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Reduction of Fuzzy Rules–An Approach Using Hybrid FLC with Equilibrium Value

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Abstract: **Conventional fuzzy logic controllers (FLC) are frequently being used to wherever the load is non-linear or when the mathematical model of a plant is unknown or to make a system or plant robust to external disturbances. The main working of the fuzzy logic controller depends upon the number of rules present in the rule base. Higher the number of rules better is the performance. However, with the increased rules the computational memory and computational time required increases considerably. This increase in memory and time slows down the process there by reducing the effectiveness of the FLC. In this paper, the focus is to reduce the rules while keeping performance of the FLC similar to that of the large fuzzy rules using a novel method of Hybridization with equilibrium value. The proposed method reduces the number of rules present in the fuzzy logic controller reducing the computational time and memory resulting in better performance of the FLC. Simulations are performed and analyzed to show the effectiveness of the proposed FLC.**

Index Terms: **MISO, Fuzzy Logic Controller, Reduced rule FLC, Hybrid FLC, Equilibrium value.**

I. Introduction

Fuzzy logic controllers find a lot of applications due to the robustness it offers to any plant or system. It offers a methodology for epitomizing human knowledge for controlling a system. FLCs are being applied to household appliances such as washing machines, video recorders, vacuum cleaners, auto contrast and brightness control in television. Fuzzy logic rule based expert system utilizes a collection of conditional statements that are derived from the knowledge base for approximating and constructing the control surface [1, 2]. The FLC is synthesized from collection of "IF-THEN" rules that are present in the knowledge base of the fuzzy controller.

The number of rules that are present in the rule base of FLC mainly depends upon the number of inputs and the linguistic variables (LV) assigned to each input. With increased rules the output becomes linear function of input [3-5]. However with increased rules the computational memory and time required increases resulting in the system taking more time to produce the result and even the hardware becomes more complicated.

The recent focus of the researchers is on designing a FLC with lesser number of rules without compromising the performance of the FLC. To achieve this reduction of fuzzy rules for robotic manipulator and its issues was presented in [6] and reduction of rules for vacuum cleaner in [7]. In [8], a method to reduce the number of parameters to optimize the fuzzy controller response was presented. Conditional firing rule was proposed in [9] in which the rules are fired whenever a condition is satisfied; however the number of rules remained the same. Various methods were proposed in [10, 11] to reduce the rules by calculating the average deviation and then obtained the response of the system by using compensating factor. Although the response was similar to that of large rule FLC the calculation of compensating factor was found to be complicated. In [12-14] reduction of rules was achieved using clustering while keeping the response of the fuzzy controller similar to that of large rule FLC and applied to first order, second order, third order and non-linear systems. The method proposed in [15] focused on rule base division technique for reducing the power consumption of FLC that were based on various priorities and conditions without reducing the number of rules. A fuzzy local information c-means algorithm was proposed in [16] that can detect image clusters thereby overcoming the disadvantage of fuzzy c-means. Design of fuzzy controller with reduced rules is also presented in [17, 18] in which the computational memory and time are reduced for the performance improvement of the process control under consideration.

In this paper a novel method based on equilibrium value with hybridization is proposed for a three input single output fuzzy logic controller.

II. Three Input Single Output FLC

To improve the performance of any fuzzy controller the rules present in the rule base are increased which is given by

$$R = N^i \tag{1}$$

Where "R" is the number of rules, "i" is the number of inputs and "N" is the number of linguistic variables (LV) for each input. From eq. (1) we can see that the rules can be increased by increasing either the number of inputs or by increasing the linguistic variables of each input. As can be seen from eq. (1) increase in the rules by increasing input is more when compared to increasing the linguistic variables. Hence, in this paper at first the rules are increased by increasing the number of inputs, i.e. the inputs are increased from 2 to 3 with 7 linguistic variables thereby increasing the rules from 49 to 343. If the linguistic variables are 9 then the rules will increase from 81 to 729 rules.

The conventional three input single output FLC is as shown in Fig. 1 [13] where G_1, G_2, G_3 are input gains, G_0 is output gain, "r" is the required response, "y" is the obtained response.

The three inputs to the FLC are error "e", change in error Δe and change in change in error $\Delta\Delta e$. The equations for Δe and $\Delta\Delta e$ is given as

$$\Delta e(k) = e(k) - e(k-1) \tag{2}$$

$$\Delta\Delta e(k) = \Delta e(k) - \Delta e(k-1) \quad (3)$$

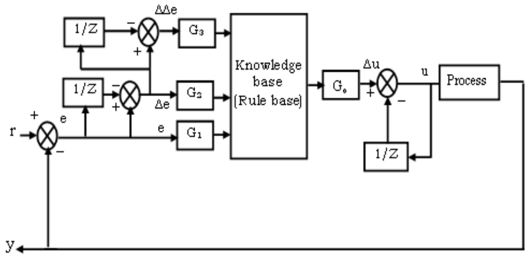

Fig. 1 Conventional three input single output FLC

The output of the FLC is given by u and Δu is the change in output given by eq. 4.

$$\Delta u(k) = u(k) - u(k-1) \quad (4)$$

III. FLC USING HYBRIDIZATION

The conventional three input fuzzy controller is as shown in Fig. 1. The above controller is modified and proposed as shown in Fig. 2 [13].

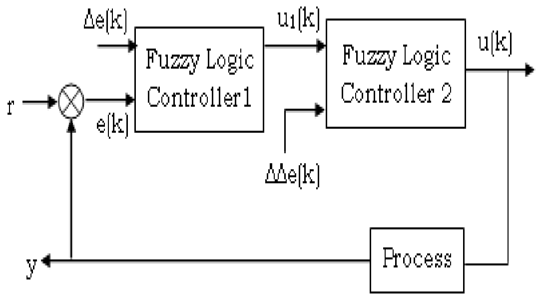

Fig. 2 FLC using Hybridization

Conventional controllers have three inputs for one fuzzy controller. In the proposed hybrid FLC there are two FLCs with two inputs and single output as shown in Fig. 2. The number of inputs is same as in conventional and proposed controllers' i.e. e, Δe and ΔΔe are same. The inputs to FLC1 are e, Δe and inputs to FLC2 are ΔΔe and $u_1(k)$ which is the output of FLC1. In this way, for 7 LV FLC1 and FLC2 will have 49 rules each and for 9 LV FLC1 and FLC2 will have 81 rules each. The rules present in the rule base of FLC1 and FLC2 for input with 7 LV are given in Table I. After obtaining the output of FLC1, FLC2 is activated. In this way the total number of rules becomes 98 for input with 7 LV and 162 for 9 LV.

Table I No. of rules in rule base of FLC1 and FLC2 for & L.V.

e / Δe	LN	MN	SN	Z	SP	MP	LP
LN	LN	LN	LN	LN	MN	SN	Z
MN	LN	LN	LN	MN	SN	Z	SP
SN	LN	LN	MN	SN	Z	SP	MP
Z	LN	MN	SN	Z	SP	MP	LP
SP	MN	SN	Z	SP	MP	LP	LP
MP	SN	Z	SP	MP	LP	LP	LP
LP	Z	SP	MP	LP	LP	LP	LP

The output of FLC1 is given by eq. (5) and the output of FLC2 is given by eq. (6)

$$u_1(k) = \Delta u_1(k) + u_1(k-1) \quad (5)$$
$$u(k) = \Delta u(k) + u(k-1) \quad (6)$$

IV. HYBRID FLC WITH EQUILIBRIUM VALUE

For further reduction of rules equilibrium value FLC (EVMFLC) proposed in [18] is applied to FLC1 and FLC2 individually. In the proposed equilibrium value method, a value is assigned to each input linguistic variable in the range [-1, 1]. An equilibrium value is calculated for the inputs of a two input fuzzy controller. If the assigned value of any one input linguistic variable is less than the obtained equilibrium value then the rule is not fired. If the both inputs have a value more than the equilibrium value then that rule is fired. In this, way, the rules that are fired for two input FLC with 7 and 9 linguistic variables having 49 and 81 rules respectively will be only 16. Therefore, the total number of rules that will be fired for both FLC will be 32 only. This is great reduction from 343 and 729 original rules for a three input single output fuzzy controller.

V. SIMULATION RESULTS AND DISCUSSIONS

The proposed Hybrid FLC with equilibrium value (HEFLC) is applied non-linear system given in eq. (7).

$$G_2(s) = \frac{d^2y}{dt^2} + \frac{dy}{dt} + 0.75y^2 = u(t-L) \text{ for L=0.1} \quad (7)$$

The simulations are performed for a conventional FLC and the proposed HEFLC. The results are compared to show the effectiveness of the proposed fuzzy controller.

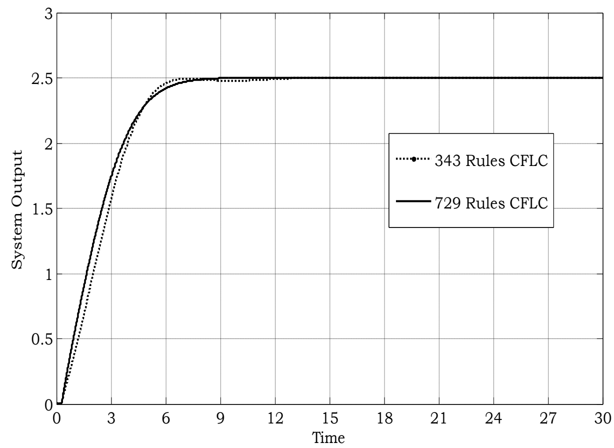

Fig. 3 Response of CFLC with 7 and 9 LV

In Fig. 3 the response of non-linear system considered in eq. (7) for conventional FLC with 7 and 9 linguistic variables is shown. Fig. 4 shows the response of the process for HFLC and Fig. 5 shows the response of the proposed HEFLC with 32 rules compared with conventional FLC with 729 rules. In Table II the comparison of the response of the process for various controllers is shown. In time M_p is maximum peak overshoot, t_r is the rise time and t_s is the settling time.

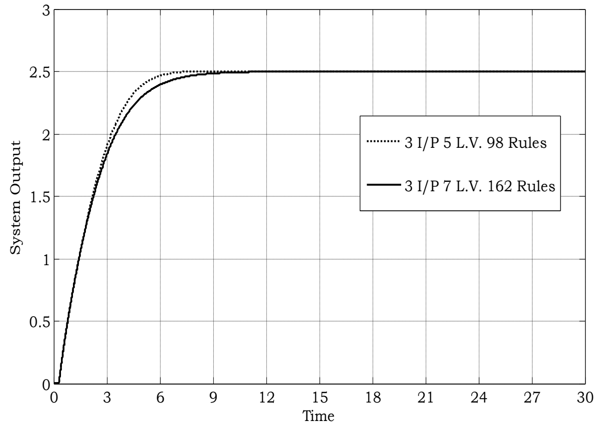

Fig 4. Response of HFLC with 98 and 162 rules

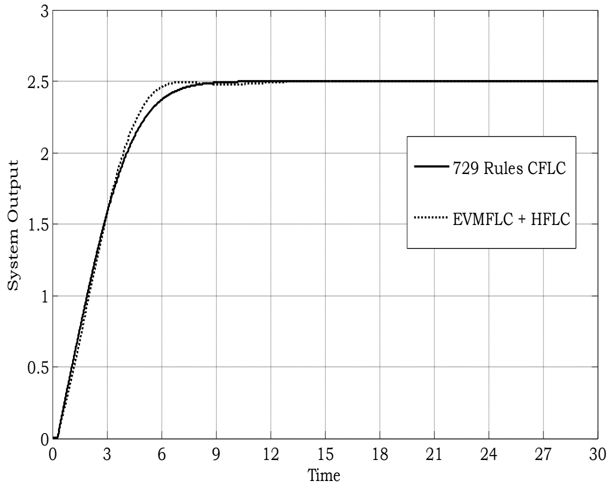

Fig. 5 Response of CFLC and proposed HEFLC

Table II: Performance Comparison of various controllers.

Controller	Rules	Mp	tr (sec)	ts (sec)	Memory used (Kb)	Computational time (sec)
CFLC	343	0	5.9	6	4400	210
	729	0	5.9	6	10200	320
HFLC	98	0	5.8	6	1500	75
	162	0	7.5	8	3350	95
HEFLC	32	0	7.6	8	500	15

As can be observed from the table the M_p, t_r and t_s are remaining nearly the same for CFLC and proposed HEFLC. However the memory utilized is reduced from 10200 Kb to 500 Kb and the computational time is reduced from 320 sec to 15 sec thereby the process becomes fast and improves the performance of the system.

VI. CONCLUSIONS

Conventional controllers are frequently being replaced by fuzzy controllers. However the increase of rules in the fuzzy controller slows down the process. Hence, in this paper a novel method utilizing Hybrid FLC with equilibrium value is proposed which reduces the rules that are fired from 343 and 729 to 32 rules. Due to the reduction of rules the computational memory and computational time are also reduced as can be observed from Table II.

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