A NOVEL HYBRID FUZZY PID CONTROLLER BASED ON GA-PSO OPTIMIZATION

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Abstract - In this paper,a hybrid fuzzy PID controller is presented which uses the combined GA-PSO algorithms for parameters optimization. To improve the performance of the controller, a new formula for the acceleration factor of particle swarm optimization is proposed. This formula is based on the decreasing and increasing features of acceleration factors, c_1 and c_2.Thisapproach is applied to a nonlinear dynamic system to show the effectiveness of the proposed controller. The simulation results show the superiority of the proposed method in terms of overshoot, rise time and settling time.

Key Words - Fuzzy Control, PID Control, Genetic Algorithm, Particle Swarm Optimization

I. INTRODUCTION

Proportional-Integral-Derivative (PID) controller is the simplest and themost effective solution of many control problems [8]. Many tuning methods of PID Controllershave been introduced over the years, including traditional methods such as Ziegler and Nichols and evolutionary algorithms based methods [8,15]. Ziegler and Nichols tuning method is limited to the First Order Plus Dead Time (FOPDT) or small order plants.An optimized performance is assured while evolutionary algorithms based methods areapplied to higher order plants. In practice, many systems have nonlinear characteristics, which can cause degrading to PID controller performance. Fuzzy control is an application of fuzzy set theory was first proposed by professor L.A.Zadeh in 1965 [3], later in 1974 Mamdani used fuzzy sets to model and control a system that is structurally difficult to model, and proved that fuzzy logic can improve the performance of the controller in the case of nonlinear plant.During the years, fuzzy logic control (FLC) has attracted attention of researchers in different control problems [16-17].However, utilizing thePID controller and ordinary fuzzy controller individually, the desired characteristics of the closed loop control system such as fast responseand dealing with nonlinearity are not achieved perfectly. Therefore, the concepts of PID control and fuzzy control are combined to combine the advantages of this two control strategies.

The common form of fuzzy controllers belongs to fuzzy-PID [4] and fuzzy-PI [5] controllers, which as mentioned, combines the fuzzy control theory and the classic concept of PID controller. Therefore, fuzzy-PID controller not only is fast and robust according to PID controller but also deals with nonlinear process due to fuzzy controller [14]. However, to achieve a good performance of fuzzy-PID, it is necessary to design proper membership functions for fuzzy section of the fuzzy-PID controller. Therefore, hybrid genetic algorithms and particle swarm optimization are used to optimize the start and finish point of the fuzzy membership functions. Genetic Algorithms briefly called GA inspired by natural evolution theory was first invented by John Holland[1].Particle Swarm Optimization (PSO) is a strategy to explore in the search space of an optimization problem; first was developed by a Dr. Kennedy and Dr. Eberhart in 1995 [2]. PSO is inspired by the behavior of the birds while searching for food. In this research, using GA, PSO is initialized to make a stronger and faster optimization and improve the solution of optimization algorithms. Actually, hybrid GA-PSO with a novel acceleration formula is used to optimize the start and finish point ofmembership functions of PID controller coefficients.In [6-7] the fuzzy-genetic controller is used for speed control of a DC motor assuming the linear behavior, while in this paper a novel fuzzy GA-PSO controller is proposed for control of a nonlinear dynamic system described by a differential equation.In this paper, using genetic algorithm and particle swarm optimization the performance of fuzzy controller is optimized. The rest of the paper is organized as follows: In section 2, fuzzy PID controller and its tuning methods such as GA and PSO is discussed. Section 3 contains the design of hybrid fuzzy GA-PSO controller. Section 4 is devoted to results and discussions. In section 5, a conclusion is presented.

II. PID CONTROLLER OPTIMIZATION METHODS

In the past years, several tuning methods were proposed for tuning of PID controllers including:
Ziegler and Nichols (Z&N) [8] is a notable example of traditional methods; GA [9] and PSO [10-11] are outstanding examples of evolutionary algorithms based methods.

A. Genetic Algorithms

In GA,first, an initial population is created and solutions of the optimization problem are encoded in

0 and 1 bit. In each generation three main operators of selection, crossover and mutation are applied to each individual.These parameters have a significant effecton the good performance of the algorithm. Population size is the number of individuals in each generation, the mutation rate is the ratio of population, which mutation acts on, and selection rate is the ratio of population that moves to the next generation [12-13].

B. Particle Swarm Optimization

PSO is inspired by natural phenomenon like birds searching for food. In conventionalPSO, first,algorithm is initialized with a random population and then using each particle position and velocity the next position of the particle is calculated as below:

$$V^{j+1} = \omega * V^{j} + c_1 * (\mathrm{P} - \mathrm{x}^{j}) + c_2 * (G - \mathrm{x}^{j}) \quad (1)$$

$$x^{j+1} = x^{j} + V^{j+1} \quad (2)$$

Where V^{j+1} is the updated particle velocity, P is each particle best position, G is the best position of all particles, ω is the inertia weight, which is a constant between 0 and 1, V^{j} is the particle velocity, c_1 and c_2 are acceleration factors which pull each particle toward P and G; normally, in the range of 0 and 1, x^{j} is particle position and x^{j+1} is the updated position of the particle.

The first term on the right hand side of equation (1) is particle's velocity in previous iteration, the second term reflects "self learning" by the particle based on its own history, and the last term represents "social learning" through information sharing among individual particles in the swarm.

Typically, c_1 and c_2 are supposed to be constants. As previously mentioned, c_1 and c_2 pull each particle toward P and G, therefore, they keep a balance between the particle best position (P) and best position of all particles. The new formula presented in this paper is based on increasing c_2 toward global convergence and decreasing c_1,which can prevent from trapping in a local minimum.

Small values of c_1 and c_2 limit the movement of the particles while large values tend to explode to infinity.

C. Fuzzy Control

A fuzzy PID controller is based on three main rules, which are:

- If difference of output and desired setpoint is large then proportional gain is large.
- If steady state error is large then integral gain is large.
- If maximum overshoot is large then derivative gain is large.

In a fuzzy PID, inference inputs are error and change of error rule base, and inference outputs are Kp, Ki and Kd rule base.

III. DESIGN OF HYBRID FUZZY GA-PSO CONTROLLER

In this paper, design of hybrid fuzzy GA-PSO controller is studied. The main aim isto improve the performance of the proposed controller by optimizing the membership functions of fuzzy logic controller. These membership functionsare initialized using GAin the first instance,then PSO runs to make the best membership functions. Suppose the triangular membership function:

$$f(x) = \begin{cases} 0 & x < a \\ \dfrac{x-a}{b-a} & a < x < b \\ \dfrac{c-x}{c-b} & b < x < c \\ 0 & x \geq c \end{cases} \quad (3)$$

Based on equation (3), Z-shaped membership function and S-shaped membership function, a hybrid GA-PSO algorithms with new acceleration formula is used to optimize the start and finish point of the fuzzy membership functions to minimize the Integral Square Error (ISE).Consider the following Figure.

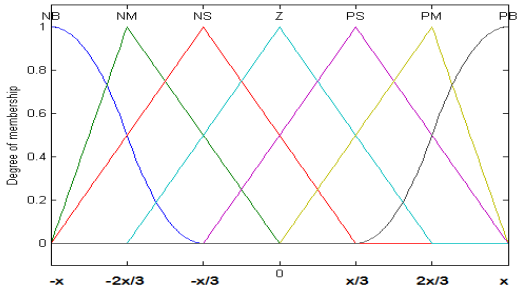


Figure 1. Form of membership functions

As it is shown in Figure 1, the first membership function is Z-shaped, the last one is S-shaped and between them triangular membership functionsare placed. In this study, assuming the range of [-x,x] for outputs Kp, Ki and Kd, start and finish point of membership functions is divided to six points and using hybrid GA-PSO to optimize the value of "x".

GA and PSO are combined to collect advantages of GA and PSO, and make a fast and completely accurate optimization algorithm. Actually first GA is executed and optimal values for the controller are fed to the PSO algorithm as the initial values of PSO in the first iteration. Since, small values for the number of population and generation in GA are chosen;the speed of the algorithm is controlled. In addition to the mentioned method, in this research a new formula for acceleration factors of PSO ispresented which improves the performance of PSO and finally the hybrid GA-PSO method. This new formula is presented in equations (4) and (5).

$$c_1 = 0.35 * \cos^2\left(\frac{j}{j_{\max}} * 1.57\right) + 0.6 \quad (4)$$

$$c_2 = \sin^{0.5}\left(\frac{j}{j_{\max}} * 1.57\right) + 0.6 \quad (5)$$

Where j is the number of iterations and $j_{\max}$ is the maximum number of iterations. As previously mentioned, the constant acceleration factor c_1 can cause trapping in a local minimum while c_2 leads the particles toward global solution, so a decreasing sinusoidal formula for c_1 and an increasing sinusoidal formula for c_2,Using the proposed formula of c_1 and c_2 instead of constant values, the performance of the hybrid GA-PSO is improved.

IV. RESULTS AND DISCUSSION

In this paper, a nonlinear and frequently cited benchmark is studied which its nonlinear differential equation is represented in equation (6):

$$\ddot{y} + y^2(t)\dot{y} + y^5(t) + y(t) = u(t) \quad (6)$$

Using the preceding case study, the hybrid fuzzy GA-PSO with new acceleration formula is designed and represented that this approach improves the fuzzy controller performance.
Inputs of all three applied methodsi.e. ordinary fuzzy GA-PSO and novel fuzzy GA-PSO are error (e) and change of error (de) varying from -3 to 3 with seven membership functions which first one is Z-shaped, last one is S-shaped membership function and between them triangular membership function is placed. The mentioned membership functionincludes negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive big (PB) rule bases and outputs membership functions in all three cases are “Kp”, “Ki” and “Kd”. The fuzzy controller rule base is given in table 1.

Using the first case (fuzzy controller), the variation domain of “Kp”and “Ki” ismanually selected with trial and error from -10 to 10 and “Kd” from -100 to 100. As mentioned previously, in the case of ordinary fuzzy GA-PSO and novel fuzzy GA-PSO, similar to the case of fuzzy controller, inputs are error (e) and change of error (de) varying from -3 to 3 with seven membership functions.

In Figure 2 and Figure 3 the membership functions of inputs “e” and “de” are plotted. In the case of ordinary fuzzy GA-PSO the optimized “Kp”, “Ki” and “Kd” are [-533.7,533.7], [-876.8,876.8] and [-458.8,458.8]. It is important to note that in accordance with Figure 1, in the case of ordinary and novel fuzzy GA-PSO these mentioned domains are divided into six equally divided regions. Variation domain of “Kp”, “Ki” and “Kd” is obtained using novel fuzzy GA-PSO, which are [-43.988,43.988] , [-928.641, 928.641] and [-233.626, 233.626] respectively. For example, in Figures 4,5 and 6, outputs membership functions for the case of novel fuzzy GA-PSO is plotted.

The output signal of the system controlled by the fuzzy controller, ordinary fuzzy GA-PSO controller and novel fuzzy GA-PSO controller is plotted in Figure 7.

It is obvious that the system controlled by ordinary fuzzy controller makes big overshoot and a steady state error about 0.045, hence optimization algorithms such as GA and PSO are used to optimize the fuzzy controller parameters and output signal. Parameters of the fuzzy controller, ordinary fuzzy GA-PSO and novel fuzzy GA-PSO are presented in table 2.

As it is obvious in table 2, using fuzzy controller the quality factors of the system are not satisfied; system is very slow and suffer from significant overshoot, hence a hybrid GA-PSO is utilized to optimize the parameters of the fuzzy controller. As GA-PSO was used, the maximum overshoot of the system optimized using the proposed method improved from 9.35% to 9.087% (which in both cases of ordinary and novel fuzzy GA-PSO it is halved and significantly improved from 19.2% to about 9%). Settling time is decreased from 3.96s to 2.94s (which in both cases of ordinary and novel fuzzy GA-PSO, it is improved from 34.92s to 3.96s and 2.94 for ordinary and novel fuzzy GA-PSO, respectively). ISE decreased from 0.5951 to 0.5942 (which in both cases of ordinary and novel fuzzy GA-PSO, it is improved from 1.9707 for fuzzy controller to about 0.5951 and 0.5942 for ordinary and novel fuzzy GA-PSO, respectively). Hence, the quality factors of the system controlled by improved novel fuzzy GA-PSO are better than ordinary fuzzy GA-PSO controller.

CONCLUSION

In this paper a new formula for updating the acceleration factors in PSO is presented.Using this new formula, GA and PSO are combined to optimize the fuzzy controller parameters. The proposed fuzzy GA-PSO controller was applied to a nonlinear dynamic system which improves the control performance in terms of maximum overshoot, rise time, and settling time in comparison with an ordinary fuzzy controller.

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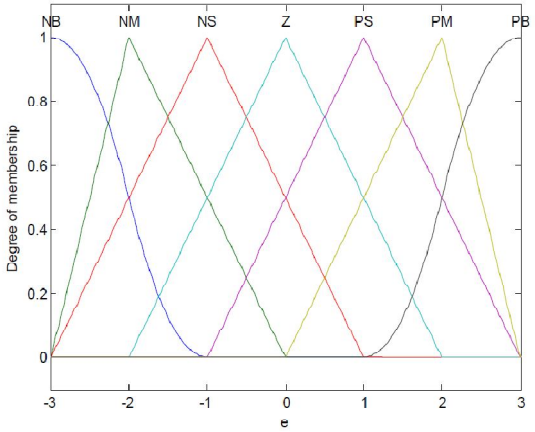


Figure 2. Membership Functions of Input "e"

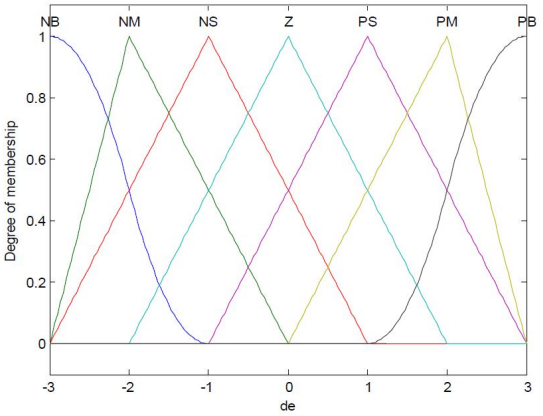


Figure 3. Membership Functions of Input "de"

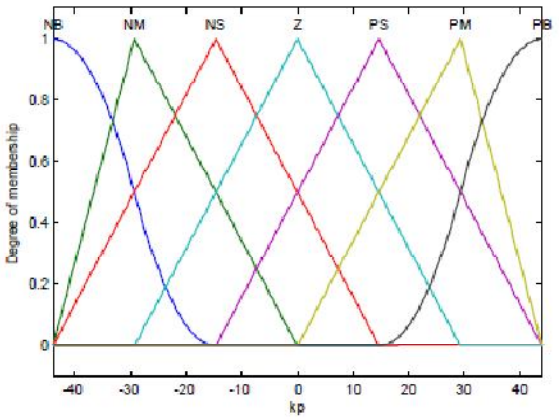


Figure 4. Membership Function of Output "kp" Optimized Using GA-PSO

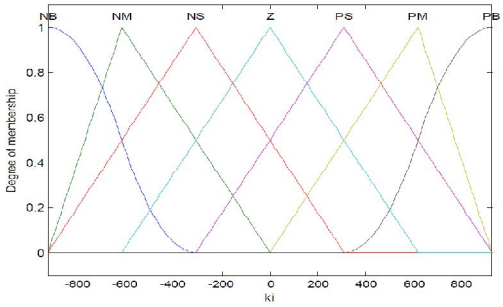


Figure 5. Membership Function of Output "ki" Optimized Using GA-PSO

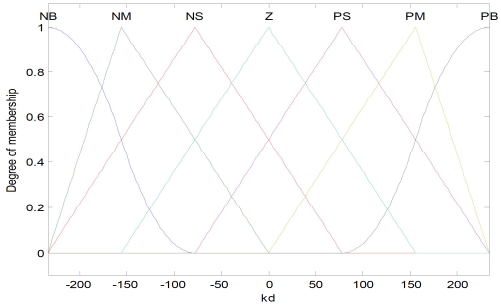


Figure 6. Membership Function of Output "kd" Optimized Using GA-PSO

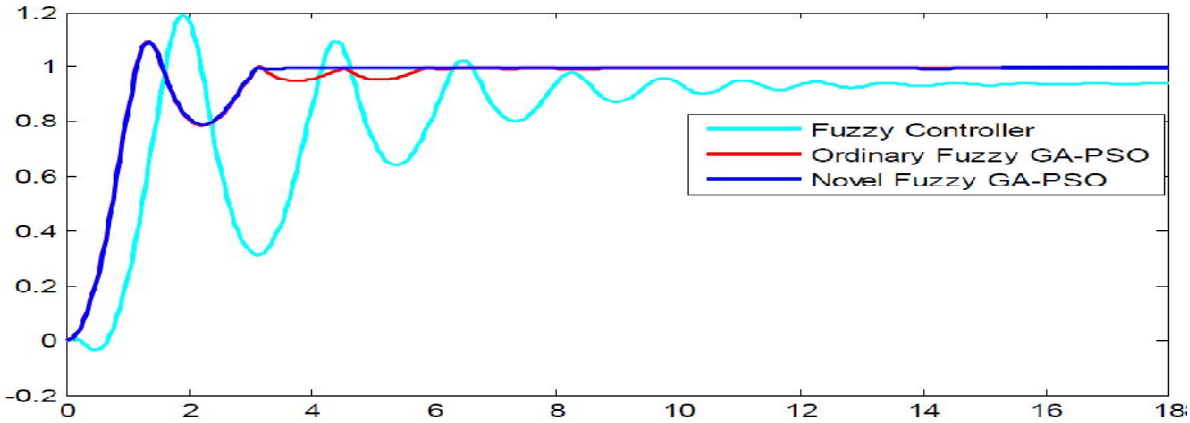


Figure 7. Comparison of Output Signal of the System

Table1. Rule base of the fuzzy controller

	Kp / Ki / Kd						
e\de	NB	NM	NS	Z	PS	PM	PB
NB	PB/NB/PS	PB/NB/NS	PM/NM/NB	PM/NM/NB	PS/NS/NB	Z / Z / NM	Z/Z/PS
NM	PB/NB/PS	PB/NB/NS	PM/NM/NB	PS/NS/NM	PS/NS/NM	Z / Z / NS	NS/Z/Z
NS	PM/NB/Z	PM/NM/NS	PM/NS/NM	PS/NS/NM	Z / Z / NS	NS /PS/NS	NS/PS/Z
Z	PM/NM/Z	PM/NM/NS	PS/NS/NS	PS/Z/NS	NS/PS/NS	NM/PM/NS	NM/PM/Z
PS	PS/NM/Z	PS/NS/Z	Z / Z / Z	NS/PS/Z	NS/PS/Z	NM /PM /Z	NM/PB/Z
PM	PS/Z/PB	Z/Z/PS	NS/PS/PS	NM/PS/PS	NM/PM/PS	NM/PB/PS	NB/PB/PB
PB	Z/Z/PB	Z/Z/PM	NM/PS/PM	NM/PM/PM	NM/PM/PS	NB/PB/PS	NB/PB/PB

Table 2. Parameters of Fuzzy Controller, Ordinary Fuzzy GA-PSO and Improved Fuzzy GA-PSO

	Kp Range	Ki Range	Kd Range	ISE	Maximum Overshoot	Rise Time	Settling Time
Fuzzy Controller	30	6	150	1.9707	19.2%	1.56 s	34.92 s
Ordinary Fuzzy GA-PSO	533.7	876.8	485.8	0.5951	9.35%	0.96 s	3.96 s
Novel Improved Fuzzy GA-PSO	43.988	928.641	233.626	0.5942	9.087%	1.05 s	2.94 s

★★★