Design of Genetic Fuzzy Logic based Hybrid Temperature Controller and comparison with other Controllers

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Abstract - Water bath systems are nonlinear in behaviour thus conventional controllers like P, PI, PID are not so efficient. The Fuzzy Logic Controller has found better than PID in temperature control of water bath system in literature because the FLC processes user-defined rules governing the system, it can be modified easily to add, improve or alter system performance. This work presents Genetic Algorithm for the optimization of Fuzzy Logic Controller rule base for the temperature control of water bath system with goal of Zero response error. MATLAB is used for the simulation with Genetic Algorithm toolbox. Simulation results show that performance of Fuzzy Controller improves when optimized by Genetic Algorithm. A comparison has been made among controllers studied.

Keywords: PID Controller, Fuzzy Logic Controller, Genetic Algorithm.

1. INTRODUCTION

Temperature is the most important quantity which is measured and controlled in the industries and household appliances. Temperature controllers are needed in any situation requiring a given temperature be kept stable. Some of the biological processes, certain chemical reactions, and even electronic circuits perform best when they are carried out within limited temperature ranges. These processes, no matter it is a process of large industrial plants, or a process in home appliance, share several unfavorable features such as non-linearness, interference, dead time, and external disturbance, etc. Due to these internal and external disturbances operating temperature of the process varies continuously. In order to get the optimum result, the operating temperature of the process has to be controlled within specified limits. In order to optimize the process, a temperature controller is needed.

The aim of this work is to control the temperature of the water bath at the desired set point and thereby optimize the process. This research work shows the design of temperature controller for water bath using PID, FLC and the optimization of FLC rule base using Genetic Algorithm. Then the comparison has been made and final conclusion has been drawn.

2. DEFINING PROBLEM

Changes of temperature of a water bath is one of the industrial problems needed to be controlled. The continuous time temperature control system [1] is described as

$$\frac{dy(t)}{dt} = \frac{f(t)}{C} + \frac{Y_0 - y(t)}{RC} \quad \text{..................(1)}$$

where t denotes time, f(t) is heat flowing into the system, y(t) is output temperature in ^{0}C, Y_0 is the room temperature (assumed constant for simplicity), C denotes system thermal capacity and R is the thermal resistance between system border and surroundings. Assuming R and C constant, obtaining the pulse transfer function for (1) using step input, the result obtained is represented by equation (2).

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

where k is the discrete time index u(k) and y(k) represent the system input and output respectively and Ts is the sampling period. Denoting by α and β some constant values depending on R and C, so that parameters can be expressed by

$a(Ts) = e^{-\alpha(Ts)}$ and

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

For simulation the parameters α=1.00151E-4 and β=8.67973E-3 and Y_0=25^{0}C, which are obtained from a real water bath plant. Now the simulated system is equivalent to single input and single output temperature control system for water bath for which various controller has to be design and compare the response obtain.

3. PID CONTROLLER

Proportional-Integral-Derivative (PID) controller has been widely used for processes and motion control system in industry.

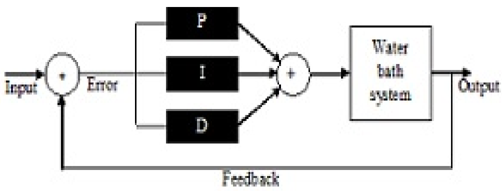

Fig.1. Schematic of the PID Controller

PID controller consists of Proportional Action, Integral Action and Derivative Action. It is by far the most common control algorithm. The proportional derivative controller has following general form

$$U(t) = K_p E(t) + K_i \int_0^t E(t)\,dt + K_d \frac{d}{dt} E(t) \quad ....(4)$$

where $U(t)$ = controller output, $E(t)$ = error signal, K_p= proportional gain, K_i= integral gain and K_d= derivative gain. By selecting appropriate value of these three gains we find the response of water bath system with PID Controller.

4. FUZZY LOGIC CONTROLLER

A Fuzzy Controller can be handled as a system that transmits information like a conventional controller with inputs containing information about the plant to be controlled and an output that is manipulated variable. Fig.2 shows the basic configuration of a Fuzzy Logic Controller (FLC). An FLC consists of fuzzification interface, knowledge base, decision making logic and defuzzification interface.

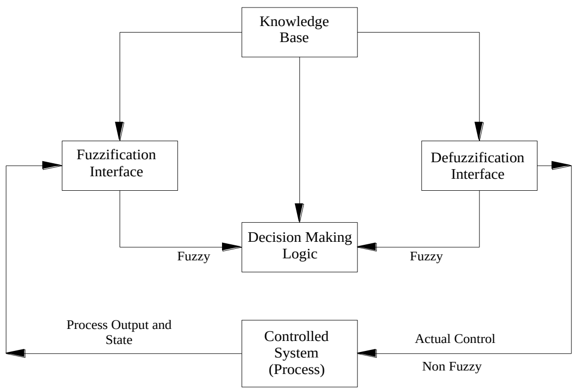

Fig.2. Basic Configuration of FLC

The water bath system shown in fig.3 uses 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. The water bath system uses 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 .

A. Fuzzy Rule

The Fuzzy Logic incorporates a simple, rule-based IF X AND Y THEN Z approach for solving a control problem rather than attempting to model a system mathematically. The FL model is empirically-based, depending on an operator's experience rather than their technical understanding of the system. For example, rather than dealing with temperature control in terms such as "SP = 500F",

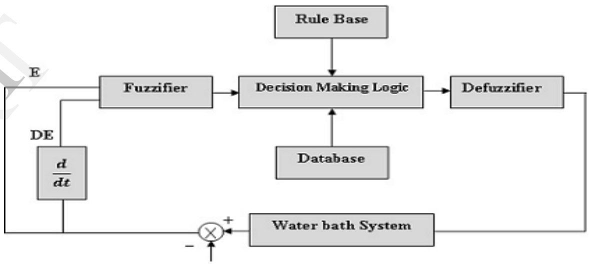

Fig.3. Water bath temperature control system based on Fuzzy Logic Controller

"T <1000F", or "210C <TEMP <220C", terms like "IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)" or "IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)" are used. These terms are inaccurate and yet very descriptive of what must actually happen. Consider what one does in the shower if the temperature is too cold: he will make the water comfortable very quickly with slight trouble. Fuzzy Logic is capable of imitating this type of behaviour but at a very high rate [2].

Following rule list has been implemented in this work. Different column of rule list represent input1 input2 output1 weight AND respectively.

Rule List

1	1	1	1	1
1	2	1	1	1
1	3	2	1	1
2	1	1	1	1
2	2	2	1	1
2	3	3	1	1
3	1	2	1	1
3	2	3	1	1
3	3	3	1	1

B. Fuzzy Membership Function

For simplicity Triangular Membership Function (MF) has been chosen. Input MFs E, DE and output MF U are shown in fig.4. membership function range is put [-10 10].

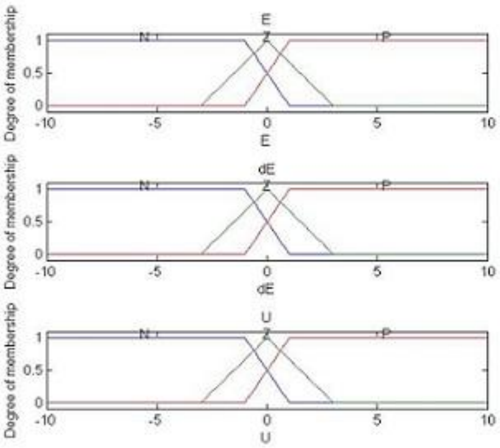

Fig.4. Fuzzy Membership Functions

5. OPTIMIZATION OF FLC USING GENETIC ALGORITHM

Genetic Algorithm is a stochastic algorithm; randomness as an essential role in Genetic Algorithms [3]. Generally, the initial population is produced randomly. Then, the genetic algorithm loops over an iteration process to make the population evolve. Each iteration consists of the four main steps.

Selection: The first step consists in selecting individuals for reproduction. This assortment is completed randomly with a probability depending on the relative fitness of the individuals so that best ones are often chosen for reproduction than poor ones.

Reproduction: In the second step, offspring are bred by the selected individuals. For generating new chromosomes, the algorithm is able to use both recombination and mutation.

Evaluation: Then the fitness of the new chromosomes is calculated.

Replacement: Through the last phase, individuals from the old population are killed and replaced by the new ones [4].

Both selection and reproduction needs random procedures. Genetic Algorithms always consider a population of solutions. Keeping in memory more than a single solution at each iteration, offers a lot of advantages.

In our system we have optimised the rules base of FLC using Genetic Algorithm. The basic four steps used in simple Genetic Algorithm to solve a problem are the representation of the problem, the fitness calculation [4], various variables and parameters involved in controlling the algorithm. The representation of result and the way of terminating the algorithm is shown in flow chart in fig. 5.

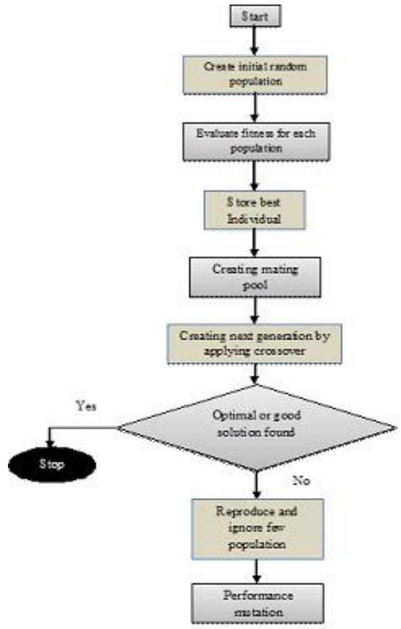

Fig. 5. Flow chart of Genetic Algorithm

The implementation of optimization of FLC rule base using GA [5] in water bath system is shown in fig.6.

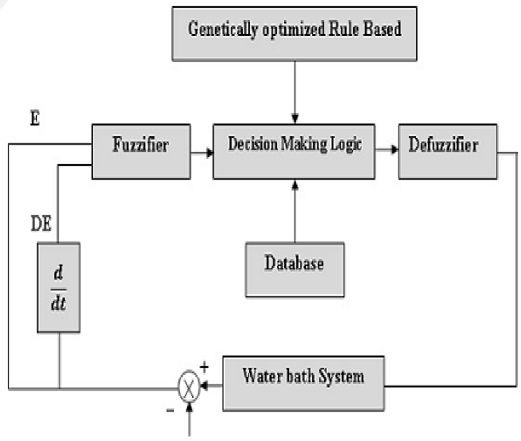

Fig.6. Water bath temperature control system based on GA-Fuzzy Logic Controller.

6. SIMULATION RESULTS

Using the mathematical model of real water bath, the proposed approach has been tested. The performances of various controllers are shown here for different set points 30^0C, 40^0C and 50^0C. Reference signal, output and error are shown in the figures of various controller responses. The output alongwith error of PID controller is shown in Fig.7.

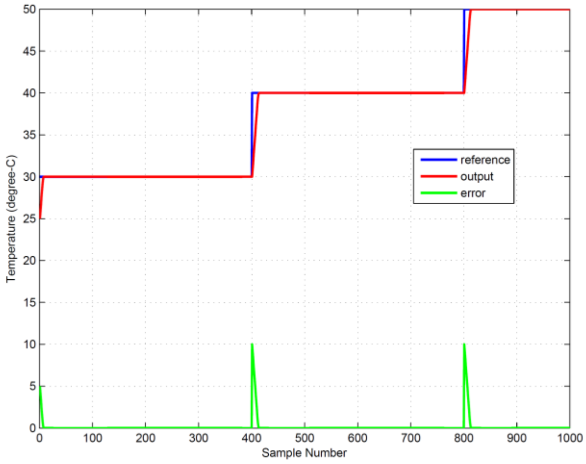

Fig.7. Results with PID Controller

The output alongwith error of Fuzzy Logic Controller is shown in Fig.8. From the result it is clear that the error has been reduced when compare with PID controller. The result has been evaluated at different set points of temperature of water bath system.

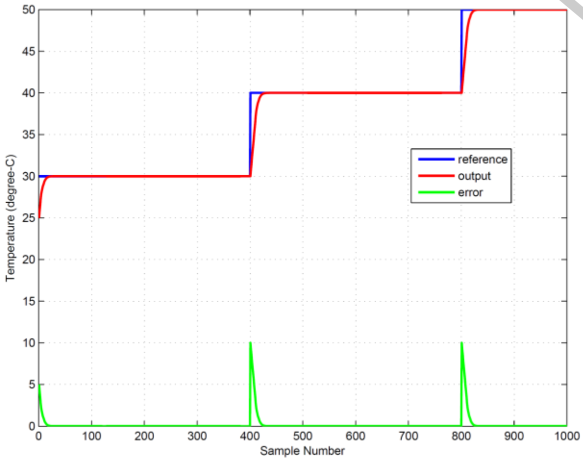

Fig.8. Results with Fuzzy Controller

The output of optimised rule base of FLC using Genetic Algorithm alongwith error is shown in Fig.9. The resulting error in this hybrid GA-Fuzzy Logic Controller is reduced significantly.

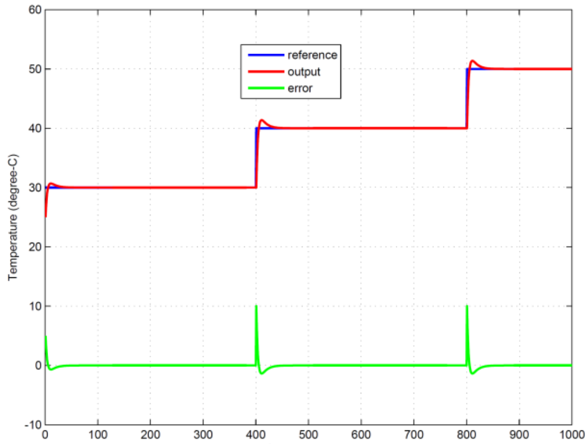

Fig.9. Results with optimized fuzzy controller

The combined output of PID, FLC and GA-FL hybrid controller is shown in Fig.10.

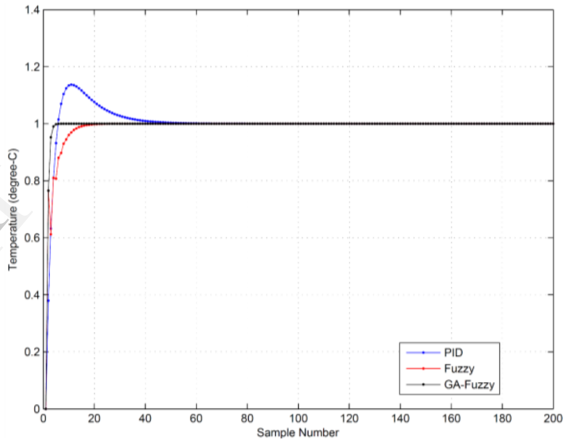

Fig.10. Step response of water bath tank with various controllers

7. COMPARISON OF SIMULATION RESULT AND CONCLUSION

Comparison of various controllers in Table 1 shows that the various parameters. When we move from conventional PID Controller to Fuzzy Logic Controller and moreover when we optimize the Rule Base of FLC with optimisation tool Genetic Algorithm again there is a reduction in absolute error.

Table 1. Comparison of responses of various controllers

Evaluation Parameters	PID	Fuzzy Logic	GA-Fuzzy Hybrid
Rise Time	3.4772	5.9460	1.5896
Settling Time	32.9754	12.3894	3.7275
Overshoot	13.6797	0	0
Peak Time	11	118	25

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