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Water Tank Level Control System using Self-Adaptive Fuzzy-PID Control

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***Abstract* - This paper demonstrates the performance of self-adaptive fuzzy-PID controller to control level of an automatic water level control system. The traditional PID controller cannot give satisfactory response to liquid level systems, because there exists time delay in this type of systems. Therefore, a self-adaptive fuzzy control is developed by combining the advantages of fuzzy and PID controller is applied to water level systems. In this paper, mathematical model for a first order tank system with valve lag, measurement lag and time delay are considered. For the water tank level control system (WTLCS), the measurements are carried out from process plant which is located at process dynamics and control laboratory, VIT University. The performance analysis of the self-adaptive fuzzy-PID controller and conventional PID controller has been implemented in MATLAB and Simulink for the first order WTLCS. The comparison of various time domain parameters is performed to prove that the self-adaptive fuzzy-PID control is superior to conventional controllers.**

Keywords : self-adaptive fuzzy-PID control, valve lag, measurement lag, dead time.

I. INTRODUCTION

An industrial process control system consists of many constraints like non linearity, inertial lag, time delay, time varying parameters and so on. Because of these features, it is very difficult to develop the mathematical model of such systems. Thus conventional PID controller [5] doesn't give good results for such systems which consist of disturbances. Therefore, a new approach which is a combination of fuzzy and PID control is considered that can deal with these limitations. The fuzzy logic controller [1] is applicable to non-linear systems and it is based on the human thinking and experience about the plant to be controlled. Fuzzy modeling doesn't depend on the precise mathematical model. When Compared toconventional PID control, self-adaptive fuzzy PID control [2] has many advantages such as fast response, minimal overshoot and good anti-inference ability.

An adaptive controller adjusts itsparameters according to the situation. The variation in the plant or in the disturbance characteristics are the most important situations that demands for the adaptive control. Fuzzy logic can be understood as computation using linguistic variables instead of numbers, whereas fuzzy control uses IF-THEN statements [12] instead of equations. If the controller further takes the corrective action without human intervention then it is said to be adaptive control.

Dynamics of level control are influenced by the lags in the tank, the measuring device, and the control valve. For small changes in level, a tank with a control valve in the exit line behaves as a first-order system.PID controller [7] requires the exact model of the system. Fuzzy control is an intelligent control method [4] and this feature makes it self-adaptive. This self-adaption mechanism provides faster response, small overshoot, insensitive to the changes of process parameters, and strong robustness. This paper combines the traditional PID controller and fuzzy controller, and this self-adaptive fuzzy-PID controller strategy is implemented in the water tank level control system.

In this paper, section-II describes the development of mathematical model of plant and performance of conventional controllers. Section-III deals with the design and development of self-adaptive fuzzy-PID controller [2]. Results and simulations are illustrated respectively in section-IV. Section-V concludes with the performance evaluation of self-adaptive fuzzy-PID controllers over conventional controllers.

II. METHODOLOGY

In the liquid level control system, water level measurement and precise water level control is an important process in improving the manufacturing quality of products. However, there are many difficulties in controlling of water level system. In some cases, the system is operated under unstable condition, for example, above set-point level or below set-point level. Therefore, it seems to be quite challenging to perform an accurate leveling process. Thus this project has been conducted to perform precise water level control using self-adaptive fuzzy controller to overcome the above difficulties. The measured data is compared with conventional PID controller which has been developed from MATLAB control system toolbox.

A) Automatic water tank level control system:

The water tank level control system with conventional controllers is implemented in the plant shown in figure2. This plant is located at process dynamics laboratory, VIT University. The components employed on the process plant are summarized in table1. The plant is applicable to operate either in manual mode or automatic mode to control the water level. The project was conducted by choosing an automatic mode controller. The principle of this tank is explained below.

A pump discharges the water from reservoir and flows through the rotameter and control valve. Tank level is sensed by level transmitter. Computer is acting as an error detector as well as controller, which detect the difference between the user's defined set point and digital form of level transmitter output. The output of controller is used to actuate the electro pneumatic converter conversion thereby the controlling of valve is done. It controls the flow of the fluid in pipeline by varying stem position of the control valve opening. The block diagram of water tank level system is shown in figure1.

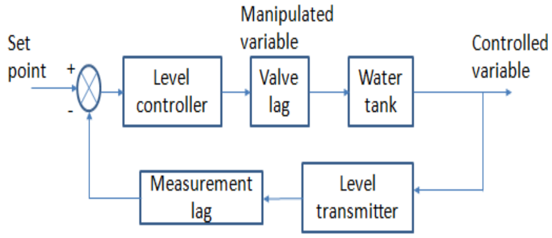

Fig.1.Block diagram of water tank level control system

B) *Mathematical model:*

The level process station is a single tank system, which consists of a tank of uniform cross-sectional area A to which is attached a flow resistance R such as a valve and a pipe. Assume that q_0, the volumetric rate of flow through the resistance, is related to the head of tank 'h' by linear relationship given by,

$$q_0(t) = \frac{h}{R} \tag{1}$$

We can analyze this system by writing a transient mass balance around the tank:

The accumulation of mass in the tank is the difference between the input flow rate and output flow rate and is given by

$$q(t) - q_0(t) = A\frac{dh}{dt} \tag{2}$$

Substitute equation (1) in equation (2) ,

$$q(t) - \frac{h}{R} = A\frac{dh}{dt} \tag{3}$$

Applying Laplace transform on both sides

$$Q(s) = \frac{1}{R}H(s) + AsH(s) \tag{4}$$

The process transfer function is

$$P(s) = \frac{H(s)}{Q(s)} = \frac{R}{Ts+1} \tag{5}$$

Fig.2. Level process station located at VIT University

TABLE.1. COMPONENTS EMPLOYED IN THE PROCESS PLANT

Equipment Name	Ratings	Function
Level transmitter (RF Capacitance)	Height: (0-800)mm Water column Range: (0-700)mmWater column	It measures the level of the tank at every instant.
Process tank	Capacity: 35 liters Height: 800mm	It stores the water.
Rotameter (variable area)	Range: (100-1000)LPH	It measures the flow rate of water.
Pump	RPM: 2700 Motor rating: 0.5 HP Discharge: 1500 LPH	It pumps the water to fill the tank.
Pneumatic control valve (single seated globe)	Valve action: Air to open Flow rate: 500/1000 LPH	It controls the flow of water in tank through pressure.
Electro pneumatic converter	Input air: 20 psi Output: 3 to 15 psi	It converts electrical signals to pressure signal.

Assume R = 2.

From the experiment it is observed that measurement lag, T_m=2sec, and valve lag, T_v=20sec

The transfer function of measuring lag is,

$$M_{lag}(s) \quad =\frac{1}{2s+1} \qquad (6)$$

Similarly, transfer function for control valve lag is,

$$C_{lag}(s) \quad = \frac{1}{20s+1} \qquad (7)$$

By using Ziegler –Nicholas method tuning of PID controller [9] is done. The complete transfer function of the given system is,

$$T(s) = \frac{K_p\ P(s)C_{lag}(s)}{1+K_p P(s)M_{lag}(s)C_{lag}(s)} \qquad (8)$$

$$T(s) = \frac{kp\left(\frac{2}{23s+1}\right)\left(\frac{1}{20s+1}\right)}{1+\left(\frac{2}{23s+1}\right)\left(\frac{1}{20s+1}\right)\left(\frac{1}{2s+1}\right)kp} \qquad (9)$$

Characteristic equation is given as,

$$1+K\pi\Pi(\sigma)M_{lag}(s)\ C_{lag}(s)=0 \qquad (10)$$

$920\sigma^3+546\sigma^2+45\sigma+1+2K_\pi=0$(11)

By substituting$s = j\omega$ in the equation (11)

We get, K_p =12.85 and ω=0.22.

The ultimate period P_u is given as,

$$P_u = \frac{2\pi}{\omega} = 28.41\ \sigma\varepsilon\chi\sigma. \qquad (12)$$

Now calculating the settings of PID controller using Z-N method

$$K_c = 0.6K_p. \qquad (13)$$

So, K_c=7.71

$$T_i = \frac{Pu}{2} = 14.205 \qquad (14)$$

$$T_d = \frac{Pu}{8} = 3.55 \qquad (15)$$

By using these values the closed loop performance of PID controller is shown in figure 3. It has been observed that the response of PID controller has more oscillations, large settling time and large peak overshoot. Hence, fuzzy controller is considered in parallel with PID controller, in order to improve the response of the given system.

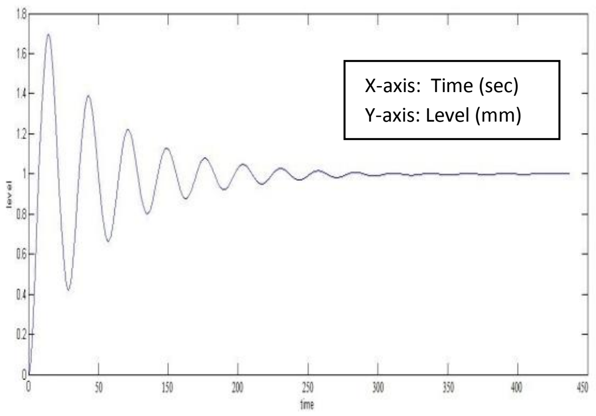

Fig.3.PID controller response

III. ADAPTIVE FUZZY LOGIC CONTROLLER

Fuzzy inference system (FIS) is a knowledge based rule base system. The fuzzifier performs conversion of inputs, outputs and physical constraints into fuzzy variables by assigning appropriate membership functions [12]. Fuzzy rules are framed accordingly in the inference engine with the consent of knowledge base and the firing of rules proposes fuzzy outcomes. The defuzzifier converts the fuzzy outcomes into real world physical quantities.

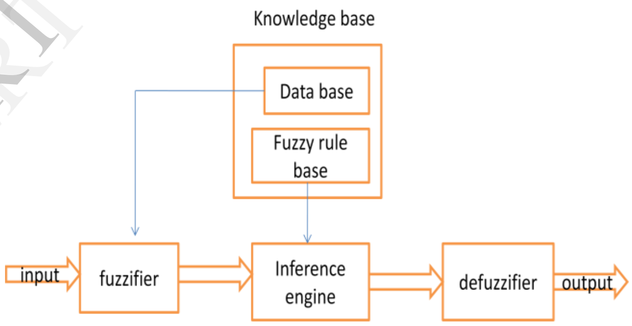

Fig.4. Block diagram of fuzzy logic control

A) *Designing of fuzzy logic controller:*

In the design of fuzzy controller, we considered deviation, $e(t)$ andrate of deviation change,$\Delta e(t)$ as the inputs for the fuzzy controller. The position of the valve is denoted as 'valve position' was considered as output variable. Gaussian membership function was considered for the input variables and triangular membership was considered for the output variable. Also settings of the PID controller, from Ziegler-Nichol's method were optimized and used in fuzzy control. Accordingly the rules were framed and written in the rule editor. The firing of rules makes the fuzzy controller to perform the necessary action and governs the opening of valve.

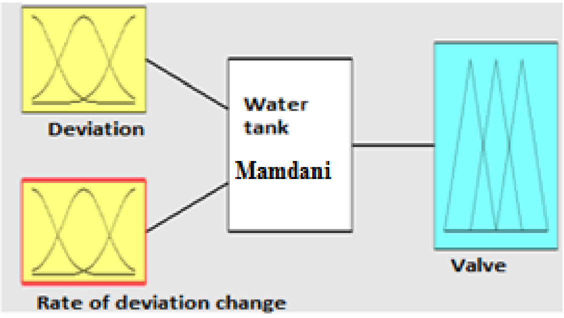

Fig.5.Mamdani type fuzzy controller

B) *Fuzzy set characterizing the input:*

1) Deviation

Fuzzy variable	Crisp input range
High	(-0.3,-1)
Zero	(0.3, 0)
Low	(0.3, 1)

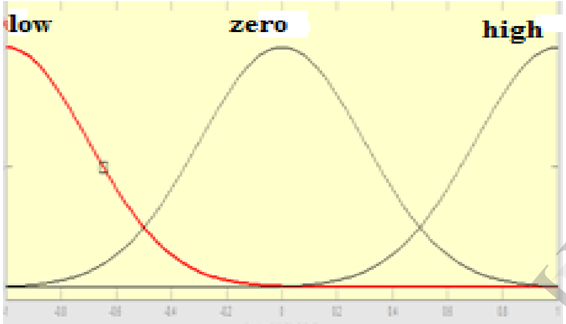

Fig.6.Membership function characterizing the input variable 'deviation'

2) Rate of deviation change

Fuzzy variable	Crisp input range
Positive	(-0.03,-0.1)
Zero	(0.03, 0)
Negative	(0.03, 0.1)

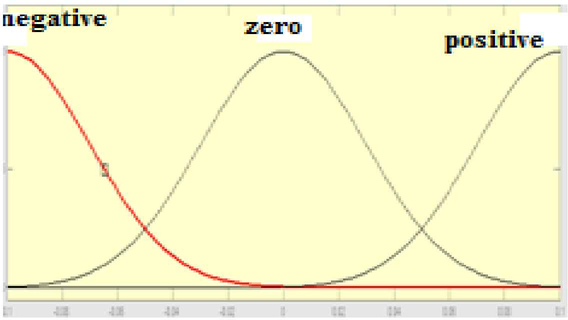

Fig.7. Membership function characterizing the input variable 'rate of deviation change'

C) *Fuzzy set characterizing the output:*

3) Valve position

Fuzzy variable	Crisp output range
Close fast (CF)	(-1.0,-0.9,-0.8)
Close slow(CS)	(-0.6,-0.5,-0.4)
No change (NC)	(-0.1, 0, 0.1)
Open slow (OS)	(0.2, 0.3, 0.4)
Open fast (OF)	(0.8, 0.9, 1.0)

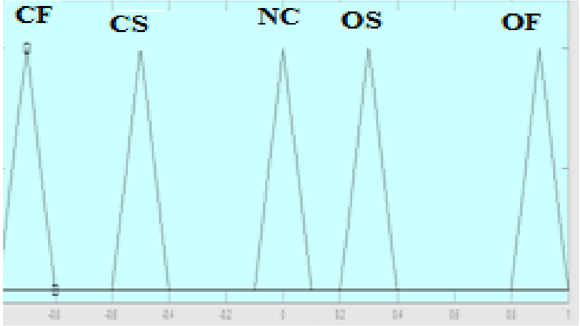

Fig.8. Triangular membership function characterizing output variable 'valve position'

D) *Rule editor:*

Using the graphical rule editor interface rules are constructed based on the descriptions of the input and output variables defined in the FIS editor [14]. The rules are framed as follows:

1. If $e(t)$ is low and $\Delta e(t)$ is zero then valve position is open slow
2. If $e(t)$ is high and $\Delta e(t)$ is negative then valve position is close fast
3. If $e(t)$ is zero and $\Delta e(t)$ is negative then valve position is close slow
4. If $e(t)$ is low and $\Delta e(t)$ is positive then valve position is open fast
5. If $e(t)$ is zero and $\Delta e(t)$ is positive then valve position is open slow
6. If $e(t)$ is zero and $\Delta e(t)$ is zero then valve position is no change
7. If $e(t)$ is high and $\Delta e(t)$ is zero then valve position is close slow
8. If $e(t)$ is low and $\Delta e(t)$ is negative then valve position is open fast
9. If $e(t)$ is high and $\Delta e(t)$ is negative then valve position is close fast

IV. SIMULATION DIAGRAM& RESULTS

The simulink diagrams for PID controller and self-adaptive fuzzy PID controller are illustrated respectively in figures 9 and 10.In the model given, the control step setting value is r(t)=u(t). In the controller, the proportional factor$K_p = 7.71$, the integral factor $K_i = 0.074$, the differential factor $K_d = 3.55$ were obtained. The qualification factor in the fuzzy controller is $K_e = 6, K_{ec} = 120$, the proportion factor of fuzzy output is $K_u = 0.833$ and simulation time is 500sec.The simulation result of self-adaptive fuzzy PID is illustrated in figure11.

V. CONCLUSION

The control method adapted in this paper infers that the self-adaptive fuzzy- PID controller has small settling time, minimum peak overshoot and has high disturbance rejection capability compared to conventional PID controller. Self-adaptive fuzzy-PID controller reaches the goal of improving the controller process dynamics and steady performance. Thus the control effect of self-adaptive fuzzy-PID is better than the conventional PID control. The future scope is that the adapted strategy can be applied for higher order systems with more number of physical constraints and increased rules.

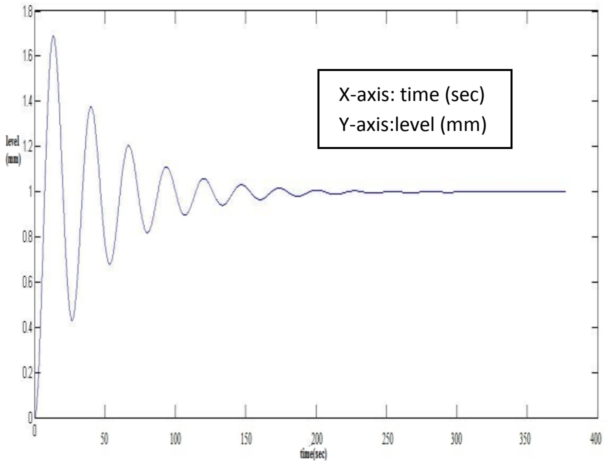

Fig.11. Simulation result of self-adaptive fuzzy-PID controller.

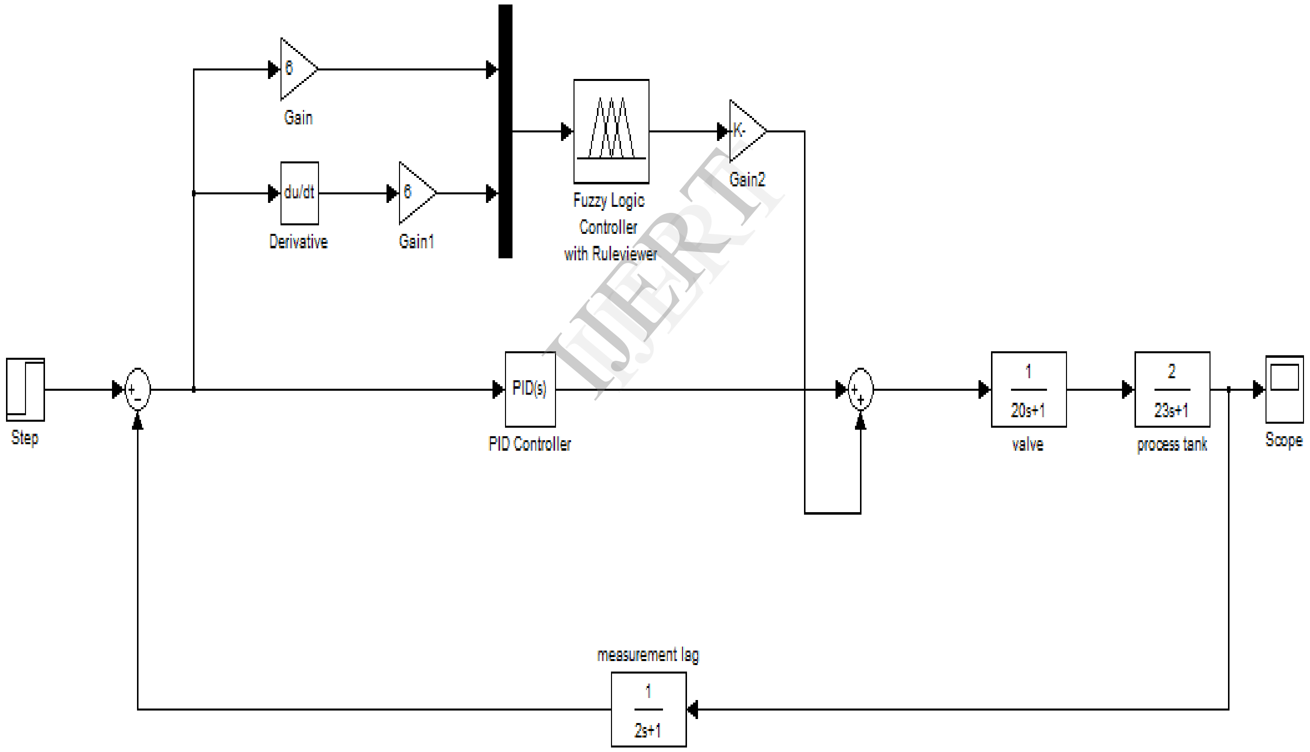

Fig.9 .Simulink diagram using self-adaptive fuzzy PID controller.

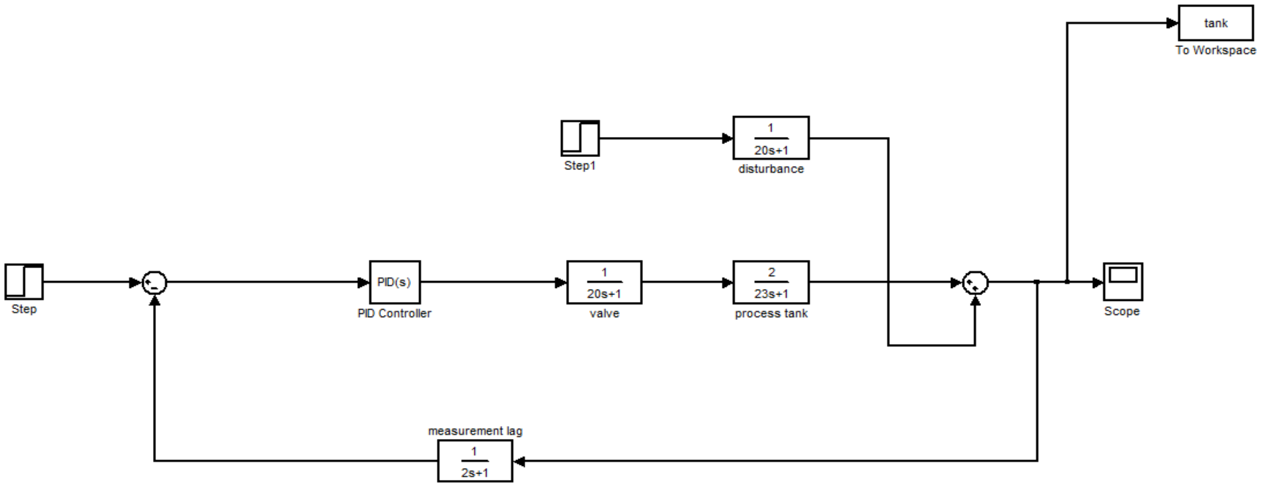

Fig.10. Simulink diagram using PID controller.

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