Design of Optimized Fuzzy logic Controller for Magnetic Levitation Using Genetic Algorithms

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Basil Hamed
Islamic University of Gaza

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Basil Hamed and Hosam Abu Elreesh

Abstract-This paper presents an optimum approach for designing of fuzzy controller for nonlinear system using Genetic Algorithms (GA). In this paper, a magnetic levitation system is considered as a case study and the controller is designed to keep a magnetic object suspended in the air counteracting the weight of the object. Genetic Algorithm (GA) is used in this paper as optimization method that optimizes the membership, output gain and inputs gains of the fuzzy controllers.The proposed algorithms are implemented using Matlab and Simulink

Index Terms-Fuzzy control, PI, Genetic Algorithms, Magnetic Levitation Ball.

1 INTRODUCTION

In the recent years Genetic Fuzzy Systems (GFS) are used to control complex engineering problems which are difficult to solve by classical methods. The Hybridization between GA is one of methods of Evolutionary Algorithms (EA) and FLC so called soft computing. Fig. 1 shows a family of computing techniques.

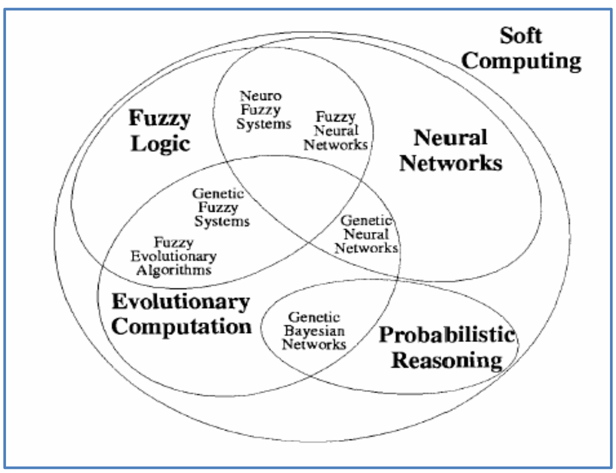


Fig. 1: Hybridization in Soft Computing

There are many ways of how to use GA in fuzzy control. The most extended GFS type is the genetic fuzzy rule-based system (GFRBS), where an EA is employed to learn or tune different components of an FRBS. The objective of a genetic tuning process is to adapt a given fuzzy rule set such that the resulting FRBS demonstrates better performance [1]. In recent years many studies emerged illustrate the different ways to use fuzzy control with genetic algorithm in different application. J.E. Bonilla, V.H. Grisales and M.A. Melgarejo [2]; the fuzzy controller architecture in this paper focused on the treatment of errors and changes in errors with tuning gains. The controller is probed with magnetic levitation. GA is used as a tuning tool to obtain a particular overshoot in the transient response of the control system. S. Ravi and P. A. Balakrishnan [3] presented Genetic Algorithm based Fuzzy Logic Controller for temperature control in a plastic extrusion is developed and tested through a simulation study. A novel GA based FLC method is implemented to design a practicable advanced controller. MohanadAlata, Mohammad Molhem and Khaled Al Masri [4] presented a solution of first, second, and third order systems, using the absolute average error as a fitness function, the genetic algorithm manipulate all parameters of the fuzzy controller to find the optimum solution.

2 FUZZY CONTROL

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth.There are not two values (true or false) but there are two limits (1) completely true and (0) completely false and the result can have different degree between these limits [5]. Fuzzy Control applies fuzzy logic to the control of processes by utilizing different categories, usually 'error' and 'change of error', for the process state and applying rules to decide a level of output. There are many models of FLC, but the most famous are the Mamdani model, Takagi- Sugeno-Kang (TSK) model and Kosko's additive model (SAM) [5]. This paper uses Mamdani model.

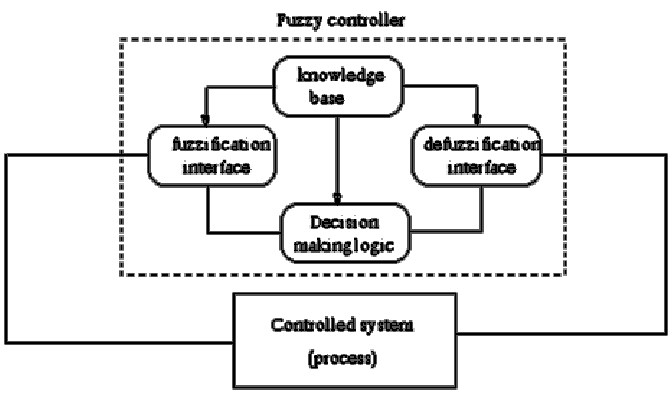


Fig. 2: Mamdani Model

Fig. 2 shows the block diagram of Mamdani fuzzy system model, the rule base of this model is in the next form.

IF (X is A) and (Y is B) … THEN (Z is C)

Where A and B membership of the inputs, C is membership of the output as shown in Figure 2. Mamdani model block consist of three stages.

- **Fuzzification: -** Fuzzification means converting a crisp value of process variable into a fuzzy set. In order to make it compatible with the fuzzy set representation of the process state variable.
- **Fuzzy Associative Memory (FAM): -** FAM is a set of fuzzy associations between the input and the output [6]. This stage consists of two parts:

A. Knowledge base: - Knowledge base contains a data base and rule base. Data base provides necessary definitions for linguistic rules, and the rules base consist of the IF-THEN rules, which can be derived by using four ways:

- Expert Experience and control engineering knowledge.
- Based on fuzzy modeling of human operators central action.
- Based on learning
- Based on fuzzy model of a process.

B.Decision-Making: - Decision-Making means choosing the most appropriate action from several possible actions.

Defuzzification: - Defuzzification strategy is aimed at producing a non-fuzzy control action, or we can say defuzzification means the conversion of the fuzzy output values into crisp values.

3 GENETIC ALGORITHM

Genetic Algorithms are reliable and robust methods for searching solution spaces [7]. GA is general purpose search algorithm which uses principles inspired by neutral genetic to find solutions to problems [8][9] by using Survival of the fittest principle. The basic idea is to maintain a population of chromosomes, which represent candidate to the concrete problems that will be solve, through a process of computation and controlled variation. Each structure of chromosome in the population represent one of the possible solution of the problem and the fitness test of these chromosomes can determine which chromosomes are used to form a new chromosomes that will be used in computational process. As in natural the new chromosomes are created by some operations such as crossover and mutations. There is another operation which called reproduction. This operation is added to achieve the survival of the fittest principle. In recent years, GA is used in many applications specially in optimization and search problems and had a great measure of success; the main reason of this success that it can start from any solutions, and generate other solutions that converge to the optimal solution in less time versus other classical search tools (enumerative, heuristic). "GA is theoretically and empirically proven to provide a robust search in complex spaces; thereby offering a valid approach to problems requiring efficient and effective searches" [1]. Figure 3 shows the steps of GA.

Fig. 3 shows that there are three basic operations in GA:

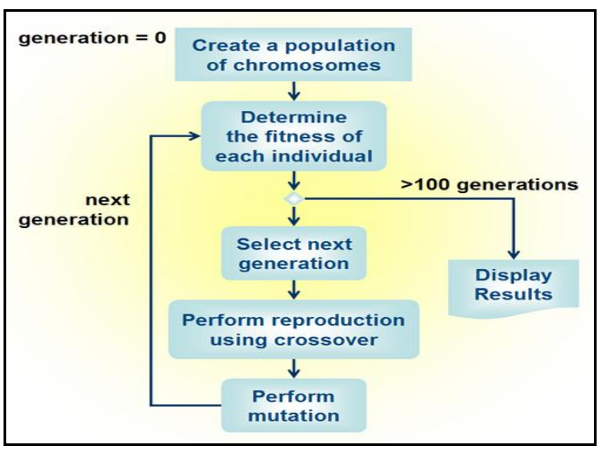


Fig. 3: The basic Genetic Algorithm

1- **Selection**: In this process the developer will choose the pairs of parents that will be crossed. There are many methods can be used such as Roulette Wheel Selection (Fig. 4), Rank Selection and Stochastic Universal Sampling [10].

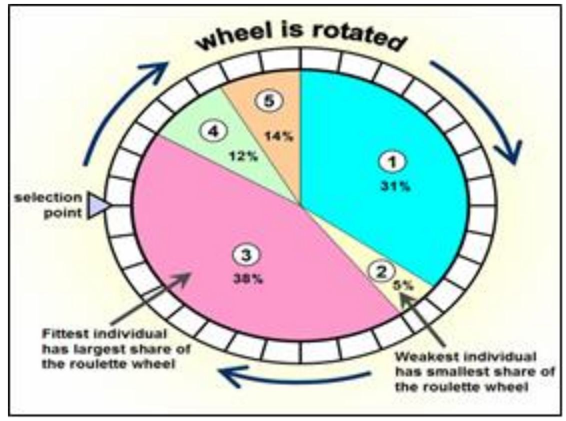


Fig. 4: Roulette Wheel Selection.

2- **Crossover**: Crossover is the process that takes two parents of solutions and generates a new offspring. There are many methods can be used such as Single-Point Crossover (Fig. 5), two-point crossover and uniform crossover [10].

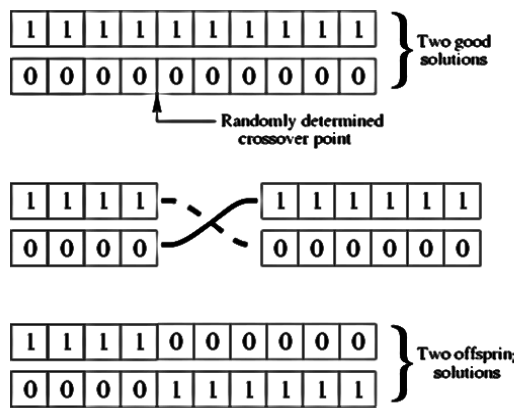


Fig. 5: Single Point Crossover

3- **Mutation**: Mutation means swap one bit in binary coding or changes one number if the chromosome consists of numbers [10].

There are many optimization methods, but GA has some advantages over these methods such as [11]:

1- GA does not deal with data directly but works with encoded data.

2- GA uses least information such as fitness function to solve problems an does not need derivation.

3- GA uses probability laws rather than certain laws.

4- GA generate populations of answer not just one answer.

5- Almost all conventional optimization techniques search from a single point but GA always operates on a whole population of points (parallelism).

4 GENETIC FUZZY SYSTEMS

Fuzzy control depends on good knowledge of the system, which is intended to control it. So control engineer must have a good experience with this system. The fuzzy controller of any system can be found by try and error. Try and error method is not simple in fuzzy control and may be take very long time, because there are many parameters have an effect of the fuzzy controller, such as membership shape, rules (number of rules or architecture of rules), inputs gains and outputs gains, and the interval of the membership of the inputs and outputs. There are two ways for using GA with fuzzy control [1]:

4.1- Genetic Tuning of the Data Base

The tuning of the scaling gains and fuzzy membership functions is an important task in FLC design. Scaling gains applied to the inputs and outputs of an FLC. Because the most FLC is normalized, the universes of discourse in which the fuzzy membership functions are defined (all inputs and outputs are in the rang [-1 1]. The individual is refer to scaling gain and by using fitness function can calculate the best individual which gives the best scaling function. In the case membership function, the parameters of the membership is tuned; Triangular membership functions are usually encoded by the left, right, and center of the membership

4.2- Genetic Learning of the Rule Base

In this way the membership of the fuzzy inputs and outputs and the scaling gain of them do not changed, but the sequence of IF THEN rules will be modified to gives the best result. In this way the individual is represent the one rule or the all rules. The RB is representing by a relational matrix, a decision table or a list of rules.

In this paper the fuzzy membership inputs and output membership functions will be used as variables that will be optimized using GA. Every triangular membership has three variable can effect on the shape of it; so the each chromosome will has the number of genes every genes refer to one parameter that effect on the membership shape. For example every triangular membership can represents be three genes because it has three parameters that control of its shape (center edge, left edge and right edge). If the inputs of fuzzy controller have seven triangular memberships, then every chromosome of the population will have twenty one genes (7x3). The main problem in GA is how to choose fitness function. Minimize output error is one of importance aims in control systems. In control applications there are different fitness function that may be used [12].

1- Sum of squared error

$$fitness.value = \int_0^\infty e^2(t)\,dt \quad (1)$$

Where (e) is the error signal, this function can track error quickly, but easily gives rise to oscillation.

2- $fitness.value = \int_0^\infty |e(t)|dt$ Sum of absolute error (2)

This function can obtain good response, but its selection performance is not good.

3- $fitness.value = \int_0^\infty te^2(t)dt$ Sum of time weighted squared error (3)

This function can gives fast tracking and good response.

In this paper the sum of absolute value of error will be used as fitness function.

5 APPLICTION and RESULTS

The CE 152 Magnetic Levitation Model is one of the ranges of educational scale models offered by Humusoft Company for teaching system dynamics and control engineering principles. The model belongs to the range of teaching systems directly controllable by a PC computer in real time. The CE 152 Magnetic Levitation model is one dimensional strongly unstable system designed for studying system dynamics and experimenting with number of different control algorithms based on classical and control theory. Fig. 6 shows CE 152 model [13].

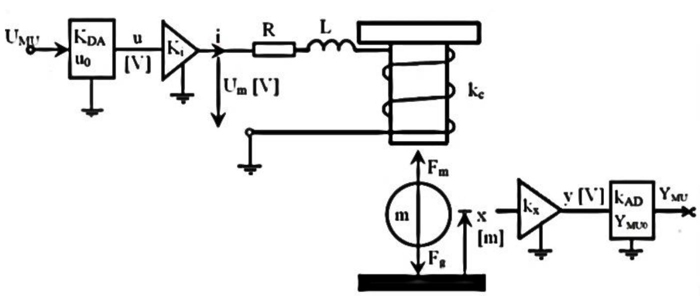


Fig. 6: CE152 Magnetic Levitation Model.

The model shown in Figure 6 consists of the following blocks:

1. D/A converter.
2. Power amplifier.
3. Ball & coil subsystem.
4. Position sensor.
5. A/D converter.

The mathematical equation of this model is:

$$\begin{bmatrix} \dot{x}_1 = x_2 \\ \dot{x}_2 = \dfrac{i^2 k_c}{m_k (x_1 - x_0)^2} - g - \dfrac{k_{fv} x_2}{m_k} \\ \dot{x}_3 = \dot{I} \end{bmatrix} \quad \text{(nonlinear state space model)}$$

Where x_1 is the ball position, x_2 ball velocity and x_3 coil current

m_k = ball mass [kg].

g = gravity acceleration constant [m.s^-2].

k_{fv}= viscose friction.

x_0 = coil bias [m].

K_c= coil constant.

5.1 Fuzzy Controller Design for CE152 Model

To apply the fuzzy logic controller to the magnetic levitation CE 152, certain properties of the system are exploited so that the design of the controller can be made easier. As the system is symmetrical, it is assumed that symmetrical membership functions about the y-axis will provide a valid controller. A symmetrical rule-base is also assumed.The fuzzy controller of magnetic levitation uses Mamdani model. The FLC has two inputs which are error and change of error and the output is the change of voltage. Fig. 7 shows the membership functions of fuzzy controller using Fuzzy Toolbox of Matlab software. The ranges of the inputs and output is [-1 1]. All have 7 membership functions.

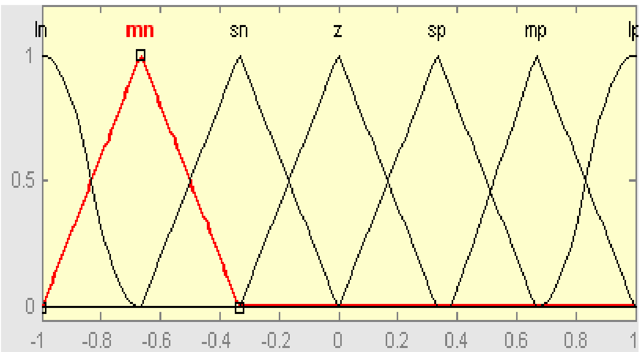


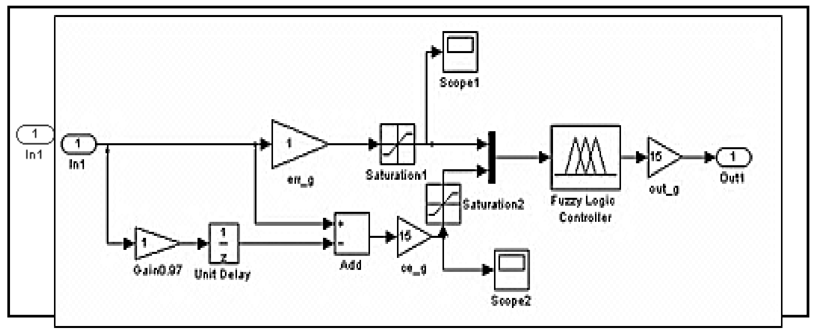
Fig. 7: Memberships of inputs and output fuzzy controller

The next step after designing the membership functions is to write the rules of the fuzzy controller. These rules are chosen based on knowledge base and experts. Table 1 shows the rules base as a matrix

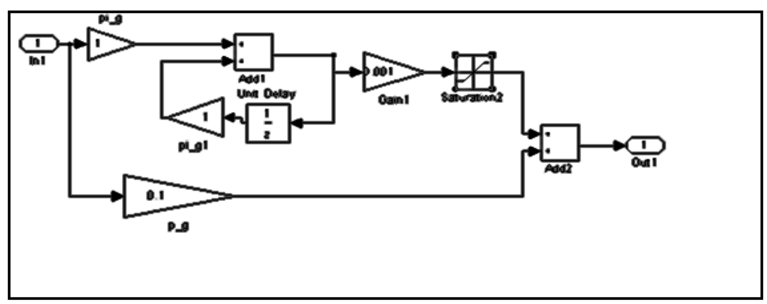
Table 1 Fuzzy Control Rule Base of Magnetic Levitation

e / ce	ln	mn	sn	z	sp	mp	lp
ln	ln	ln	ln	ln	mn	sn	z
mn	ln	ln	ln	mn	sn	z	sp
sn	ln	ln	mn	sn	z	sp	mp
z	ln	mn	sn	z	sp	mp	lp
sp	mn	sn	z	sp	mp	lp	lp
mp	sn	z	sp	mp	lp	lp	lp
lp	z	sp	mp	lp	lp	lp	lp

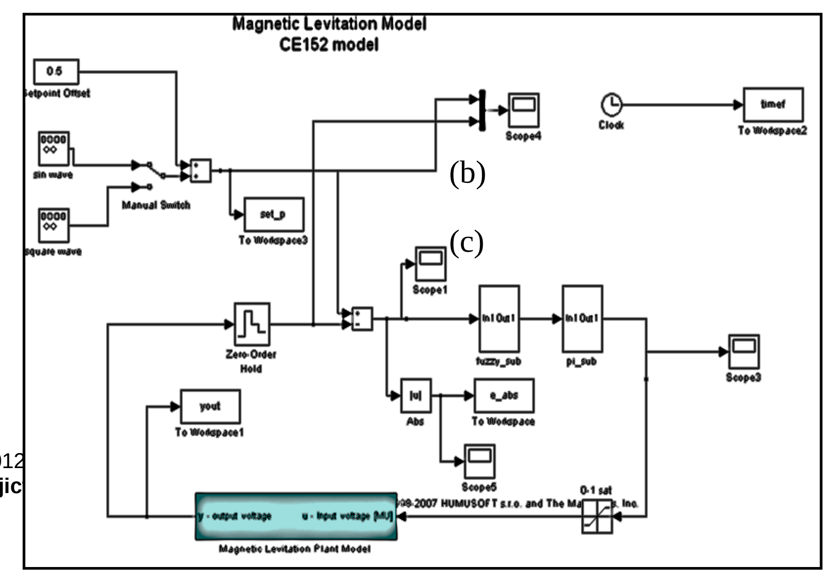
After designing fuzzy controller, the controller will be connected to the CE152 magnetic levitation Matlab Simulink model. Figure 8 a, b and c shows the fuzzy controller, proportional integral controller (PI) subsystems and all system respectively. The integral part is used to convert the change of voltage value that come from fuzzy controller to real voltage which will act on the magnetic levitation CE152. Using tuning method the good proportional gain is 0.1 and the integral gain is 1.



(a)



(b)



(c)

Fig. 8: a) Fuzzy Controller subsystem - b) PI Subsystem –c) Magnetic Levitation Model

Fig. 9 shows the output of the magnetic levitation after connecting to the fuzzy controller. The set point is unit step has value 0.5 which is in the center of the gap; this point is one of the equilibrium points of magnetic levitation CE152 model. There is no overshoot and the settling time is nearly 0.2 sec, rising time is 0.106 sec.

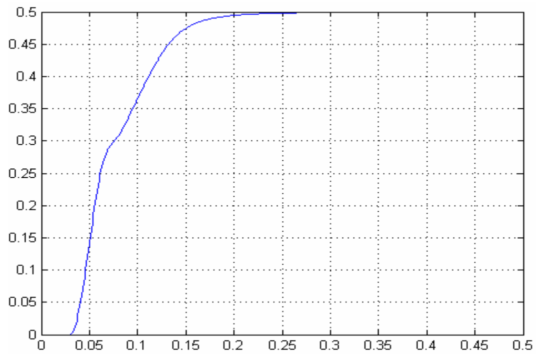


Fig. 9: Step Response of the System

Fig. 10 and Fig. 11 show the output response with two additional set points. These figures show that the fuzzy controller can keep the stability of the system with various set points.

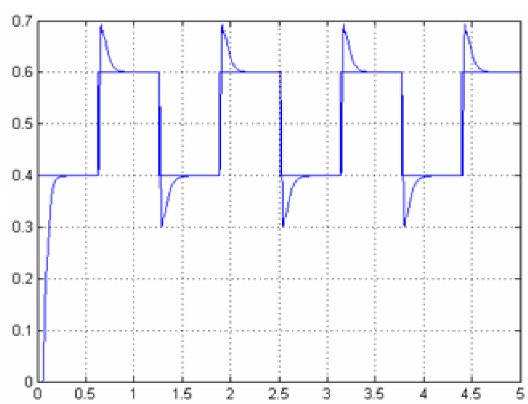


Fig. 10: Square Wave Output Response of the System

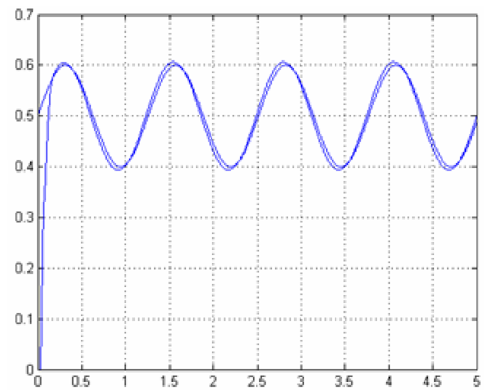


Fig. 11 Sine Wave Output Response of the System

5.2 Fuzzy Controller Design with GA for CE152 Model

There are many parameters effect on the control process of the CE152 model as shown in Figure 8 a,b in addition to the shape of the memberships of the inputs and output of fuzzy controller. These parameters are p_g (proportional gain), pi_g (integral gain), ce_g (change of error gain), err_g (error gain) and out_g (fuzzy output gain). (See Figure 8 a,b and c) These gain parameters can be tuned to give near optimal results. GA is used to optimize these parameters and optimize the shape of memberships of fuzzy controller. The GA Matlab code uses next parameter

Population size= 50.

Number of gens in one chromosome = 13.

Crossover probability=0.9.

Mutation probability= random (0.0 to 1.0)

Stopping condition: 100 generations.

Fig. 12 shows the change of the fitness values after running the Matlab code.

Gains	with GA optimization	without GA optimization
err_g	1.0955	1
ce_g	15.4941	15
out_g	15.4932	15
p_g	0.15797	0.1
pi_g	2.7363	1

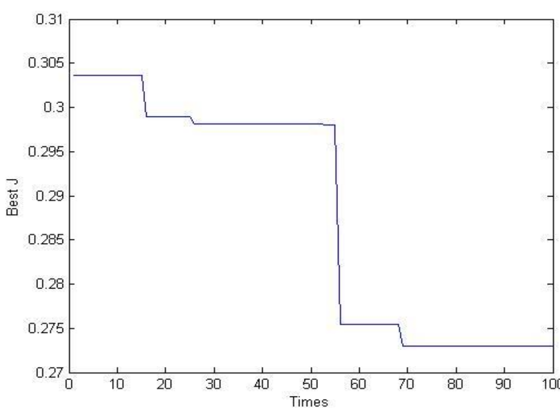


Fig. 12: Fitness Values

Fig. 13 shows the memberships shape of the inputs and output.

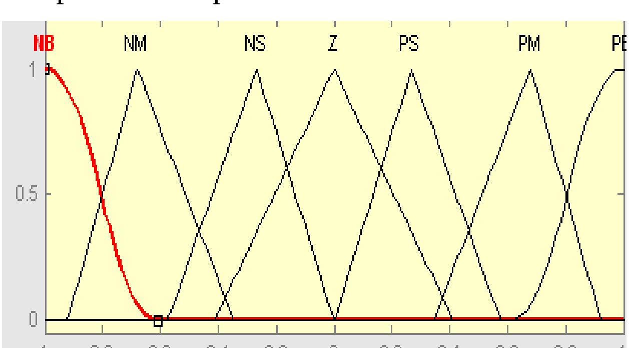


Fig.13: Membership Functions of the Fuzzy Controller with GA

Table 2 shows the difference between gain parameters with and without GA optimization

Table 2 Gain Values with and without GA

Figures 14, 15 and 16 show the system response of step, sin wave and square wave inputs with these new values.

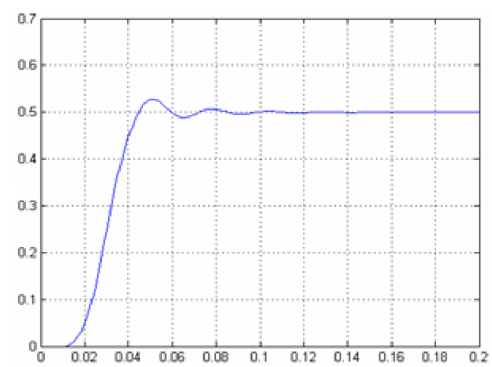


Fig. 14: Step Response of the System with GA

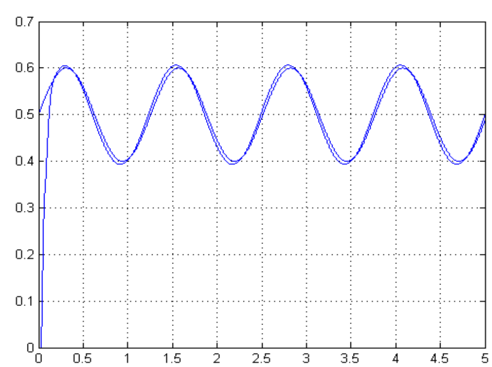


Fig. 15: Sine Wave Output Response with GA

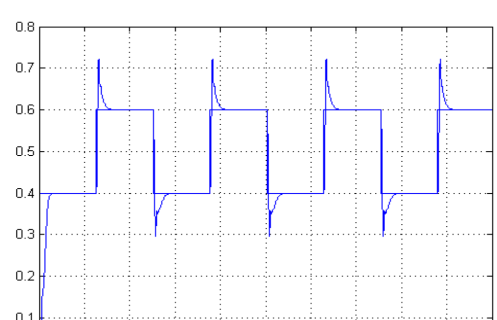


Fig. 16: Square Wave Output Response with GA

Fig. 14 shows that the overshoot of step input is nearly 6%, the settling time is 0.046 sec and rising time is 0.023 sec. table 3 shows the comparison

Between the system response with and without GA optimization

Table 3 System Response with and without GA optimization

System response for step input	With GA optimization	Without GA optimization
Overshoot	6%	No overshoot
Settling time	0.046 sec	0.2 sec
Rising time	0.023 sec	0.106 sec

As shown in Table 3 the Maglev response of fuzzy controller with GA optimization method is superior to fuzzy controller without GA.

6 CONCLUSION

In this paper the magnetic levitation CE152 Model is used as practical example of nonlinear systems. The fuzzy controller was designed with Matlab software and this controller was tested with the CE152 Model. The fuzzy controller stabilized the magnetic levitation CE152 model under different set points. The GA optimization method was used to optimize the membership function of the inputs and output of the fuzzy controller and also to optimize the gains p_g, pi_g, ce_g, err_g and out_g, The CE152 was tested with the new membership functions and the result shows that is better than the results of old fuzzy controller under different set points.

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Dr. Basil Hamed is Associate Professor of Electrical Engineering Department, Islamic University of Gaza, Palestine, since 1999. He has Bachelor Degree in Electrical Engineering from New Mexico State University, NM. USA in the year of 1989, he received Master degree from University of New Orleans, La. USA in the year

of 1992, and earned his PhD (Fuzzy Control System) from New Mexico State University, NM USA in the year 1999. He has 15 years of teaching experience and has published many papers in national and international journals. His fields of interest include Control Systems, Fuzzy Control, Simulation & Modeling, FPGA, Genetic Algorithm, SCADA System, Signal and Image Processing.

Hosam Abu Elreeshreceived B.S degree in

electrical engineering, and M.S degree in control system both are from Islamic University of Gaza, in 2000 and 2011 respectively. His current researches are fuzzy logic controllers, FPGA, and Genetic Algorithms.