Real-time Implementation and Performance Analysis of Two Dimension PID Fuzzy Controller for Continuous Stirred Tank Reactor

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Abstract— **Tuning the parameters of a controller is very important in system performance. Ziegler and Nichols tuning method is simple and cannot guarantee to be effective always. In order to overcome the parameter uncertainties, enhance the fast tracking performance of a process system, a brand-new two-dimension PID fuzzy controller, fuzzy PI+ fuzzy ID, is proposed in this paper. The self-tuning fuzzy PI+ fuzzy ID controller is fast; computing on-line easily and can reduce stability error. To demonstrate the advantages of the fuzzy PI+ fuzzy ID controller, has been applied to an application in the control of Continuous Stirred Tank Reactor (CSTR) level loop. The simulation and real-time implementation were executed and its results show that the proposed control scheme not only enhances the fast tracking performance, but also increases the robustness of the system. From the simulation it is clear that there is substantial improvement in the Self-tuning Fuzzy PID controller in terms of peak overshoot, settling time, peak time, rise time, Integral Square Error (ISE) and Integral Absolute Error (IAE).**

Keywords- ***PID Controller; Fuzzy Logic Controller, Self tuning controller; CSTR ;ISE;IAE.***

I. INTRODUCTION

Process control is of vital importance in the operation of chemical, pharmaceutical, power plant, paper and bleach processes. Chemical process present many challenging control problems due to their nonlinear dynamic behavior and time varying parameters, constraints on manipulated variable, interaction between manipulated and controlled variables, unmeasured and frequent disturbances, dead time on input and measurements. Because of the inherent nonlinearity, most of the chemical process industries are in need of traditional control techniques. 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 the system that are structurally difficult to model. 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 nonlinear 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. Nonlinear tanks are used in many process industries as storage of cryogenic liquids, fuels and other liquids also as surge tanks and find wide application in gas plants. Control of a level in a tank is important, because the change in shape gives rise to the nonlinearity. Fuzzy logic has gained great attention in the area of process control due to its ability to incorporate human intuition in the design process. Three- dimensional fuzzy controller [2] which has a good control effect and performance, needs great capacity in computing, and is not suitable for on-line transaction for the design sophisticates. Self-organized fuzzy controller with neural network demands large quantity of training time. The parameters affecting its control effect primarily include gain factor, scaling factor and proportion factor, and in a two dimensional fuzzy controller these factors are usually fixed.

When the model or parameters of the object are changed, two dimensional fuzzy controller [3] can’t self-tune and the control performance becomes bad. So it needs to seek a kind of controller which has self-tuning function. For above reasons the paper puts forward a kind of controller of which factors can be self-adjusted according to the status and adopt a load observer to observe load torque. In order to evaluate the performance of the fuzzy PI+PD controller the paper adopts the ITAE index [4], rules of the fuzzy controller analysis born. The de-fuzzy method is based on centroid together with phase surface [5]. There are several types of control systems that use FLC as an essential system component. The majority of applications during the past two decades belong to the class of fuzzy PID controllers. Several forms of decomposed proportional-integral- derivative fuzzy logic controllers (fuzzy P + fuzzy I + fuzzy D form, fuzzy PD + fuzzy I form, fuzzy PI + conventional D form, fuzzy P + conventional ID form and fuzzy PI + fuzzy PD form) have been tested and compared [1]. To obtain simple structures, the activities of the proportional, integral and derivative parts of the fuzzy PID controller are defined with simple rules in proportional rule base, integral rule base and derivative rule base.

The analysis, design and simulation of the proposed self-tuning fuzzy PI+ fuzzy ID controller are described. The self-tuning fuzzy PI+ fuzzy ID controller is fast, computing on-line easily and can reduce stability error. Good control performance, both in the command-tracking and parameters robust of the level process, is achieved. This paper is organized in the following manner. In Section II, the experimental setup is described. In Section III & IV, self-tuning fuzzy PI+ fuzzy ID control scheme is presented. To verify the methodology, computer simulations and the discussions are provided in Section V. A brief conclusion is outlined in Section V & VI.

II. EXPERIMENTAL SETUP

Figure. 1 Real-time CSTR Plant

Figure 1 show the real time experimental setup of a CSTR Plant. The plant consists of a tank, a water reservoir, pump, Rota meter, a differential pressure transmitter, an electro pneumatic converter (I/P converter), and a pneumatic control valve with positioner, an interfacing module (DAQ) and a Personal Computer (PC). The differential pressure transmitter output is interfaced with computer using data acquisition RS232 port of the PC.

A pump discharging the water from the reservoir and it flows through the rotameter and electro pneumatic positioner. The accumulation of the liquid in the tank is known as level of the tank. The level of the water in the tank is measured by means of the pressure transmitter and is transmitted in the form of current signal (4-20 mA) to the interfacing module & hence to the PC. PC is acting as an error detector as well as controller. After computing the control algorithm in the PC, control signal is transmitted to I/P converter in the form of current signal (4-20 mA) is used to actuate the electro pneumatic positioner to control the valve opening. It controls the flow of the fluid in pipeline by varying stem position of the valve opening. For maintaining the level of the process tank, flow is manipulated and rotameter visualizes the flow of the fluid in the pipe line.

The mathematical model of CSTR tank system is obtained using System identification method. For fixed input water flow rate and output water flow rate of the CSTR tank, the tank is allowed to fill with water up to 500mm. At each sample time the data from differential pressure transmitter is being collected and fed to the system through interfacing module.

III. STRUCTURE OF CONTROLLERS

A. Coventional PID Controller

The general expression of traditional PID controller can be stated as:

$$u(t) = Kpe(t) + Ki \int e(\tau)d\tau + Kd\, de(t)/dt \qquad (1)$$

The structure of PID controller is shown in Fig.2, where the error value e is the deviation of input and feedback values. The controller regulates the output according to the PID parameters.

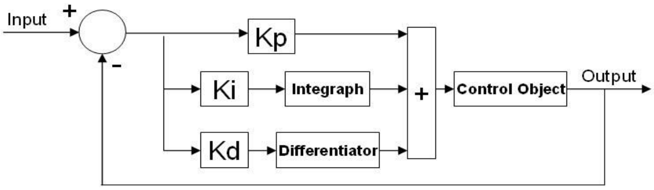

Figure.2 Block diagram of PID controller

Conventional linear PID controller signals in digital form can be represented by three controller actions with respect to the error response. The incremental controller output signal can be found by taking

$$u(n) = u(n-1) + \Delta u(n) \qquad (2)$$

$$\Delta u(n) = Kp * \Delta e(n) + Ki * Ts\, \Delta e(n) + \left(\frac{Kd}{Ts}\right)\Delta^2 e(n) \qquad (3)$$

The error state variables are defined as,

$$\left.\begin{aligned} e(n) &= r(n) - y(n) \\ \Delta e(n) &= e(n) - e(n-1) \\ \Delta^2 e(n) &= \Delta e(n) - \Delta e(n-1) \end{aligned}\right\} \qquad (4)$$

T_S - sampling time, $r(n)$ - desired response, $y(n)$ - actual plant response, n - sampling instance (at time t=0, n=0, $\Delta e(0)$=0), K_P, K_D and K_I are Proportional, Derivative and Integral constants related to a linear PID controller. $e(n)$-error, $\Delta e(n)$-error change, $\Delta^2 e(n)$-rate of error change. According to the Eq. (2), we can make up of the next structure.

$$\left.\begin{aligned} u(n) &= u(n-1) + \Delta u1(n) + \Delta u2(n) \\ \Delta u1(n) &= Kp * \Delta e(n) + \frac{Kd}{2Ts}\Delta^2 e(n) \\ \Delta u2(n) &= Ki * Ts * \Delta e(n) + \frac{Kd}{2Ts}\Delta^2 e(n) \end{aligned}\right\} \qquad (5)$$

B. Self-Tuning Fuzzy PD+Fuzzy ID Controller

Based on the Eq. (5), a new PID fuzzy controller, which are composed of fuzzy PD controller FC1 and fuzzy ID controller FC2, namely incremental fuzzy PD+ fuzzy ID, is designed. $r(kt)$ the reference signal, $y(kt)$ the process output, input variables, including error $e(kt)$, change of error $ec(kt)$, rate of change of error $ed(kt)$, $\Delta u(kt)$ the output variables. G_I (gain for error) is the input scalar for $e(kt)$, G_P (gain for error change) the input scalar for $ec(kt)$, G_D (gain for rate of error change) the input scalar for $ed(kt)$ and G_U (gain for controller output) the output scalar of the FLC.

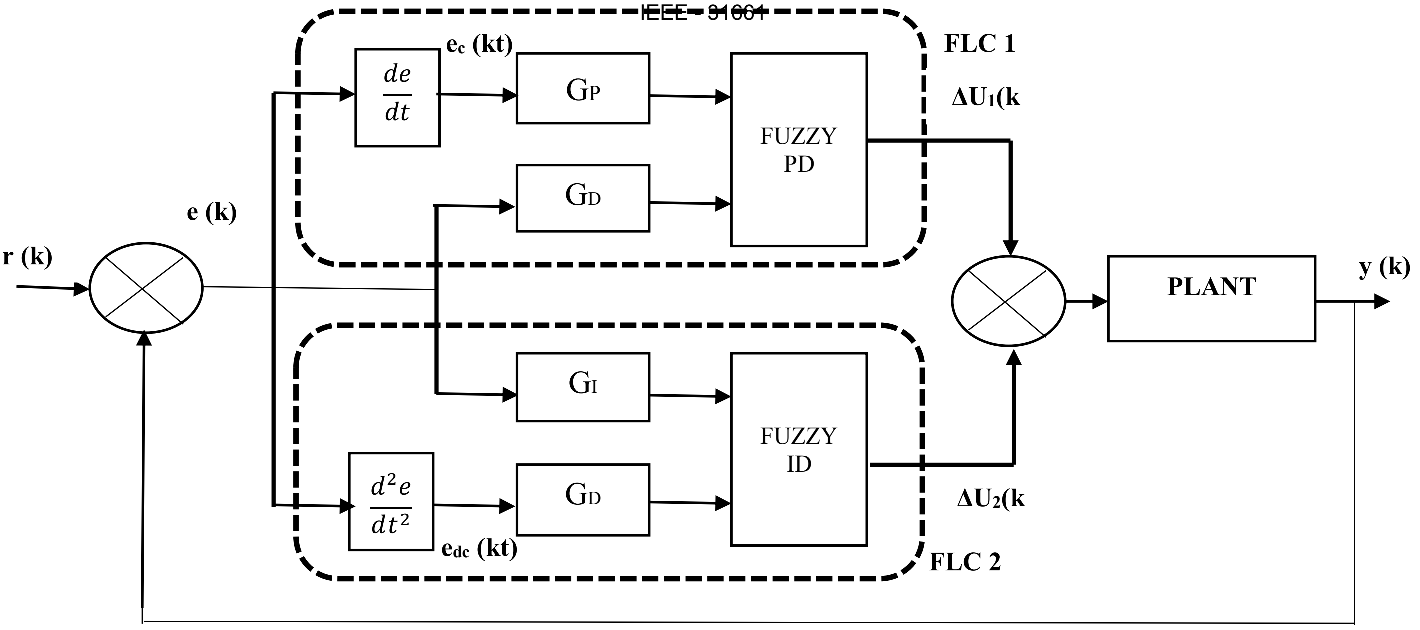

Figure. 3 Block diagram of Two dimension Fuzzy PID Controller

IV. DEVELOPMENT OF SELF TUNING FUZZY PD+FUZZY ID CONTROLLER

A. Input Stage and Fuzzification

The incremental fuzzy PD+ fuzzy ID controller employs three inputs: error $e(kt)$, change of error $ec(kt)$ and rate of change of error $ed(kt)$.The inputs times the input scalars G_P, G_I, G_D, they can express below. The fuzzy set error $e(kt)$, the scaled change of error $ec(kt)$ and the scaled rate of change of error $ed(kt)$' has seven members PB(Positive Big), PM(Positive Medium), PS(Positive Small), Z(Zero), NS(Negative Small), NM(Negative Medium), NB(Negative Big). The scaled error $e(kt)$, the scaled change of error $ec(kt)$ and the scaled rate of change of error $ed(kt)$ are within the range $[-L,L]$ of the fuzzification algorithm shown in Fig.2.

$$\left.\begin{aligned} Gi * e(kt) &= Gi * (r(kt) - y(kt)) \\ Gp * \ ec(kt) &= Gp * (e(kt) - e(k-1)t))/T \\ Gd * ec(kt) &= Gd * (ec(kt) - ec(k-1)t))/T \end{aligned}\right\} \quad (6)$$

B. ouput Stage and Fuzzification

The incremental fuzzy PD+ fuzzy ID controller has two outputs, called the incremental control outputs and are denoted by $\Delta u_1(kt)$, $\Delta u_2(kt)$. The fuzzy set 'output1' and 'output2' has three members P(output positive), Z(output zero) and N(output negative) for the fuzzification of the incremental outputs of fuzzy control FC1 and FC2.

The out of the incremental fuzzy PD+ fuzzy ID controller:

$$\Delta u(kt) = Gu1 * u1(kt) + Gu2 * u2(kt) \qquad (7)$$

C. Fuzzy Rule Base

The control structure of the 49 control rules are established for the fuzzy PD controller (FC1) shown in the table 1. Using the aforementioned membership functions, the following control rules are established for the fuzzy PD controller (FC1).

TABLE I. OUTPUT**Δu_1(kt)** FUZZY CONTROL RULE TABLE

Δu_1(kt)		$G_I * e(kt)$						
		PB	***PM***	***PS***	***Z***	***NS***	***NM***	***NB***
$G_P * ec(kt)$	***NB***	Z	Z	NM	NM	PB	PB	PB
	NM	PS	Z	NS	NS	PM	PB	PB
	NS	PM	PS	Z	Z	PS	PM	PB
	Z	PB	PM	PS	Z	PS	PM	PB
	PS	PB	PM	PS	Z	Z	PS	PM
	PM	PB	PB	PM	NS	NS	Z	PS
	PB	PB	PB	PB	NM	NM	Z	Z

The control structure of the 49 control rules are established for the fuzzy ID controller (FC2) shown in the table 2.Using the aforementioned membership functions, the following control rules are established for the fuzzy ID controller (FC2).

TABLE II. OUTPUT Δ **u_2(kt)** FUZZY CONTROL RULE TABLE

Δ u_2(kt)		$G_I * e(kt)$						
		NB	***NM***	***NS***	***Z***	***PS***	***PM***	***PB***
$G_D * ed(kt)$	***NB***	PB	PM	PB	PB	PB	Z	NB
	NM	PM	PS	PM	PM	PM	NS	NB
	NS	PS	Z	PS	PS	PS	NM	NM
	PS	NM	NB	PS	PS	PS	Z	PS
	PM	NB	NS	PM	PM	PM	PS	PM
	PB	NB	Z	PB	PB	PB	PM	PB

V. RESULTS AND DISCUSSIONS

A. Using MATLAB Simulink

In order to verify the performance of proposed controller and make a comparative study with PID controller, a CSTR level process was chosen.

The plant was initially simulated using MATLAB Simulink software for PID and Proposed Fuzzy PID Controller. Before experimenting it in real-time, software simulation was preferred in order to have easy troubleshooting and to prevent damage of the plant in case of unexpected results.

The system was identified and found to be:

$$G(S) = \frac{0.011863s+0.00184055}{s+0.00231489} \qquad (8)$$

In this section, computer simulations of CSTR Plant (level loop) using the proposed self-tuning fuzzy PI+ fuzzy ID control scheme are performed. Performance comparisons between the proposed method and the conventional scheme are executed.

For investigating the effectiveness of the proposed controllers, two kinds of uncertainties, servo tracking and disturbance rejection are considered here. According to the above cases, simulation results are given here. The simulation results with the adaptive fuzzy PI+ Fuzzy ID controller are shown in Fig.4. The robust control performance of the proposed controller, both in command tracking and load regulation, are obvious. The curve (blue) represents the simulation result with the proposed adaptive fuzzy PI+ fuzzy ID controller. The curve (red) represents the simulation result of Fuzzy control.

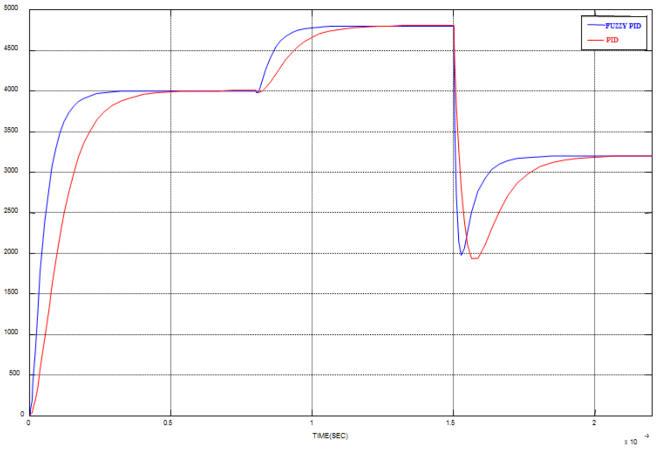

Figure. 4 Comparison controller response of CSTR plant

B. Using LabVIEW

Virtual instrumentation combines mainstream commercial technologies such as PC with flexible software and wide variety of measurement and hardware. National Instruments LabVIEW- a premier Virtual Instrumentation graphical development environment uses symbolic or graphical representation to speed up development. Consolidating functions with rapidly deployed graphical blocks further speeds up development.

The PID and Proposed controller were implemented through LabVIEW 8.6. As a part of real-time implementation, a loop (level) of CSTR setup is interfaced to the developed virtual PID environment through DAQ (Data Acquisition) card which provides interface between the input/output and the system. The output of the system is given to the control valve which is the final control element for controlling the level inside the tank. Both the input from the level transmitter and the output to the final control element corresponds to (1-5) V.

Coding is done in the LabVIEW for the proposed design without using any inbuilt functions present in LabVIEW.

Figure. 5 shows the Servo-Regulatory response of PID controller for the CSTR liquid level process. A set-point of 125 mm was given at the zeroth instant and after the system settled, the set-point was varied to 150 mm. After the system settled at 150 mm, a disturbance was applied by varying the outflow of the tank from 50% (initial value) to 70% (final value).

The process output was found to deviate from the set-point, takes a long time to settle and has much offset.

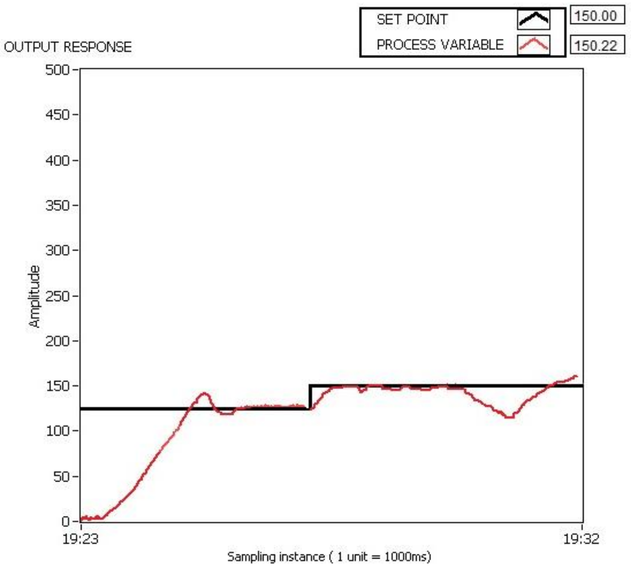

Figure. 5 Servo-regulatory response of PID

Figure. 6 shows the servo-regulatory response of proposed controller for a CSTR liquid level process. The set-point and disturbance settings are same as in the previous case. The process output was found to stay much closer to the set-point and settles much faster.

The improvement of the responses with the augmentation of the adaptive fuzzy PI+ Fuzzy ID controller is also obvious. The CSTR level loop based on proposed adaptive fuzzy PI+ fuzzy ID controller shows good results for the operation against the servo tracking and the load disturbance.

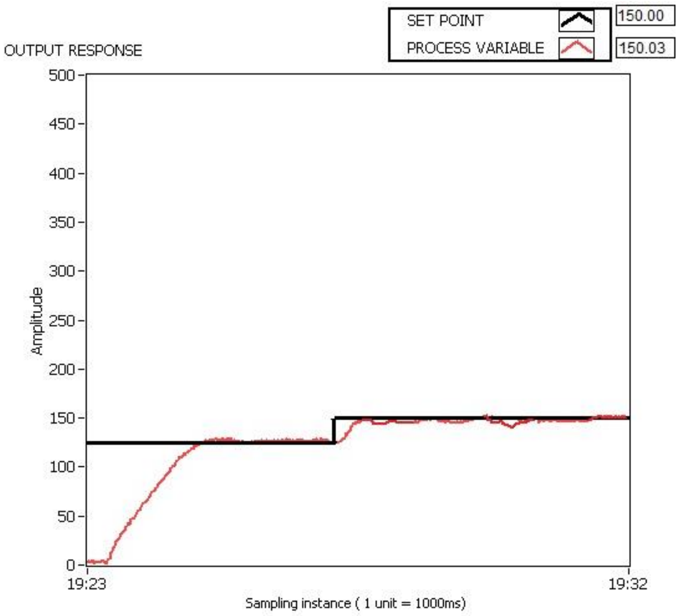

Figure. 6 Servo-regulatory response of Proposed Controller

The performances of controllers are also examined using ISE and IAE. ISE and IAE value for Fuzzy PD + Fuzzy PI controller is less compared to PID in all the operating regions. The performance indices in terms of ISE and IAE for servo and regulatory response are also shown in table 3.

TABLE III. PERFORMANCE INDEX PARAMETERS FOR PID AND PROPOSED CONTROLLER

	PID CONTROLLER		FUZZY PD+FUZZY ID CONTROLLER	
	SERVO RESPONSE	REGULATORY RESPONSE	SERVO RESPONSE	REGULATORY RESPONSE
ITAE	1.86121E+9	6.00948E+9	6.0209E+8	5.2344E+8
IAE	2.67801E+7	2.77830E+8	876000	889510
ISE	3.52133E+9	3.00434E+8	3.9585E+5	8.42166E+5

VI. CONCLUSION

The adaptive self-tuning fuzzy PI+ fuzzy ID controller is fast, computing on-line easily and can reduce stability error. The simulation results show that the proposed control scheme not only enhances the fast tracking performance, but also increases the robustness of the process plant. Thus Fuzzy PID can be applied not only to precise process control, as its results shows it can be applied to obtain control with precision in various other applications like Medical robotics, Industrial Testing and measurements.

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