Two Region Fuzzy Logic Controller for a Two Capacity Interacting Nonlinear Level Process

N.Jaya[1], D.Sivakumar[2], R.Anandanatarajan[3]

Abstract

Although a fuzzy logic controller is generally nonlinear, a PI- type single region fuzzy controller that uses only control error and change in control error is not able to detect the process nonlinearity and make a control move accordingly. In this work, a two region fuzzy logic controller is developed for a nonlinear second order process. The simulation study is carried out on a two capacity interacting process and the results are compared with those obtained using a conventional PI controller based on the transfer function model and single region fuzzy logic controller about the operating point of 50%.

Keywords : Nonlinear control, two region fuzzy logic controller, two capacity interacting nonlinear process.

1. Introduction

Recently, fuzzy logic controllers have been successfully applied to a wide range of industrial processes as well as consumer products, and show certain advantages over the conventional PI and PID controllers. Although, fuzzy logic controllers have been extensively used for many industrial processes, there are still a very few FLC's can achieve better performance. Recent studies report that, replacing a conventional PI controller with a nonlinear fuzzy PI controller can provide satisfactory performance. A typical fuzzy logic controller is composed of three basic parts: input signal fuzzification, a fuzzy engine that handles rule inference and defuzzification that generates continuous signals for actuators such as control valves.Fig.1 depicts such a fuzzy logic Controller. The fuzzification block transforms the continuous input signal into linguistic fuzzy variables small, medium and large. The fuzzy engine carries out rule inference where human experience can experience can easily be injected through linguistic rules. The defuzzification block converts the inferred control action into a continuous signal that interpolates between simultaneously fired rules. Owing to defuzzification, fuzzy logic is sometimes referred to as continuous logic or interpolative reasoning [3]. The resulting relation is actually a nonlinear function relationship rather than a logic relationship. Two distinct features of fuzzy logic control are 1) the human experience can easily be integrated and 2) it provides a nonlinear relationship induced by membership functions, rules and defuzzification. These features make fuzzy logic a promising method for process control where human operator experience exists and conventional control technologies fails.

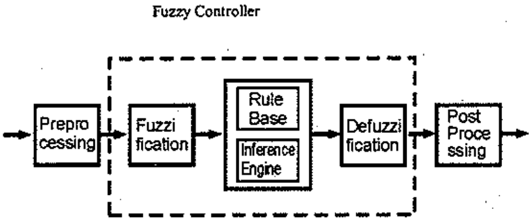

Figure 1 : Block Diagram of FLC

Most of the works found in literature use control error (e) and change of the control error (Δe) as inputs. Using

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only these inputs, the fuzzy controller is not able to identify in which region the process operates. Therefore, such a fuzzy controller cannot make a control action based on the knowledge of the process nonlinearity associated with different regions. In this paper, a two region fuzzy logic controller that uses auxiliary variable is used to indicate in which region the process is operating. Such fuzzy logic controller can compensate for process nonlinearity so that the control performance can be made more uniform throughout different nonlinear regions.[1]

The design and simulation of multi region fuzzy logic controller for a first order nonlinear process is suggested by Joe Qin [1] and higher order multi level fuzzy logic controller is presented by Savkovic [2]. The main contribution of this paper is the implementation of two region fuzzy logic controller for a second order nonlinear process with time delay. The present work reveals the effectiveness of this technique when applied to a two capacity interacting process. This is evident from the encouraging results obtained through simulation.

2. Fuzzy Controller With An Auxiliary Process Variable

Most industrial processes demonstrate considerable nonlinearity with respect to different regions of operation. Depending on process characteristics, the process regions can often be categorized as high gain, low gain and large time-constant and long time-delay and so on. If the process gain (G_p), the time constant (T_c) and the time delay (T_d) are used to characterize a nonlinear process, they depend on different process regions. For example, Fig.2 illustrates different situations of gain nonlinearity. The sigmoid shape of the nonlinear gain in Fig. 2 has two low gain regions and one high gain region. If an auxiliary variable (AV) is used to indicate different regions of the nonlinear process, the process nonlinearity has shown in Fig.1.represents the three different fuzzy regions

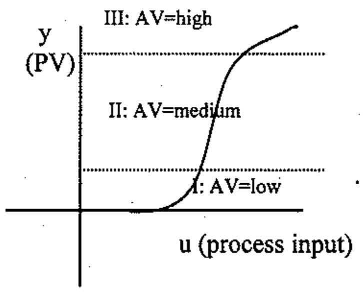

Figure 2 : Process Characteristics With Nonlinear Gain

IF AV is in Region I, THEN G_p =low;

IF AV is in Region II, THEN G_p =high;

IF AV is in Region III, THEN G_p =low.

It is very difficult to design a fuzzy logic controller for this characteristics by using only the control error and change in the control error (as shown in Fig.1).For example, it is desired to design a FLC for this situation, one has to assure that the controller is stable in the high gain region while sacrificing performance in the low-gain regions. In this work, design of a fuzzy logic controller that gives satisfactory performance for different regions of gain nonlinearity is carried out. A two region fuzzy controller as shown in Fig.3 that uses an auxiliary variable is developed so as to allow designing of control strategies in different regions. In addition to using control error and change in the control error as inputs, an auxiliary variable is used as another input to determine in which region the process is operating. The functional relationship represented by such a controller can be described as follows:

$$\Delta u = FLC(\Delta e, e, AV) \qquad (1)$$

where FLC(.) stands for the nonlinear relationship of the fuzzy controller. The auxiliary variable can be process input(u_k) or the process output (y_k) depending on how the operation regions are defined. For example, it is convenient to use yk as AV in the case of sigmoidal nonlinear gain as shown in Fig.2.

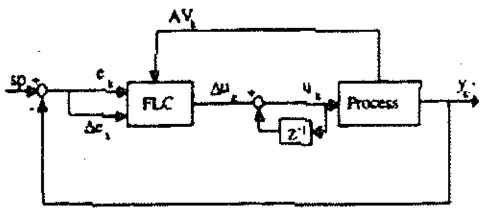

Figure 3 : Block Diagram of FLC With Auxiliary Variable

Membership Function Definition

The fuzzy membership functions associated with each controller input can be defined based on prior knowledge about the process. The auxiliary variable for the case of Fig.2 should have three regions: High, Medium and Low. For the control error (e), change in control error (Δe) and control action (Δu), it is convenient to use scaled variables as

$$e^{*} = \frac{e}{s_e} \tag{2}$$

$$\Delta e^{*} = \frac{\Delta e}{s_{\Delta e}} \tag{3}$$

$$\Delta u^{*} = \frac{\Delta u}{s_{\Delta u}} \tag{4}$$

where Se, $S_{\Delta e}$ and $S_{\Delta e}$ are scaling factors for e, Δe and Δu respectively. The membership partitions are symmetric from -1 to 1, however, the partition of AV should be according to process knowledge. The number of membership functions for each variable can vary depending upon the resolution required for that variable. Generally speaking, more membership functions offer more degrees of freedom to the functional relationship of the controller; however, it requires more effort to implement.

Rule Definition

A general fuzzy inference rule for the two region fuzzy controller can be described as follows:

If AV is A_i and e is B_i and Δe is C_i

then make Δu D_i (5)

where A_i, B_i, C_i and D_i are adjectives for AV, e. Δe and Δu respectively. With a three- region fuzzy controller using 5 adjectives, the number of possible rules is 75. If the controller uses 7 adjectives, a total of 147 rules are resulted. Because more rules require more computing time and memory, it is recommended to reduce the number of rules without affecting the controller performance.

3. Application Of Two Region Flc To Two Capacity Nonlinear Interacting Process

The mathematical model of the two capacity interacting level process considered for study is expressed as

$$q_{in} - \beta_{12} a_{12} \sqrt{2g(h_1 - h_2)} = A_1 \frac{dh_1}{dt} \tag{6}$$

$$\beta_{12} a_{12} \sqrt{2g(h_1 - h_2)} - \beta_2 a_2 \sqrt{2gh2} = A_2 \frac{dh_2}{dt} \tag{7}$$

where β_{12}, a_{12}, A_1, A_2 are the outflow valve coefficients and areas of tank1 and tank2 respectively. q_{in}, h_1, h_2 are the inflow rate, levels of tank1 and tank2 respectively. g is the gravitational constant. The steady state operating conditions and parameters of the process are given in Table1 and 2 which are obtained from our laboratory two tank process test rig.[4]

Table : 1 Operating Conditions of the Process

h_1, cm	h_2, cm	q_{in}, lph
46.8	24.6	170

Table : 2 Parameters of the Process

A_1, A_2 ,m^2	β_{12}	β_2	a_{12}, a_2 ,m^2	g , m/sec^2
0.0154	1.0	0.9499	5e-5	9.81

4. Tuning Of Fuzzy Controllers

Tuning of the two region fuzzy controller includes 1) tuning of scaling factors, 2) tuning of fuzzy membership functions, 3) tuning of fuzzy rules and 4) tuning of AV membership functions for smooth regional transitions. The scaling factors should be tuned with first priority because they are global tuning parameters that affect the overall control performance. A membership function, which has an effect on one subset of rules, can be tuned secondly. Individual fuzzy rules should be tuned last because they affect only the local nonlinearity of the controller. A conventional PI controller that has the following form:

$$u(t) = k_p \left[e(t) + \frac{1}{T_i} \int e(t)dt \right] \tag{8}$$

Whereas its discrete form version is

$$\Delta u = k_p \left(\Delta e + \frac{\Delta t}{T_i} e \right) \tag{9}$$

one can easily see that k_p and T_i relate to the scaling factors through the following equations:

$$k_p = 0.5 \frac{s_{\Delta u}}{s_{\Delta e}} \tag{10}$$

$$T_i = \left(\frac{s_e}{s_{\Delta e}} \right) . \Delta t \tag{11}$$

where k_p is the proportional gain, T_i is the integral time and Δt is the sampling time. Therefore, if one wants to strengthen proportional action, one can either increase $s_{\Delta u}$ or decrease $s_{\Delta e}$. To strengthen the integral control action, one should either decrease se or increase sΔe because the small integral time represents strong integral control action.

5. Control Of A Two Capacity Interacting Nonlinear Level Process With Two Region Flc

The responses are compared with a conventional PI controller tuned about operating point of 50% and fuzzy logic controller. The time constant, dead time, damping ratio and gain of linearized model are 115.86 secs, 94 secs, 0.6985 and 1.447 respectively. The Haalman's method of tuning parameters for the linearized model are K_c=0.7722 and T_i=162.4419 secs.[5]

The simulation is carried out by taking 50% as nominal level. The two region FLC , single region FLC and the conventional PI controllers are implemented on the two capacity interacting nonlinear level process through simulation and the respective servo and regulatory responses are obtained. Further, the robustness of the two regions FLC is tested by obtaining the servo and regulatory responses for operating points of 35% and 70% when the controller tuned at 50% nominal level. The Integral Square Error (ISE) values are computed and shown in Tables II-1V. It is observed from Fig 4. that for a 10% increase in load at nominal operating point 50% (refer to Fig.4) show that the two region FLC provides an improved performance. Also ISE value has reduced drastically almost 41% less than that for a conventional PI controller and 15% less than that for a single region FLC.

Table : 3 ISE of Regulatory Responses for 10% Increase in Load

Operating point	Convent PI	Single region FLC	Two region FLC
50%	823500	700700	489100
35%	754321	609400	397800
70%	947700	823925	612200

Regulatory responses for a 15% increase in load at nominal operating point 35% (refer to Fig.5) show that the proposed two region FLC provides an improved response (47% lesser ISE) compared with the conventional PI controller.

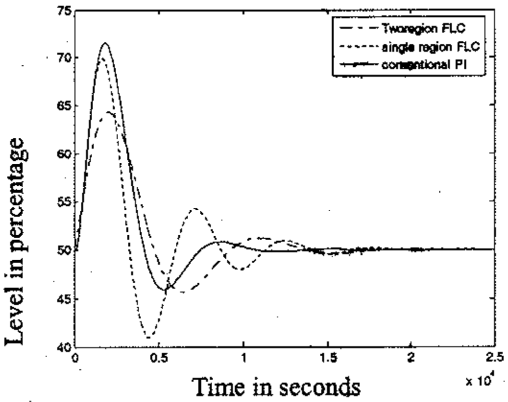

Figure 4 : Regulatory responses for a 10% increase in load at 50% nominal operating point.

Table : 4 ISE of Regulatory Responses for 15% Increase in Load

Operating point	Convent PI	Single region FLC	Two region FLC
50%	1853000	1577000	1005000
35%	1552590	1306780	835800
70%	2023659	1707980	1227000

Regulatory responses for a 15% increase in load at 70% operating point but tuned at 50% (refer to Table -IV) show that the proposed two region FLC provides a better response (40% lesser ISE) than the single region FLC and 16% lesser ISE than the conventional PI controller.

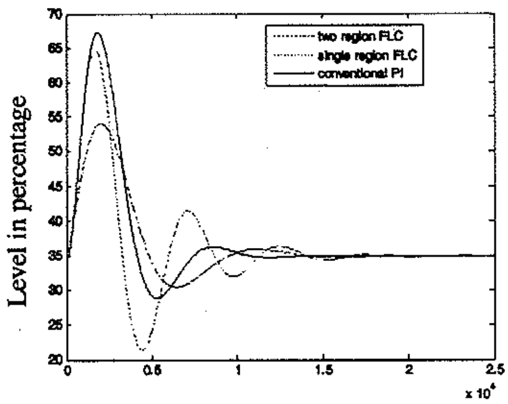

Figure 5 : Regulatory Responses For A 15% Increase In Load At 35% Nominal Operating Point.

Regulatory responses for a 10% decrease in load at 35% operating point but tuned at 50% (refer to Fig.6) show that the proposed two region FLC provides a better performance (77% lesser ISE) than the conventional PI controller.

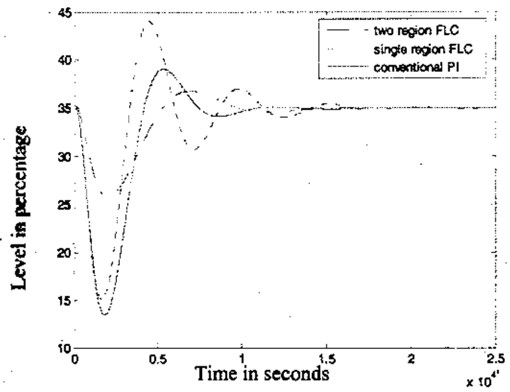

Figure 6 : Regulatory Responses For A 10% Decrease In Load At 35% Nominal Operating Point.

Servo responses for a 10% increase in set point at 50% operating point (refer to Fig.7) show that the proposed controller provides a better performance (31% lesser ISE) than the conventional PI controller and 22% lesser ISE than the single region FLC.

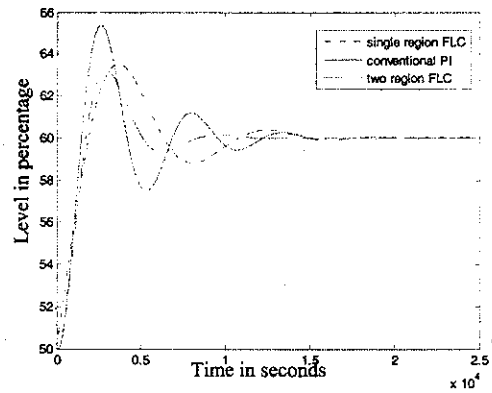

Figure 7 : Servo Responses For A 10% Increase In Set Point At 50% Nominal Point

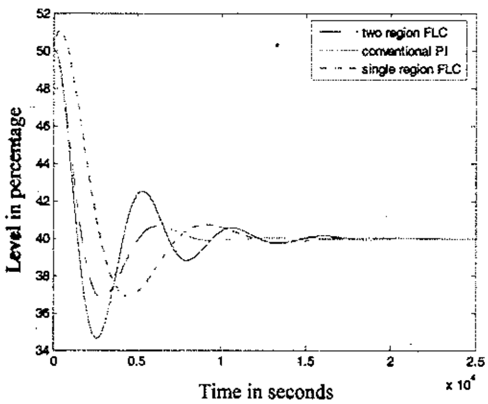

Figure 8 : Servo Responses For A 10% Decrease In Set Point At 50% Nominal Operating Point.

Servo responses for a 10% increase in set point at 35% operating point but tuned at 50% (refer to Fig.9) show that the proposed controller provides a better performance (31% lesser ISE) than the conventional PI controller.

Table : 5 ISE of Servo Responses for 10% Increase in Set point

Operating point	Conven PI	FLC	Two region FLC
50%	126630	99780	87980
35%	120900	94050	84170
70%	132889	106430	95630

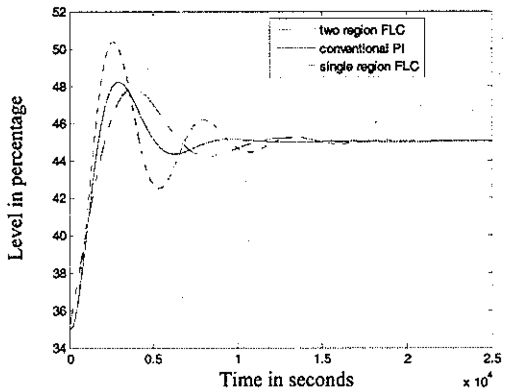

Figure 9 : Servo Responses for a 10% increase in set point at 35% nominal operating point.

6. Conclusion

A two region fuzzy logic controller is designed for a two capacity interacting nonlinear level process. The performances are compared with the conventional PI controller and single region fuzzy controller. The conventional PI controller and single region fuzzy logic controller gives oscillatory response for decrease in set point even at a nominal operating point. The situation becomes worse when the operating point is shifted to 70%.

The simulation results show the robustness of the two region fuzzy logic controller. The proposed controller outperforms the conventional PI and single region fuzzy controller when the operating point of the process is shifted over the entire span of the tank.

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