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Fuzzy Logic Based Water Bath Temperature Control System

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Abstract**—Since last two decade a substantial amount of research has reported in the field of control of non-linear dynamical system using fuzzy logic[1]. The work presents in this paper water bath temperature control system which is most widely used process in the process industry. Water bath conventional controllers are derived from control theory techniques to be controlled. The purpose of the feedback controller is to guarantee a desired response of the output y.**
The study devoted to control design method using Fuzzy Logic Controller (FLC) based non-linear control for water bath temperature to obtain the desired output water temperature of water bath and to implement them in a real world environment.

Keywords**— Industrial Automation; Process Control; Fuzzy Logic Control; Fuzzy Inference System; MATLAB-7 software.**

I. Introduction

This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website. Temperature control of water bath is most widely used application in process control. For example of application in the production of a variety of drink products such as chocolate drink, strawberry milk produces etc. and the example of process industries which uses it are Nestle, Yeoh Hiop Seng, F&N, etc. Therefore the concept of different controller for control problem has been developed into a popular research topic in recent years. Like PID controller[2], Fuzzy Controller, Neural Network, Hybrid Controller.

The reason for developing concepts of fuzzy logic control on classical control theory is that the classical control theory usually requires a mathematical model. The inaccuracy of mathematical modeling of the plants degrades the performance of the controller, especially for non-linear and complex control problems.

In 1973, Lotfi Zadeh, a Professor at the university of Calfornia, Berkley proposed the concept of linguistic or ‘fuzzy’ variables, like temperature, defined by fuzzy sets and linguistic values such as hot and cold.

Fuzzy logic control do not require mathematical models of the plants information and expert knowledge into control signals and are preferred over traditional approaches such as optimal and adaptive control techniques.

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.

Despite the advantages of the conventional FLC over traditional approaches, there remain a number of drawbacks in the design stages. Even though rules can be developed for many of the process, the complexity in developing these rules increase with the complexity of the process. And also the tuning of parameters of FLC is very complex. FLC’s also consists of a number of parameter that are needed to be selected and configured in prior, such as selection of scaling factors, configuration of center and width of the membership function and selection of the appropriate fuzzy control rules.

Water bath temperature control system is nonlinear to some extent. However, nonlinear system theory is both limited and intricate. Such difficulty makes most of the designers resort to linear system analysis with its simple and abundant analytical and graphical techniques for design and analysis. The nonlinear system to be controlled has to be linearized. Hence, the linear control of nonlinear systems oftentimes requires adjustment or even fails once the system departs from the design operating region and, hence, a desired system performance can no longer be achieved.

Designing a controller for a linearized model is not an issue but ensuring that this controller will work for operating conditions outside the linearization region is trivial. Fuzzy logic was proposed for modeling and control of systems.

This paper addresses an application that involves the temperature control system. In presents a FLC that uses fuzzy inference system (FIS)[3]. FIS is a popular computing framework based on the concept of fuzzy set theory, fuzzy IF-THEN rules, and fuzzy reasoning.

II. SYSTEM OVERVIEW

The objective of this article is to implement a FLC for a temperature controller system. The process considered here is one of most widely used processes in the process industry, a Water Bath Temperature Control System. The schematic diagram of Water Bath System is shown in figure 1.

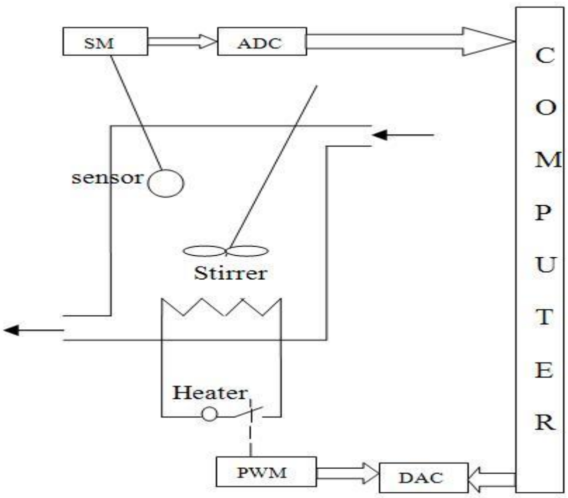

Fig 1: water bath system

The Water Bath System consists of water tank in which cold water is entering the tank from one side and hot water is leaving from the other side. The aim is to obtain the output water at the desired temperature.

The assumptions made for the system are as follows:-

1. The volume of water tank is constant.
2. The inlet flow rate is equal to the outlet flow rate.
3. There is no change of state
4. Uniform temperature is maintained in tank.

The equation of water bath continuous time temperature control system is described by:-

$$\frac{dy(t)}{dt} = \frac{F(t)}{C} + \frac{y0-y(t)}{RC} \quad \ldots\ldots (1)$$

Where t denotes time, y(t) is output temperature in °C, F(t) is the heat flowing inward the system , y0 is the room temperature (constant, for simplicity), C denotes the system thermal capacity and R is the thermal resistance between the system borders and surroundings. Assuming that R and C are essentially constant, obtaining the pulse transfer function for the system in (1) by the step response criterion results in the discrete-time system:

$$y(k+1) = a(Ts)y(k) + b(Ts)u(k) \quad \ldots\ldots. (2)$$

where k is the discrete time-index, u(k) and y(k) denotes the system input and output, respectively, and Ts is the sampling period.

Denoting by α and β some constants values depending on R and C, the remaining parameter can be expressed by:

$$a(Ts) = e^{-\alpha(Ts)} \text{ and } b(Ts) = \frac{\beta}{\alpha}(1-e^{-\alpha(Ts)}) \quad \ldots\ldots (3)$$

the system described in (1)-(3) was modified to include a saturating non-linearity so that output temperature cannot exceeds some limitations.

The discrete-time control plant equation described by:

$$y(k+1) = a(Ts)y(k) + \frac{b(Ts)}{1+e^{(-0.5y(k)-\gamma)}}u(k) + \{1-a(Ts)\}y0 \quad \ldots\ldots (4)$$

Where a(Ts) and b(Ts) are given by (3). The parameters are α = 1.00151E-4, β = 8.67973E-3, γ = 40.0 and y0 = 25.0°C, which were obtained from a real water bath plant. And linearzing the final simulate d discrete-time linear equation for control plant is

$$y(k+1) = 0.988y(k) + 0.222u(k) \quad \ldots\ldots (5)$$

The plant input u(k)was limited between 0 and 5, and it is also assumed that the sampling period is limited by Ts>=30 sec.

III. DESIGN PROCEDURE

A. FLC

Fuzzy logic is more effective in feedback control system and easier to implement. Fuzzy control system divides into the single variable fuzzy control system and the multi-variables fuzzy control system. The water bath temperature controller uses the two-dimensional fuzzy controller model shown in figure 2.

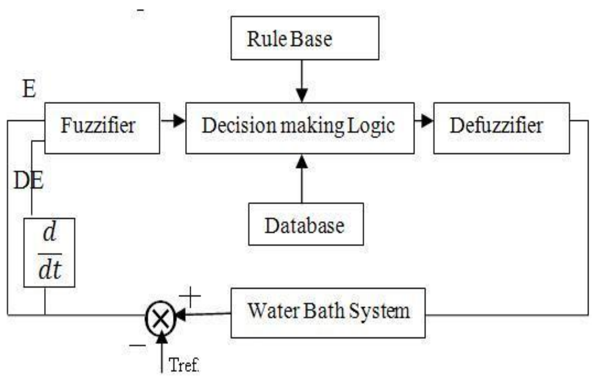

Fig 2: Fuzzy controller model

The system used two input variables error (E) change of error (DE) and one output variable (U). The computational structure of fuzzy logic control scheme is composed of fuzzification, inference engine and defuzzification. The input to the fuzzy controller is error E(k) and the change in error ΔE(k) are computed from the reference output U(k) based on error and change in error.

B. Membership Function

All membership functions (MF's) for 1) controller inputs, i.e., error and change of error and (2) incremental change in controller output for FLC are defined on the common interval [-1 1]; we use gaussian membership function with equal base and 50% overlap with neighbouring MF's as shown in figure 3.

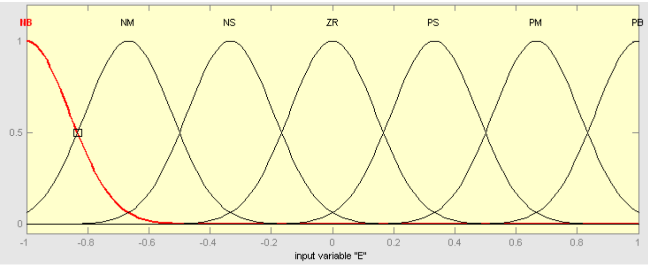

Fig 3: membership functions

TABLE I

NB : negative big	PS : positive small
NM :negative medium	PM: positive medium
NS : negative small	PB : positive big
ZR : zero	

The fuzzy control rules have the form:

R1: if X is A1 and Y is B1 then Z is C1
R2: if X is A2 and Y is B2 then Z is C2
. . . . .
. . . . .
Rn: if X is An and Y is Bn then Z is Cn

Where X, Y and Z are linguistic variables represents two process state variables and one control variable; Ai, Bi and Ci are linguistic value of the linguistic variable X, Y and Z in the universe of discourse U, V and W respectively with i=1,2,….,n; here AND operator and MAMDANI[4] type FIS is used. Rule base and Surface Viewer is shown in figure 4 (a) & (b) respectively.

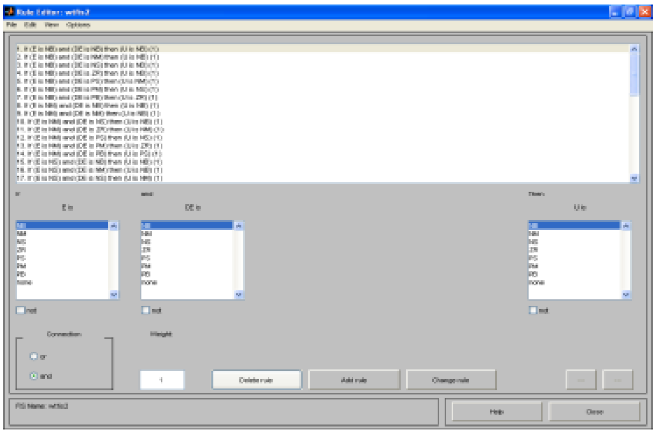

Fig 4: (a) rule base

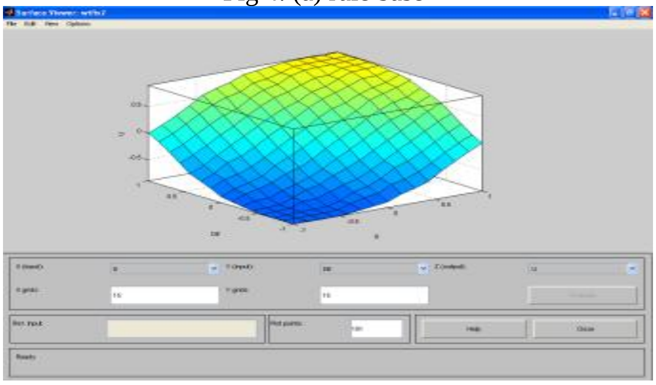

Fig 4: (b) surface viewer

For controlling the inferred fuzzy control action to real value, centroid method is used.

IV. RESULTS & DISCUSSIONS

The execution of simulation was done using the MATLAB simulink tool box. The goal is to design a Fuzzy Controller what will controlled the water temperature to follow a reference profile;

TABLE III

Reference Temperature (°C)	Time(minute)
35	0 <= t <= 30
45	30 < t <= 60
55	60 < t <= 90
65	90 < t <= 120
75	120 < t <= 150
85	150 < t <= 180

With sampling time (Ts) = 30sec.

There are 49 rules used for this system. The output of the controller is U(k), the voltage that limited to between 0 to 5 volts. The performance of the simulated water bath temperature process using proposed simulink approaches are shown in figure 5 & 6.

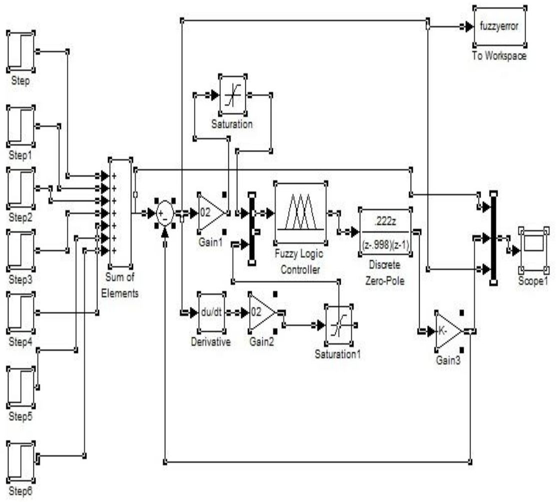

Fig 5: simulink model

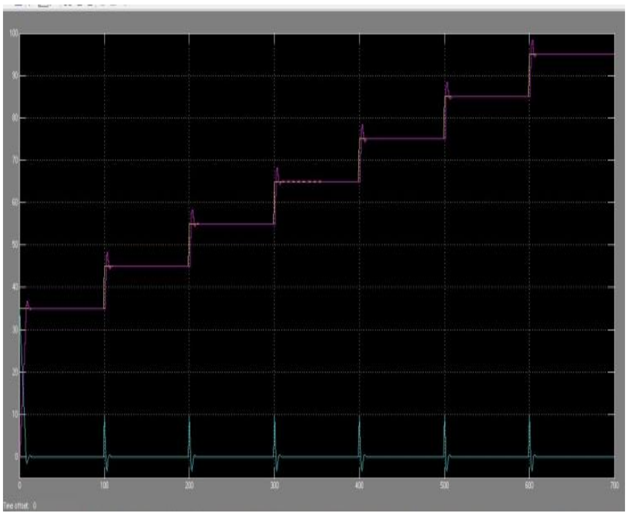

Fig 6: performance of the model

Here reference is shown by yellow, actual output is by magenta and the error is shown by green colour.

V. CONCLUSION

All this paper has presented a FLC where all of its gain parameters can be simultaneously tuned for water bath temperature process GE = .02, GDE = .02 and GU = 150 respectively where GE is gain of error, GDE is gain of change of error and GU is gain of output. The performance indices used was rather straight forward and simple. Yet results are satisfactory system response point changes and sudden disturbances.

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