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Intelligent Controller for Coupled Tank System

Himanshu Gupta [1]
Department of Instrumentation and Control
himanshugiriraj@gmail.com

Om Prakash Verma [2]
Department of Instrumentation and Control

Abstract: **Controlling of process variables in any process is very important so as to achieve the desired output. But as all the real system exhibits non-linear nature, conventional controllers are not always able to provide good and acceptable results. When designing intelligent control system, the corresponding model for simulation should reflect all characteristics of the system to be controlled. All the assumptions should be made before the development of the model else it may lead to the degraded performance. In the recent past, so many researchers works on the fuzzy logic controllers (FLCs)[1] to provide a better controlling. In this paper, we design a FLC to control the liquid level of a coupled tank system.**

Index Terms: **Coupled tank system, Fuzzy Controller, Intelligent controllers, Level control, MATLAB.**

I. INTRODUCTION

The vast majority of conventional control techniques have been devised for linear-time-invariant systems which are assumed to be completely known and well understood. In the real world, however, the systems to be controlled are generally nonlinear and the basic physical processes in it are not completely known. These types of model uncertainties are extremely difficult to manage even with the conventional adaptive techniques.

Fuzzy logic is a form of logic whose underlying modes of reasoning are approximate instead of exact. Unlike crisp logic, it emulates the ability to reason and use approximate data to find solutions. FLCs are knowledge based controllers consisting of linguistic “IF-THEN” rules that can be constructed using the knowledge of experts in the given field of interest.

The process industries such as petro-chemical industries, paper making and water treatment industries require liquids to be pumped, stored in tanks, and then pumped to another tank. The control of liquid in tanks and flow between tanks is a basic problem in the process industries.

The objective of the controller in the level control is to maintain a level set point at a given value and be able to accept new set point values dynamically.

This paper presents a FLC method for the level control of two tank coupled system.

The different advantages of fuzzy logic are as follows:

1. Fuzzy Logic is inherently robust since it does not require precise, noise-free inputs and degrade gradually when system components fail like if a feedback sensor quits or is destroyed.
2. Since the FLC processes user-defined rules governing the system, it can be modified easily to add, improve or alter system performance. so Fuzzy logic are flexible.
3. Because of the rule-based operation, system can be easily designed for any reasonable number of inputs and outputs. Defining the rule base become complex if number of inputs and outputs become large. It would be better to break the system into smaller parts and use several smaller Fuzzy Logic modules distributed on the system, each with more limited responsibilities.
4. Fuzzy logic can model non-linear functions of arbitrary complexity. One can create a fuzzy system to match any set of input-output data.
5. It can be easily combined with conventional and allied control techniques.

II. SYSTEM OVERVIEW

Before designing a controller, it’s important to understand the system. The schematic diagram of coupled tank system is shown in fig.1. The basic control principle of the coupled-tank system is to maintain the level of fluid in the tank constant when there is inflow of fluid into tank and outflow of fluid out of the tank i.e. the input flow rate has to adjust in order to maintain the level at the previous condition. Here it’s assumed that the fluid is non viscous and incompressible.

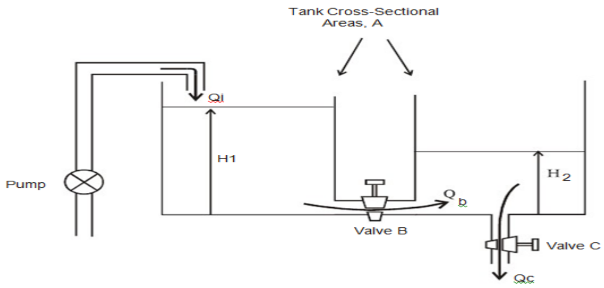

Fig. 1: schematic diagram of coupled tank system

III. MATHMATICAL MODELLING

Based on the fig 1, a simple nonlinear model is derived. Let H1 and H2 be the fluid level in each tank, measured with respect to the corresponding outlet. If the control input is the pump flow rate Q_i, then the variable to be controlled would be the second state level H_2, with disturbances caused by variations in the rate of flow out of the system by valve B or by changes in valve C. Considering a simple mass balance, the rate of change of fluid volume in each tank equals the net flow of fluid into the tank. Thus for each of tank 1 and tank 2, the dynamic equation is developed as follows-

For Tank 1:

$$Q_i - Q_b = rate \text{ of change of fluid volume in tank 1} = \frac{dV_1}{dt} = A\frac{dH_1}{dt} \quad (1)$$

For Tank 2:

$$Q_b - Q_c = rate \text{ of change of fluid volume in tank 1} = \frac{dV_1}{dt} = A\frac{dH_1}{dt} \quad (2)$$

where H_1& H_2 are the height of fluid in tank 1 and tank 2, V_1& V_2 are the volume of fluid in tank 1 and tank 2, A is the cross sectional area of tank 1 and tank 2, Q_b is flow rate of fluid from tank 1 to tank 2 through valve B, Q_c is the flow rate of fluid out of tank 2 through valve C and Q_i is the pump flow rate.

If the drain taps are assumed to behave like orifice then-

$$Q_b = C_{d1}a_1\sqrt{2g(H_1 - H_2)} \quad (3)$$

$$Q_c = C_{d2}a_2\sqrt{2gH_2} \quad (4)$$

where a_1 & a_2 are cross sectional area of orifice 1 & 2, C_{d1} & C_{d2} are discharge coefficient and g is the gravitational constant.

From equations (1) to (4) we get a set of non linear equations which describes the system dynamics of the coupled tank. After linearize the equations by considering small variations q_i in Q_i, q_b in Q_b, q_c in Q_c, h_1 in H_1 and h_2 in H_2 and solving them, the following transfer function is obtained-

$$\frac{h_2(s)}{q_i(s)} = \frac{1/k_1}{\left(\frac{A^2}{k_1k_2}\right)s^2 + \left(\frac{A(2k_1 + k_2)}{k_1k_2}\right)s + 1} \quad (5)$$

Where

$$k_1 = \frac{C_{d1}a_1\sqrt{2g}}{2\sqrt{H_1 - H_2}} \quad (6)$$

$$k_2 = \frac{C_{d2}a_2\sqrt{2g}}{2\sqrt{H_2}} \quad (7)$$

A Pseudo Random Binary Signal (PRBS) is generated externally and given as input to the system and the corresponding output is recorded. Using the input and output data the second order transfer function is computed using System identification toolbox in Matlab.

$$G(s) = \frac{0.000775701}{s^2 + 0.10707802s + 0.000523787} \quad (8)$$

IV. DESIGN PROCEDURE

The basic fuzzy structure is shown in fig 2. The development of FLC consists following steps-

a) Specify the range of controlled variable and manipulated variables;
b) Divide these ranges into fuzzy sets and attach linguistic labels which can be used to describe them;
c) Determine the rule base to specify control action;
d) Application of suitable defuzzification method.

The number of necessary fuzzy sets and their ranges were designed based upon the experience gained on the process. The standard fuzzy set consists of three stages: Fuzzification, Decision- Making Logic and Defuzzification.

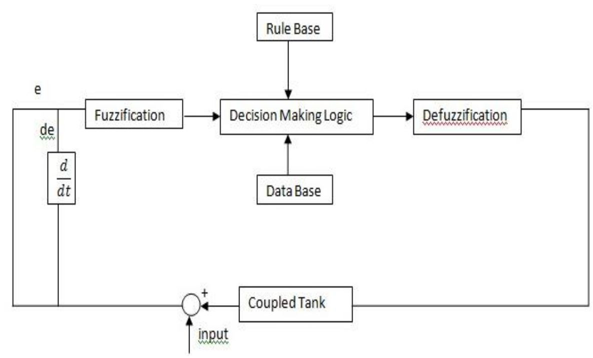

Fig. 2: Basic fuzzy structure

A. Fuzzification

It converts a crisp number into a fuzzy value within a universe of discourse. The gaussian membership functions with seven linguistic values for error (e) and change in error (de) is used and is shown in figs. 3 and 4.

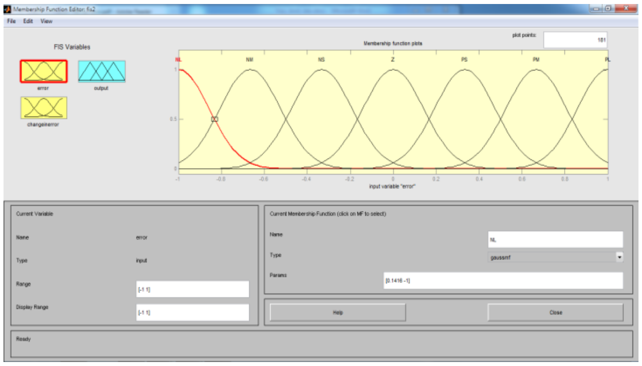

Fig 3: membership function for error

The linguistic values are NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), PL (Positive Large).

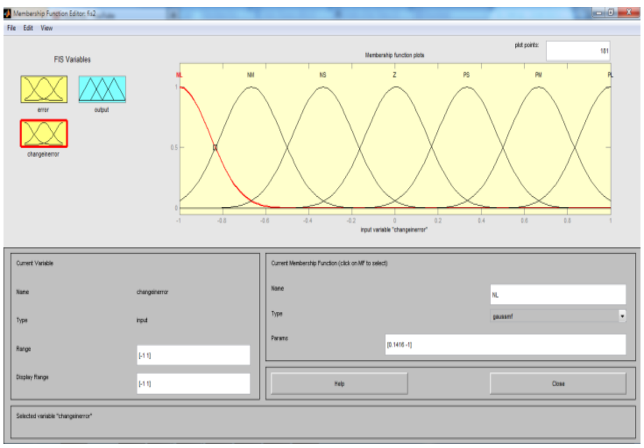

Fig 4: membership function for change in error

B. Decision-making

It is the core of the fuzzy control and is constructed from expert knowledge and experience. Based on the knowledge gained by analyzing the feedback control system decision making logic is given in Table 1 where 49 rules are used. The fuzzy logic control rule will be of the following type:

TABLE 1: FUZZY CONTROLLER RULE BASE

e de o	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

e=error, de=change in error and o=output

The fuzzy control rules are interpreted as follows and the other rules can also be interpreted in the same way-

R1: if (error is NL) and (change in error is NL) then (output is NL)

R2: if (error is NL) and (change in error is NM) then (output is NL)

C. Defuzzification

It converts fuzzy value into crisp value. In this study centroid method is used. The gaussian membership function with seven linguistic values is used and it is shown in fig. 5.

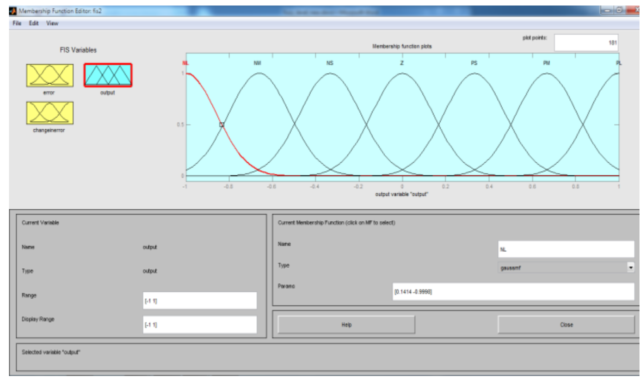

Fig. 5: membership function for output

The corresponding rule viewer and surface viewer are shown in fig 6 & 7.

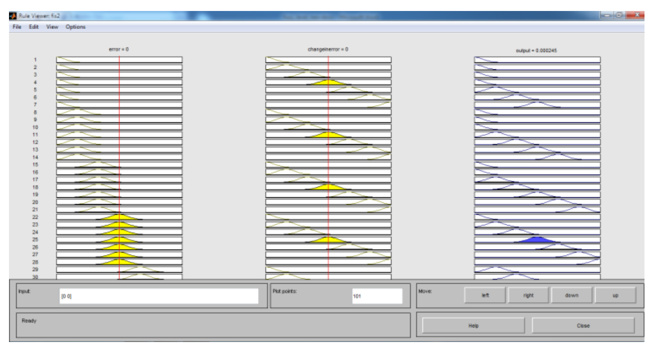

Fig. 6: rule viewer showing different rule base

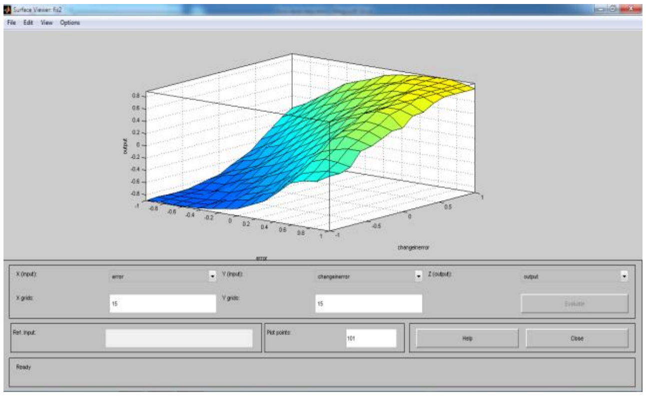

Fig. 7: surface viewer

V. SIMULATION AND RESULT DISCUSSION

The various gain parameters taken for this model are GE = 4.6, GDE = 12and GU = 30 respectively where GE is gain of error, GDE is gain of change of error and GU is gain of output respectively. The simulation is done through Matlab and the corresponding simulink model is shown in fig. 8.

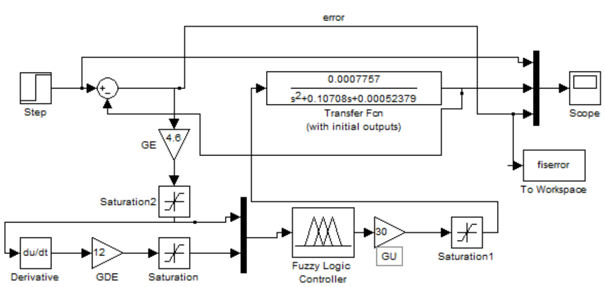

Fig. 8: simulink model

The graph shows the step response of the coupled tank in which reference is shown by yellow, actual output is by magenta and the error is shown by green colour. The absolute error generated by this fuzzy model is 11.3518. It is clear from the graph that this fuzzy model doesn't have any overshoot. Hence its very useful in those systems in which strict overshoot is required. The various parameters of controller are rise time=20 sec, overshoot=0.01% and setting time=22 sec.

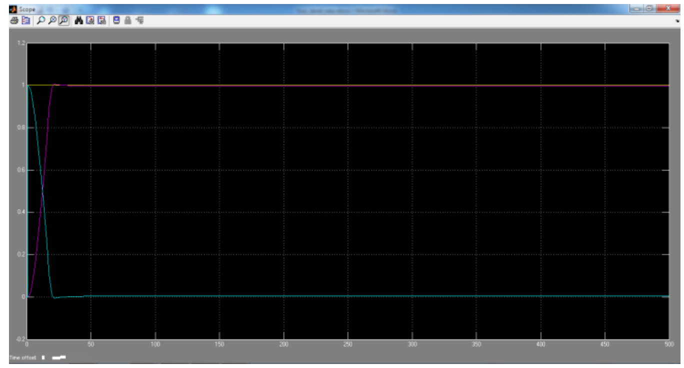

Fig. 9: simulation result

VI. CONCLUSION

The FLC model for the coupled tank system is designed and we found that fuzzy model provides very less overshoot which is sometimes a prime requirement of industries. By adjusting the gain parameters error and other parameters can further be minimized.

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