A NEW SELF-TUNING FUZZY CONTROL APPROACH

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Abstract—Design of fuzzy controller depends mainly on rule base and to derive the desired and small fuzzy rule base is still based on trial and error. This paper concentrates on choosing the rule base and gives some useful results. A fuzzy clustering technique associated with the proposed fuzzy partition validity index is used to extract the initial fuzzy rule-base and find out the optimal number of fuzzy rules. We offer a practically viable approach, which provides a superior performance in terms of robustness. It consists of computing with indices rather than symbolic rules. Thought, the symbolic rule-base is converted into an indices computing rule-base (indices-rule-base). For tuning the change in control output (Δu) the fuzzy controller is defined on error (e) and change of error (Δe) of the controlled variable using simple triangular and unbiased membership functions (MF's). The performances of this controller with indices computing rule-base are analysed and compared to the classical control law (Predictive control) [1] [2]. Experimental results show the performance of the proposed fuzzy controller and its ability to control a process.

Keywords—Fuzzy logic Controller, Symbolic rules, Indices rules, optimally.

I. Introduction

Fuzzy logic control (FLC) is one of the most successful applications of fuzzy set theory, introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an attempt to control system that are structurally difficult to model. Since then, FLC has been an extremely active and fruitful research area with many industrial applications reported [3] [4] [5].In the last three decades, FLC has evolved as an alternative or complementary to the conventional control strategies in various engineering areas. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain non linear systems. Unlike conventional control, designing a FLC does not require precise knowledge of the system model such as the poles and zeroes of the system transfer functions. Imitating the way of human learning, the tracking error and the rate of the error are two crucial inputs for the design of such a fuzzy control system [7] [8] [9][10].

However, relative importance of the input and output to the performance of a fuzzy logic control system is yet to be fully established. A skilled human operator always tries to manipulate the process input, usually by adjusting the controller based on the current process states (generally e and Δe) to get the process (optimally) controlled. The exact manipulation strategy of an operator is quite complex in nature and possibly no mathematical model can replace it accurately. Lot of research works on tuning of FLC's has been reported where either the input-output or the definitions of fuzzy sets are tuned to match the current plant characteristics [16] [18].

With a view to eliminate the overshoot caused by the accumulation of control input. It contains the proposed approach by which the controller indices-rule-base Next, we show simulation and experimental set U_p. The results obtained by applying the proposed fuzzy controller for the system will be compared with the still used Predictive Control. Finally, we draw conclusion for the experimental and simulated results.

II. Fuzzy logic controller

A block diagram of a fuzzy control system is shown in Figure 1.The fuzzy controller is composed of the following four elements:

1) A rule-base (a set of if-then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve good control.
2) An inference mechanism (also called a fuzzy inference engine), which emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.
3) A fuzzification interface, which converts controller inputs into information that the inference mechanism can easily use to activate and apply rules.
4) A defuzzification interface, which converts the conclusions of the inference mechanism in to actual inputs for the process.

For choosing the inputs and outputs of fuzzy controller, the controller is to be designed to automate how a human expert who is successful at this task would control the system. First, the expert tells us (the designers of the fuzzy controller) what information the user will use as inputs to the decision making process. Suppose that for the process [13] [15], the expert says that the user will use:

$e(t) = r(t) - y(t)$ and $\Delta e(t) = de(t)/dt$

$e(nT) = r(nT) - y(nT)$ and $\Delta e(nK) = (e(nT) - e(nT-T)/T)$

the controlled variable of fuzzy controller is $u(t)$ but in this paper the incremental change in controller output Δu is taken as output. This will be helpful for common rule base for any type of fuzzy controller. Once the fuzzy controller inputs and outputs are chosen, one must think about what are the membership functions (MFs) are for these input and output variables. After surveying the literature, for a two input fuzzy controller MFs are 9 for each input are mostly used. It is a general view that if the number of MFs between the defined ranges is larger, then the possible rules increases and the response will be good. In this paper, all membership functions for controller inputs (i.e., e and Δe) and incremental change in controller output (i.e., Δu) are defined on the common normalized domain [-1; 1]. Here, the 9 membership functions are shown in Figure 2. Similarly all other MFs when the number 9 can be divided into the normalized domain.

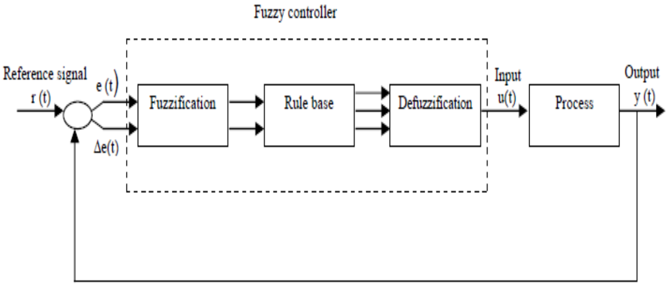

Fig. 1. Block diagram of fuzzy controller.

Now the next step is to design the rule base. The incremental change in controller output Δu for a fuzzy controller is determined by the rules of the form: If e is e and Δe is Δe, then Δu is Δu.

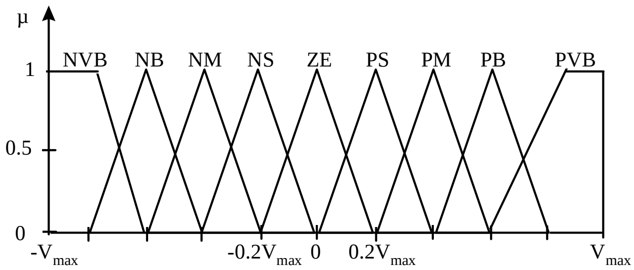

Fig. 2 Membership Functions of E, ΔE and ΔU.

NVB: negative very big
NB: negative big
NM: negative medium
NS: negative small
ZE: zero
PS: positive small
PM: positive medium
PB: positive big
PVB: positive very big

The rule-base for computing Δu is shown in table I. This design of rule-base with two-dimensional phase plane is often used

ΔE \ E	NVB	NB	NM	NS	ZE	PS	PM	PB	PVB
NVB		NVB	NB	NM	NS	ZE	PS	PM	PB
NB		NVB	NB	NM	NS	ZE	PS	PM	PB
NM		NVB	NB	NM	NS	ZE	PS	PM	PB
NS		NVB	NB	NM	NS	ZE	PM	PM	PB
ZE	NVB	NB	NM	NS	ZE	PS	PM	PS	PM
PS	NVB	NB	NM	NS	ZE	PS	PS	PS	PM
PM	NB	NM	NS	ZE	PS	PS	PM	PM	PB
PB	NB	NM	NS	ZE	PS	PM	PM	PM	PB
PVB	NM	NS	ZE	PS	PM	PM	PB	PB	PVB

Table I: Symbolic Fuzzy Rules for computational of ΔU

Fig. 1 shows an algorithm of fuzzy control inference. It consists of three basic parts; fuzzification where continuous input variables are transformed into linguistic variables, fuzzy rule inference that handles rule inference consisting of fuzzy IF–THEN rules, and defuzzification that ensures exact and physically interpretable values for control variables. The design of fuzzy control may include; the definition of input and output variables, the selection of data manipulation method, the membership function design and the rule base design. Using fuzzy rules and membership functions, fuzzy control converts linguistic variables into numerical values required in most applications[6] [11] [12] [14].

The design of the fuzzy controller began to select the response quantities to be used as inputs to the fuzzy controller and the distribution and type of membership functions to be used for the selected input variables. Moreover, we must consider what control functions are needed, and then define them as output variables. Then, fuzzy inference rule is completely based on the selected input variables. Usually, we use the form if (a set of condition to be satisfied) Then (a set of consequences to be inferred) to describe the expert knowledge. For example, the multiple-input multiple-output IF–THEN rules of the fuzzy control are shown in the form:

R_j : if x_1 is A_{j1} and … and x_p is A_{jp} Then y_1 is B_{j1} and … and y_m is B_{jm}

where R_j denotes the j rule of the fuzzy inference rule, j = 1,2,. . .,q, $x_1, x_2, \ldots, x_p$ are the inputs of the fuzzy controller, A_{ji} is linguistic value with respect to x_i of rule j, $y_1, y_2, \ldots, y_m$ are the outputs of the fuzzy controller and B_{ji} is a fuzzy singleton function defined by experts.

Then, the inference conclusion obtained via fuzzification is defuzzified into a crisp output. This paper adopts the center-of-gravity (COG) method among the defuzzification methods. COG method is defined as follows:

$$y_i = \frac{\sum_{l=1}^{N} B_{jl}\left[\prod_{i=1}^{p} \mu_{A_{ji}}(x_i)\right]}{\sum_{l=1}^{N}\left[\prod_{i=1}^{p} \mu_{A_{ji}}(x_i)\right]}$$

where $\mu_{A_{ji}}$ is the membership function of A_{ji} .

III. SIMULATIONS AND RESULTS

Computer simulation were conducted to examine the results of theoretical and heuristics task. For tracking performances of the proposed FLC, we have taken a ramp as a reference. Let's consider the process governed by:

$$A(q^{-1})y(t) = q^{-d}B(q^{-1})u(t) + w(t) \quad (1)$$

Where

$$\mathrm{A}(\mathrm{q}^{-1}) = 1 - 1.71\mathrm{q}^{-1} + 0.73\mathrm{q}^{-2} \quad (2)$$

$$\mathrm{B}(\mathrm{q}^{-1}) = -0.02 + 0.032\mathrm{q}^{-1} \quad (3)$$

and the delay d=1. u(t) and y(t) are respectively input, output of the process and w(t) is an independent random variable with zero mean values and finite variances.

The FLC affect the time response and the stability of the system. The simulation of the process showed that the best time response and stability. The control input u(t) and the corresponding process output y(t) are shown in figure 3 Evolution of the process output the Predictive Control and Figure 4 Evolution of the process output the fuzzy controller rule base and compared to the predictive control law fuzzy controller rule base.

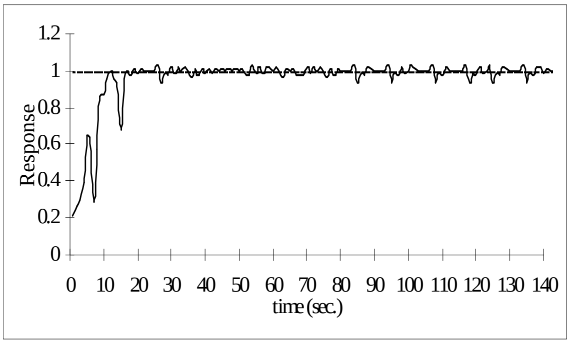

Fig. 3 Evolution of the process output the Predictive Control

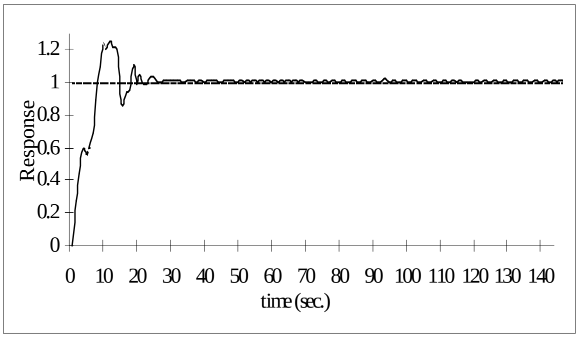

Fig. 4 Evolution of the process output the fuzzy controller rule-base

It is seen that the use of the predictive control (fig. 3) did not affect the stability of the system. However, after a transient period the system response gives good regulation (fig. 4) as compared to fig. 3. Experimental results show the performance of the proposed fuzzy controller and its ability to control a process.

IV. CONCLUSION

This paper presents two valuable results regarding rule base of fuzzy controller. Firstly it has established that rules should be in a certain limit. Increasing the rules beyond that limit is ineffective. Secondly, the rules can be reduced using FLC and gives the similar performance as by the larger rule set.

The FLC proposed in this work consists of the mathematical principals for the fuzzy controller design, the mechanism and simple yet effective indices-rules. The method proposed to design the fuzzy controller rule-base, where the conventional symbolic rule-base was converted to an indices-rule-base. The universe of discourse of inputs and output variables were partitioned into nine sets. The change of error and change of control output in order to compensate the fuzzy behavior of the "IF-THEN" rules control.

The most important advantages of the use of the indices-rules against symbolic-rules, to represent knowledge, are:

Make simple and easy for a human operator to add or to suppress any rule.

Economise memory space.

Faster two times controller response.

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