A Switching Type of Fuzzy Controller

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Abstract

This paper propose a switching type fuzzy controller to obtain a satisfactory performance (fast rise time, small overshoot and small steady state error) in the step response by constructing some specific scaling factors in five control regions of system. We provide a method to select suitable scaling factors of the fuzzy controller in each region. It is shown by simulation that the proposed scheme has the ability to improve the transient and steady state performance of the controlled system simultaneously. The simulation also shows that this scheme can be used to curb the effect of load disturbance in the control process.

I. Introduction

Recently, fuzzy control (FC) has emerged as one of the most active and fruitful fields for research in the application of fuzzy set theory, and many practical applications to industrial process, as well as studies on the theory itself, have been reported in many works [1]. Essentially, the FC provides an algorithm to convert a linguistic control strategy based on expert knowledge into an automatic control strategy. The main advantage of FC is that it is easy to implement in accordance with experience and knowledge. The expression of the FC strategy consists of a set of linguistic control rules. In practical, FC usually used the following linguistic variables: error (e), change in error (ce), change in error rate (cce), and control signal (u) or change in control signal (cu) [2-10]. Basically, the Proportional-Integral Fuzzy Controller (PIFC) uses the linguistic variables {e, ce, cu} as basic linguistic variables. The control signal is represented by $u(k)=u(k-1)+cu(k)$. It is guarantees that the control signal in the steady state can be preserved. Therefore, the PIFC will yield superior performance in steady state. On the other hand, the Proportional-Derivative Fuzzy Controller (PDFC) uses {e, ce, u} as linguistic variables, and the control signal u(k) is directly inferred from the defuzzification at kth sampling interval. In general, the PDFC will yield rapid response in transient state. But, in the steady state, the error (e) and the change in error (ce) are possibly too small such that the control signal through fuzzy inference will become zero. This zero control signal will cause large steady state error or oscillation in the steady state. It is seen that the PDFC can reduce the time required to reach steady state, and the PIFC will reduce the steady state error in system response. But it is difficult to simultaneously take into account both the transient response and the steady state response either by conventional PDFC or by PIFC. In this paper, we propose a new FC structure such that the system performance can be improved both in transient state and in steady state. In order to get a good performance, we divide the system response into five control regions and propose a algorithm to switch and adjust the scaling factors of FC. From the simulation, we see that the proposed FC has the ability to improve the transient response and steady state performance of the controlled system simultaneously.

0-7803-1896-X/94 $4.00 ©1994 IEEE

II. Switching Structure of Fuzzy Control System

The structure of the three-input and one-output FC is shown in Figure 1, where

$se(k)=[s-y(k)]\times\frac{1}{K_e}$

$sce(k)=[e(k)-e(k-1)]\times\frac{1}{Kce}$,

$scce(k)=[ce(k)-ce(k-1)]\times\frac{1}{Kcee}$,

$cu(k)=scu(k)\times Kcu$,

with

k: the sampling instance,
s: the set-point,
y(k): the plant output,
e(k): the control error,
ce(k): the change in error (error rate),
cce(k): the change in error rate,
u(k): the control input,
cu(k): the incremental control input,
$\frac{1}{K_c}, \frac{1}{K_{ce}}, \frac{1}{K_{cee}}, K_{cu}$: the scaling factor.

Based on the knowledge of an expert operator, the rule base is shown in Table 1 [6]. For example, the ith rule is

Rule i:

If e is E_i and ce is CE_i and cce is CCE_i then cu is CU_i.

where e, ce, cce, and cu are linguistic variables and E_i, CE_i, CCE_i, and CU_i are linguistic values with membership functions E_i:Ue→[0,1], CE_i:Uce→[0,1], CCE_i:Ucce→[0,1], and CU_i :Ucu→[0,1], respectively. The membership functions of the above fuzzy sets are shown in Figure 2, where the universe of discourse of each input is normalized in the interval [-1,1]. In this method, we discuss a simplified fuzzy reasoning method where triangular-shaped membership functions and the real values (singletons) are used for characterizing these linguistic values of the antecedent part and the consequent part, respectively.

When the inputs se(k), sce(k), and scce(k) are input to the FC, the truth value of the antecedent part in the ith rule is calculated by

$$w_i = E_i(se(k)) \bullet CE_i(sce(k)) \bullet CCE(scce(k))$$

The incremental control input cu(k) by taking the weighted average is then obtained by the following equation

$$scu(k) = \frac{\sum_{i=1}^{27} w_i \bullet v_i}{\sum_{i=1}^{27} w_i}$$

And the control input is calculated as follows:

$$u(k)=u(k-1)+cu(k)$$

Three requirements we considered are (a) the fast rise time; (b) the smaller overshoot; and (c) the smaller steady state error. Intuitively, for a large error e, we should set a larger u or cu. Besides the error e, the change in error ce also provides the information of tracking velocity. For the requirements, we must have the strategies that the system has the positive larger acceleration at the beginning such that the rise time is reduced and that the system limit the maximum variation of the incremental control input (cu) to somewhat small one such that the overshoot is reduced or prevented. From our experiment, the controlled region is divided into the following 5 regions, where each region is depended on the set-point and plant output.

(1) $y(k) < 0.2s$ (large positive acceleration region)
(2) $0.2s \le y(k) < 0.5s$ (small positive acceleration region)
(3) $0.5s \le y(k) < 0.75s$ (large negative acceleration region)
(4) $0.75s \le y(k) < 0.9s$ (small negative acceleration region)
(5) $0.9s \le y(k)$ (stability region)

In Region (1) and Region (2), the present position is very far away from the set-point. Therefore, it requires a large control value to turn the output to the set-point quickly, i.e., the output value cu(k) of fuzzy controller must be chosen as large as possible to accelerate the system response. Note that the values of e(k), ce(k) and cce(k) in these regions always be e(k)>0, ce(k)<0, and cce(k)<0, respectively. In Region (3) and Region (4), the system output is approaching the required position. Thus, the value of cu(k) is chosen as small as possible in contrast to Region (1) and (2) in order to prevent the overshoot. Note that the values of e(k), ce(k) and cce(k) in these regions always be e(k)>0, ce(k)<0, and cce(k)>0, respectively. In Region (5), the set-point is very nearly reached. The oscillation will occur when the value cu(k) is too large or too small, so the scaling factor must be appropriate chosen by the medium value such that the output approaches the steady state value. Based on the above description, we propose the strategies about the adjusting of the scaling factor in each region as shown in Table 2. For example in Region (1), in order to reduce the rise time, we set Ke to be small, Kce to be large and Kcce to be large by considering the rules of Table 1 such that se(k)=1/Ke*e(k)>>0, sce(k)=1/Kce*ce(k) $\rightarrow$0, and scce(k)=1/Kcce*cce(k)$\rightarrow$0, then the incremental control input cu(k) is large enough to reduce the rise time. Because the larger value of cu will increase the acceleration, so the rise time can be reduced further by increasing the cu value. But the maximum variation of the incremental control input (cu) in Region (2) must be limited to somewhat small one to prevent overshoot of the transient response. So the different strategies used in Region (1) and Region (2) is on the selected magnitude of Kcu value. It can be considered that the method used in Region (1) is a coarse tuning and that in Region (2) is a fine tuning. Similarly, the relationship between Region (4) and Region (3) is the same as that between Region (2) and Region (1).

III. Simulation and Result

To evaluate the performances and characteristics of the proposed scheme, this technique is applied to a three order plant with time delay of the following form:

$$G(s) = \frac{41.6654}{s^3+6.3383s^2+27.6256s+40.62290} \bullet e^{-0.96s}$$

The set-point response is shown in Figure 3, where the sampling interval is chosen to be 0.064 and the values of scaling factors in each control region are described in Table 3. The set-point changes at 0, 20, 40 second, and the closed-loop system is quickly settled at the new set-point. The simulation result shows that the proposed FC has ability to reduce the rise time, the overshoot and the steady state error. Thus the proposed FC yields a good performance. Figure 3 also shows the load disturbance response of the control system for some sudden constant load inserted at 30 and 50 second in the process. We find that the closed-loop system recovers remarkably.

IV. Conclusion

In this work, we have proposed a new fuzzy controller structure. A high order system with time delay is selected for simulation analysis. The simulation shows that the scheme yields a superior transient and steady state performance. The result also shows that the control system can provide good load disturbance response. In this paper, the range of five regions is set from the experiment. How to find a fine region such that the performance is best is our future study.

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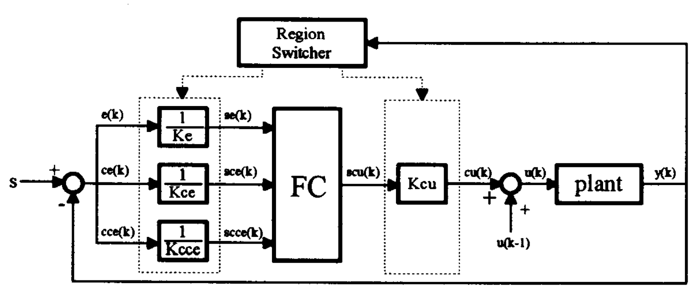

Figure 1. Switching type of FC

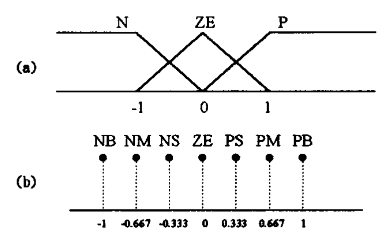

Figure 2. Membership functions (control rules)
(a) Antecedent (b)Consequent

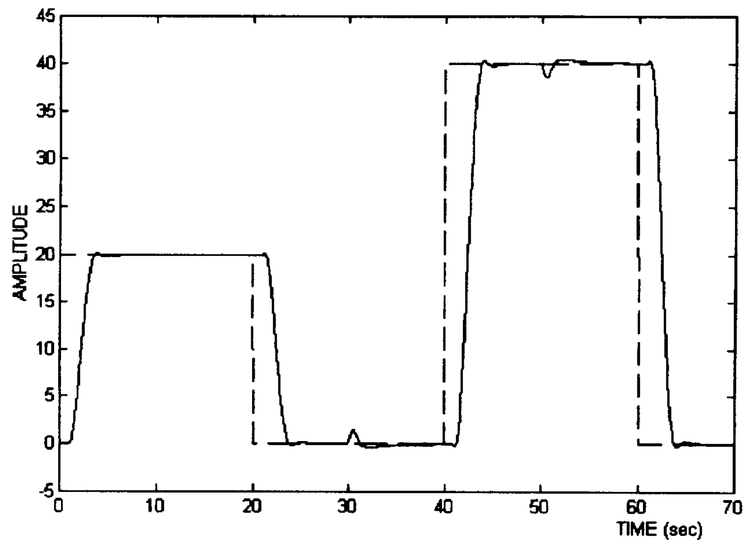

Figure 3. The set-point and load disturbance response of G(s).

Table 1. Linguistic control rules

Δe \ $\Delta^2 e$	N	Z	P
Δu for 'e is P'			
P	PM	PB	PB
Z	PS	PM	PB
N	ZE	PS	PM
Δu for 'e is Z'			
P	PM	PB	PB
Z	NS	ZE	PS
N	NM	NS	ZE
Δu for 'e is N'			
P	NM	NS	ZE
Z	NB	NM	NS
N	NB	NB	NM

P: Positive, N: Negative, Z: Zero, PB: Positive Big,
PM: Positive Medium, PS: Positive Small, ZE: Zero,
NS: Negative Small, NM: Negative Medium, NB: Negative Big.

Table 2. State representation of scaling factors

Region \ Scaling Factor	K_e	K_{ce}	K_{cee}	K_{cu}
1	Small	Large	Large	Large
2	Small	Large	Large	Small
3	Large	Small	Large	Large
4	Large	Small	Large	Small
5	Medium	Medium	Small	Medium

Table 3. Values of scaling factors

Region \ Scaling Factor	K_e	K_{ce}	K_{cee}	K_{cu}
1	0.8s	s/6	s/12	s/60*3.0
2	0.8s	s/6	s/12	s/60*0.5
3	1.2s	s/60	s/12	s/60*3.0
4	1.2s	s/60	s/12	s/60*0.5
5	s	s/10	s/60	s/60