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Optimization of the Membership Functions for a Fuzzy Controller Using an Improved Genetic Algorithms

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Abstract: Fuzzy control is a practical alternative for a variety of challenging control applications since it provides a convenient method for constructing nonlinear controllers via the use of heuristic information; this is done through the application of the techniques that use human judgment and experience rather than precise mathematical models. However, obtaining an optimal set of fuzzy membership functions (i.e. transferring the operator experience) is not an easy task. Different ways are suggested to deal with this problem. In this paper, we will use a powerful tool based on genetic algorithm to design a fuzzy logic controller that is used as a supervisor of PID controller that is the fuzzy controller is used to tune the PID controller for a feed water of a steam generation system. The simulation results show that the proposed technique is very useful to get an effective control action for the system.

Keywords: Fuzzy control; hierarchical genetic algorithm; supervisory control; PID.

1. INTRODUCTION

Boilers were a major part of the Industrial Revolution beginning about 1700. They are major consumers of industry and building energy consumption today. They are used for power generation, process heat (refineries, petrochemicals, paper mills, tire manufacturing …) and heating [1].introduction section must contain theory related to the paper topic along with state of art study and well referenced citations. Make this section as informative as possible to justify the work and situate it with respect to the literature.

The function of a boiler is to deliver steam of a given quality (temperature and pressure) either to a single user, such as a steam turbine, or to a network of many users. Then, a properly functioning boiler must satisfy the following basic requirements:

1) The ratio of air to fuel must be carefully controlled in order to obtain good, safe, and efficient Combustion.
2) The level of water in the drum must be controlled at the desired level in order to prevent overheating of drum components or flooding of steam lines.
3) A desired steam pressure must be maintained at the outlet of the drum despite variations in the quantity of steam demanded by users [2].

The objective of a feed water controller may seem simple: it is to supply enough water to the boiler to match the evaporation rate but as is so often the case with boilers, this turns out to be a surprisingly complex mission to accomplish. The design of the control system is then further complicated by the many interactions that occur within the boiler system and by the fact that the effects of some of these interactions are greater or smaller at various points in the boiler's load range. The performance of a fuzzy logic controller depends on its control rules and membership functions. Hence, it is very important to adjust these parameters to the process to be controlled. A method is presented for tuning fuzzy control parameters by genetic algorithms to make the fuzzy logic control systems behave as closely as possible to the operator or expert behavior in a control process [3].

In this paper, we will use a fuzzy controller to describe the optimization of membership functions, its parameters and its shapes such that the reference shape for our membership functions is trapezoidal function, and employing it in the design of a fuzzy supervisory PID controller for feed water of a steam generation system.

2. FUZZY LOGIC

In recent years, the number and variety of fuzzy logic applications have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection [4].Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multi-valued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with un-sharp boundaries in which membership is a matter of degree [5]

2.1 Fuzzy logic control

The basic structure of a fuzzy logic controller is shown in Fig.1

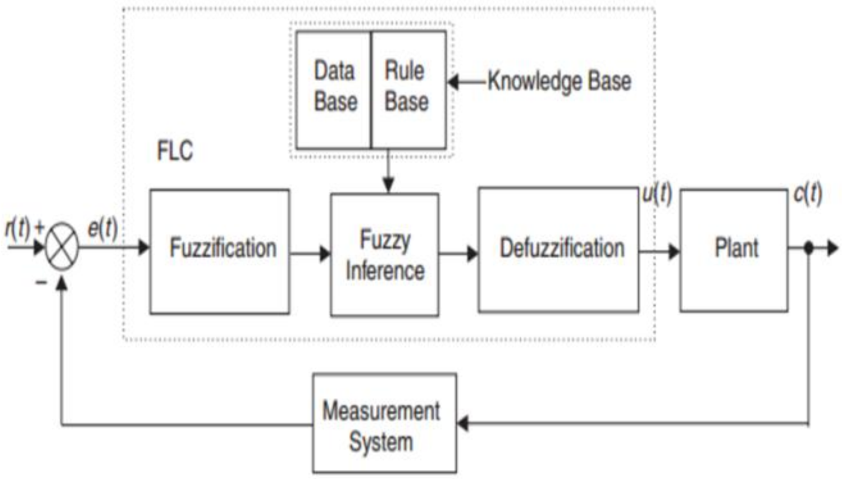


Fig. 1 Block diagram for a fuzzy logic controller

The control operation is realizedthrough the following steps:

- *The fuzzification stage*: which consists in defining the fuzzy sets for the input and output variables. Decision need to be made regarding the number of inputs and outputs, the number and shapes of fuzzy sets, the size of universe of discourses.
- *The inference stage:* This is the stage where the fuzzy rules are established. The fuzzy rule base consists of a set of antecedent- consequent linguistic rules of the form: IF (antecedent) THEN (consequent). The rule base is constructed using a priori knowledge from different sources such as physical laws and data from other controllers….
- *Defuzzification stage:* The defuzzification is the procedure for mapping from a set of inferred fuzzy control signals contained within a fuzzy output window to a non-fuzzy (crisp) control signal. Several methods are used in the defuzzification process as it is described in [6] [7].

2.2 Fuzzy supervisory control

Fuzzy Supervisory controller is a multilayer (hierarchical) controller with the supervisor at the highest level, as shown in Fig.2. The fuzzy supervisor can use any available data from the control system to characterize the system’s current behavior so that it knows how to change the controller and ultimately achieve the desired specifications. In addition, the supervisor can be used to integrate other information into the control decision-making process [8].

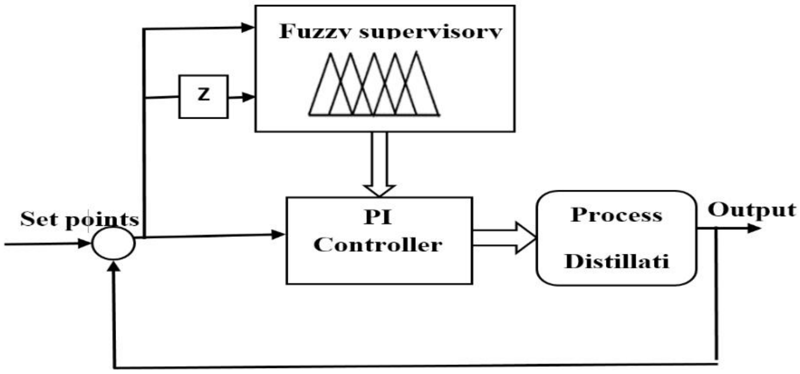


Fig. 2 Block diagram for a PI fuzzy supervisory PI I controller

3. GENETIC ALGORITHMS

A genetic algorithm (GA) is a search optimization algorithm based on the mechanics of natural selection and natural genetics. It uses the concept of Darwin's theory of evolution. Darwin's theory stressed the fact that the existence of all living things is based on the rule of "survival of the fittest) Darwin also postulated that new breeds or classes of living things come into existence through the processes of reproduction, crossover, and mutation among existing organisms .[9],[10]

3.1 General mechanism of genetic algorithm computation

GA s typically compute through the following steps, summarized in the flowchart of Fig 3.maintaining a population of bits strings representing candidate solutions of a problem.

- Step 1: Randomly generate N chromosomes on initial population in the search
- Step 2: Calculate the fitness for each chromosome.
- Step 3: Perform reproduction, i.e. select the better chromosomes with probabilities based on their fitness values.
- Step 4: Perform crossover on chromosomes selected in above step by crossover probability.
- Step 5: Perform mutation on chromosomes generated in above step by mutation probability
- Step 6: If reach the stop condition or obtain the optimal solution, one may stop the process, else repeat Steps 2-6 until the stop condition is achieved.
- Step 7: Get the optimal solution.

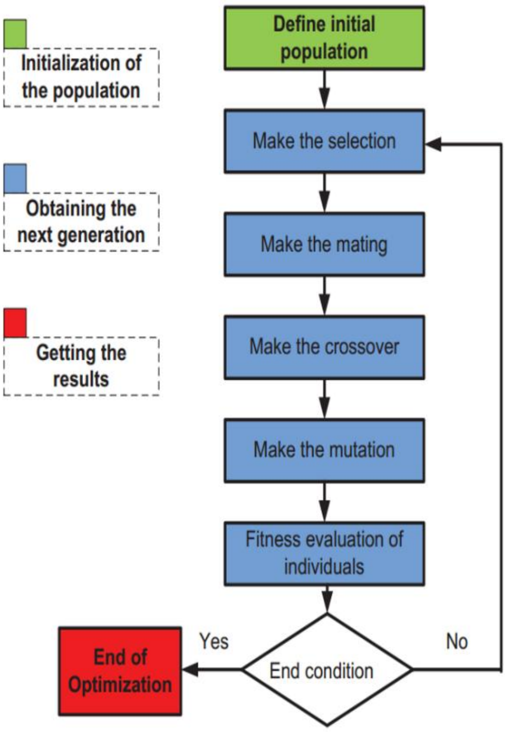


Fig. 3 General mechanism for GA computation

3.2 Hierarchical genetic algorithm

Hierarchical genetic strategy is a new evolutionary method which gives good computation complexity in solving global optimization problems by using different length genotypes. In other wordsA Hierarchical Genetic Algorithm (HGA) is an algorithmic technique of artificial intelligence that converges on a solution at both the atomic and structural levels [11]

4. HIERARCHICAL GENETIC ALGORITHM CODING FOR FUZZY CONTROL

The basic procedures of designing a fuzzy logic controller (FLC) have been well established .The operating procedures for these variables are usually done manually, but this often yields a suboptimal performance, despite some other automatic tuning schemes

Considering that the main attribute of the HGA is its ability to solve the topological structure of an unknown system, then the problem of determining the fuzzy membership functions and rules could fall into this category. This approach has a number of advantage [12].[13]

- An optimal, and the least, number of membership functions and rules is obtained;
- No prefixed fuzzy structure is necessary;
- Simpler implementing procedures and less cost are involved;
- It meets design criteria that can be multi-objective and constrained.
- The conceptual idea is to have an automatic and intelligent scheme to tune the fuzzy membership functions and rules, in which the closed-loop fuzzy control strategy remains unchanged.

5. PROCESS DESCRIPTION

A boiler of a chemical plant is taken as a case study and the temperature control of the boiler is achieved using fuzzy supervisory controller. The boiler is mathematically modeled using experimental data available and its transfer function is given as [15]

$$G(s) = \frac{s(s+1)}{s(s+6)(s+1)} \quad (1)$$

6. SIMULATION AND RESULTS

Our objective in this paper is to minimize the error which represents the difference between the response of our system and the set point. Hence the fitness function is defined as follow:

$$J = \sum_{i=1}^{k} ei^2 \qquad (2)$$

In our case we will choose our fitness function as f=0.01/j

The HGA parameters are indicated in table 1

Table 1 The HGA parameters

	Membership Chromosome
Representation	Real
Population size No. of Offspring	20 1
Crossover Crossover rate	One point crossover 0.9
Mutation Mutation rate	Random mutation 0.01
Selection	Roulette wheelselection

The parameters of the fuzzy system are:

- e □ [-0.01,0.01] and Δe □ [-0.1,0.1];
- The range of “KP” is [10;16] and “KI” is [5;6.5] and “KD” [1;2].
- Minimum inference engine (Mamdani inference);
- Center average defuzzifier.

The optimal rules for the inference table are indicated in Table 2.

Table 2 The HGA parameters

	Δe			Δe			Δe	
	D1	D2		D1	D2		D1	D2
E1	U2	U2	E1	V2	V2	E1	W1	W2
E2	U2	U1	E2	V2	V1	E2	W2	W1
E3	U2	U2	E3	V1	V2	E3	W1	W2

The fitness values for different generations are shown in Fig.4 which indicate that the generation n=13 includes the best solution.,

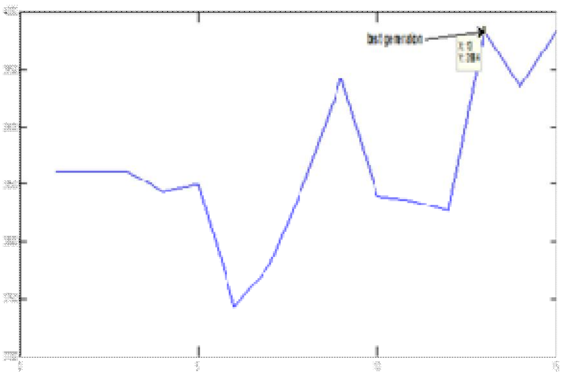


Fig. 4 the fitness values of different generations .

Whereas the fitness function value of the chromosomes of this generation is illustrated in Fig.5 hence we can conclude that the chromosome 18 contains the best solution.

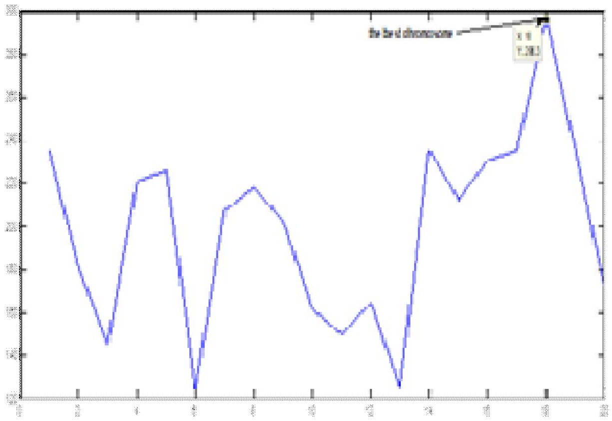


Fig. 5 the fitness values of different chromosomes of generation 13

The optimum number and shape of the fuzzy inputs (error and delta error) are shown in Fig.6and Fig 7

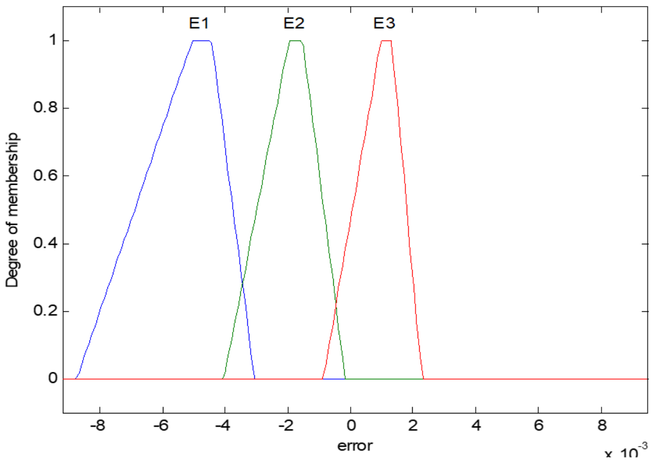


Fig. 7 the membership functions for input 1 (error)

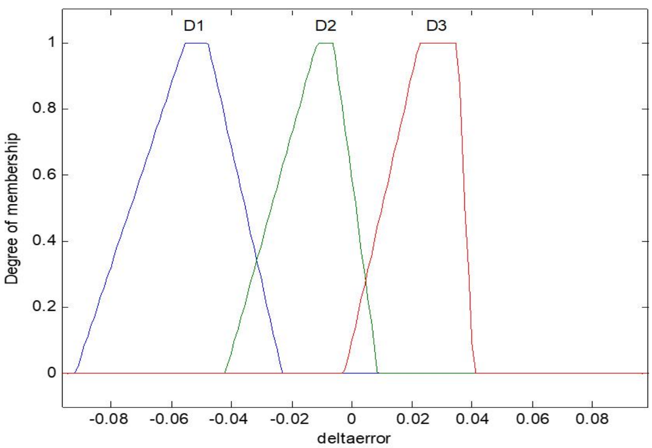
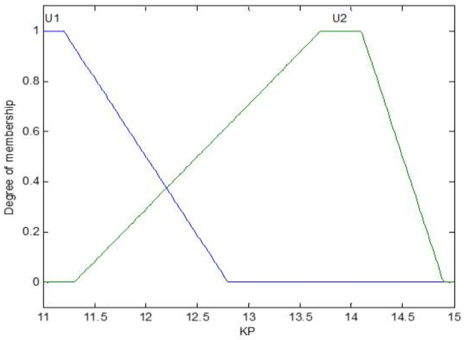
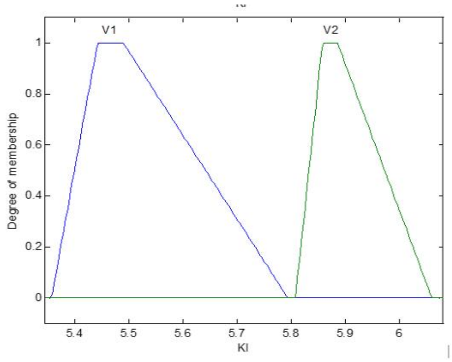


Fig 8 the membership functions for input 2 (Delta error)

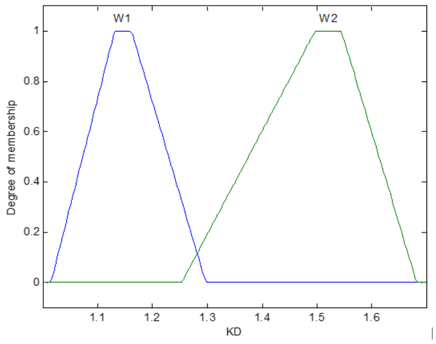
And Figs 9 includes the optimum membership functions for the fuzzy controller which are KP,KI and KD



(a) Kp



(b) Ki



(c) kd

Fig. 9 the membership functions for the fuzzy controller outputs.

For a particular case where the error is 0.01 the optimum values of the PID controller are Kp= 13 , Ki=5.71 , and Kd= 1.3495, the corresponding responses for a unit step response is given in Fig.10.whereas Fig 11 indicate the control action of the controller.

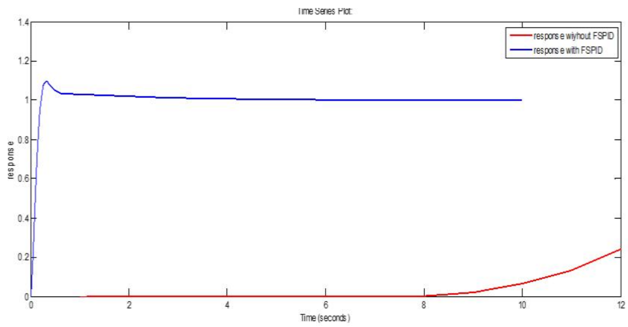


Fig. 10the unit step response for the system

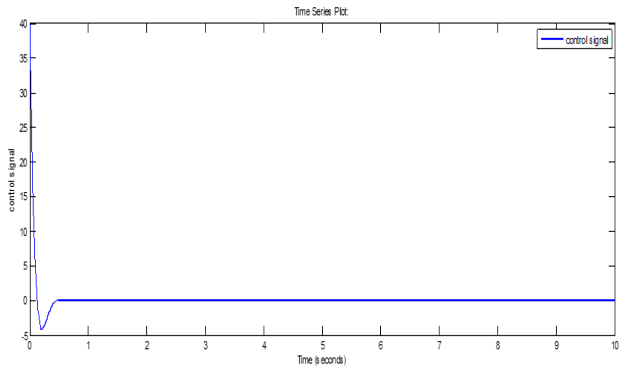


Fig. 11 control signal

From the figures we notice that the The mostdesirable performance requires the controller to have the smallest possible value for the rise time, overshoot and the settling time are investigated

7. CONCLUSION

The simulation results demonstrate the efficiency of Genetic Algorithms to be a powerful search tools that can reduce the time and effort involved in designing fuzzy controllers. In our case the fuzzy is used as a supervisor that assure the tuning of a PID controller used to control a very complicated process the case of steam generation system.

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