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Study on the Robustness Based on PID Fuzzy Controller

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***Abstract*—Fuzzy control has lots of advantages compared with traditional PID control. Good performance can be obtained by fuzzy control without mathematic model of control object. Meanwhile, fuzzy controller is equipped with high stability and robustness. The characteristics of traditional PID control and fuzzy controls were integrated as fuzzy PID control, greatly enhancing performance of the controller. The work discussed the design of fuzzy parameter self-tuning PID controller. The performance of the controller was compared with traditional PID controller mainly from the robustness. Results indicated robustness of fuzzy PID controller is better after comparison.**

Keywords-PID control; fuzzy control; robust; self-tuning

I. INTRODUCTION

Fuzzy control is established based on artificial experience, while fuzzy control language is an effective means expressing thinking activities of humans and complicated things. Therefore, fuzzy control technology overcomes shortcomings of traditional control methods. It has achieved rapid development in resent 20 years due to following advantages. Compared with traditional control methods, fuzzy control can obtain desirable performance without mathematical model of the controlled object; uncertain or nonlinear control systems can be well controlled; fuzzy control has strong robustness for parameter variation of controlled object and high ability inhibiting external interference; meanwhile, fuzzy control is more acceptable due to simple components and high robustness.

II. BASIC STRUCTURE AND COMPOSITION OF FUZZY CONTROL SYSTEM

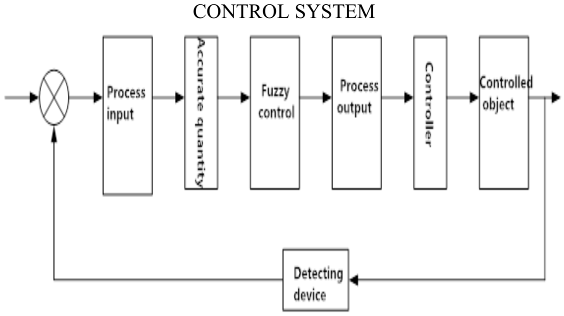

Figure 1. Basic structure of fuzzy control system.

Similar to general computer control systems, fuzzy control system was composed of controlled object, actuator, process input and output channels, detecting device and controller. Fuzzy controller consisted of fuzzy quantization, control rules, decision making and judgment. As the core of fuzzy control, controller was the difference between fuzzy control system and other automatic control systems. There was no essential difference between fuzzy control system and general computer control systems except the software realizing control algorithm.

Control rule of fuzzy controller was implemented by computer program. One-step fuzzy control algorithm was realized with the following process: the computer obtained accurate value of controlled variable through interrupting and sampling; then, the value was compared with a given value, obtaining error signal e and error rate signal e_c; the signals were used as input values of fuzzy controller. Error signal e and error rate signal e_c were transformed by fuzzy quantization into fuzzy values, expressed as relevant fuzzy language. A subset E of fuzzy language set for error and error rate was derived (E was actually a fuzzy matrix); then, according to E and control rule R (fuzzy relation), fuzzy decision was conducted based on logical combining rules, obtaining

$$U = E \times R \tag{1}$$

where U was a fuzzy quantity which was transformed into accurate quantity to achieve accurate control of the object, namely fuzzy quantization. The accurate quantity was converted into analog quantity and sent to the actuator, achieving further control of the object. Then, the process was interrupted for the second sampling ......, cycling these steps until the achievement of fuzzy control.

III. DATABASE OF FUZZY PID

The database contained various rules of fuzzy control and parameters of fuzzy data processing, including scaling parameters, fuzzy space division and membership function.

A. Conversion of input quantity

The input quantity should be firstly converted into the required range of domain through linear or non-linear conversion methods. For example, if the input quantity was x^*, then conversion range was $[x^*_{\min,} x^*_{\max}]$. Linear conversion was adopted if the required domain was $[x_{\min,} x_{\max}]$, then

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$$x_0 = \frac{x_{\min} + x_{\max}}{2} + k\left(x_0^* - \frac{x_{\min}^* + x_{\max}^*}{2} \right) \quad (2)$$

$$k = \frac{x_{\max} - x_{man}}{x_{\max}^* - x_{man}^*} \quad (3)$$

where k was scale factor.

The domain could be continuous or discrete. Continuous domain should be discretized or quantized if a discrete domain was required, while both uniform and non-uniform quantization methods were available.

B. Fuzzy space partition

In fuzzy control rules, linguistic variables of premise constituted fuzzy input space, while linguistic variables of conclusions constituted fuzzy output space. The value of each language variable was the name of a group of fuzzy language, constituting a set of language names. The name of each fuzzy language corresponded to a fuzzy set. Number of the fuzzy set determined the extent of fuzzy control refinement. Generally, there were meanings in the language names. For example, NB meant negative big; NM was negative medium, NS negative small, ZE zero, PS positive small, PM positive medium, and PB positive big. Figure 2-5 showed two examples of fuzzy partition, while the domains were both [-1, 1] and the fuzzy partition was completely symmetrical. It was assumed that pretreatment has been performed in scale conversion to obtain the standard condition. Both asymmetrical and non-uniform distribution of fuzzy language names were available in the partition.

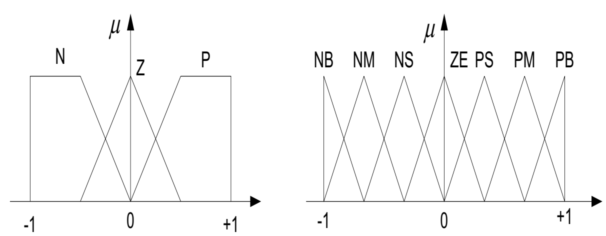

Figure 2. Examples of fuzzy partition.

The number of fuzzy partition determined maximum number of fuzzy rules. For the fuzzy system with two inputs and single output, if numbers of fuzzy partition for x and y were 3 and 7, respectively, then maximum possible number of rules was 3 × 7 = 21. Therefore, number of fuzzy divisions increased with the number of control rules. Too refined fuzzy division would result in excessive control rules. In addition, too small number of division resulted in rough fuzzy control, difficulty adjusting the control performance.

C. Selection of Membership Function

Definition of fuzzy subset was actually to determine membership function of fuzzy subset. Membership function appeared in the form of continuous function or discrete quantization levels. The curve of determined membership function was discretized to obtain membership on a finite number of points, constituting a fuzzy subset of fuzzy variables. Common membership functions included types as follows:

1) Triangle

Shape and distribution of this membership function were expressed by three parameters as follows:

$$\text{If } a<x<c \quad \mu(x) = \begin{cases} \dfrac{x-a}{b-a} \\ \dfrac{x-c}{b-c} \end{cases} \text{ if } b<x<c \quad (4)$$

The shape of the function was related to that of straight line. Therefore, triangular membership function was suitable for adaptive fuzzy controller with on-line adjustment of membership function.

2) Gaussian

Gaussian membership function was described by two parameters as:

$$\mu(x) = \exp[-\frac{(x-c)^2}{\sigma^2}] \quad (5)$$

This function has self-adaption, self-learning fuzzy control and correction of membership function. The value of σ determined shape of membership function curve. Different shapes of membership curve had different control characteristics. Membership function with steep curve had high resolution of fuzzy subset, with high control sensitivity; on the contrary, membership function with gentle curve had relatively low resolution of fuzzy subset, with higher system stability. Therefore, in selection of membership function for fuzzy variables, fuzzy sets with low resolution should be adopted in area with larger error to ensure stability; fuzzy sets with higher resolution should be used in areas with smaller error (or closed to zero).

IV. Fuzzy Control Rule Base

Fuzzy control rule base was composed of a series of "IF-THEN" fuzzy conditional sentences. Input signals and status signals were in front of conditional sentences while control variables were at the back.

A. Selection of Antecedent and Consequent Variables for Fuzzy Control Rules

Antecedent and consequent variables of fuzzy control rules were input and output variables of fuzzy controller. Output variable referred to the control variable which was easily determined. The selection of input variable and its number was determined based on specific requirements. Error e and its derivative or integral $\int edt$ were involved in input variables. Selection of input and output variables and their membership functions played a critical role in performance of controller. These variables were determined mainly based on experience and engineering knowledge.

B. *Establishment of Fuzzy Control Rules*

Fuzzy control rule was the core of fuzzy control, thus establishment of fuzzy control rules had become a critical issue. Establishment of fuzzy control rules was mainly based on: (1) experience of experts and knowledge of control engineering; (2) actual control process of operators; (3) fuzzy model of processes; and (4) learning function. These methods were not mutually exclusive; instead, they can be integrated to better establish fuzzy control rule base.

V. SIMULINK SIMULATION BASED ON FUZZY PID

Simulink was used to establish control system as follows.

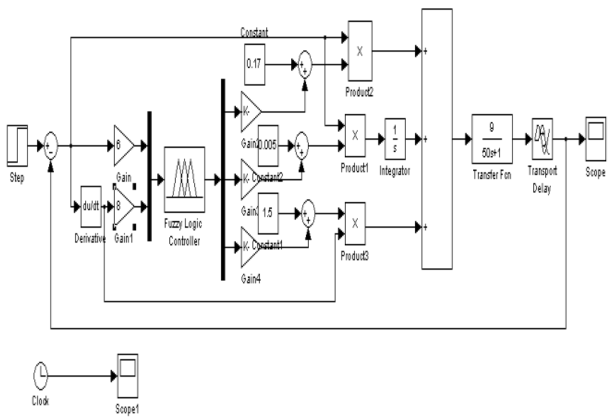

Figure 3. Block diagram of fuzzy PID control parameter self-tuning.

In terms of first-order lag $G(s)=\dfrac{9}{50s+1}e^{-18s}$ of controlled object, the following curves were obtained through simulation based on the above control system. Figure 4 showed the comparison of step response curves between fuzzy PID control and conventional PID control.

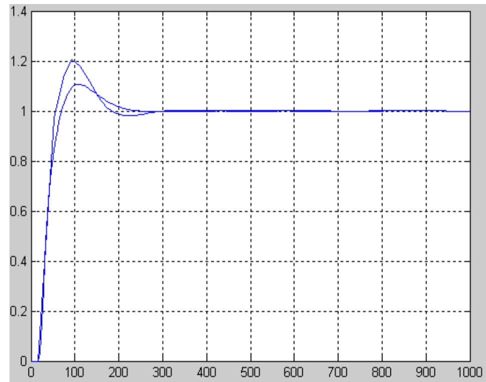

Figure 4. (a) Step response curve of conventional PID control; (b) Step response curve of fuzzy PID control.

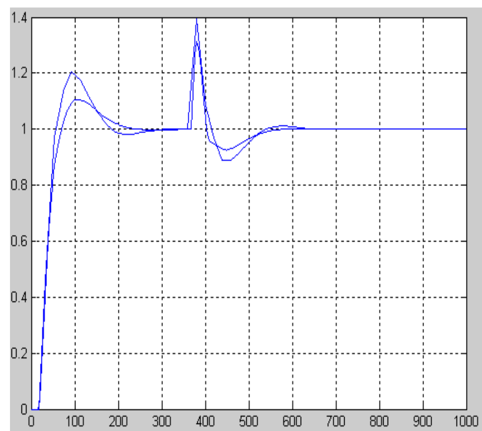

Figure 5. (a) Pulse perturbation curve of conventional PID control; (b) Pulse perturbation curve of fuzzy PID control.

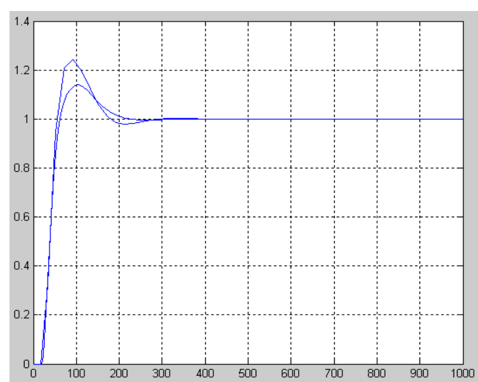

Figure 6. (a) Pulse perturbation curve of conventional PID control; (b) Pulse perturbation curve of fuzzy PID control.

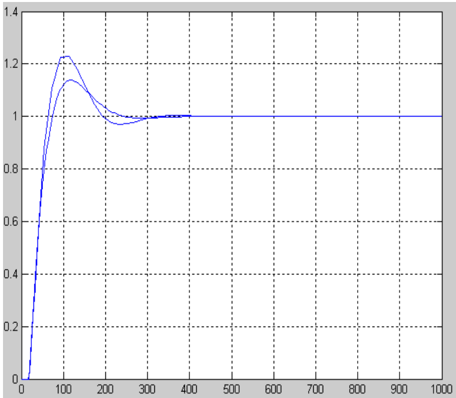

Figure 7. (a) Conventional PID control curve when parameter T increased by 20%; fuzzy PID control curve when parameter T increased by 20%.

According to simulation results, fuzzy PID controller obtained better performance than conventional PID controller when K, T and τ increased by 20%, respectively, especially significant in terms of overshoot. Therefore, it was concluded that robustness of fuzzy PID controller was better than conventional PID controller.

VI. Conclusion

Dynamic performance of fuzzy PID control is better than conventional PID control. The overshoot is much lower than that of fuzzy PID control, indicating that system stability has been enhanced; adjusting time of PID controller is decreased, indicating that response speed of the system is better than that of conventional PID control system. According to control curves of system on disturbance, parameters and structural changes, the robustness of fuzzy PID control is better than that of conventional PID control.

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