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Design of Controllers for Liquid Level Control

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Abstract
The liquid level control system is commonly used in many process control applications. 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 error rate but it cannot handle complex problems. Fuzzy logic controllers are rule based systems which simulates 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 proposes Inverse fuzzy with fuzzy logic controller for controlling liquid level system for a plant. This paper also compares the transient response as well as error indices of PID, Fuzzy logic controller, inverse fuzzy controllers. The responses of the controllers are verified through simulation. From the simulation results, it is observed that inverse fuzzy-PID controller gives the superior performance than the other controllers. The inverse fuzzy-PID controller gives better performance than the PID and fuzzy controller in terms of overshoot and settling time. Performance analysis is carried out with Liquid Flow Control System Design with Fuzzy logic controller. Results are evaluated by comparing the response time of conventional PID, fuzzy logic and Inverse fuzzy controller. Comparative analysis of the performance of different controllers is done in MATLAB and Simulink.
Keywords—PID controller, Fuzzy Logic Controller, Inverse Fuzzy Logic Controller

I. INTRODUCTION

Flow control is critical need in many industrial processes [1]. Liquid level system is very complex system because of nonlinearities and uncertainties of a system. In this paper, a model is designed for simulating the flow control. The three techniques used for modeling are PID[2], FLC, and inverse fuzzy controller. PID controller has a simple control structure which is easy to understand but the response of PID[3] is not satisfactory. To overcome these problems we use intelligent fuzzy logic controller is adopted. Fuzzy logic control implement human reasoning into fuzzy logic language (membership functions, rules).

A simple liquid level control system is explained here in the block diagram [8]. This conversion take place as the control valve acts on pneumatic signals only. The control valve controls the fluid flow to maintain the fluid level in tank. The tank is fitted with a capacitive level sensor and a transmitter. Valve could be controlling, the pressure in a pipe, the flow through a pipe, the level in a tank, or any other process control system

In flow and out flow can be adjusted by valves. Level of the liquid flow can also be adjusted by input or inlet valves. The rules for controlling the system are: If the level is above the set point then remove liquid. If it is below set point then add liquid. Our aim is to fill the tank to the desired set point as quickly and smoothly as possible to minimize the amount of overshoot.

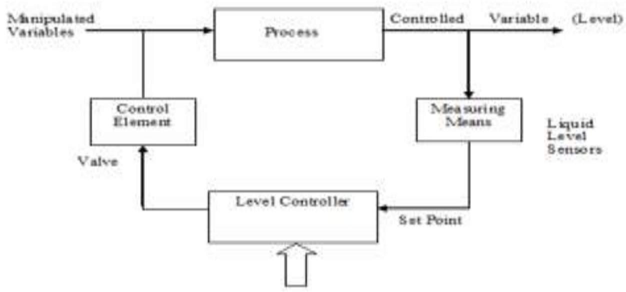


Fig.1.A typical industrial Single Tank Liquid Level control Problem

A.S. Kamal et al (1996)[9] set out to apply the fuzzy logic to control the liquid flow of a refrigeration system. Elangeshwaran et al.[10] (2006) illustrates the advantages of a fuzzy based controller from a traditional PID controller and the simulated results are obtained. M.M et.al.(2011) concluded that when Fuzzy control is added with conventional PID controller constitutes an intelligent control, which adjusts the control parameters depending upon the error. Fahid et.al (2002) discussed the applicability of using Proportional integrated Derivative (PID) controllers in process control for industrial applications.

II. MATHEMATICAL MODELING

Model of the tank is mathematically represented based on mass balance relation equation. In Mass-balance equation, there is a relation between the incoming and outgoing fluid.

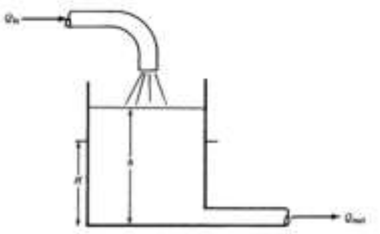


Fig.2.Model of the Tank

$Q_{in} = Q + Q_{out}$ (1)

Q_{in} ◊ Flow rate of water coming into the tank
Q ◊ Net rate of water stored in the tank
Q_{out}◊Flow rate of water going out from the tank

From,(1) ◊Q_{in} = A $\frac{dh}{dt}$ + Q_{out} (2)

A ◊ Cross sectional area
h ◊ Height of water in the tank SISO Tank System
$\frac{dh}{dt}$ ◊ Rate of change of water inside the tank
Water pumped into the tank at rate of flow of Q_{in}
From Bernoulli's equation
$Q_{out} = a * \sqrt{2gh} * c_d$
A $\frac{dh}{dt}$ = Q_{in} _a*$\sqrt{2gh} * c_d$ (3)
Where a◊ area of tank outlet
c_d ◊ discharge coefficient

From Equation (3), nonlinear relationship that exists b/w the inflow rate and the height of water inside the tank. The equation can be linearized for small perturbation about an operating point. When the inflow rate q_{in} becomes constant, the rate of water flow obtained from water coming out of the tank through the opening would reach a steady state value.
$Q_{out} = Q_o$ & the height of the water h becomes a constant h_0
So we can write it as
$Q_0 = c_d * \sqrt{2g\, h_0}$ (4)
If we consider a small perturbation δQ_{in}, the input flow rate around the steady state value
$Q_0 = Q_{in}$- Q_0 Leads to the fluid level h be perturbed around h_0
$\delta h = h - h_0$
A $\frac{d\delta h}{dt}$ + C_d *A*$\sqrt{2g(\delta h + h_0)} = \delta Q_{in} + Q_0$ (5)
(5) can be linearized using Taylors series

- $f(x) = f(x_0) + \frac{df}{dx}\frac{(x-x_0)}{1!} + \frac{d^2f}{dx^2}\frac{(x-x_0)^2}{2!}$ +……
- $f(x) - f(x_0)\, \frac{df}{dx}\frac{(x-x_0)}{1!}$
- $\delta f(x) = \frac{df}{dx}\delta(x)$

linearizing eqn(5)
A $\frac{d\delta h}{dt} + \frac{Q_0 \delta h}{2h_0} = \delta Q_{in}$ (6)
Transfer function
$\frac{h(s)}{Q_{in}(s)} = \frac{1}{AS + Q_0/2h_0}$ (7)
A Simple Simulink Model of Water Tank is given below.

$$h(f) = h(0) + \int_0^t \frac{1}{A}[Q_{in}(t') - Q_{out}(t')]dt'$$ (8)
$$h(f) = h(0) + \int_0^t \frac{1}{A}\left[Q_{in}(t') - a * \sqrt{2gh(t')}\right]dt$$

III. CONTROLLER DESIGN

A) *PID Controller*

The PID parameters proportional gain K_p, integral gain K_i and derivative gain K_d must be fine tuned to obtain the desired response for designing a PID controller. These values of the parameter Kp, K_i, K_d must be added to calculate the output of the PID controller. The error signal e(t) is used to generate the proportional, integral, and derivative actions for designing PID controller. The resultant output signal is obtained and these signals are weighed and summed to form the control signal u(t) which is applied to the industrial plant model.

$$u(t) = K_p e(t) + K_i \int_0^t e(x)\,dx + K_d \frac{de(t)}{dt}$$

PID controller is a feedback type controller. One of the disadvantages of PID is that controller take corrective action after output is affected by error. Response of system overshoot and transient behavior is oscillatory.

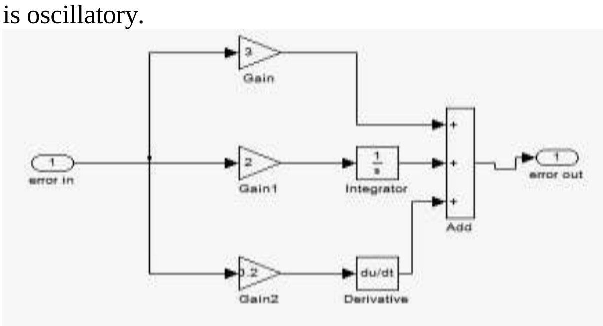


Fig.3. Block Diagram of PID Controller module

Conventional PID controller is not very efficient for complex problems and it may result to less accurate results... Proportional (P), integral (I) and derivative (D) are the parameters of PID controller. The parameter values are interpreted in terms of time ,where ,'P' depends on the current error, 'I' on the accumulation of past errors and 'D' is a prediction of future errors, based on current rate of change. The fine tuning of these parameters in PID controller algorithm provides control action designed for specific process control requirements.

B). Fuzzy Logic Control

Fuzzy Logic deals with uncertain and imprecise data values. It provides a technique to deal with imprecision. Fuzzy theory[11] provides a mechanism for representing vague definitions such as "many," "low," "medium," "often," "few." Fuzzy logic provides a structure that enables human reasoning capabilities. Fuzzy logic systems have faster and smoother response than conventional systems and control complexity is less. Fuzzy Logic Control (FLC)[5][7] and NeuroFuzzy Control[6] has the capability of dealing with systems that are complex, ill-defined, non-linear or time-varying. FLC is relatively easy to implement, as it usually does not require mathematical modeling of the control system.

Fuzzy logic toolbox in MATLAB is used to simulate the two input and one output system. Three fuzzy levels are considered for each of the two inputs and five levels for the output parameter. The five rules of the Rule base is activated to follow-up the desired liquid level. The rule viewer is used to obtain the crisp defuzzified values for the corresponding crisp inputs given. The representation of fuzzification and defuzzification process is denoted by the red line in Fig 6.

IV. RESULTS AND DISCUSSION

Various time domain parameters are compared to prove that the FLC has less overshoot and quick response as compared to PID controller. The controller designed in the paper is a Mamdani based one of two inputs – level, rate, and one output –liquid flow valve.

There are two inputs :

1) Error in liquid level e(t)=h(t)-hd and

2) Rate of change of liquid level e'(t)=h'(t) and one output parameter: the inlet valve control angle u(t).Triangular membership functions are selected to fuzzify the inputs and output variables. Fuzzy sets are taken (N, O and P) for each of the two inputs and five rule based fuzzy sets for obtaining the output signal.

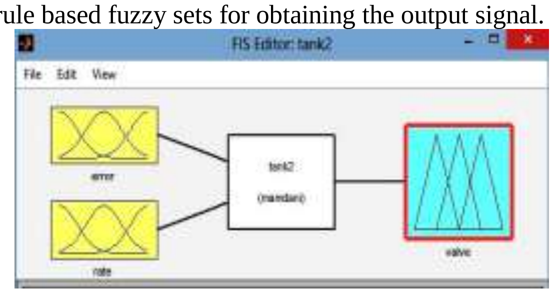


Fig.5. Number of inputs (Level & Rate) and output (Liquid Flow) for designing Fuzzy Inference Structure (FIS) for Fuzzy Logic controller.

a)

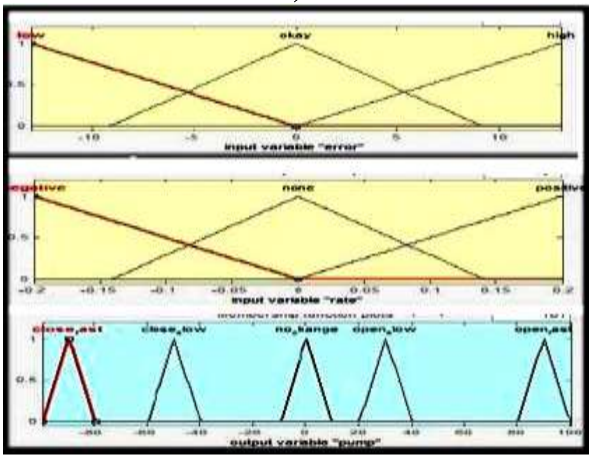


Fig.6. Membership Functions inputs and output

b) TABLE 1. Fuzzy set of characterizing the Input & Output

Level	Rate	valve
Fuzzy Variable	Fuzzy Variable	OF _OPEN FAST
High	Negative	OS_OPEN SLOW
Ok	Zero	CF _CLOSE FAST
Low	Positive	CS _CLOSE SLOW
		NC_NO CHANGE

c) TABLE 2.Fuzzy rule matrix which has 9 fuzzy rules

RULE MATRIX	Low	Ok	High
Negative	OF	OS	CF
Zero	OF	NC	CF
Positive	OF	CS	CF

d) Following five rules are used to make up the rule base:

Rule 1: If error is okay then valve is no change.

Rule 2: If error is positive then valve is open fast.

Rule3: If error is negative then valve is close fast.

Rule 4: If error is okay and rate is positive then valve is close slow. Rule 5: If error is okay and rate is negative then valve is close fast.

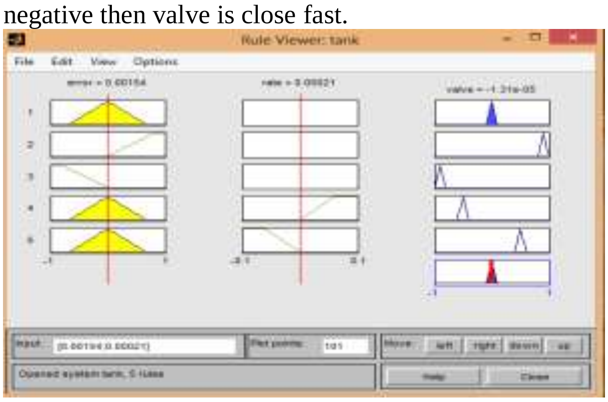
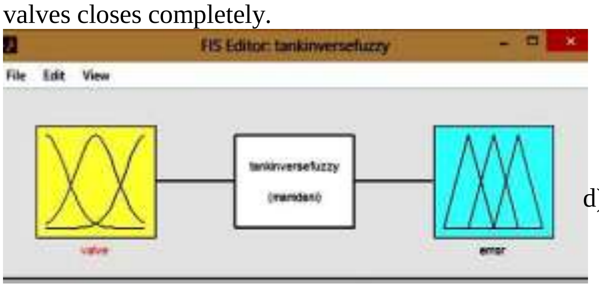


Fig.6.RuleBased System for Fuzzy Controllers

C) .Designing Fuzzy Logic Controller with Inverse Fuzzy Model - Proposed Method

Inverse fuzzy model is constructed for a system in order to eliminate the unknown plant variations and disturbances. Stability and perfect control with zero error. Outputs of the model inverted and the output of the original system becomes the input. The proposed fuzzy controller using inverse fuzzy model is a one-input one-output system. The output is y(t) is given as the input to the fuzzy controller and the input error e(t) will be the output of the fuzzy controller

The positioning of the valve is decided by rules. If the liquid level in the tank is low then valve open completely. If liquid level is high then the valves closes or open up to an extent. If the level is full then valves closes completely.



d)

Fig.7. Fuzzy Logic Controller using Inverse Fuzzy Model

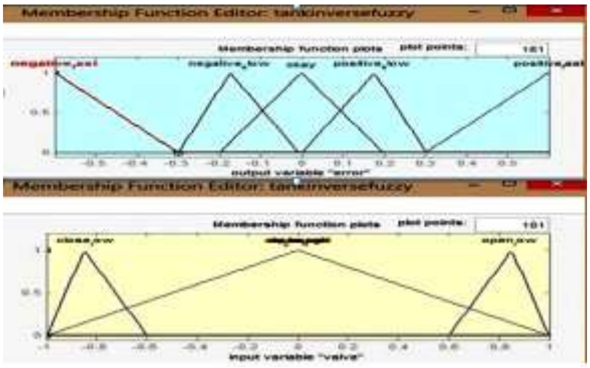
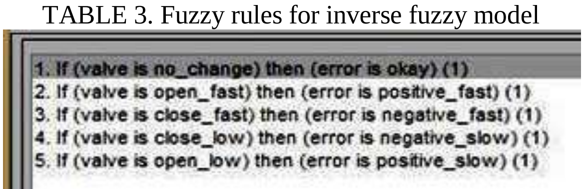


Fig.8. Membership function of input variable (valve) and output variable (error)

TABLE 3. Fuzzy rules for inverse fuzzy model



1. If (valve is no_change) then (error is okay) (1)
2. If (valve is open_fast) then (error is positive_fast) (1)
3. If (valve is close_fast) then (error is negative_fast) (1)
4. If (valve is close_low) then (error is negative_slow) (1)
5. If (valve is open_low) then (error is positive_slow) (1)

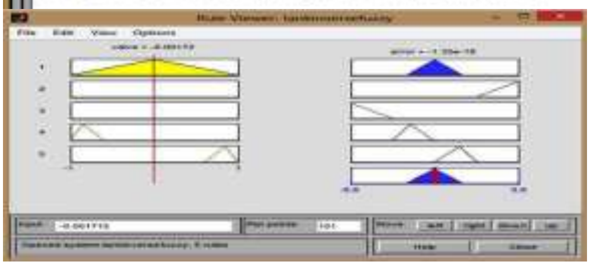


Fig.9. Fuzzy rule viewer for inverse fuzzy model

a. Performance analysis of different controllers

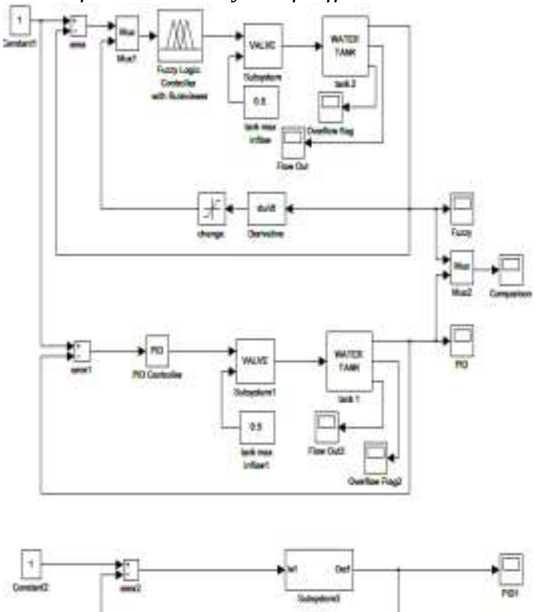


Fig.10. MATLAB/Simulink block for controller combines with plant

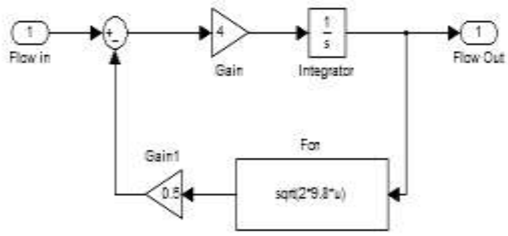


Fig.11. Design of Water Tank module

a. Response of the system using different controllers

The performance analysis of fuzzy and PID controller in terms of transient response for the desired level is plotted in Fig.12. Pink line represents PID and yellow one indicates fuzzy. It is evident from the graph that the PID controller has a high overshoot compared to the fuzzy controller and also it consumes a lot of time to achieve stability at the desired level. But Fuzzy logic has less overshoot and minimal steady state error and it stabilizes quickly providing a better accuracy for level control. Generally fuzzy controller is used for rapid control (coarse adjustment) applications and PID controller is used for accurate control (fine adjustment).The response time[4] is calculated by plotting time on x-axis and water level in the tank on y-axis. Experiments are simulated by using MATLAB 2012 and Simulink software.

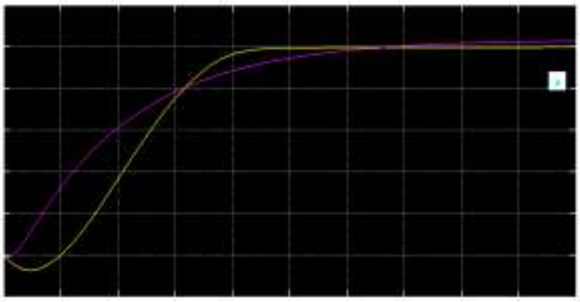


Fig.12. Performance analysis of PID controller and fuzzy controller in terms of response time

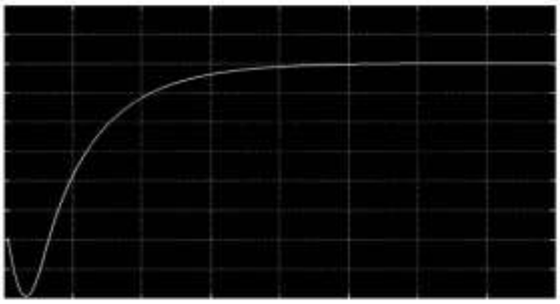


Fig.13. Plot of system response using inverse fuzzy Model

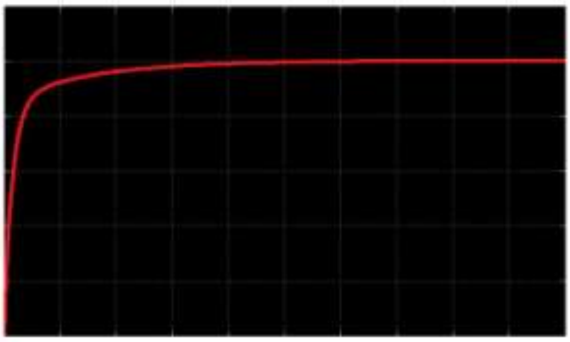


Fig.14.Plot of Liquid Level at the Tank using PID Controller

V. CONCLUSION

In this paper, the performance analysis of different controllers for liquid level flow is discussed. PID controller produces the response with less delay and rise time compared to fuzzy logic controller, but it reaches stability at a faster time due to the oscillatory behavior in transient period. Severe oscillations may affect the performance of the system adversely. Fuzzy logic controller tries to reduce these dangerous oscillations and provides smooth operation in transient period. The performance of the system is evaluated in terms of the response time, overshoot and settling time obtained from Fuzzy, PID and Inverse fuzzy controller. We conclude that inverse fuzzy performs better than other controllers in handling the complex process control problems.

TABLE 4.Comparison results of PID and FLC

Parameter	PID	FLC
Overshoot	Present	Not Present
Settling Time	More	Less
Transient	Present	Not Present
Rise Time	Less	More

REFERENCES

[1] B. W. Bequette, *Process Control: Modelling, Design and Simulation*. Prentice Hall, 2003.

[2] Z. Yu, J. Wang, B. Huang and Z.Bi “Performance assessment of PID control loops subject to Setpoint changes,” *J. of Process Control*, vol. 21, pp. 1164-1171, 2011.

[3] R. Vilanova, “IMC based Robust PID design: Tuning guidelines and automatic tuning,” *J. of Process Control*, vol. 18, pp.61-70, 2008.

[4] C. C. Hang, “Improvement of transient response by means of variable set point weighting,” *IEEE Trans. on Ind. Electron.*, vol. 43, pp. 477-484, 1996.

[5] Z. Aydogmus, “Implementation of a fuzzy-based level control using SCADA,” *J. of Expert Syst. with Applicat.*, vol. 36, pp. 6593-6597, 2009.

[6] T. Tani, S. Murakoshi and M. Umano, “Neuro-Fuzzy Hybrid Control System of Tank Level in Petroleum Plant,” *IEEE Trans. on Fuzzy Syst.*, vol. 4, no. 3, pp. 360-368, 1996.

[7] Ahilpa Sindageri, Halse, “Siimulink Modeling for Liquid Level Comtrol using Fuzzy Logic Controller”, Vol 4, Issue 2, pp 77-81, 2015

[8] Dharamniwas, Aziz, Varun, Umesh,”Liquid level control by using Fuzzy Logic Controller”, Vol 4, Issue 1, pp 537-549, 2012

[9] J.Y.M. Cheung, A.S. Kamal,” Fuzzy Logic Control of refrigerant flow”, Proceedings of UKACC International Conference on Control September 1996.

[10] Elangeshwaran Pathmanathan, Rosdiazli Ibrahim,” Development and Implementation of Fuzzy Logic Controller for Flow Control Application, Proceedings of Intelligent and Advanced Systems (ICIAS),2010

[11] Chuen Chien Lee, “Fuzzy logic in control systems i.e. fuzzy logic controller,”IEEE Transactions on Systems, man and cybernetics, Vol 20, No.2, March/April 1990