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Performance Comparison of De-Centralized Controllers in Twin Tank Interacting System

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Abstract**—***Most of the problems faced by a traditional controller can be solved by the use of intelligent control schemes. This paper is a comparison between conventional Proportional and Integral (PI), Derivative (PID) controller using Cohen-Coon(C-C) tuning method and Fuzzy Logic Controller. Above mentioned controllers are applied to a control system bench mark Twin Tank Process. Simulation of the process and the above controllers are obtained from MATLAB. Proposed controller's performance is supported with better tracking, disturbance rejection and performance indices in terms of Integral Time Absolute Error (ITAE), Integral Absolute Error (IAE) Integral Square Error (ISE).*

Index Terms—Non-linear, two tank interacting process, PID, Fuzzy control

I. INTRODUCTION

Most of the chemical process industries require the proper control of liquid level and flow for their proper functioning. Industrial control problems are difficult to control since they depend on various parameters resulting in interactions among the loops [1, 2]. Any sort of deviations may result in serious impacts which result in big losses. Liquids will be processed by chemical or mixing treatment in the tanks, but the level of fluid in the tanks must be controlled and the flow between tanks must be regulated in the presence of nonlinearity and inexact model description of the plant [3]. Due to the easiness in installation and reasonable robustness, PI controllers are popular in industrial applications. But these controller will not give satisfactory results for non-linear processes [4].

Intelligent control schemes are therefore preferred for the better dynamic performance and strong robustness of this two tank interacting system with non-linearity and interactions [7]. Fuzzy Logic Controller is such an intelligent scheme well suited for the Level Control in a two tank Interacting process for which the conventional controllers are not providing satisfactory results [13, 14]. This technology has emerged as one of the best nonlinear control technology in industrial applications. It has got greater applications in areas related on universal approximations, where the human knowledge and this logical inferences together produce best results [6, 8].

The PID and FLC controllers are designed and the simulation results for servo and regulatory responses are presented in this paper. Performance analysis was made based on the tracking error, disturbance rejection and performance indices in terms of Integral Time Absolute Error (ITAE), Integral Absolute Error (IAE) Integral Square Error (ISE).

This paper is further organized as follows. Section II describes about the system while section III describes about the system modelling. It also describes about the Relative Gain Array (RGA) analysis of the system to know the degree of interaction present in the system, as well as the design of decouplers to minimize this interaction. Section IV discusses about the controller design where both PID and Fuzzy controllers were designed. Simulation results are compared in section V and finally conclusions are made on section VI.

II. SYSTEM DESCRIPTION

The coupled interacting tank apparatus used in the work is shown in the figure below. The tank system is a model with a pump, two cylindrical tanks of same size and cross sectional area, two control valves, and two level transmitters .The two tanks are installed in a manner as shown in the figure 1. Input flow to both tanks are provided with two separate pumps whose outlets are throttled using control valves. Disturbances to the system are introduced by using separate hand valves.

The two tanks are connected by means of hand valve, so, there exists the interactions between the two tanks. The level of first tank will affect the second and that of second will affect the first tank. This Two

Tank system is one of the most commonly available systems which represent a coupled Multiple Input Multiple Output (MIMO) system.

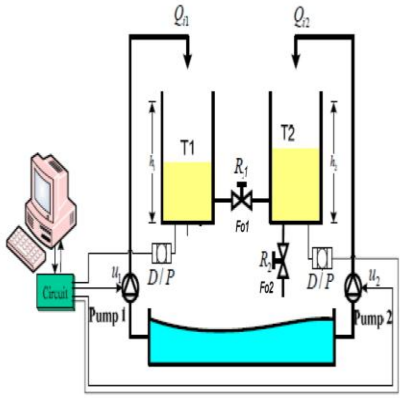

Fig.1 Two tank interacting system

It have two inputs and two outputs. It is of greater difficulty to control level of such a multivariable coupled tank system because this multivariable coupling causes interaction in the two subsidiary tanks. A de-coupler is therefore designed to minimize this interaction effect between the two loops and thus render two non-interacting control loops. The cross coupling effects have been affected to the system. In order to avoid the cross coupling effects decoupling is done in the case of multi input multi output system. Water will flow in either of the two directions, depending upon the present level in the two tanks.

III. MATHEMATICAL MODELLING

A. Modelling of the two tank system

Consider the process as shown in the schematic figure 2, there are two tanks with cross sectional areas A_1 and A_2 respectively. There are two separate inputs fin1and fin2 to each tank which is throttled using control valves. Outputs of the tanks are fout1and fout2 respectively. The levels h1 and h2 represents the liquid levels of the two tanks.

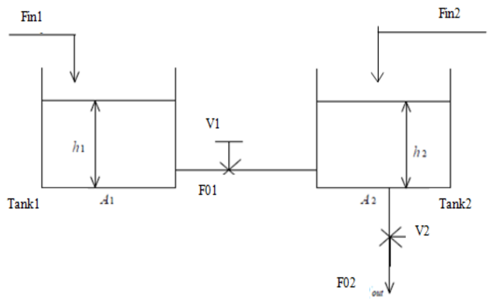

Fig. 2. Two tank Interacting system schematic diagram

The overall material balance on the cylindrical tank is:

Rate of mass accumulation in the system =

Rate of mass entering in the system-Rate of mass leaving the system

There for the dynamics of the tank system can be written as

$$A_1 \frac{dh_1}{dt} = F_{in1} - F_{out1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$A_2 \frac{dh_2}{dt} = F_{in2} + F_{out1} - F_{out2} \quad \ldots\ldots\ldots (2)$$

By Bernoulli's equation for a non-viscous incompressible fluid in steady flow,

$$F_{out1} = b_1\sqrt{h_1 - h_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$F_{out2} = b_2\sqrt{h_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where b_1 and b_2 are proportionality constants which depends on the coefficient of discharge (coefficient of connecting pipes) s, cross sectional area of connecting pipes a, and gravitational constants, ie; $b_1 = s_1 a_1 \sqrt{2}$ g and $b_2 = s_2 a_2 \sqrt{2}$ g.

Substituting we obtain the final equations in non linear form as

$$A_1 \frac{dh_1}{dt} = F_{in1} - b_1\sqrt{h_1 - h_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$A_2 \frac{dh_2}{dt} = F_{in2} + b_1\sqrt{h_1 - h_2} - b_2\sqrt{h_2} \quad \ldots. (6)$$

If the operating point is known and does not change quite often then it is convenient to linearize the system obtained above. This makes the process significantly simpler and model works well in a region chosen around the operating point.

The nonlinear equations are linearized by Jacobian method to obtain the state space parameters A, B, C and D.

Numerical values are obtained [3] as b_1 = 2.2, b_2 = 1.9, h_1 = 4, h_2 = 3.5, A_1 = 0.1963m^2 and A_2 = 0.159m^2 .

The open loop transfer function matrix is calculated and given in equation 7.

$$G(s) = \begin{bmatrix} \frac{5.093s+66.056}{s^2+20.89s+25.26} & \frac{49.81}{s^2+20.89s+25.26} \\ \frac{49.81}{s^2+20.89s+25.26} & \frac{6.288s+49.81}{s^2+20.89s+25.26} \end{bmatrix} \quad \ldots (7)$$

B. Modelling of decouplers

The theoretically modeled system is as shown above .G11(s) represents the dynamics of tank 1 and G22(s) represents the dynamics of tank 2.The effect of tank 1

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on tank 2 is given by G21(s) and the effect of tank 2 on tank 1 is given by G12(s).This coupled tank system is having high interaction and it also exhibits nonlinear characteristics. Because of the interaction between processes, the control design needs the decoupling controllers to minimize the cross coupling effects. The purpose of using decoupler is to decouple the multivariable system.

In ideal decoupling procedure, decoupler elements on the diagonals are taken as 1.

$$D = \begin{bmatrix} 1 & D12 \\ D21 & 1 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

Also off diagonal elements of G*D=0,

Substituting the values,

$$D_{12} = \frac{-49.81}{5.093s+66.056} \quad \& \quad D_{21} = \frac{-49.81}{6.28s+49.81} \quad \ldots. (9)$$

C. Analysis of the system

Relative Gain Array (RGA) analysis is useful to obtain intensity of process interaction based on the open-loop gains. RGA elements should possess positive values and closeness to unity shows best pairing with most minimal interactions. Thus the relative gain array for a 2 × 2 system can be expressed as Λ, which is calculated as $G(0)*G(0)^{-T}$. RGA matrix indicates that the output-input pairings should be fout1-fin1 and fout2-fin2.

$$\lambda = \begin{bmatrix} 0.8234 & 0.1766 \\ 0.1766 & 0.8234 \end{bmatrix}$$

D. Open loop Response of the system

Figure.3 shown below is the simulated open loop responses of both tanks. The level of tank 2 changes from 0 to 34 cm, when applying a step input of 10 cm, also the level of tank 1 changes from 0 to 52 cm due to interaction when a step of 20 cm is applied. This response shows the need of a proper controller for the accurate control of the process.

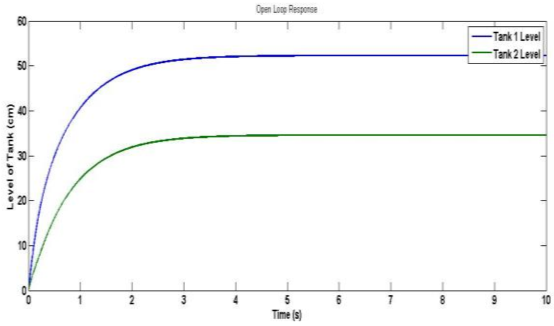

Fig. 3. Open loop response of the two tanks

IV. CONTROLLER DESIGN

The open loop behavior of the process shown in fig. 3 above shows the need of a proper controller design for the accurate control of the process. The most commonly used controller in the industries are the PID type controller. So whenever we introduce a modern intelligent controller, it has to be compared with our existing conventional PID controller.

A. PID Controller

The acronym PID, stands for Proportio-Integro-Differential control. Among these, the P, the I and the D are terms in a control algorithm, and each one have a special purpose. The combinational control of PI, PD, PID, or just P can be made possible as a control scheme but it is very rare to use an ID control. The PID controller contains all three of the most important controller structures in a single package. The transfer function model of the controller is as shown below.

$$C(s) = K_P + \frac{K_I}{s} + K_d s$$
$$= K_P\left(1 + \frac{1}{T_I s} + T_d s\right)$$

Where Kp = Proportional Gain, Ki = Integral Gain, Ti= Reset Time =Kp/Ki, Kd = Derivative gain, Td = Rate time or derivative time.

In this paper Cohen Coon tuning method which gives better response than Ziegler Nichol's tuning method has been used for modelling a PID controller and is compared with the advanced Fuzzy intelligent controller.

- Cohen-Coon Tuning Method

This technique is an open loop tuning technique in which the control action is removed from the controller by placing it in manual mode and a step change in the signal to the valve is used to induce an open loop transient. It was proposed by Cohen and Coon and is often used as an alternative to the Z-N method.

TABLE I. COHEN-COON TUNING RULES

Controller Type	Proportional gain(Kp)	Integral time (Ti)	Integral gain(Ki)	Derivative time (Td)	Derivative gain(Kd)
P	$\frac{\tau}{K.td}[1+\frac{td}{3\tau}]$				
PI	$\frac{\tau}{K.td}[0.9+\frac{td}{12\tau}]$	$td\,[\frac{30+\frac{3td}{\tau}}{9+\frac{20td}{\tau}}]$	Kp/Ti		
PID	$\frac{\tau}{K.td}[\frac{4}{3}+\frac{td}{4\tau}]$	$td\,[\frac{32+\frac{6td}{\tau}}{13+\frac{8td}{\tau}}]$	Kp/Ti	$td\,[\frac{4}{11+\frac{3td}{\tau}}]$	Kp* Td

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TABLE II. PID CONTROLLER SETTINGS FOR TWO-TANK INTERACTING PROCESS

PID MODE PARAMETERS FOR TANK 1			PID MODE PARAMETERS FOR TANK 2		
Kc	Ti	Td	Kc	Ti	Td
5.194	0.329	0.049	3.937	0.313	0.185

Table I and Table II, represents the Cohen Coon tuning rules and parameters obtained by mathematical calculations respectively. By knowing the parameters, a de-centralized PID Controller as shown in figure 4 was designed for the control of our twin tank interacting system.

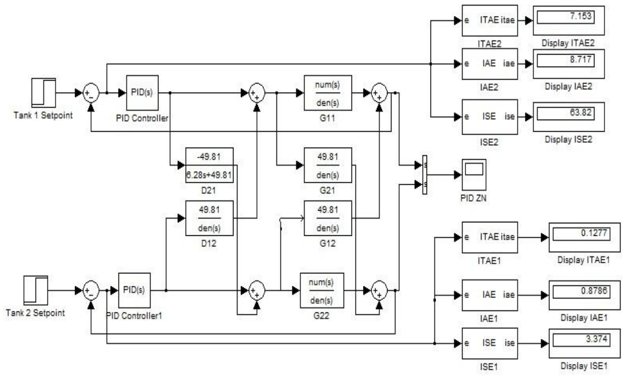

Fig. 4. Simulink block diagram of De-centralized PID Controller

B. Fuzzy Controller

The conventional control scheme, which includes the classical feedback control had faced many problems in their applications. The design as well as the analysis of traditional control systems depends on their precise mathematical models, which are normally very difficult to achieve due to the complexity, nonlinearity, time varying and incomplete characteristics of the existing practical systems. To eradicate such problems, it is convenient to use the technique of intelligent control system and intelligent control techniques.

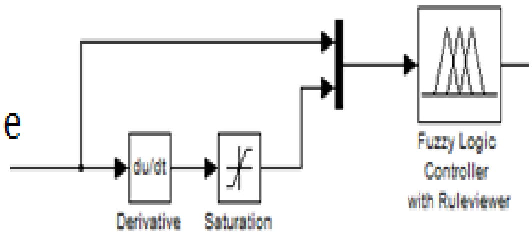

Fig.5. Fuzzy Controller

An option for use of such an intelligent controller in nonlinear complex environment is the fuzzy controller. The above figure 5 shows how a fuzzy controller is implemented. The controller takes two input and have one output, error and rate of change of error are given as input to the fuzzy controller, and depending on the input the fuzzy controller produces required control action. For all input and output triangular membership functions are used. The Fuzzy logic controller based on the mamdani fuzzy inference model has following steps, namely, fuzzification, fuzzy rule base and defuzzification. Simulink block diagram of a de-centralized fuzzy controller is shown in figure 6 below.

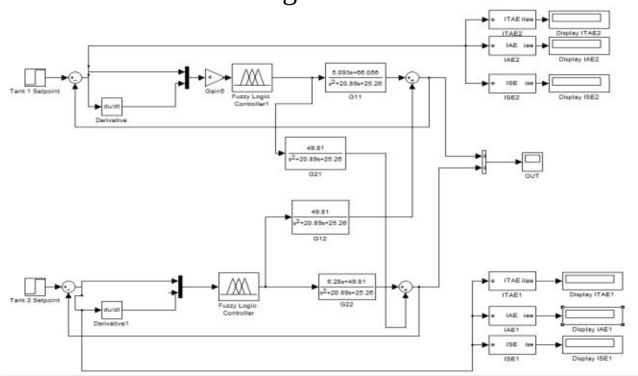

Fig. 6. Simulink block diagram of De-centralized Fuzzy Controller

Inputs and Output variables of the fuzzy controller is set with the knowledge and assumptions about the working of the system in various conditions. It is shown in figure 7 below.

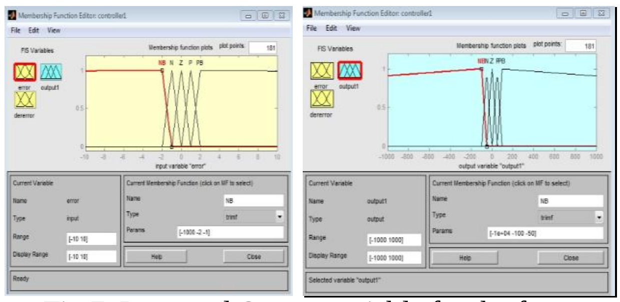

Fig.7. Input and Output variable for the fuzzy controller

The fuzzy rules represent the degree of knowledge and abilities of human who adjusts the system for the least error and faster response. The rules are obtained based on the frequent checking of the output response. The fuzzy rules used in this two tank system is shown in figure 8.

de / Error	NB	N	Z	P	PB
NB	NB	NB	N	N	Z
N	NB	N	N	Z	P
Z	N	N	Z	P	P
P	N	Z	P	P	PB
PB	Z	P	P	PB	PB

Fig. 8. Fuzzy Rule base

V. SIMULATION RESULTS

A. *Servo Response*

Simulation result below compares the set point tracking for level h1 and h2 respectively with CC-PID and fuzzy controllers**.** Initial step of 8 cm was maintained for first 30 seconds. A step increase of +2 cm was given after 30 seconds for tank1 (h1) and after 30 cm another decrease of 1 cm was given and the output was monitored for tank 1 level and is shown in figure 9 below.

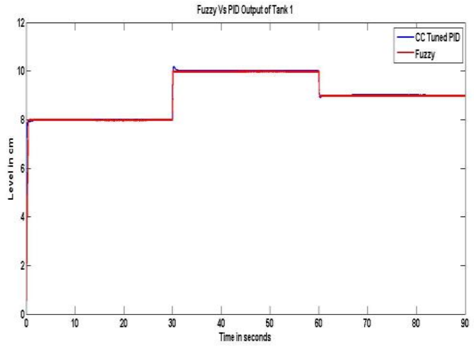

Fig. 9. Servo Response for tank 1 level

A similar action was given for tank 2 (h2) and the response obtained is shown below in figure 10, where from an initial set point of 5cm, an increase of +2cm was given after 30 seconds and after another 30 seconds a decrease of 1 cm was given and the tracking response was obtained.

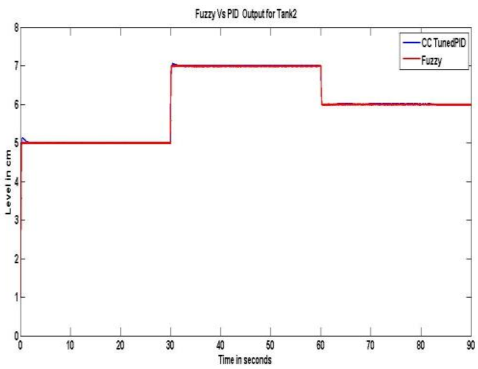

Fig. 10. Servo Response for tank 2 level

B. *Regulatory Response*

A sudden load disturbance of +10% is given in inlet flow rate of tank1 and tank2 after 45 seconds and responses are obtained as shown in figures below. Due to this level increase of +10%, from 10 to 11 cm (referring Figure 11), controllers takes necessary action to reduce the flow rate, and returns to the initial set point value sooner.

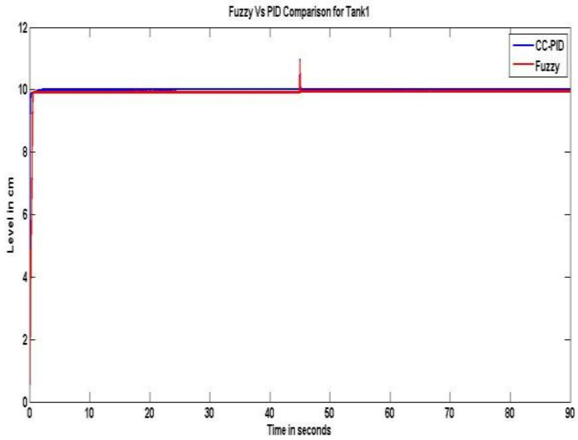

Fig. 11. Regulatory Response for tank 1 level

A similar load change or disturbance was introduced for tank 2 also. The response comparison is shown in figure 12 below.

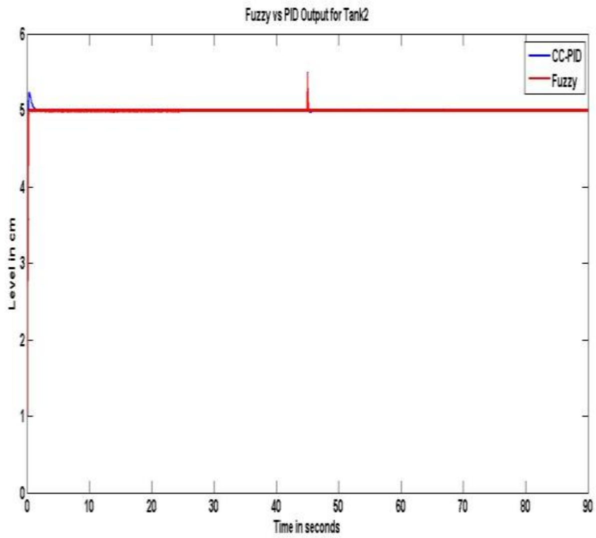

Fig. 12. Regulatory Response for tank 2 level

A comparison of performance of CC tuned PID and fuzzy controllers are given in Table III in terms of ISE, IAE and ITAE. It can be observed that settling time and peak overshoot of fuzzy is lesser than the conventional PID. Similarly disturbance rejection is more effective in fuzzy than other controller. Also performance indices are lower in fuzzy compared to response of PID.

TABLE III. PERFORMANCE INDICES OF CONTROLLERS

Controller	Performance measures					
	Tank 1 (h1)			Tank 2 (h2)		
	IAE	ISE	ITAE	IAE	ISE	ITAE
PI(CC)	7.045	34.86	122.9	4.618	10.92	91.38
PID(CC)	7.693	24.947	70.95	2.097	4.784	19.49
FUZZY	2.774	10.35	18.36	1.22	2.04	13.64

VI. CONCLUSION

De-centralized fuzzy controller is developed to control the level of two tank interacting process. The controller results are compared with that of decentralized PID for servo and regulatory responses. From the servo response it can be concluded that the system settles faster and from regulatory response the disturbance rejection is faster in Fuzzy controller.

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