e(t)$ is the error, $u(t)$ is the output of the controller, t_u is overshoot, ω_1, ω_2 and ω_3 are weights.

Chaotic Optimization Steps are as follows [8].

1) parameter initialization and initial choice.
2) initial value into logistic map.
3) aotic variables are used in optimization search.
4) the better optimization target J*, k_p'*, k_i'* and k_d'*.
5) eat No.(3) and No.(4) several times, then get the best optimization target J*, k_p'*, k_i'* and k_d'*.

5 Simulation Results Discussion

In order to evaluate the effectiveness of fuzzy adaptive PID control based on chaos optimization algorithm over the boiler drum water level, parameters set as follows.

Sampling time is 5 second, $\omega_1 = 0.999$, $\omega_2 = 0.001$, $\omega_3 = 2$. Chaotic optimization is carried out after 150-step chaotic searching. k_p=3, k_i=0.05 and k_d=2.5 are selected in traditional PID control. To compare the results, k_p'=3, k_i'=0.05 and k_d'=2.5 are also selected in fuzzy adaptive PID control algorithm based on chaos optimization.

When input is step signal, the system simulation comparison is shown in Figure 5.

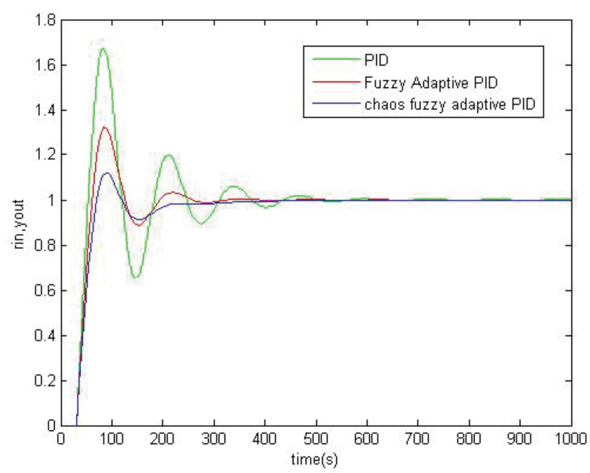

Figure 5. Step signal input and the system simulation comparison

If 30% disturbance signal is added in the system at the time of 600 seconds, the system simulation comparison is shown in Figure 6.

Through simulation results shown in Figure 5 and Figure 6, fuzzy adaptive PID control algorithm based on chaos has the best control quality.

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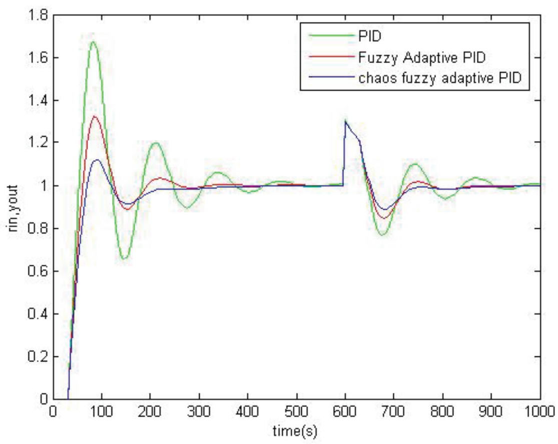

Figure 6. 30% disturbance signal and the system simulation comparison

6 Summary

According to the characteristics of mathematical model for the boiler drum water level, fuzzy adaptive PID control algorithm based on chaos optimization is proposed. Simulation results and comparisons with the traditional PID control and fuzzy adaptive PID control show that fuzzy adaptive PID control algorithm based on chaos optimization can effectively enhance the searching efficiency and greatly improve the searching quality. The proposed algorithm can make Smaller overshoot, faster response time and better robustness. It improves the accuracy and reliability of parameter estimation and has an important meaning to be promoted.

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