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A Design of PID Parameters Self-tuning Fuzzy Control System and Its Incorporation with Practical Realization on PLC

LIU HONGLING, JIANG CHUANWEN, ZHANG YAN
Department of Electrical Engineering
Shanghai Jiaotong University
Huashan Road 1954, Shanghai, P.R China, 200030
CHINA

Abstract: - In this paper, for nonlinear, time-varying and delayed system, PID parameters self-tuning fuzzy control was applied to a level process. The method of using VC++ programming to realize fuzzy control algorithm and obtain the discrete fuzzy control table is proposed, which simplified the computing process greatly. Furthermore, combing the inquiry of fuzzy control table and PID function module in PLC, the bottom-layer of fuzzy control on PLC is realized. Simulation by M-language of MATLAB validates the effectiveness of PID parameters self-tuning fuzzy control system.

Key-Words: - Fuzzy PID parameters self-tuning, discrete fuzzy control table, fuzzy inference programming, PID function module, PLC, M-language

1 Introduction

Despite the huge development of control theory, the majority of the industrial process is controlled by the well-established proportional-integral-derivative (PID) controller. So far, great effort has been devoted to develop methods to reduce the time spent on optimizing the choice of controller parameters [9]. Over the last few years, significant development has been established to adjust the PID controller parameters automatically in the process control area, which ensure adequate servo and regulatory behavior for the closed-loop system ([10], [11]). But PID controller parameters are adapted mostly on-line based on parameter estimation, which requires certain knowledge of the process, e, g, the structure of the plant model [1], [8]. Fuzzy control need not build up accurate model of system, only need a set of high-performance fuzzy rules, and the application of knowledge-based systems in process control is growing, especially in the field of fuzzy control [3], [4], [5]-[7]. In fuzzy control, linguistic descriptions of human expertise in controlling a process are represented as fuzzy rules or relations. This knowledge base is used by an inference mechanism, in conjunction with some knowledge of the states of the process (say, of measured response variables) in order to determine control actions.

PID controllers are often available at little extra cost since they are often incorporated into the programmable logic controllers (PLC) that are used to control many industrial processes.

In this paper, a PID parameters self-tuning fuzzy controller is proposed for level process control, and its fuzzy control is realized on PLC in practical. Furthermore, good control performance is simulated.

In the next section the level plant is described. Section 3 presents the construction of parameters self-tuning PID controller. Section 4 describes the realization of fuzzy control on PLC. Finally, shows the simulation of the PID parameters self-tuning fuzzy control closed-loop system.

2 Process Description

The river course extends down the reservoir, which is supplying the industrial water and lower agricultural irrigation. The demand of water level before strobe is satisfied by the control of lower strobe over upper level. And maintaining the level before the strobe properly is the premise of water intake. The control process is a nonlinear, time-varying and delayed system. It is difficult to construct an accurate mathematic model. So, a plan fusing fuzzy logic technique with general PID control technique is put forward, and the realization of parameters self-tuning fuzzy PID control is completed on PLC.

The plant is a stable system so that it is adequate to practice identification. The model parameters are calculated from the data obtained by dynamic test in which the step signal is used. However, the control system is a PID close-loop system, so a very accurate object model is not required. As for the control process, for the far distance between the upper and lower, lift of lower strobe has biggish delay. Therefore we can fit the controlled object through lower order transfer function under the satisfaction of precision. By the reaction curve of the open-loop response, the plant can be expressed approximately the parameters of the first-order mathematical model. The transfer function of model is given by

$$G(s) = \frac{Ke^{-\tau s}}{Ts+1} \qquad (1)$$

Furthermore, in the part of simulation, the controlled object can be simplified to three-order plant through the simplification of delayed section. This is convenient to the realization of simulation.

3 The Construction of Parameters Self-tuning PID Controller

The PID control algorithm, which is realized by computer, discrete control principle of it is expressed as:

$$u(k) = K_p \left\{ e(k) + \frac{T}{T_i} \sum_{j=0}^{K} e(j) + \frac{T_d}{T} \left[e(k) - e(k-1) \right] \right\} \qquad (2)$$

Here $u(k)$ is the control signal, $e(k)$ is the error between the reference and the process output, T is the sampling period of controller, T_i T_d are the integral and derivative time constants.

If parameters of PID controller (K_p, K_i, K_d) can be tuned on-line, adaptive performance of PID controller will be perfected further. On-line estimation is adopted extensively, based on special control requirements or objective function, parameters of PID controller can be tuned on-line. However, for nonlinear structure, time-varying parameters and uncertainty of model, the effectiveness of estimation is not always available. Therefore, this paper adopts PID parameters fuzzy controller self-tuning to tune the parameters on-line.

Based on PID algorithm and the computing of the error and the change of error of plant, fuzzy inference is carried out on-line using fuzzy rules and PID parameters are tuned by look-up fuzzy matrix. Thus a PID parameters self-tuning fuzzy controller is constructed. Its structure is shown in Fig.1.

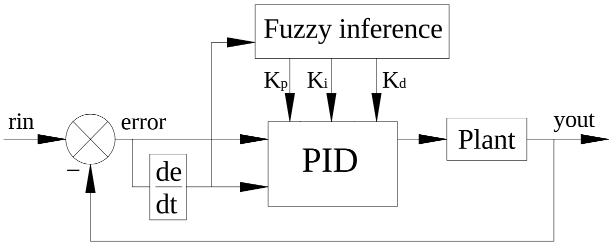

Fig.1 PID parameters self-tuning fuzzy controller

The whole design of fuzzy control algorithm can be expressed with flow chart Fig.2.

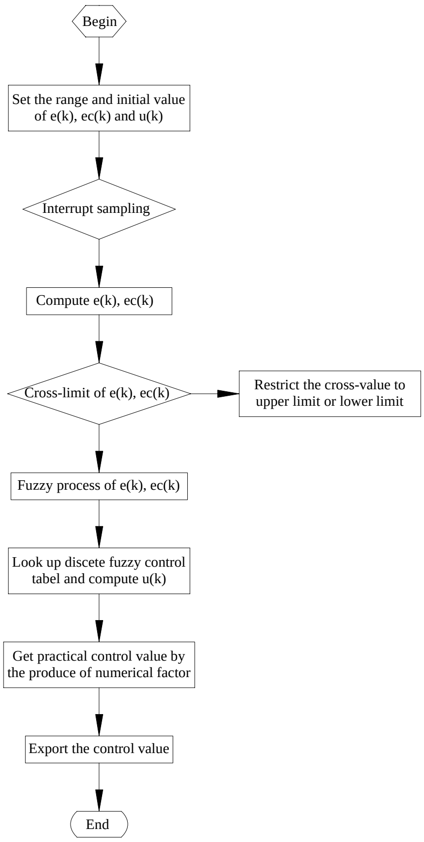

Fig.2 Flow chart of fuzzy control algorithm

In the proposed scheme, the varieties of PID parameters are determined by error $e(k)$ and the change of error $ec(k)$. The membership functions of these fuzzy sets for $e(k)$ and $ec(k)$ are defined with three membership functions.

The membership functions of $e(k)$ and $ec(k)$ is shown in Fig.3. In this figure, N represents negative, P positive, ZO approximately zero, S small, M medium, B big. Thus NM stands for negative-medium, PB for positive big, and so on.

		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

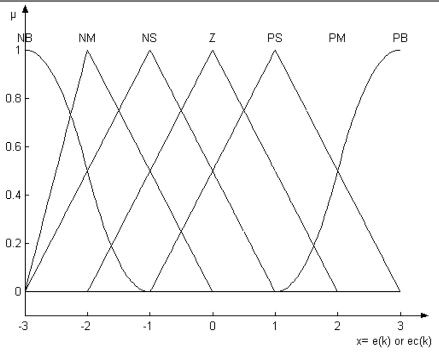

Fig.3 Membership function of $e(k)$ and $ec(k)$

By CRI inference mechanism, fuzzy controller always presents in look-up control table. The table represents the corresponding connection between input and output at the discrete points, which is computed with fuzzy algorithm based on fuzzy control rules. The action and interconnection of three PID parameters at different time must be taken into account during the tuning of PID parameters. The core of designation of fuzzy control is constructing a proper fuzzy rules table after summing up the technique and practical operating experiences. Thus we can get three fuzzy control tables corresponded to three parameters separately, which are shown as Table 1, Table 2, Table 3. The final section is getting clear digital values using center average defuzzifier.

Table 1

Fuzzy control table of 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 control table of ΔK_i

Table 3

Fuzzy control table of ΔK_d

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

4 Realization of fuzzy control on PLC

In this paper, the fuzzy inference system is dispersed to 13 points with MATLAB function *discfis*. There are several variables obtained simultaneity, XI and YI are the coordinates for the input membership functions. And the columns of XO and YO are the coordinates for the output membership functions. The corresponding discrete range of $\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$ is obtained after the roundness of the product of these variables and their numerical factors.

Then min-max inference computing can be processed with the discrete input and output values, but many fuzzy rules will participate in computing for each control output value. If all of these are computed with manual work, it will be a huge workload. Thus this paper proposed competing inference computing with VC++ programming according to fuzzy inference principle. The process of programming can be described as fellows: according to the discrete fuzzy input value, fuzzy inference can be processed based on the fuzzy control base rules, then clear the fuzzy output values with center average defuzzifier. Making use of the fuzzy control table I we get in the section 3, obtain the final digital control value through 4-layered circulative nesting. And followed the parameter of ΔK_p can be obtained by the product of fuzzy control value and their numerical factors.

For the difference of three fuzzy control tables, the discrete fuzzy control inquiry tables of the other two PID parameters can be obtained through changes of the elements of matrix of EEC (presents fuzzy control table). The practical variety of PID parameters values can be obtained with the produce of control values and numerical factors.

The paper completes the inquiry of discrete fuzzy control tables by the method of base address & offset address on PLC programming [2]. The process of inquiry can be described as fellows: if the base address of control value is defined as 100 and its offset address is $e*13+ec$, the address of control value is $100+e*13+ec$. The range of $e(k)$ and $ec(k)$ is defined as [-3, 3]. Multiplied with numerical factors after dispersion, range of $\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$ is obtained. For the requirement of query on PLC programming, the universe of fuzzy input elements are all added 6, the discrete range of $\{0,1,2,3,4,5,6,7,8,9,10,11,12\}$ is obtained. The elements of tables are enclosed into PLC memory along the rules as from left to right and from up to down. Then the fuzzy output value can be inquired as the manner of base address & offset address, and ΔK_p , ΔK_i , ΔK_d can be obtained by multiplying their numerical factors.

The realization of PID function can be described as fellows: In the first scan, subprogram is called and initialized. In the subprogram, loop table of PID instruction is initialized, and regular interruption is set to execute PID instruction. The computing of PID control output values is completed finally.

5 Simulation of closed-loop PID parameters self-tuning fuzzy control system in MATLAB

A notable character of MATLAB is that it provides an advanced M-language to program. MATLAB becomes an open and strong practical tool for its foundation and safeguard of expansibility was provided by strong M document. In this paper, a M document script is programmed to realize PID parameter self-tuning fuzzy control, by the combination of a series of instruction of MATLAB, the simulation is completed. The programming flow chart is shown in Fig.4.

The process of programming is described as fellows:

a) To Construct fuzzy control system with M-language, membership function and fuzzy rules are added, fuzzy system characters are set and the mechanism of defuzzier is selected.

b) To get discrete output of system, LTI object is dispersed, sampling cycle is fixed and impulse transfer function of discrete system is obtained. If the description of difference equation of linear discrete constant system is:

$$C(nT) = -\sum_{i=1}^{n} a_i c[(n-i)T] + \sum_{j=0}^{m} b_j r[(n-j)T] \quad (3)$$

Under the zero initialization condition, by the Z-transform form of (3) and real displacement theorem, a changed form of (3) is:

$$C(z) = -\sum_{i=1}^{n} a_i C(z) z^{-i} + \sum_{j=0}^{m} b_j R(z) z^{-j} \quad (4)$$

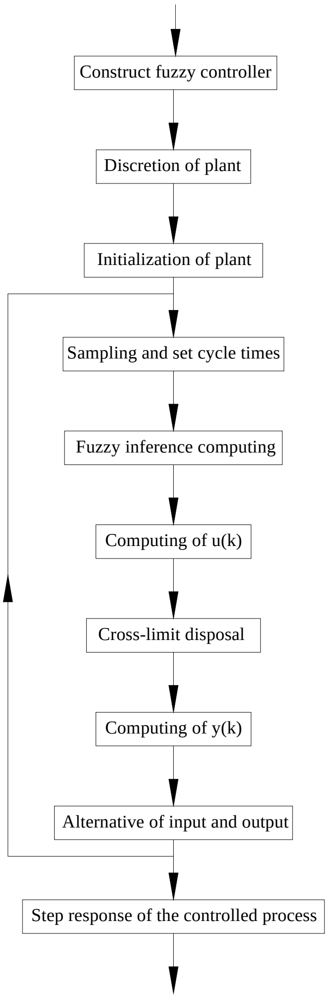

Fig.4 Flow chart of simulation programming

The impulse transfer function can be obtained after a further change:

$$G(z) = \frac{C(z)}{R(z)} = \frac{\sum_{k=0}^{m} b_k z^{-k}}{1 + \sum_{k=1}^{n} a_k z^{-k}} \quad (5)$$

With the connection of impulse transfer function and difference equation, the evaluation formula of discrete output values will be deduced.

c) Sampling circulation is set, fuzzy inference computing is executed during the circulation, the tuning of PID parameters is completed, the output control values of PID controller are computed and corresponding limit disposal is processed, then the output values of closed-loop control system is obtained using the connection of impulse transfer function and difference equation. Before the end of circulation, input and output values of system and output values of PID controller should be transferred alternatively.

d) Step response of PID parameters self-tuning fuzzy control system is shown in Fig.5, and good effect is validated.

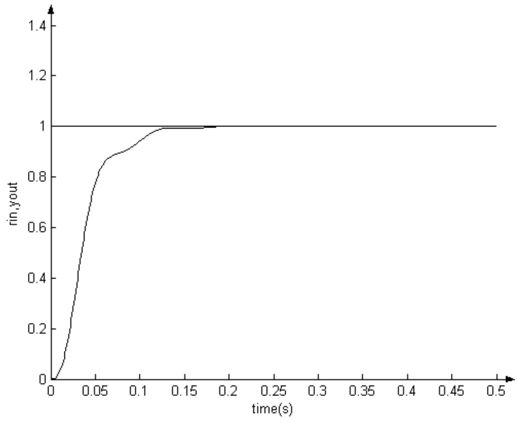

Fig.5 Step response of PID parameters self-tuning fuzzy control system

6 Conclusion

Over the last few years, significant development has been established in the process control area to adjust the PID controller parameters automatically, which ensures adequate servo and regulatory behavior for the closed-loop plant. Furthermore, PID controllers are often available at little extra cost since they are often incorporated into the programmable logic controllers that are used to control many industrial processes. This paper pays more attention on how to realize the fuzzy mechanism more effectively and fuse it into PLC programming more fluently. By VC++ programming, the process is simplified greatly and breaks a new path to realize PID parameters self-tuning fuzzy control on PLC. The simulation also validates its effectiveness.

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