

Designing a Controller for Two Tank Interacting System

Miral Changela¹, Ankit Kumar²

Department of Instrumentation and Control, Atmiya Institute of Technology and Science, Rajkot, India

Abstract: The control of liquid level in tank system and flow between tanks is main problem in process industries like petroleum refineries, chemical, paper industries, water treatment industries. The control of liquid level and flow between tanks which is must be controlled. The control of level of tank in the interacting system is the major task. As in the interacting process dynamics the dynamics of tank 1 affects the dynamics of tank 2 and vice versa. For the study purpose two tank interacting level process is considered. While simulating in MATLAB it is observed that: 1. In PI controller, the offset is removed but makes the system response slow. 2. In PID controller the system response is fast but there are oscillations and overshoot. 3. In Fuzzy Control Logic the performance is without overshoot, Faster settling time, Better set-point tracking and very minimum steady state error.

Keywords: Liquid level system , Interacting System , PID Controller , Fuzzy Controller

1. Introduction

The most of industrial application of liquid level control is hazardous in chemical petroleum industries, paper chemical, mixing treatment industries, pharmaceutical & food processing industries [1]. Level of tank and flow between tanks controlled using different controller like that PI , PID , FUZZY etc. the most widely used controller in industrial applications are the PI type controller because of good performance and easy to understand and installable structure. For highly nonlinear system, the performance of PI controllers can deteriorate quite fast. It is necessary to develop nonlinear PI controllers for controlling nonlinear processes [1]. PI controller has high overshoot and large settling time so to overcome this disadvantage of PI controller we use PID controller. The proportional- integral-derivative (PID) controllers are used for a wide range of process control, motor drives, magnetic and optic memories, automotive, flight control, instrumentation, etc. In industrial applications, PID type controllers were widely used. With its three-term functionality covering treatment to both transient and steady-state responses, proportional- integral-derivative (PID) control offers the simplest and yet most efficient solution to many real-world control problems[3]. The PID controller cannot give corrective action in advance. It can only initiate the control action only after error has developed. The only way to achieve better performance is to use fuzzy logic controller instead of conventional controllers [4].

2. Process Descriptions

A. Working Principles

Fig.1 shows the Universal process control trainer. It consists of pumps, control valves, process tanks, overhead tank, differential pressure transmitter, level transmitter, rotameter. Instrumentation panel consists PI, PD and PID controller, main power supply switch, pump switches, auxiliary switches for individual components.

Fluid level in the tank is measured by level transmitter (LT). Output of LT is given to the data acquisition setup. It consists of analog to digital converter and digital to analog converter. The differential pressure level transmitter (DPLT) measures

the flow by sensing the difference in level between the tanks. The DPLT then transmits a current signal (4-20mA) to I/V converter. The output of I/V converter is given to the interfacing hardware associated with the personal computer (PC). A control algorithm is implemented in MATLAB software. It compares and takes corrective action on the control valve Based on how much control valve open or close. The controller compares the controlled variable against set point and generates manipulated variable as current signal (4-20mA). Here the controlled variable is the level (h_2) and the manipulated variable is the flow rate (q_{in}). The Control valve gives restriction to the flow through the pipeline and hence the desired level is achieved [1].



Figure 1: Instrumentation diagram of two-tank interacting process

Table 1: Specification of Two Tank Interacting Process

Components	Specification	Value
Control Valve	Size	1/2"
	Characteristic	Linear
	Type	Pneumatic (air to open)
Pump	Input	3-15 psi
	RPM	2700
	Type	centrifugal
	Voltage	230V AC
	Volumetric Discharge	600 lph

Rotameter	Type	Variable Area
	Range	40 to 400 lph
	Float Material	316 SS
Process Tank	Capacity	7.5 liters
	Height	0-500 mm
	Diameter	135.8 mm
Level Transmitter	Input	24 V DC
	Height	0-600 mm
	Type	Electronic two wire
Differential Pressure Transmitter	Calibrate	0-500 mm H ₂ O
	Type	Capacitance, two wire
	Supply	10 - 24 V DC
	Output	4-20 mA

B. Mathematical Modeling of Two Tank Interacting Level Process

The process consisting of two interacting liquid tanks shows in fig 2. The height of the liquid level is h_1 (cm) in tank1 and h_2 (cm) is tank2. Volumetric flow into tank 1 is q_{in} (cm³/min), the volumetric flow rate from q_1 (cm³/min), and the volumetric flow rate from tank 2 is q_0 (cm³/min). Cross sectional area of tank1 is A_1 (cm²) and area of tank2 is A_2 (cm²).

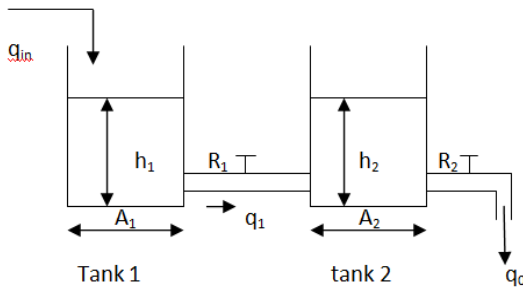


Figure 2: interacting system

For tank 1,

$$A_1 \frac{dh_1}{dt} = q_{in} - q_1 \tag{1}$$

Assume linear resistance to flow,

$$q_1 = \frac{h_1 - h_2}{R_1}$$

$$A_1 \frac{dh_1}{dt} = q_{in} - \left(\frac{h_1 - h_2}{R_1} \right) \tag{2}$$

$$A_1 R_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2 \tag{3}$$

Time constant of tank 1,

$$T_1 = A_1 R_1$$

$$T_1 \frac{dh_1}{dt} = R_1 q_{in} - h_1 + h_2$$

$$T_1 \frac{dh_1}{dt} + h_1 - h_2 = R_1 q_{in} \tag{4}$$

Taking Laplace transform on both sides ,

$$T_1 s h_1(s) + h_1(s) - h_2(s) = R_1 q_{in}(s)$$

$$h_1(s)(T_1 s + 1) - h_2(s) = R_1 q_{in}(s)$$

$$h_1(s) = \frac{R_1 q_{in}(s)}{(T_1 s + 1)} + \frac{h_2(s)}{(T_1 s + 1)} \tag{5}$$

For tank 2,

$$A_2 \frac{dh_2}{dt} = q_1 - q_0 \tag{6}$$

Assume linear resistance to flow,

$$q_0 = \frac{h_2}{R_2}$$

$$A_2 \frac{dh_2}{dt} = \frac{h_1 - h_2}{R_1} - \frac{h_2}{R_2} \tag{7}$$

$$R_1 A_2 R_2 \frac{dh_2}{dt} = (h_1 - h_2) R_2 - h_2 R_1$$

Time constant of tank 2,

$$T_2 = A_2 R_2$$

$$R_1 T_2 \frac{dh_2}{dt} + h_2 R_2 + h_2 R_1 = h_1 R_2$$

Taking Laplace transform on both sides,

$$R_1 T_2 s h_2(s) + h_2(s) R_2 + h_2(s) R_1 = h_1(s) R_2$$

$$(R_1 T_2 s + R_2 + R_1) h_2(s) = h_1(s) R_2 \tag{8}$$

In equation (8) putting value of equation (5),

$$(R_1 T_2 s + R_2 + R_1) h_2(s) = \frac{R_1 R_2 q_{in}(s)}{(T_1 s + 1)} + \frac{R_2 h_2(s)}{(T_1 s + 1)}$$

Solving above equation,

$$(R_1(T_1 s + 1)(T_2 s + 1) + R_2(T_1 s + 1)) h_2(s) - R_2 h_2(s) = R_1 R_2 q_{in}(s)$$

$$(T_1 T_2 s^2 + s(T_1 + T_2 + A_1 R_2) + 1) h_2(s) = R_2 q_{in}(s)$$

Convert above equation in form of $\frac{h_2(s)}{q_{in}(s)}$

$$\frac{h_2(s)}{q_{in}(s)} = \frac{R_2}{T_1 T_2 s^2 + s(T_1 + T_2 + A_1 R_2) + 1} \tag{9}$$

Equation (9) is a transfer function of interacting system.

Designing of plant transfer function:

- Setup the interacting tank system as shown in fig. 1.
- Give constant 193 lph input liquid flow to the system and wait for the level of tank at steady state point. This is called initial state of system.
- Write down the reading of liquid level in tank1 and tank 2 at particular flow which is continuously apply to system.
- Now give a step change in flow e.g. 305 lph
- Again write down the reading of liquid level in tank1 and tank2. This is final state of system.

Table 2: Experimental result taken from real time system

Flow in lph	Height in tank1 (mm)	Height in tank2 (mm)
193	56	35
305	102	55

Now we know that,

$$R_1 = \frac{dh_1}{dQ}$$

Putting measured value in above equation,

$$R_1 = \frac{(102 - 56)mm}{(305 - 193)lph}$$

The value of R1= 1478.57 sec/m²

Similarly for R₂

$$R_2 = \frac{dh_2}{dQ}$$

Putting measured value in above equation,

$$R_1 = \frac{(55 - 35)mm}{(305 - 193)lph}$$

The value of R2 = 642.86 sec/m²

Time constant is T₁=R₁A₁ & T₂=R₂A₂

Where area of tank1 and tank 2 is 0.0145 m²

The value of time constant T₁ = 21.42 and T₂ = 9.31

All this value put into equation (9) so we get transfer function of interacting tank system

$$\frac{h_2(s)}{q_{in}(s)} = \frac{642.86}{199.42s^2 + 40.04s + 1} \quad (10)$$

Transfer function of system in s- domain, that present gain of system is 642.86 with two poles at -0.029 and -0.171. Damping coefficient is 1.41 and damped natural frequency is 0.0708 rad.

3. Simulink Block Diagram Description

Simulink model for liquid level control with open loop close loop without any controller, PI controller, PID controller by using program MatlabR2013a. Based on the transfer function of the plant which is derived using mathematical modelling. Fig. 3 shows the open loop model of the plant. Where input flow in tank 1 is 305 cm³/s.

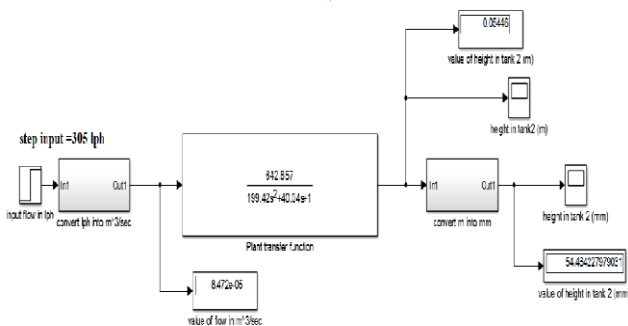


Figure 3: Open loop model for interacting tank

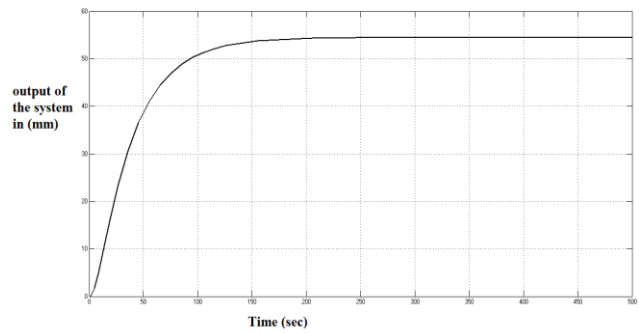


Figure 4: Simulation result of open loop model

Next task is simulink the close loop response without any controller. Fig.5 shows close loop model of the plant. Where as a set point level of tank2 which is desired to maintain in tank2.

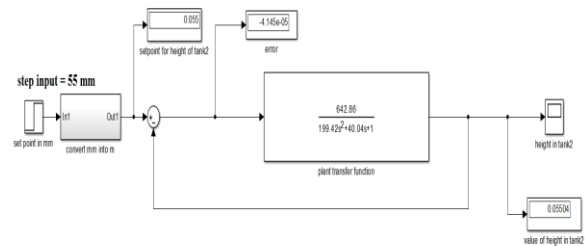


Figure 5: Closed loop model for interacting tank

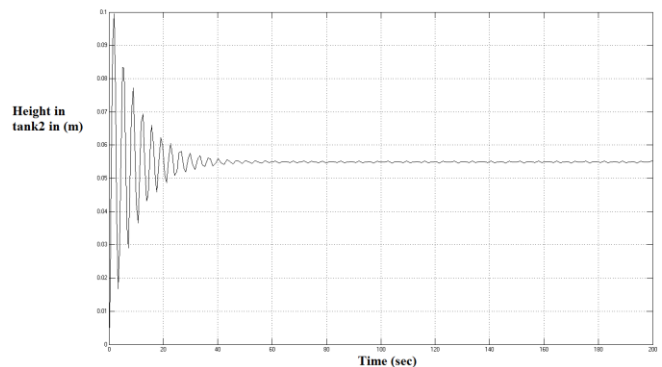


Figure 6: Simulation result of close loop model

4. Designing of PID Controller

We are using PID controller to compare with PI controller, for finding constants controller use tool "PID" in simulation of MatlabR2013a program, which depends on the frequency response at the calculate of constants controller. PID parameter obtained using good gain method. The PID parameters are given in tabulated form in table 3.

Table 3: Parameters of PID controller

Controller	K _p	K _i	K _d
PID	0.0142	0.03623	0.00905

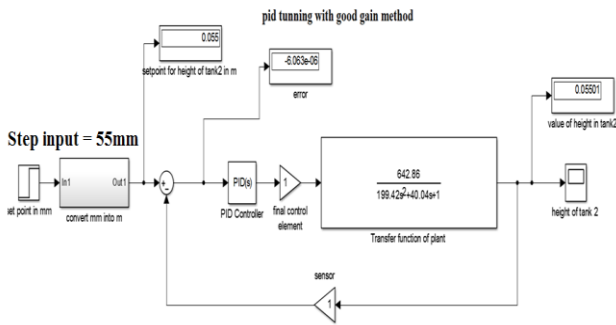


Figure 7: Closed loop model with PID controller for interacting tank

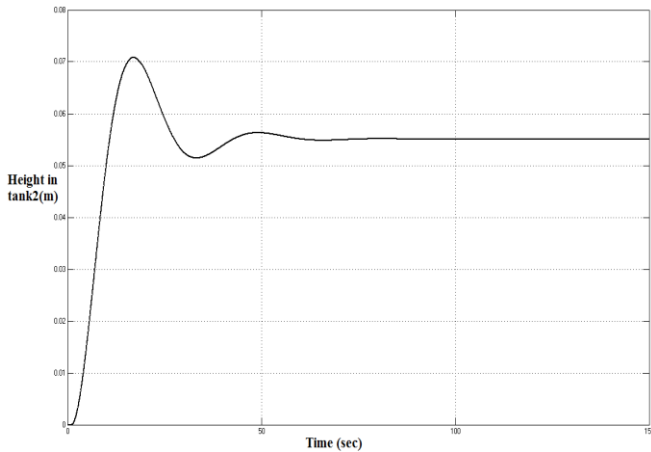


Figure 8: Simulation result for closed loop model with PID controller

5. Designing of Fuzzy Controller

A. Introduction of Fuzzy Controller

- Fuzzy logic is a part of machine or artificial intelligence which interprets a human's action. To control several fields fuzzy techniques have been successfully used. The modes of reasoning in fuzzy logic are appropriate instead of exact.
- Fuzzy logic is takes the inputs from the sensors which are a crisp value and transforms it into membership values. Unlike crisp logic, it emulates the ability to reason and use approximate data to find solutions.
- Fuzzy logic controllers (FLCs) are knowledge-based controllers consisting of linguistic rules "IF-THEN" that can be constructed using the knowledge of experts in the given field of interest.
- There is a variety of possible fuzzy controller structures, the Fig.9 is shown all common types of controllers consist of:
 - a) Input fuzzification (binary-to-fuzzy [B/F] conversion)
 - b) Fuzzy rule base
 - c) Inference engine
 - d) Output defuzzification (fuzzy-to-binary [F/B] conversion)

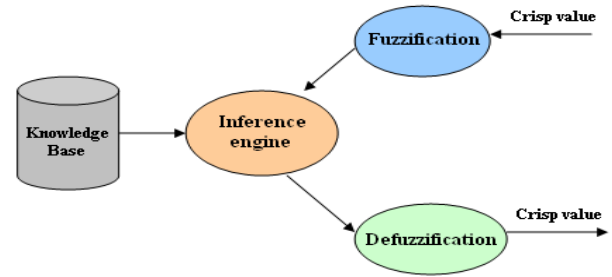


Figure 9: Structure of fuzzy system

B. Inputs and Output for System

We have defined two inputs and one output for the fuzzy logic controller may be shown as Fig.10 One is error which is generated difference between set point and measured value of the liquid in the Tank2, it is denoted as "error" and the other one is rate of change of liquid in the Tank2 so also change error, it is denoted as "rate of change of error". Both these Inputs are applied to the Rule Editor. According to the Rules, the controller takes the action and governs the opening or closing of the Valve which is the Output of the controller and is denoted by "valve". The input "error" is divided into five membership functions are "Negative big", "Negative small", "zero", "Positive small" and "positive big", either input "change in error" is divided into five membership functions are "Negative big", "Negative small", "zero", "Positive small" and "positive big", the output "valve" is divided into five membership functions "close fast", "close low" and "no change", "open low" and "open fast" and are used triangular membership functions in the inputs and output.

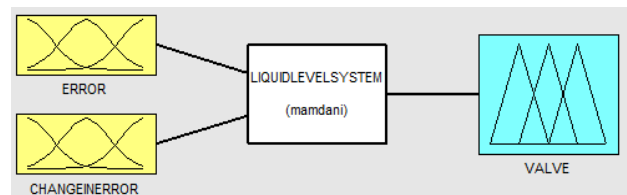


Figure 10: Fuzzy Inference System (FIS) Editor

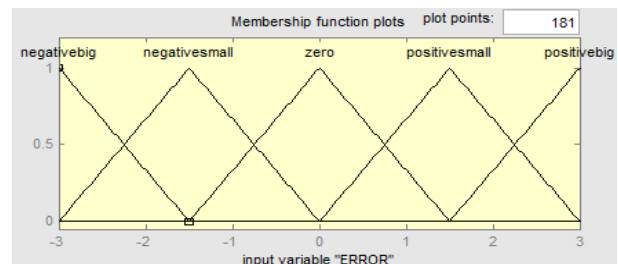


Figure 11: Input Membership Function Editor for error

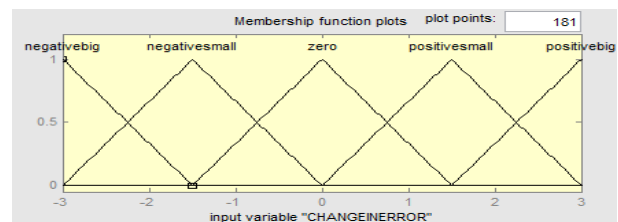


Figure 12: Input Membership Function Editor for change in error

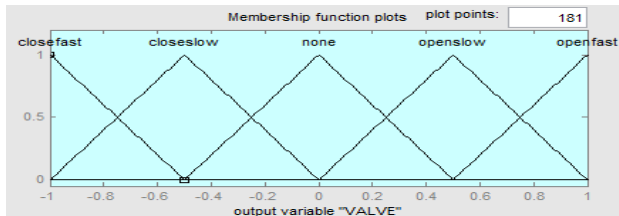


Figure 13: Output Membership Function Editor for valve

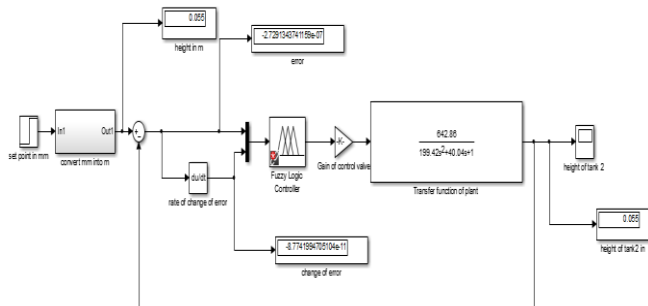


Figure 14: closed loop model with fuzzy controller for interacting tank

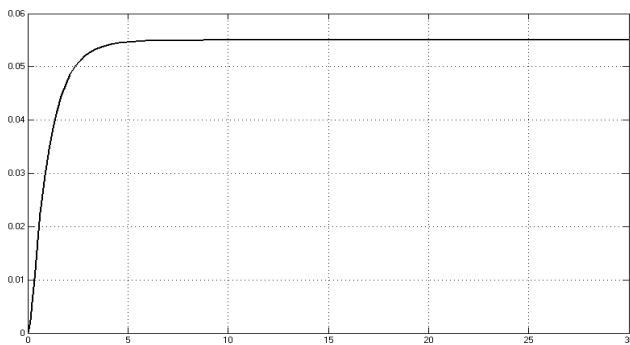


Figure 15: Simulation result for closed loop model with Fuzzy controller

6. Discussion

The FLC is applied to the plant described above in Fig.15 obtained FLC simulation results are plotted PI & PID controller for comparison purposes. The simulation results are obtained using a 25 rule FLC. Rules shown in Rule Editor. Here these rules are implemented to the above control system. For comparison purposes, simulation plots include PI & PID controller, and the fuzzy algorithm. FLC provide good performance in terms of oscillations and overshoot in the absence of a prediction mechanism. The FLC algorithm adapts quickly to longer time delays and provides a stable response while the PID controllers drives the system unstable due to mismatch error generated by the inaccurate time delay parameter used in the plant model. To strictly limit the overshoot, using Fuzzy Control can achieve great control effect. In this paper, we take the two tank interacting system, and use MATLAB to design a Fuzzy Control. Then we analyze the control effect and compare it with the effect of PID controller. As a result of comparing, Fuzzy Control is superior to PID control. Especially it can give more attention to various parameters, such as the time of response, the error of steadying and overshoot. Comparison of the control results from these systems indicated that the fuzzy logic controller significantly reduced overshoot and steady state error. Comparison results of PID and FLC are shown above.

The overall performance may be summarized as:

Table 4: Time response parameter comparison

Controller	Open loop	Close loop	PID	Fuzzy
Rise Time (s)	77.06	0.6056	6.6	33
Settling Time (s)	140.22	38.67	51.4	47.2
Overshoot (%)	-	83.87	28.69	1.45

7. Conclusion

In this paper, we developed the two tank interacting system mathematical model and simulated with PID controller and Fuzzy controller using MATLAB/Simulink. From the analysis of above table we conclude that two tank interacting system with PID controller gives relatively slow response with peak overshoot for unit step input. To achieve an optimum response without overshoot, we simulated the two tank interacting system with fuzzy logic controller with fuzzification and defuzzification techniques. The comparative analysis based on the simulation for two tank interacting system with fuzzy controller is tabulated which shows the superiority of fuzzy is more compare to PID. This analysis is useful especially for optimum level control in industries like food processing, petro chemical industries. As a future work one can develop design a FLC for a couple tanks system as adaptive Fuzzy Logic Controller like PID algorithm, which gives high performance for systems and high intelligence.

References

- [1] L.ThillaiRani, N.Deepa, S.Arulselvi, " Modeling and Intelligent Control Of two tank Interacting Level Process", International Journal of Recent Technology and Engineering (IJRTE) ,ISSN: 2277-3878, Volume-3, Issue-1, March 2014.
- [2] Abdelalah Kidher Mahmood , Hussam Hamad Taha , "Design Fuzzy Logic Controller for Liquid Level Control ", International Journal of Emerging Science and Engineering (IJESE) ,ISSN: 2319-6378, Volume-1, Issue-11, September 2013
- [3] Bhuvanewari N S, Praveena R,Divya R , "System Identification And Modelling For Interacting And Non-Interacting System Using Intelligence Techniques " , IJIST-2012 ,Volume-2,no-5,pp23-25, September 2012
- [4] Dharamniwas , Aziz Ahmad , Varun Redhu , Umesh Gupta , "Liquid Level Control By Using Fuzzy Logic Controller " , International Journal of Advances in Engineering & Technology (IJAET), ISSN: 2231-1963 , July 2012
- [5] Gao Qingji, Li Zheng , " Fast and Accurate Motion Control Based on Good Gain Method", Telkommika, Vol.11, No e-ISSN: 2087-278X , Volume-11, No.3, pp. 1236 ~ 1244 , March 2013,
- [6] Li Qi , Fang Yanjun ,Song Jizhong ,Wang Ji , "The Application of Fuzzy Control in Liquid Level System", International Conference on Measuring Technology and Mechatronics Automation , IEEE , ISSN : 978-0-7695-3962-1 , 2010
- [7] Fuzzy Logic Toolbox User's Guide ©COPYRIGHT 1995 - 1999 by The MathWorks, inc.