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Design of Fuzzy- PID Controller for First Order Non-Linear Liquid Level System

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Abstract : This paper deals with a controlling of first order non-linear liquid system to desired level. Mathematical model[1] of non- linear liquid level system is derived using basic principles of science. Different control strategies are applied on level system like conventional Proportional –Integral-derivative (PID) controller which gave unsatisfactory response when used alone. Fuzzy controller[2] was used ,which is based on set of empirical rules to meet the desired set-point .Fuzzy control worked better than PID control but there were several drawbacks of fuzzy controller which were addressed by combining the both the controllers and introducing that in level control loop. This paper compares the response of all three controllers-PID, Fuzzy and Fuzzy-PID[4] after simulation in LabVIEW[3]. Integral of Time-Weighted Absolute value of Error (ITAE) was calculated and it was found that for fuzzy-PID, value of ITAE was best. Fuzzy-PID control was best suited for non-linear liquid level system with water as the process liquid, as it had the best set point tracking, least oscillations and the value of ITAE was the least.

Keywords : PID,Fuzzy Controller, Fuzzy-PID and ITAE.

1. INTRODUCTION

Process control is an discipline that deals with algorithms for maintaining the output at desired range. It is extensively used in industry and enables mass production. Owing to its widespread use and applications, various control mechanisms are needed depending upon a number of factors related to the process which is used. Liquid level control is one of those processes which are widely used in petrochemical industries, pharmaceutical industries etc. It is necessary for engineers to understand the working of liquid-filled tank and find the means of regulating the level of tank at desired level. The response of system is characterized in terms of overshoot, rise time, peak time and Time-Integral performance criteria etc. The commonly used controller in a feedback loop is PID controller, whose performance is simple and reliable. The PID controller has three tunable parameters called as proportional, integral and derivative gain. The values of these gains must precisely give for the better performance of the control loop. The most popular tuning method used is Ziegler Nichols (Z-N) method. There are certain limitations of PID controller like performance with respect to non-linear systems is variable. In order to solve this problem hybrid controller was required, hence Fuzzy logic controller [2] was chosen. Fuzzy logic controller is an intelligent controller, which gives better robustness when compared with conventional PID controller. Fuzzy controller can be combined with conventional PID controller for the better performance.

In this paper, combination of PID and Fuzzy logic controller (fuzzy-PID) is designed and implemented on non-linear liquid level tank system. Fuzzy-PID controller[4] made system faster,reliable with low steady-state error value.

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2. MATHEMATICAL MODEL FOR A TANK SYSTEM AND PID CONTROLLER

The liquid system is shown in Figure 1.The equation parameters are defined as follows :

- $m(t)$ is mass of water
- ρ is density of water
- g is the gravitational constant
- $h(t)$ is the height of water in tank
- $q_{in}(t)$ is the inlet flow rate
- $q_{out}(t)$ is the outlet flow rate
- A is area of the tank(assumed to be 8 m^2
- K_u is the constant for intlet flow rate (assumed to be 0.75)
- K_v is the constant for outlet flow rate(assumed to be 0.65)

The following assumptions were made for modeling the system :

- The density of the liquid is same in the tank, in outlet and in inlet.
- The walls of the tank are vertical and straight.
- The mass and level of liquid are related as

$$m(t) = \rho A h(t)$$

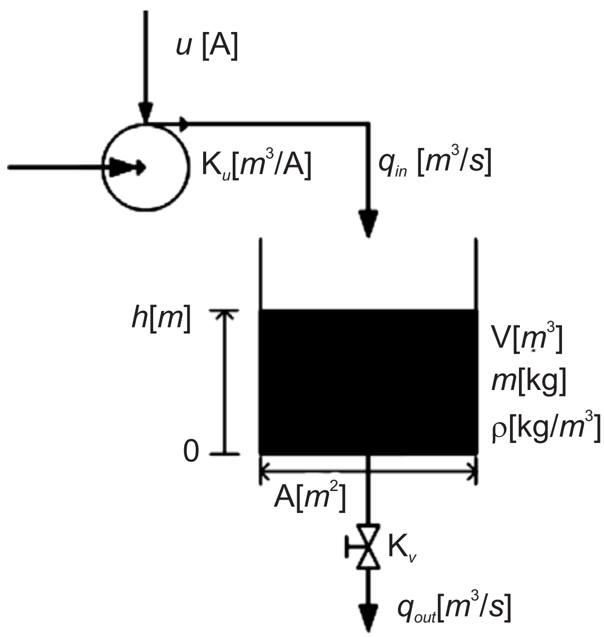

Figure 1: System model

- Using Mass Balance equation,

$$\frac{d}{dt}m(t) = \rho q_{\text{in}}(t) - \rho q_{\text{out}}(t)$$

where $q_{in}(t) = K_u u(t)$ and $q_{\text{out}}(t)\ K_v\sqrt{\rho g h(t)}$

Final equation is given below

$$\frac{d}{dt}h(t) = \frac{1}{A}\left\{K_u u(t) - K_v\sqrt{\rho g h(t)}\right\} \quad \text{.......................Equation1}$$

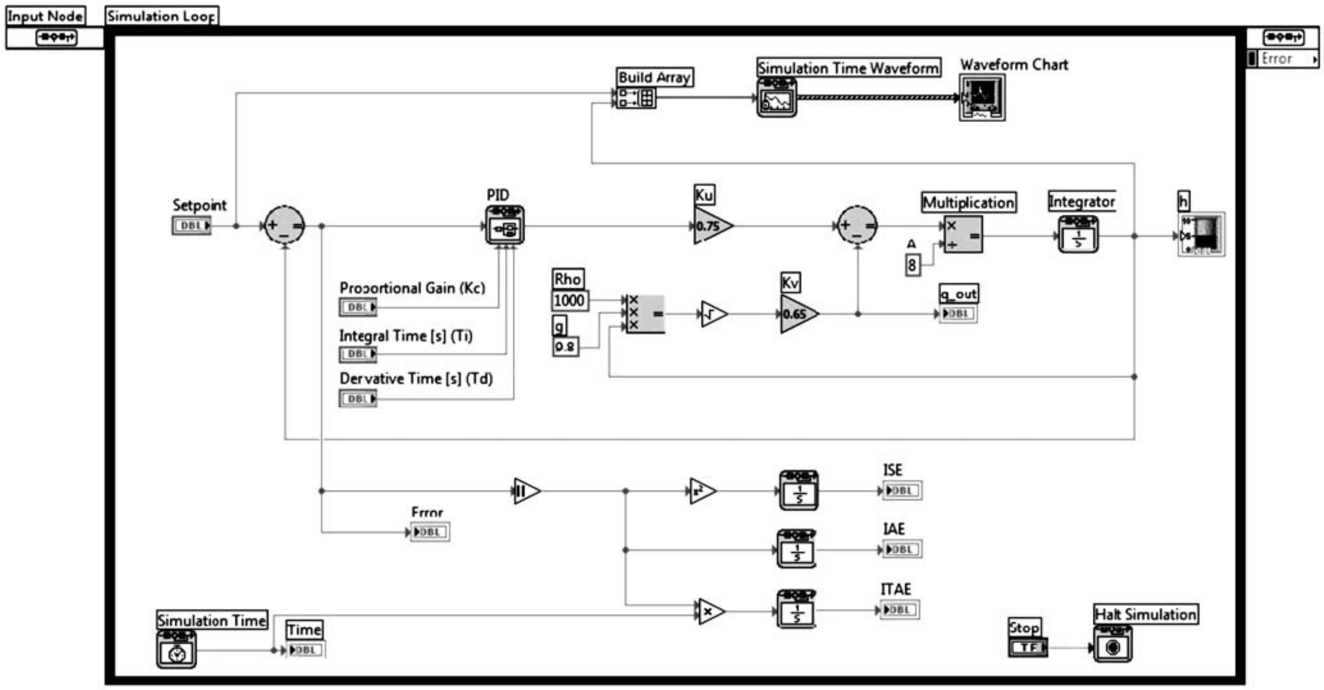

Figure 2 : LabVIEW implementation of PID control loop for tank system

PID controller is the simplest and the popular controller, which is widely used for controlling a close-loop system in industries. Inspite of its simplicity, it fails to give accurate output when used for tuning complex and non-linear systems.

The PID equation is given as: $$m(t) = k_p e(t) + k_p k_i \int e(t)dt + k_p k_d \frac{d}{dt} e(t)$$

where $m(t)$ is PID output equation.

Figure 1 shows the model of the tank and Figure 2 is the block diagram of liquid level system in LabVIEW. Equation (1) shows that the model derived is non-linear in nature. This non-linear model can be linearized using Taylor series expansion. Fuzzy-PID controller for a linearized model is been addressed in many papers.But in this paper we have used non-linear model for the simulations. Using the Ziegler-Nichols Tuning method, PID gains values were obtained. The values of proportional gain, integral gain and derivative gains are as follows:

- **Proportional gain:** 5.29
- **Integral gain:** 0.072sec
- **Derivative gain:** 0.01875sec

3. FUZZY CONTROLLER

For designing the Fuzzy Controller, triangular Membership Function (MF) is taken.

There are two inputs to the Fuzzy Controller – Error and Change in Error. There is one output of the Fuzzy Controller – Controller Output.Both the inputs and output were divided such that we have 7 Membership Functions for each input and output. In total, 49 rules were designed .The response of the controller is better when 49 rules were taken than compared to 25 rules[4].

Labels used for input –

NL – Negative Large , NM – Negative Medium, NS – Negative Small, Z – Zero, PS – Positive Small, PM – Positive Medium, PL – Positive Large

Labels used for output –

VVS – Very Very Small,VS – Very Small,S – Small,M – Medium,L – Large,
VL – Very Large,VVL – Very Very Large

Table 1

Rules for Fuzzy Controller

		Error						
		NL	*NM*	*NS*	*Z*	*PS*	*PM*	*PL*
Change In Error	NL	VVL	L	S	VVS	S	S	S
	NM	VL	L	VS	VVS	S	S	S
	NS	VL	M	VS	VVS	S	S	S
	Z	VL	M	VS	VVS	VS	M	VL
	PS	S	S	S	VVS	VS	M	VL
	PM	S	S	S	VVS	VS	L	VL
	PL	S	S	S	VVS	S	L	VVL

4. FUZZY-PID CONTROLLER

- There are two inputs to the Fuzzy Controller – Error and Change in Error. There are two outputs of the Fuzzy Controller – Proportional Gain and Integral Gain.

Table 2

Fuzzy rules for proportional gain

			Error						
			NL	*NM*	*NS*	*Z*	*PS*	*PM*	*PL*
Kp	**Change In Error**	NL	VVL	VL	L	M	M	M	M
		NM	VL	L	L	M	M	M	M
		NS	L	M	M	M	M	M	M
		Z	M	M	M	M	M	M	M
		PS	M	M	M	M	M	M	L
		PM	M	M	M	M	L	L	VL
		PL	M	M	M	M	L	VL	VVL

Table 3

Fuzzy rules for integral gain

			Error						
			NL	*NM*	*NS*	*Z*	*PS*	*PM*	*PL*
Ki	**Change In Error**	NL	VVS	VS	S	M	M	M	M
		NM	VS	S	S	M	M	M	M
		NS	S	M	M	M	M	M	M
		Z	M	M	M	M	M	M	M
		PS	M	M	M	M	M	M	S
		PM	M	M	M	M	S	S	VS
		PL	M	M	M	M	S	VS	VVS

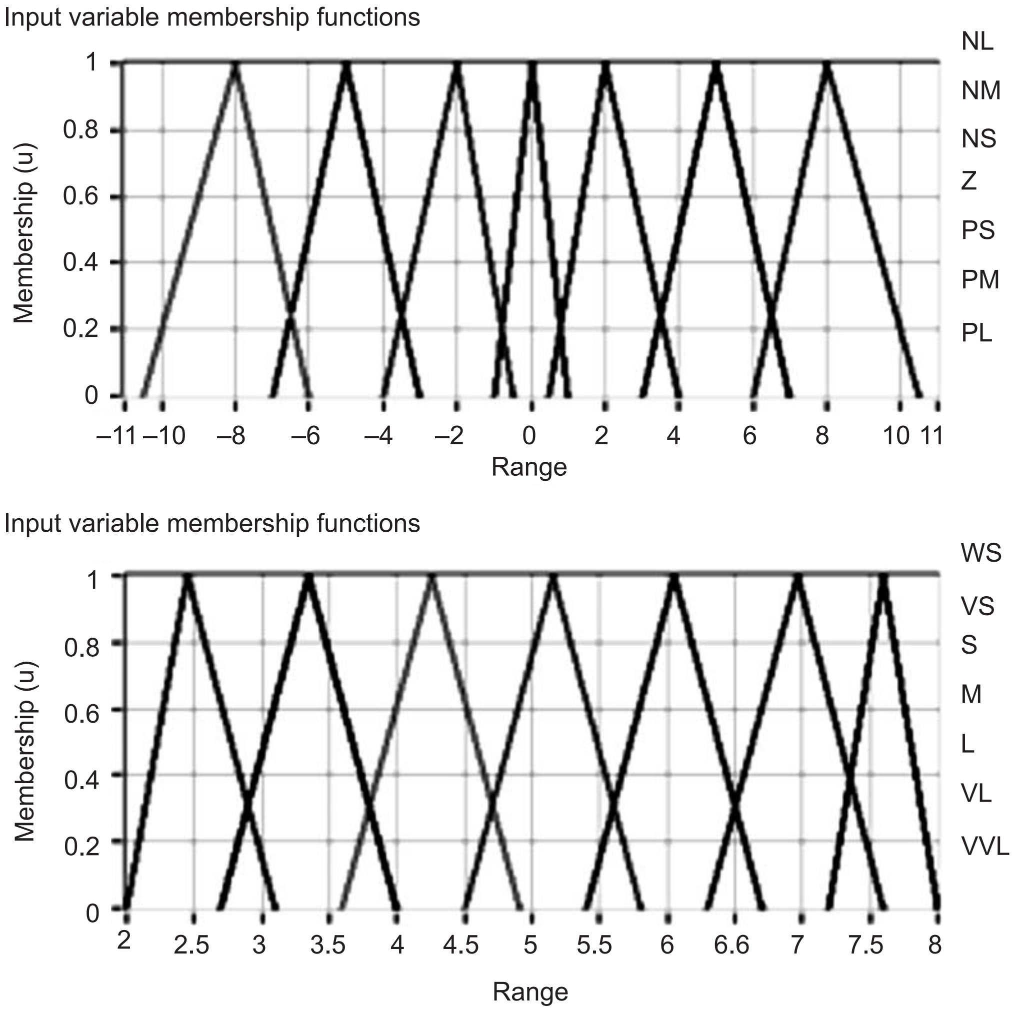

Figure 3: Fuzzy System Designer – Variables Tab – for Fuzzy-PID Controller

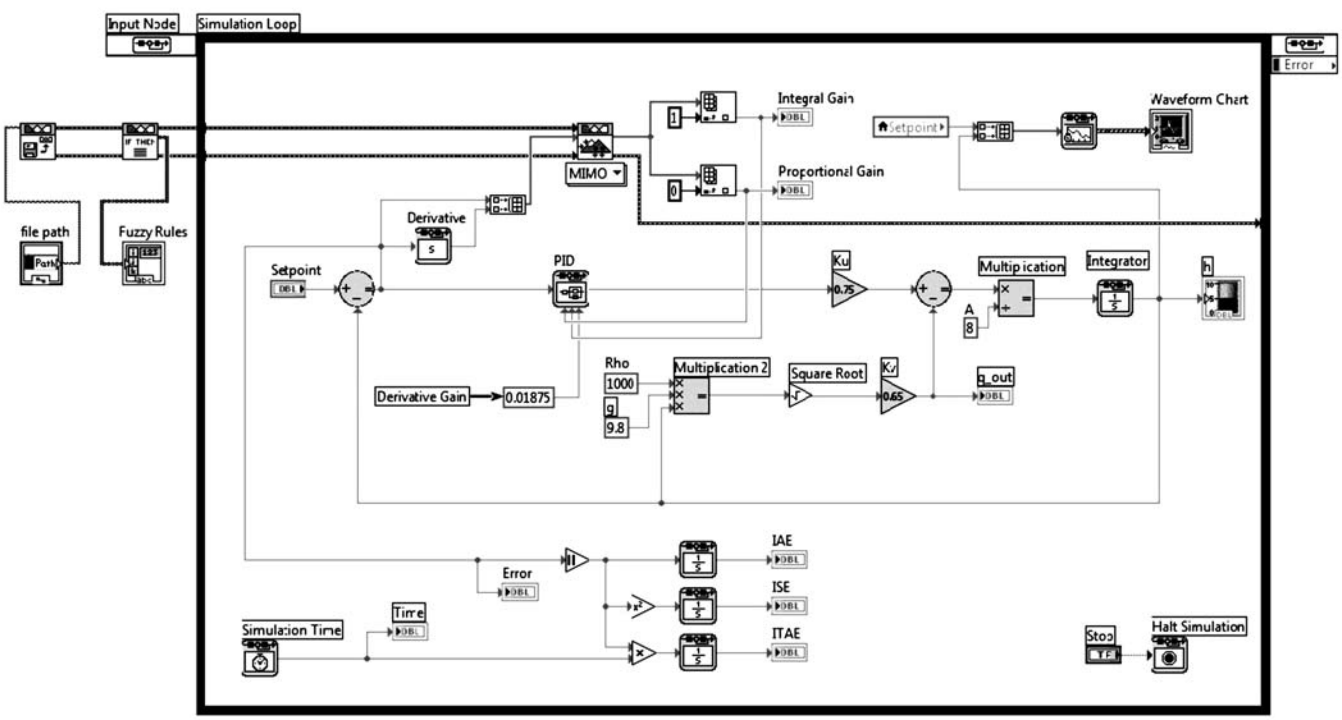

Figure 4: Block Diagram of Fuzzy-PID Controller

5. RESULT ANALYSIS

As it can be seen from the Figure 5, the set point is being tracked with almost zero error but there is an overshoot and undershoot as expected, even in a tuned PID controller. Fuzzy controller eliminates the drawbacks of PID,but the combination of both gives the better results.

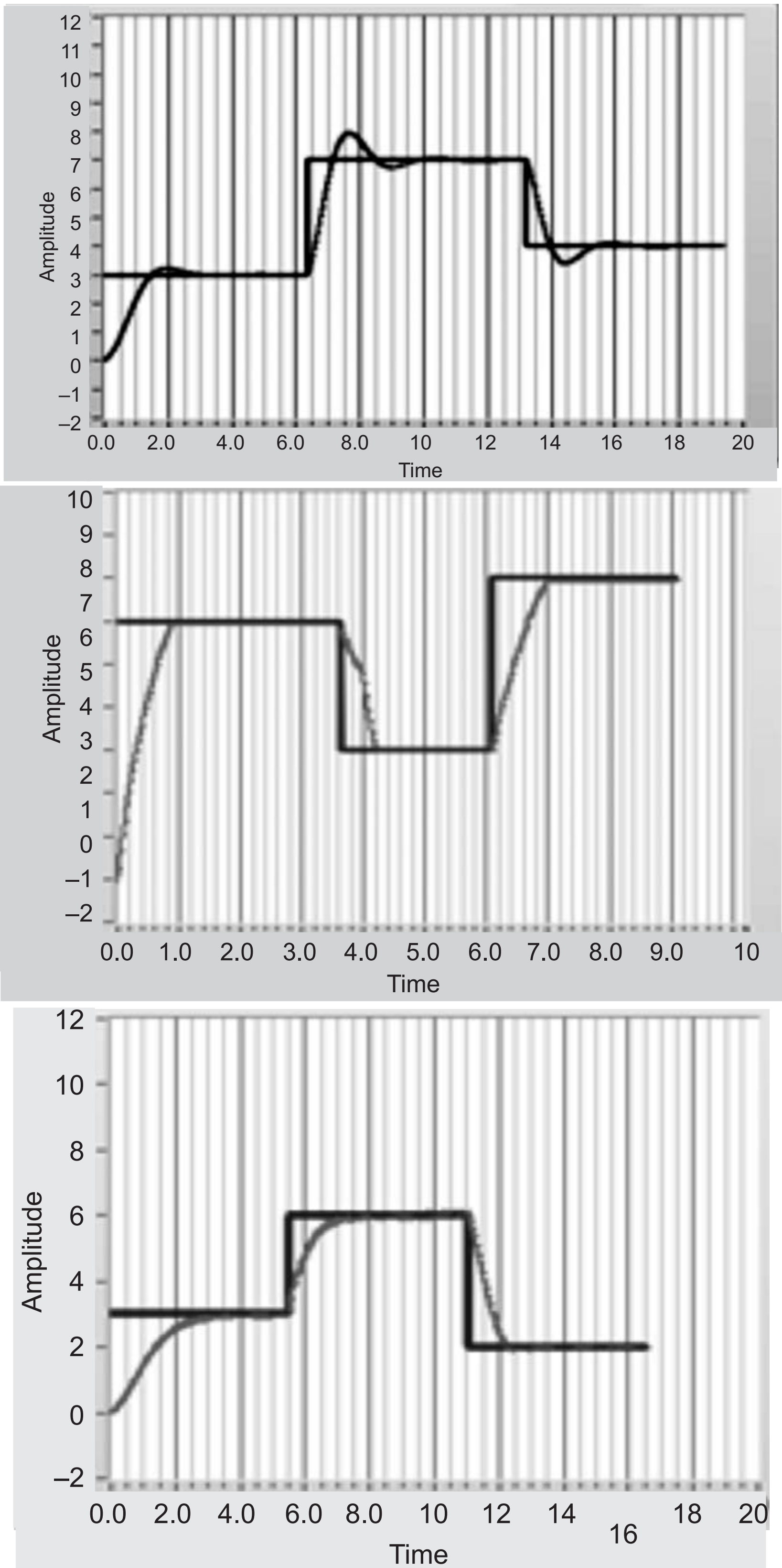

Figure 5 : Response of PID, fuzzy, Fuzzy PID controller

Table 4
Comparison of results

	PID	*Fuzzy*	*Fuzzy-PID*
ITAE	7.74	5.48	4.64

The Table 4 shows the comparison of values of Integral of Time Weighted Absolute error(ITAE) for the three controllers implemented.

6. CONCLUSION

Liquid level in the tank was kept at desired level using PID and fuzzy controllers. Fuzzy-PID controller in a control loop gave better results in terms of error indices(ITAE) in terms of simulation results for the above modelled non-linear level system. From Figure 5-7 ,it is observed that Fuzzy-PID gives better performance as compared with other two in terms of rise time ,overshoot and settling time.

7. REFERENCES

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