The Design and Simulation of Fuzzy PID Parameter Self-tuning Controller

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Abstract

Based on parameter self-tuning fuzzy PID controller, a fuzzy inference method is utilized to realize automatic regulating PID parameter, and the application of the controller in a system is studied with MATLAB in this paper. The combination of PID controller system and fuzzy controller system combines the convenience of PID control together with the flexibility of fuzzy control, and takes advantage of the traditional control, which has a great practical significance. The results of simulation show that fuzzy PID parameter self-tuning controller has a better control effect than the traditional one, and can improve the static and dynamic properties of the system well.

Keywords: self-tuning, fuzzy PID, Matlab, simulation

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1. Introduction

Due to its simple algorithm, good control effect and high reliability, fuzzy PID controller is widely used in the system of process control, especially in the nonlinear system. In production field, the conventional method of fuzzy PID parameter can function well on the operating condition attributing to its complex method, bad parameters and performance on automatic tuning. As one of the most advanced control system nowadays, the method of fuzzy inference applied in this paper not only keeps the simple principle and good control effect, but also possesses a better flexibility and ability for controlling the accuracy [1].

The system structure of parameter self-tuning fuzzy PID Controller mainly consists of two parts as the adjustable parameter PID and fuzzy control system, and its structure as Figure 1.

PID controller was used to control system, and fuzzy inference system uses error e(t) and error rate ee(t) as input, a fuzzy inference method is utilized to realize automatic regulating PID parameter, $K_p$, $K_i$, $K_d$ to satisfy different demands of controller. Fuzzy control system is not very different from traditional control system in structure, the major difference is that controller uses fuzzy controller, and it adopts a group of fuzzy conditional to describe the varies of the relationship between input and output [2].

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2. The Design of Fuzzy PID Parameter Self-tuning Controller
2.1. The Structure of Fuzzy Control System

The construction of fuzzy PID parameter self-tuning controller system mainly consists of two parts: adjustable parameter PID control system and fuzzy control system, as shown in Figure 1. In the system, by taking error and error rate of change as input, the method of fuzzy inference can be used to make online self-tuning of PID parameter $K_P$, $K_D$ and $K_I$ [3]. Accordingly, the static and dynamic performance of the controlled object can be improved well.

2.2. The Parameter Self-tuning Rules of PID Controller

Usually, the control equation of PID controller is:

$$U(k) = K_P E(k) + K_I \sum E(k) + K_D E_C(k)$$  \hspace{1cm} (1)

In the equation, $\sum E(k)=E(k)+E(k-1)$ and $E_C(k)=E(k)-E(k-1)$ (k=0, 1, 2) are the deviation of input variable and the deviation of change respectively. $K_P$, $K_D$, $K_I$ are parameters that characterize the proportion, integral and differential role respectively [4].

According to the impact of the parameters, the self-tuning principles of the parameters $K_P$, $K_D$ and $K_I$ can be changed in the controlled process of the system in the different situation:

a) When the deviation is large, $K_P$ and $K_I$ should be increased to make the system steadier. At the same time, considering system's capacity of resisting disturbance, $K_D$ should be chosen properly to avoid outputs response oscillating near the set point. The principle is as follows: when the deviation change is small, $K_D$ should be relatively bigger; when the change is big, $K_D$ should be smaller; usually, $K_D$ should be of middle size.

b) When the deviation and deviation rate of change is of middle size, $K_P$ should be small to reduce the overshoot of system response, and assure certain response speed.

c) When the deviation is big, $K_P$ and $K_D$ should be chosen to accelerate the system’s response speed, and avoid the over differential and control function probably caused by instant enlargement of deviation in the beginning. In addition, in order to avoid integral saturation and the system response’s overshoot, $K_I$ should be small, usually should be zero [4].

2.3. Ensuring Membership Function of Each Variable

As required, fuzzy controller which used to parameter adjustment of PID uses form of two inputs and three outputs. Inputs of the controller are error $e(t)$ and error rate $e_c(t)$, and outputs are $\Delta K_P$, $\Delta K_I$, $\Delta K_D$ which are revised by three parameters of PID controller as P, I, D.

fuzzy subset of inputs as $E$ and $E_C$ and outputs as $\Delta K_P$, $\Delta K_I$, $\Delta K_D$ is \{NB,NM,NS,ZO,PS,PM,PB\} [5]. The domain is [-6,6], quantization levels are{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6}.

![Figure 2. The membership degree function of E and EC](image1)

![Figure 3. The membership degree function of ΔKP, ΔKI, and ΔKD](image2)

In the fuzzy logic toolbox of the membership function editor, gaussmf is selected by membership functions of input as $E$, $E_C$ and trimf is selected by membership functions of output as $\Delta K_P$, $\Delta K_I$, $\Delta K_D$, as Figure 2 and Figure 3 shown.
2.4. Build Fuzzy Rules Charts

The center of fuzzy control is to build proper fuzzy rules chart based on the summary of designers’ knowledge and operating experience. According to the PID parameter adjustment principles above, we can get the control rules of $\Delta K_P$, $\Delta K_I$ and $\Delta K_D$, as shown in Table 1 [6].

Combine these three tables above and we can get the 49 fuzzy control rules as follows:

1. If $E$ is NB and $(EC)$ is NB then $(K_P)$ is PB $(K_I)$ is NB $(K_D)$ is PS  

2. If $E$ is NB and $(EC)$ is NM then $(K_P)$ is PB $(K_I)$ is NB $(K_D)$ is NS  

3. If $E$ is NB and $(EC)$ is NS then $(K_P)$ is PM $(K_I)$ is NM $(K_D)$ is NB  

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49. If $E$ is PB and $(EC)$ is PB then $(K_P)$ is NB $(K_I)$ is PB $(K_D)$ is PB

Table 1. The Control Rules of $\Delta K_P$, $\Delta K_I$ and $\Delta K_D$

<table>
<thead>
<tr>
<th>$\Delta E$</th>
<th>$E$</th>
<th>$E_C$</th>
<th>$\Delta K_P$</th>
<th>$\Delta K_I$</th>
<th>$\Delta K_D$</th>
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</table>

Run fuzzy function in MATLAB command window to enter the fuzzy logic editor, and create a new FIS file, choosing the control type as Mamdani. According to the analysis above, by inputting the membership degree function and quantizing intervals of $E$, $E_C$, $\Delta K_P$, $\Delta K_I$ and $\Delta K_D$ respectively, the figure of membership degree function can be achieved.
3. The Application and Simulation of Fuzzy PID Control System

3.1. Build the Simulation Block Diagram of the System Structure

The simulation block diagram designed according to Figure 1 in MATLAB’s Simulink environment is as shown in Figure 4. In the diagram, fuzzy controller and its package is as shown in Figure 5. Ke and Kec are fuzzification factors, and K1, K2 and K3 are defuzzification factors. PID controller and its package is as shown in Figure 6. \( K_{P0}, K_{I0}, K_{D0} \) are their start value. By connecting fuzzy controller with PID controller, the fuzzy-PID controller can be acquired, as shown in Figure 7.

![Figure 4. The simulation block diagram of Fuzzy PID control system](image)

![Figure 5. Fuzzy controller and its package](image)

![Figure 6. PID controller and its package](image)

![Figure 7. Fuzzy self-tuning PID Controller and its package](image)
3.2. Results and Analyses of the Experiment

The \( G(s) \) of the mathematical model of the simulation object equals \( \frac{2}{(s^2+3s+1)} \), \( K_e=K_{ec}=0.01; \) \( K_1=0.5, \) \( K_2=K_3=0.01; \) and \( K_{p0}=20, K_{i0}=1.35 \) and \( K_{d0}=3.7 \). The sampling period is \( T=0.01s \). The control curve line of fuzzy PID is as shown in Figure 8.

![Figure 8. Simulation curve line](image)

4. Conclusion

We can obviously see that fuzzy-PID controller system has a better control effect than traditional system, and we can easily simulate the system by using Matlab, which can greatly help us to revise the control rules.

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