

Implementation of Fuzzy-PID Controller to Liquid Level System using LabVIEW

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Abstract—The paper describes about the liquid level control system which is commonly used in many process control applications. The output of the level process is non-linear and it is converted into the linear form by using Taylor Series method. The aim of the process is to keep the liquid level in the tank at the desired value. The conventional proportional-integral-derivative (PID) controller is simple, reliable and eliminates the steady state error. Fuzzy logic controllers are rule based systems which are logical model of the human behavior of the process. The fuzzy controller is combined with the PID controller and then applied to the tank level control system. This paper compares the transient response as well as error indices of PID, fuzzy, fuzzy-PID controllers. The responses of the fuzzy-PID controller are verified through simulation. From the simulation results, it is observed that fuzzy-PID controller gives the superior performance than the other controllers. The absolute error of fuzzy-PID controller is 56.6% less than PID controller and 55.6% less than the fuzzy controller. The LabVIEW software is used to simulate the system. The simulated results validate the method implemented here.

Keywords—Proportional-integral-derivative (PID) controller, Fuzzy system, fuzzy-PID controller, Linearization

I. INTRODUCTION

The control of liquid level in tanks and flow between tanks is a basic problem in the process industries. The process industries require liquids to be pumped as well as stored in tanks and then pumped to another tank. Many times the liquids will be processed by chemical or mixing treatment [1] in the tanks, but always the level of fluid in the tanks must be controlled and the flow between tanks must be regulated. Tank level control systems are used frequently in different processes. All of the process industries, pharmaceutical industries, petrochemical plants, food/beverage industries and nuclear power plants depend upon tank level control systems. It is essential for control system engineers to understand how tank control systems work and how the level control problem is solved. Most of the control performances in the actual design are usually defined by overshoots, rising time, settling time, steady state error etc.

The conventional control which includes the classical feedback control, modern control theory and large-scale control system theory has encountered many difficulties in its application [2]. The design and analysis of conventional control systems are based on their mathematical models, which are usually very difficult to achieve. Proportional-Integral-

Derivative (PID) controller is the simple, reliable and accurate used in industrial feedback control loops. The performance analysis of PID controller has been discussed in [3-5]. But, PID controller can't be used to control the complex system to get the better performance. One of the most effective ways to solve the problem is to use the techniques of intelligent control system or hybrid combinations of the conventional and intelligent control techniques. Fuzzy controller is one of the intelligent controllers, which is a logical model of the human behavior of the process operator. The fuzzy controller gives the better performance than those of the conventional controllers in terms of settling time, response time, overshoot and robustness. A fuzzy-based level control using SCADA has been implemented to a tank in [6]. Now-a-days, fuzzy logic and conventional techniques have been combined for getting more desirable performances. The combined controllers can provide better control performances than the conventional PID controller alone. T. Tani [7] has implemented neuro-fuzzy hybrid control system to a tank in petroleum industry to control the tank level of a solvent dewaxing plant. The formulation of a hybrid controller and analysis of control performances have been presented by H. Ying [9]. The bounded-input/bounded output stability of fuzzy PD and fuzzy PI+fuzzy D control systems have analysed in [10] and [11]. The system is more stable when fuzzy PD and fuzzy PI+fuzzy D controller are used than the PID controller. A new design approach for hybrid fuzzy P+ID controller has proposed based on sufficient stability conditions in [12]. Many of the methods involve cumbersome calculations. Many works have been described to make the closed loop response faster while they do not reduce overshoot and settling time of closed loop responses satisfactorily.

In this paper, fuzzy-PID controller is designed and applied to the liquid level system. The accuracy of the controller in liquid level system is affected by the system order, system parameters and the control algorithm. A control algorithm is the mathematical representation of the control action to be performed. The control algorithm is difficult to design for complex processes. The fuzzy controller is used to make the system fast and stable, but cannot eliminate the steady state error [7]. However, the conventional PID controller is simple, accurate and reliable which eliminates the steady state error [3]. Therefore, the fuzzy controller is combined with the PID controller and the combined controller has to take the advantages of both PID and fuzzy controller. Then, the combined controller is applied to the tank level control system to control the level of liquid in tank.

This paper is organized as follows. Section II describes the general formulation of the tank level system model. In section III, the controllers such as PID, fuzzy and fuzzy-PID controllers are described. Section IV presents the simulations of the tank level process. Section V shows the simulation results and describes about the responses of the tank level process as well as compares the transient response of the process. Finally, the conclusion is given in Section VI.

II. GENERAL FORMULATION OF THE SYSTEM MODEL

The tank system [1-2] is shown in Fig. 1. In the figure, q_{in} is the input into the tank where as h is the output level for the tank system.

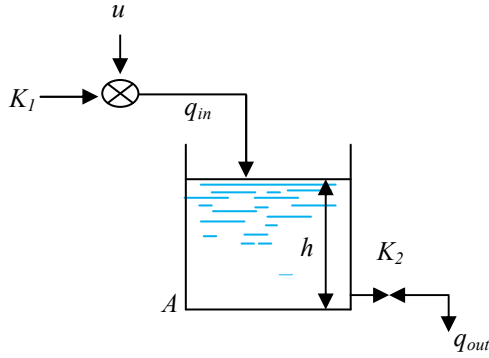


Fig. 1. Single input single output tank system

For simulating the single input single output (SISO) tank system, its mathematical model [1] can be developed. The system is designed according to the mathematical model. For developing the mathematical model for SISO tank system, the density of liquid in the inlet, in the outlet and in the tank is assumed to be same and also the tank has straight vertical walls.

The notations used in modeling the SISO tank system are

- q_{in} = Inlet volumetric flow rate [cm^3/sec]
- q_{out} = Outlet volumetric flow rate [cm^3/sec]
- h = Height of liquid in the tank [cm]
- ρ = Liquid density [gm/cm^3]
- A = Cross sectional area of the tank [cm^2]

The mathematical model of the tank system is derived using the Mass balance equation as

$$\frac{dm(t)}{dt} = \rho q_{in}(t) - \rho q_{out}(t) \quad (1)$$

$$\Rightarrow \frac{dh(t)}{dt} = \left(\frac{1}{A}\right) \times [K_1 w(t) - K_2 \sqrt{\rho g h(t)}] \quad (2)$$

The SISO tank system is designed according to the model in (2). The mathematical block diagram for the model in (2) is shown in the Fig. 2.

Equation (2) is nonlinear due to the presence of square root term. The equation can be linearized by using Taylor series which is

$$f(x) = f(x_0) + \left. \frac{df}{dx} \right|_{ss} \frac{(x-x_0)}{1!} + \left. \frac{d^2f}{dx^2} \right|_{ss} \frac{(x-x_0)^2}{2!} + \dots \quad (3)$$

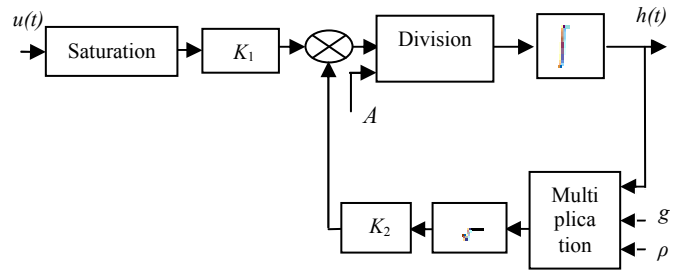


Fig. 2. Block diagram of tank system

In the Taylor series, the higher order terms except the first two terms are neglected. The linearized version of (2) using Taylor series expansion described in (3) is

$$A \frac{dH(t)}{dt} = Q_{in}(t) - C_2 H(t) \quad (4)$$

where $Q_{in}(t)$ and $H(t)$ are the deviation variables of $q_{in}(t)$ and $h(t)$ respectively.

If the process is initially at steady state, the inlet and outlet flow rates are equal. If the inlet volumetric flow rate is suddenly increased while the outlet volumetric flow rate remains constant, the liquid level in the tank will increase until the tank overflows. Similarly, if the outlet volumetric flow rate is increased while the inlet volumetric flow rate remains constant, the tank level will decrease until the tank is empty.

III. CONTROLLER DESIGN

The general form of PID controller is shown in Fig. 3. The error signal is the controller input and the actuator input is the controller output.

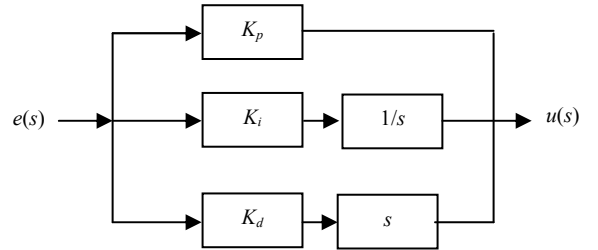


Fig. 3. Block diagram of PID Controller

The governing equation of PID controller is

$$m_{PID}(t) = K_p e(t) + K_p K_i \int e(t) dt + K_p K_d \frac{de(t)}{dt} \quad (5)$$

The PID controller output in terms of Laplace transform can be written as

$$M_{PID}(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) \quad (6)$$

Due to the simplicity and excellent performance, PID controllers are used in more than 95 % of closed-loop industrial processes for many applications. The PID controller can be tuned by using off-line control methods as well as on-line control methods. The control techniques of complex dynamic systems with nonlinear or time varying behavior are very difficult to determine the model of the process. Fuzzy controllers are able to summarize human knowledge of the system and integrate them to the laws of control.

Fuzzy logic deals with linguistic and imprecise rules based on expert's knowledge [7]. Fuzzy parameters of the membership functions have been determined by using fuzzy system designer (FSD) in LabVIEW. In fuzzy algorithm, triangular-shaped built-in membership functions have been used. The fuzzy controller has two input variables. The error $e(t)$ is the first input variable and the second input variable is the differential of $e(t)$. The output (y) of fuzzy controller is the control signal of the actuator. The fuzzy linguistic variables with FSD tools described by five membership functions are shown in Fig. 4. The fuzzy logic controller (FLC) accepts the input variables, matches them up with the linguistic variables and determines the appropriate output corresponding to the input variables. The fuzzy rule base consists of a collection of fuzzy IF-THEN rules.

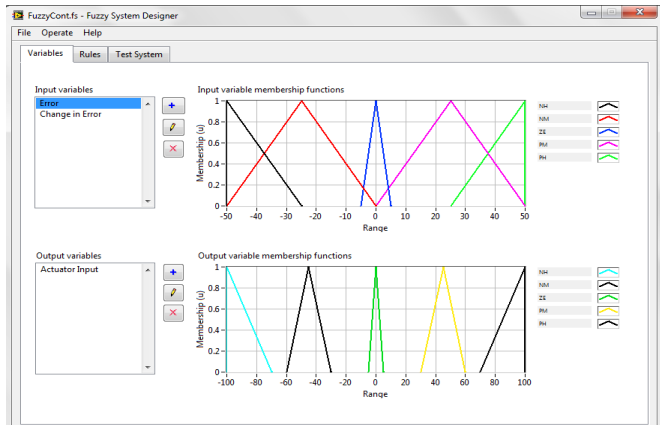


Fig. 4. Membership functions linguistic variables e , de/dt and y

Membership functions with linguistic values are described as Negative High (NH), Negative Medium (NM), Zero (ZE), Positive High (PH), Positive Medium (PM), respectively. Linear type output membership functions have been used in fuzzy rule base which has 25 fuzzy rules described in Table I.

TABLE I. SET OF FUZZY RULES

$e(t)$ \ de/dt	NH	NM	ZE	PM	PH
NH	NH	NH	NH	NM	ZE
NM	NH	NM	NM	ZE	PM
ZE	NH	NM	ZE	PM	PH
PM	NM	ZE	PM	PM	PH
PH	ZE	PM	PH	PH	PH

The input/ output relationship of the system is shown by the control surface in Fig. 5. It means that for every possible value of the two inputs, there is a corresponding output based on the rules. For example, if the error e and the changing rate of the error de/dt are given, the control output (actuator input) of the system can be obtained immediately. The input values of the error = 30.7487 and the change of rate of the error = 25.4011, the output is about 57.52. Here, only six rules are needed to calculate the output.

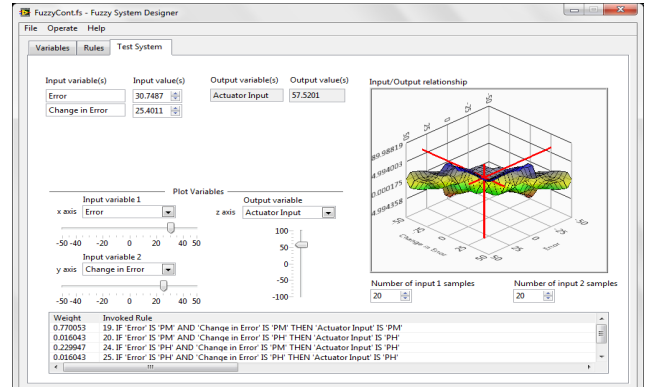


Fig. 5. Input/output relationship of the system

IV. SIMULATIONS

The nonlinear equation of $h(t)$ can be modelled using LabVIEW as shown in the Fig. 6. In the front panel of tank level process using LabVIEW, if the input flow q_{in} will change, the output level h changes accordingly. The liquid can come out from the tank through the valve.

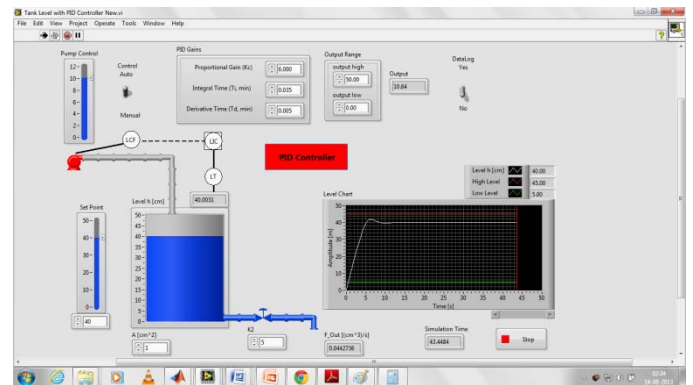


Fig. 6. Front panel of tank level process with PID controller

The area of cross-section of the tank can be represented as A . The level of the liquid has been measured through the level sensor. Then, the error is determined by the difference between the set value and process value of the level. The error signal has been applied to the PID controller. The output of PID controller acts as the actuator signal or manipulated variable to the process. The manipulated variable has been applied to the process to control the flow of liquid into the tank. The level of liquid is controlled through the flow of liquid by PID controller.

The front panel of tank level process controlled by fuzzy-PID controller is described in Fig. 7. The level sensor is used to measure the level of the liquid in tank. The error signal and the differential of error signal are the two input variables to the fuzzy controller. The error and the differential of error are processed through a series of conditional statements as

IF Error is 'NH' and Change in Error Level is 'PH' THEN Actuator Input is 'ZE'.

The PID controller and the fuzzy controller output are combined and then, the combined output has been applied to the process to control the level of liquid in tank. The combined fuzzy-PID controller gives the better performance than the conventional PID and fuzzy controller.

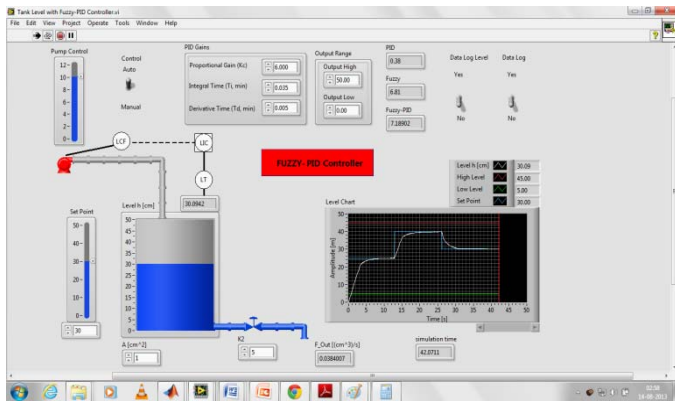


Fig. 7. Front panel of tank level process with Fuzzy-PID controller

V. RESULTS AND DISCUSSION

The PID controller is tuned by Ziegler- Nichols tuning method, where the proportional gain $K_p = 6$, integral time $T_i = 0.035$ and derivative time $T_d = 0.005$. Fig. 8 (a) represents the response of the PID controller which has overshoot of 5.07 %, settling time of 9.464 sec and rise time of 3.93 sec. The response of fuzzy controller is shown in Fig. 8 (b). The overshoot, settling time, rise time in case of fuzzy controller

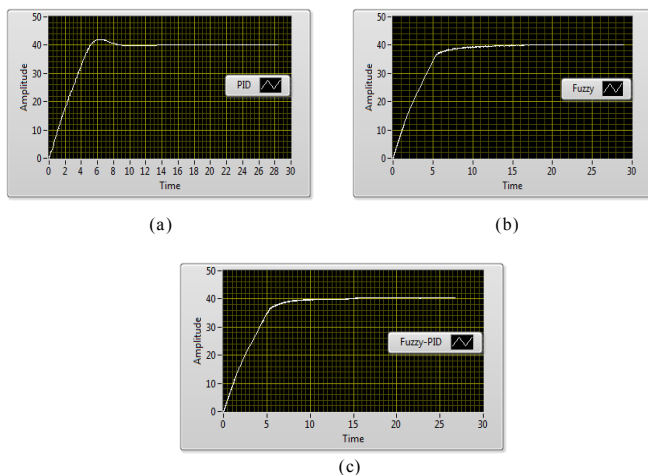


Fig. 8. Response of (a) PID controller, (b) fuzzy controller and (c) fuzzy-PID controller

are 0.58 %, 13.324 sec and 4.93 sec respectively. Similarly, the response of fuzzy-PID controller is shown in Fig. 8 (c). It has overshoot of 0.12 %, settling time of 8.935 sec and rise time of 4.84 sec respectively.

The combined transient response of PID, fuzzy and fuzzy-PID controller is presented in Fig. 9. The fuzzy-PID controller gives better performance than the PID and fuzzy controller in terms of overshoot and settling time.

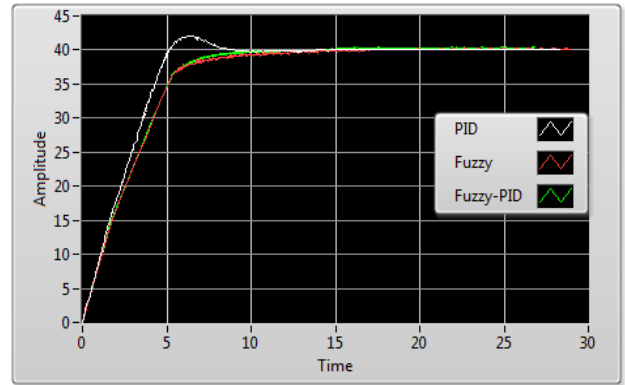


Fig. 9. Response of PID controller, fuzzy controller and fuzzy-PID controller

The comparison of transient responses such as overshoot, settling time and rise time for the different controllers are shown in Table II. From the table, it is observed that the fuzzy-PID controller shows superior performance in terms of percentage overshoot and settling time in comparison to the conventional PID controller as well as fuzzy controller. The fuzzy-PID controller has 97.6 % less than PID controller and 79.3 % less than fuzzy controller in terms of overshoot. Similarly, the settling time is also 5.6 % and 32.9 % less than that of PID and fuzzy controller.

TABLE II. COMPARISON OF TRANSIENT RESPONSE OF DIFFERENT CONTROLLERS

Type	% Overshoot	Settling Time(Sec)	Rise Time(Sec)
PID	5.07	9.464	3.93
Fuzzy	0.58	13.324	4.93
Fuzzy-PID	0.12	8.935	4.84

The error indices such as integral absolute error (IAE), integral squared error (ISE), integral of time and absolute error (ITAE) and integral of time and squared error (ITSE) for PID controller, fuzzy controller and fuzzy-PID controller are compared in Table III. From the table, the absolute error of fuzzy-PID controller is 56.6 % less than PID controller and 55.6 % less than the fuzzy controller. The squared error is also 59.8 % less than that of PID and 49.5 % less than that of fuzzy controller in case of fuzzy-PID controller. Similarly, the ITAE and ITSE of fuzzy-PID controller are 76.1 % and 87.1 % less than PID controller. Again, the ITAE and ITSE of combined controller is 76.3 % and 85 % less than fuzzy controller.

TABLE III. COMPARISON OF ERROR INDICES OF DIFFERENT CONTROLLERS

Type	IAE	ISE	ITAE	ITSE
PID	14.2567	7.58474	269.265	94.2152
Fuzzy	13.9177	6.03541	271.908	81.5788
Fuzzy-PID	6.1738	3.049	64.3187	12.1986

In Fig.10, two rising and one falling level are shown. First of all the level has been set to 25 cm at $t = 0$ sec and 40 cm at $t = 15$ sec and then the level has been set down to 30 cm at $t = 30$ sec. From the figure, it can be seen that the fuzzy-PID controller gives the better result.

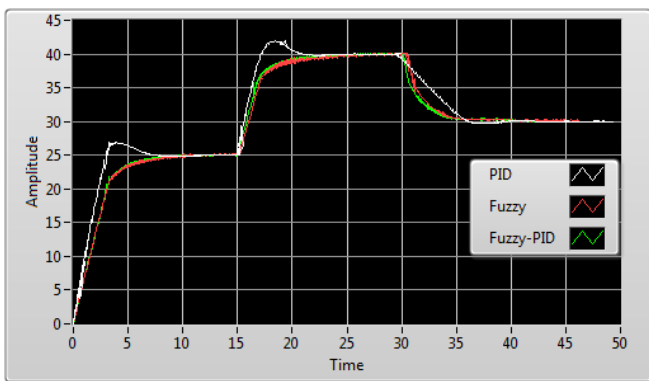


Fig. 10. Response of PID controller, fuzzy controller and fuzzy-PID controller

VI. CONCLUSION

This paper presents the control of the level in a single tank using different controllers such as PID, fuzzy and the combination of PID and fuzzy controller. Numerical simulation indicates that the fuzzy-PID controller has more advantages than the conventional PID and fuzzy controller. The fuzzy-PID controller has less overshoot, good robustness and low settling time. Also, it has a strong ability to adapt to

the changes of the system parameters and anti-disturbance performance. The controller efficiently tracks the set point. The fuzzy-PID controller gives better performance in terms of error indices such as IAE, ISE, ITAE and ITSE, respectively. The future scope of this work is the rejection of disturbance enters into the system as well as its real time implementation.

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