ISSN 2229-5518

Design and Comparison of PID Tuned with GA and FLC Optimized with GA Temperature Controller

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ABSTRACT

This paper presents design of conventional PID controller and artificial intelligence based Fuzzy Logic Controller for temperature control of water bath system that is widely used in industries and is nonlinear in behaviour. Tuning of PID controller parameter is done using Genetic Algorithm. The response of Fuzzy Logic Controller has been optimized with Genetic Algorithm. MATLAB is used for the simulation with Genetic Algorithm toolbox. Simulation results of the designed controllers are analyzed.

Keywords: PID Controller, PID Tuning with GA, FLC optimization with Genetic Algorithm, Fitness Function.

1. INTRODUCTION

In process industry such as oil and gas, pulp and paper, food and beverage, biochemical industries PID is a remarkable control strategy for controlling temperature. But improper tuning of PID parameters could lead to cyclic and slow recovery and poor robustness. Various widely used conventional tuning methods used are Zeigler Nicols and Cohen Coon. However, difficulty arises in these tuning methods when several unfavorable features such as non-linearity, interference, dead time, and external disturbances come in picture. To overcome difficulties of manual tuning Genetic Algorithm has been chosen in present work. From the literature, it has been found that Fuzzy Logic based controller improves response further from the conventional PID controllers so it has also been designed and studied. This controller is again optimized with genetic algorithm and further a comparison of simulation response of all designed controller is done and conclusion has been drawn.

The objective of the work is to control the temperature of the water bath at the desired set point using best controller so that control process response can be optimized.

2. PROBLEM FORMULATION

In process control industry, water bath system is commonly used. A change in temperature of a water bath is one of the industrial problems that needed to be controlled. The continuous time temperature control system is described as

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

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).

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

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

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

$$b(T_s) = \frac{\beta}{\alpha}(1- e^{-\alpha(T_s)}) \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

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 [1]. Now the simulated system is equivalent to single input and single output temperature control system for water bath for which various conventional and hybrid controller have to be designed.

3. TUNING OF PID CONTROLLER

The Proportional-Integral-Derivative (PID) controller is given by following equation

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

where, $U(t)$ = controller output, $E(t)$ = error signal, K_p= proportional gain, K_i= integral gain, K_d= derivative gain. The tuning of these parameters decides the response of the controller. Fig. 1 shows the schematic of closed loop PID controller

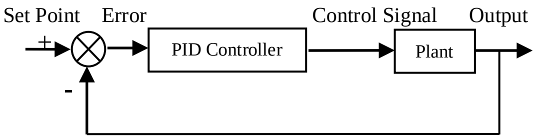


Fig.1 Schematic of the Closed Loop System

By trial and error tuning method following parameter values K_p=1.9730, K_i=0.1565, K_d=0.0606 are chosen. With these values of parameters, the response of the system is observed using MATLAB and is shown in Fig.2.

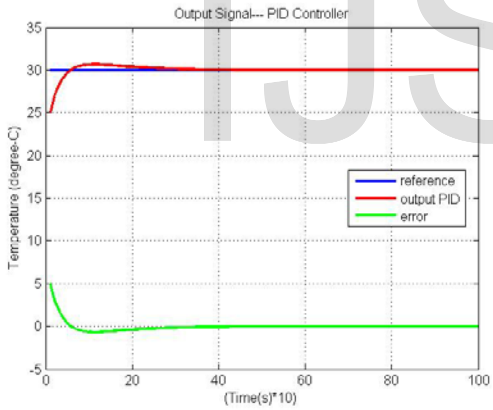


Fig.2 Response of Manually Tuned PID Controller

The simulation response shows the rise time 3.4776s, settling time 32.9690s, overshoot 2.2795 and peak time of 11s.

4. TUNING OF PID CONTROLLER USING GENETIC ALGORITHM

Genetic Algorithm is an optimization technique inspired by natural selection. Genetic Algorithm is started with initial population that contains a number of chromosomes. Each chromosome represents solution of the problem. Performance of these chromosomes is evaluated based on fitness function. Based on fitness of each individual a group of selected chromosomes undergo three stages of selection, crossover and mutation. It gives new individuals better than the parents which lead to optimal solution. Fig.3 shows the schematic of tuning of PID parameters using GA.

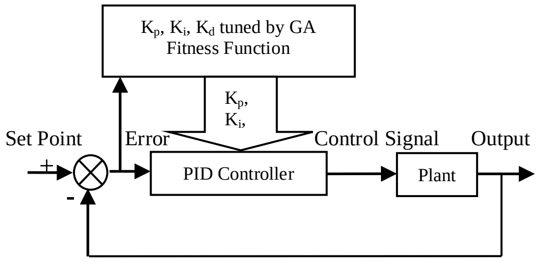


Fig.3 Tuning of K_p, K_i, K_d of PID Controller by GA

In this case, absolute error is taken as fitness function. Lower bound and upper bound for the three parameters K_p, K_i and K_d are [1 0.1 0.01] and [400 100 50] respectively. In this study, population in each generation is kept as 20. The simulation response of GA tuned PID controller is shown in Fig.4.

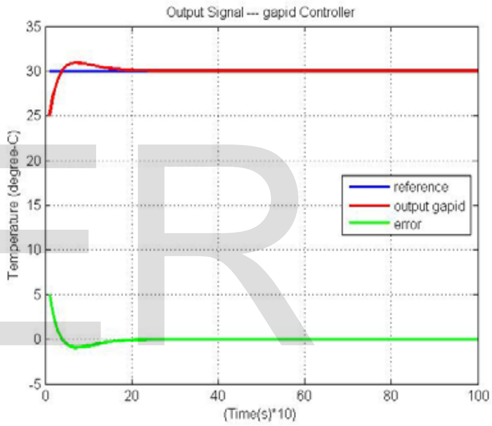
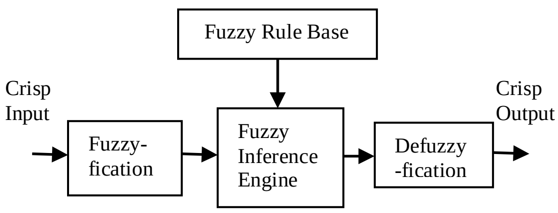


Fig.4 Response of GA Tuned PID

The simulation response shows the rise time 2.4436s, settling time 32.9690s, overshoot 3.0203 and peak time of 8s which is better than tuning of PID by trial and error.

5. FUZZY LOGIC CONTROLLER

Fuzzy Logic can be described as "computing with words rather than numbers". An FLC can include emperical rule that are useful in controlling the plant. The collection of rules is called rule base. A Fuzzy Logic Controller (FLC) consists of fuzzification interface, knowledge base, decision making logic and defuzzification interface as shown in Fig.5.



ISSN 2229-5518

Fig.5 Basic Configuration of FLC

For the water bath system represented by equation (1), two input variables error (e) and change in error (de) and one output variable (y) are considered. The closed loop system with FLC is shown in Fig.6.

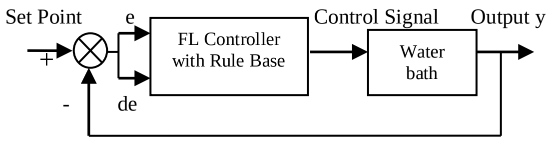


Fig.6 Closed Loop System with FLC

Fuzzy Rule Base

The Fuzzy Logic incorporates a simple, IF - THEN approach for solving a control problem rather than attempting to model a system mathematically. Following rules have been chosen for this work.

Rule1: IF E is N and DE is N THEN U is N
Rule2: IF E is N and DE is Z THEN U is N
Rule3: IF E is N and DE is P THEN U is Z
Rule4: IF E is Z and DE is N THEN U is N
Rule5: IF E is Z and DE is Z THEN U is Z
Rule6: IF E is Z and DE is P THEN U is P
Rule7: IF E is P and DE is N THEN U is Z
Rule8: IF E is P and DE is Z THEN U is P
Rule9: IF E is P and DE is P THEN U is P.

Here N, Z and P represents negative, zero and positive respectively.

Membership Function

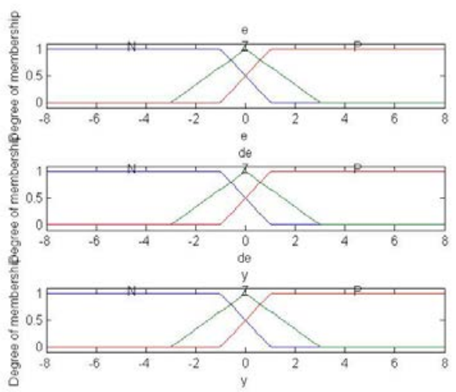


Fig.7 Fuzzy Membership Functions

In this work triangular and trapazoidal Membership Function (MF) have been chosen. MF for the input e and de output y is shown in Fig.7. Membership function ranges from -8 to 8 both inclusive.

With above stated input and output variables associated with said rule base the FLC with water bath system response has been simulated and following result has been obtained.

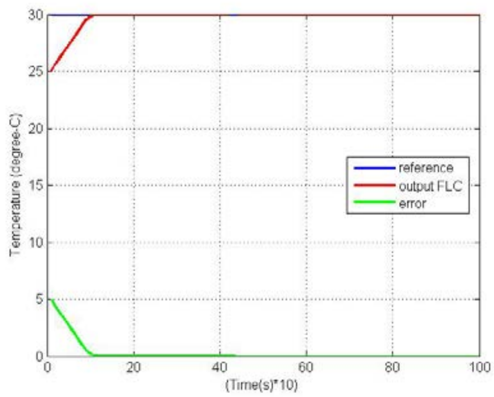


Fig.8 Response of water bath with FLC

Response of FLC shows a rise time 7.2738s, settling time10.7759s and zero overshoot.

6. FLC OPTIMIZATION USING GENETIC ALGORITHM

Genetic Algorithm is a stochastic algorithm; randomness is 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.

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

In present work, rule base of FLC have been optimised using Genetic Algorithm. The basic four steps in simple Genetic Algorithm to solve a problem use the fitness calculation [4].

Fitness function is the absolute error which has to be minimized. The randomly selected rules are passed to the Fuzzy inference system which generates output which is then given to water bath system. The output of water bath system is then used to calculate deviation from reference temperature. The error and derivative of error are calculated and given to fuzzy inference system. Before that fitness is checked by GA which decides whether further rule base need to be modified or not.

The implementation of optimization of FLC rule base using GA [5] in water bath system is shown in Fig.9.

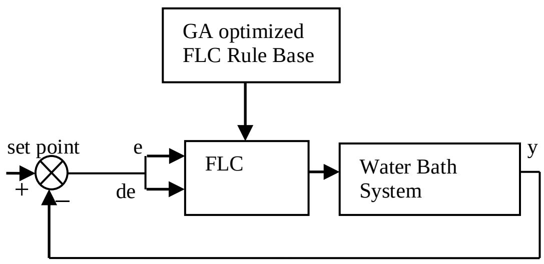


Fig.9 Water Bath Control system with GA-FLC

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With the optimized FLC, the response of GA-FLC with water bath system is shown in Fig.10.

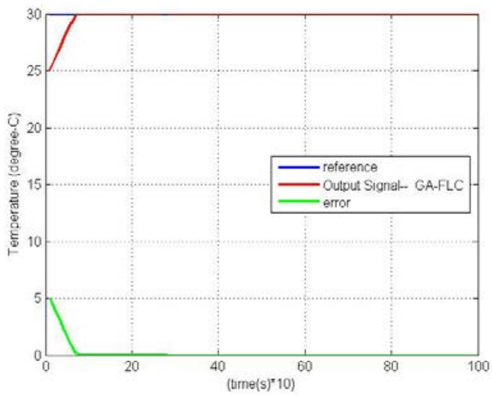

Fig. 10 Response of water bath tank with GA-FLC

The response of GA-FLC for water bath tank are rise time 4.9093s, settling time 7.5611, zero overshoot and peak time of 28s which is a good improvement as compared to FLC.

7. COMPARISON OF RESULTS

Using the mathematical model of real water bath, the proposed work has been tested and analysed. Performances of various controllers are shown here for set point of 30^0C. Comparison of various controllers responses are shown in Table 1 under various parameters. When we move from conventional PID Controller to GA tuned PID a good improvement in response is obtained. Fuzzy Logic Controller is designed and simulated. Then the optimization of the rule base of FLC with Genetic Algorithm has given a reduction in parameter values.

Table 1. Comparison of Results of Controllers

Evaluation Parameters	PID	GA Tuned PID	FLC	GA-FLC
Rise Time	3.4776	2.4436	7.2738	4.9093
Settling Time	32.9690	21.5102	10.7759	7.5611
Overshoot	2.2795	3.0203	0	0
Peak Time	11	8	44	28

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