Design of Electronic PID Controller Using Genetic Algorithms

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Abstract:

This paper presents a Genetic Algorithm (GA)-based electronic Proportional-Integral-Derivative (PID) Controller tuner. The tuning is based upon the maximization of a comprehensive fitness function constructed as the inverse of Peak Overshoot (Mp). This approach has a some advantages, it gives a clearer and simpler representation of the problem, simplifies chromosome construction, and totally avoids using binary encoding and decoding so as to simplify software programming.

This paper addresses to demonstrate the capability of GA's to solve complex and constraint optimization Problems via utilizing GA's as a general-purpose optimizing tool to solve different Control system design problems.

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1-Introduction:

It is known that PID controller is employed in every facet of industrial automation. The application of PID controller spans from small industry to high technology industry hence how do we optimize the PID controller? Do we still tune the PID as what we use to for example using the classical technique or do we make use of the power of the computing world by tuning the PID in a stochastic manner? In this paper, it is proposed that the controller be tuned using the Genetic Algorithm (GA) technique. Genetic Algorithms have been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optima as may occur with gradient decent techniques. Using genetic algorithms to perform the tuning of the controller will result in the optimum controller being evaluated for the system every time. The PID controller of the model will be designed using the classical method (using integral of time multiplied absolute error criterion ITAE) and then the results will be analyzed. The same model will be redesigned using the GA method. The results for both designs will be compared, analyzed and a conclusion will be drawn out [1, 2, 3].

Many real world control systems usually track several control objectives simultaneously at the moment, it is desirable to meet all specified goals using the controllers with simple structures like as proportional-integral (PI) and proportional-integral-derivative (PID) which are very useful in industry applications. Since in practice,

these controllers are commonly tuned based on classical or trial-and-error approaches, they are incapable of obtaining good dynamical performance to capture all design objectives and specifications [3].

This paper addresses ((to demonstrate the capability of GAs to solve complex and constraint optimization Problems via utilizing GAs as a general-purpose optimizing tool to solve different Control system design problems)).

2-Genetic Algorithms

Genetic Algorithms (GAs) are a stochastic global search method that emulates the process of natural evolution. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators (i.e. reproduction, crossover and mutation) to arrive at the best solution [4, 5].

By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions. In this way, GAs have been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality, as may occur with gradient decent techniques or methods that rely on derivative information [6].

A genetic algorithm is typically initialized with a random population consisting of between 20-100 individuals. This population (mating pool) is usually represented by a real-valued number or a binary string called a chromosome. How well an individual performs a

task is measured by the objective function, the objective function assigns each individual a corresponding number called its fitness, the fitness of each chromosome is assessed and a survival of the fittest strategy is applied.

In this paper, the magnitude of the error will be used to assess the fitness of each chromosome.
The GA process could be simplified as following:
1) Initialize a random pool of Individuals.
2) Evaluate each Individual.
3) Choose couples (Mating).
4) Breed them together (Crossover).
5) Evaluate each Individual.
6) Selection.
7) Mutation.
8) If the pool has converged, or a number of pre-determined cycles have been completed, finish the cycle. If not, return to step #3[7].

2-1- Selection

There are many mating techniques available to pick two parent chromosomes to produce child chromosome [4].

a). Roulette Wheel selection

Parents are selected according to their fitness. The better chromosomes are, the more chances to be selected they have. Imagine a roulette wheel where are placed all chromosomes in the population, every has its place big accordingly to its fitness function [5].

b). Rank Selection

Rank selection first ranks the population and then every chromosome receives fitness from this ranking. The worst will have fitness 1, the second worst 2 etc, and the best will have fitness P (where P is the number of chromosomes in

population). After this all the chromosomes have a chance to be selected [4].

2-2- Crossover

Crossover is another process that involves exchange of genetic materials between two parent chromosomes to make child chromosome. The simplest way how to do this is to choose randomly some crossover point and then everything before this point copies from the first parent and then everything after a crossover point copies from the second parent. There are many types of crossover [4, 5].

a). Single point crossover

One crossover point is selected, string from the beginning of chromosome to the crossover point is copied from one parent and the rest is copied from the second parent [5].

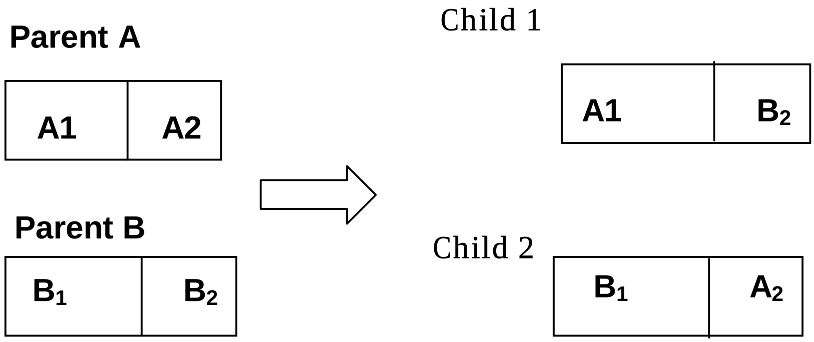
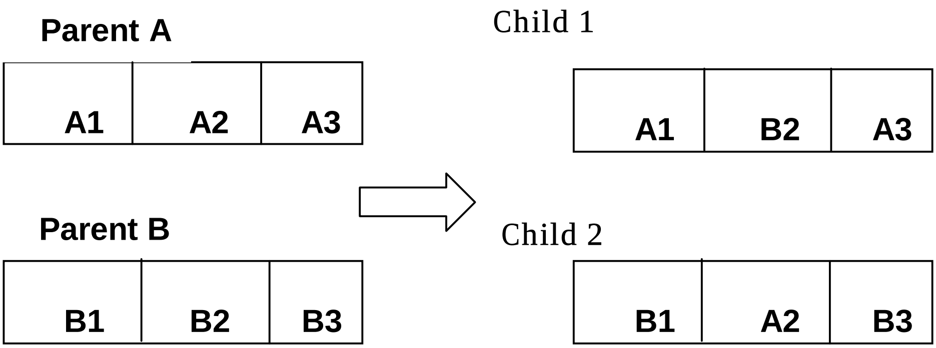


Fig. (1) One point crossover

b).Two points crossover

Two points crossover are selected, string from the beginning of chromosome to the first crossover point is copied from one parent, the part from the first to the second crossover point is copied from the second parent and the rest is copied from the first parent [5].

Fig.(2) Two point crossover



c). Uniform crossover

Genes are randomly copied from the first or from the second[5].

d). Arithmetic crossover (linear crossover)

Some arithmetic operations are performed to make a new off spring (average, and extrapolation crossover from midpoint) [4,5].

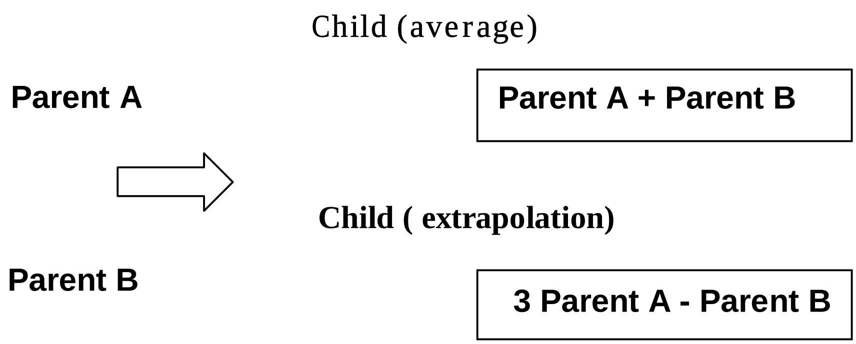


Fig.(3) Arithmetic crossover

2-3- Mutation

After a crossover is performed, mutation takes place. This is to parent falling all solutions in population into a local optimum of solved problem. Mutation changes randomly the new offspring (children).There are many types of accomplishing mutation (binary mutation, and real mutation). Real mutation is used according to the following equation, as [5,8]:

$$d_i' = \begin{cases} r(L_o, U_p) & if \quad z' \le P_m \\ d_i & otherwise \end{cases} \qquad \ldots (1)$$

Where

- z' is random number.
- $r(L_o,U_p)$ is random number with limited range (L_o,U_p).
- d_i is the value of gene before mutation.
- d_i' is the value of gene after mutation.
- P_m is probability of mutation equal to (0.5%-1%) .

3. Description of Electronic PID controllers

Fig.(1) shows the principle circuit that implements derivative and integral control action in electronic controllers. Essentially, we insert an appropriate circuit in the feedback path to generate the desired control action. The transfer function of the controllers may be obtained as follows [3]:

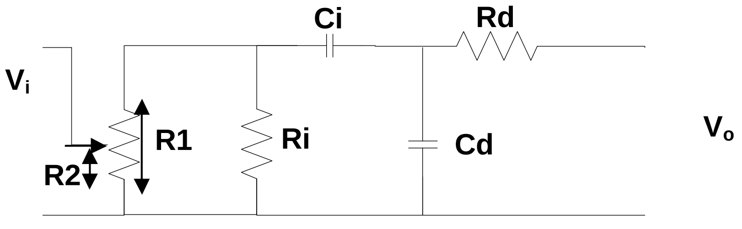


Fig.(4) Electronic Controllers(Proportional+derivative+integral Controller).

$$\frac{V_o(s)}{V_i(s)} = G = k_p a\left(1 + \frac{k_d}{a}s + \frac{1}{ak_i s}\right) = \left(k_p a + k_p k_d s + \frac{K_p}{k_i s}\right) \quad \text{......... (2)}$$

Where

$$a = 1 + \frac{R_d}{R_i} + \frac{k_d}{k_i}$$

$$k_d = R_d C_d$$

$$k_i = R_i C_i$$

The transfer function for the fig.(2) is given

$$\frac{C(s)}{R(s)} = T.F. = \frac{G}{1+GH} = \frac{\dfrac{k_i k_p as + k_p k_d k_i s^2 + k_p}{k_i s}}{1 + \dfrac{k_i k_p as + k_p k_d k_i s^2 + k_p}{k_i s}} = \frac{k_i k_p as + k_p k_d k_i s^2 + k_p}{k_i s + k_i k_p as + k_p k_d k_i s^2 + k_p}$$

$$= \frac{k_i k_p as + k_p k_d k_i s^2 + k_p}{k_p k_d k_i s^2 + (k_i + k_i k_p a)s + k_p} = \frac{k_i k_p as + k_p k_d k_i s^2 + k_p}{s^2 + \left(\dfrac{1}{k_p k_d} + \dfrac{a}{k_d}\right)s + \dfrac{1}{k_d k_i}} \quad \text{... (3)}$$

By comparison with second order equation

($\frac{C(s)}{R(s)} = \frac{w_n^2}{s^2 + 2zw_n s + w_n^2}$ **) it noticed that**

$$w_n^2 = \frac{1}{k_d k_i} \Rightarrow w_n = \frac{1}{\sqrt{k_d k_i}} \quad \text{.................. (4)}$$

$$2zw_n = \frac{1}{k_p k_d} + \frac{a}{k_d}$$

$$z = \frac{1}{2k_p k_d w_n} + \frac{a}{2k_d w_n} = \frac{1}{2k_p}\sqrt{\frac{k_i}{k_d}} + \frac{a}{2}\sqrt{\frac{k_i}{k_d}}$$

$$z = \sqrt{\frac{k_i}{k_d}}\left(\frac{1}{2k_p} + \frac{1}{2}\left(1 + \frac{R_d}{R_i} + \frac{k_d}{k_i}\right)\right) \qquad \text{..................(5)}$$

Let

$$\frac{R_d}{R_i} = \frac{1}{2}$$

Then

$$z = \frac{1}{2}\sqrt{\frac{k_i}{k_d}}\left(\frac{1}{k_p} + \frac{3}{2} + \frac{k_d}{k_i}\right) \qquad \text{..................(6)}$$

The response of the circuit shown in fig. (2) is given by [3].

$$C(t) = 1 - \frac{e^{-jzw_n t}}{\sqrt{1-z^2}}\sin\left(w_d t + \tan^{-1}\frac{\sqrt{1-z^2}}{z}\right) \qquad \text{.................. (7)}$$

Where

C (t) is the output response of the circuit

$$w_d = w_n\sqrt{1-z^2} \qquad \text{.................. (8)}$$

And maximum peak over shoot is computed from the equation

$$M_p = e^{-\frac{\sqrt{1-z^2}}{z}p} \qquad \text{.................. (9)}$$

Where

M_p is the maximum peak over shoot.

From the equation (9), the objective function is obtained as:

$$error = \frac{1}{M_p} \qquad \text{.................. (10)}$$

Then the fitness function $= 1/error$ **.................... (11)**

Where

The objective function is the calculation of its associated fitness.

The fitness function is the measure of the quality of a chromosome [1].

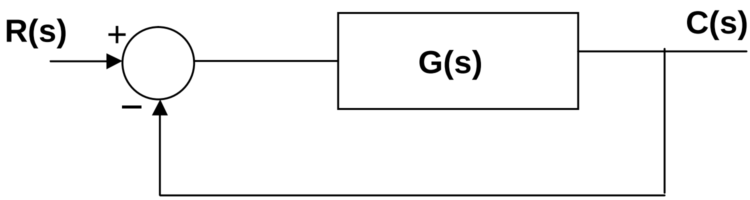


Fig. (5) Closed loop system

Implementation of the algorithm and results:-

The genetic algorithms are carried out in 6 runs of 100 iterations. The initial parent population consists of 10 sets of positive values of (Kp, Ki, and Kd). This size is chosen so that be not small in order to cover the search space, and it is not large to prevent the increasing number of computation time. The crossover is done by using one point's crossover. In this paper the Roulette Wheel selection and real mutation are used. Fig. (6) Shows the algorithm for the computation of PID parameters using genetic algorithm. Figures(7,8,9,10,11,12) show the responses PID controller using genetic algorithm and the tables (1,2,3,4,5,and 6) show the parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)). Fig. (13) Shows the comparison of the response of PID controller using integral of time multiplied absolute error criterion (ITAE) and genetic algorithms. It noticed that the peak overshot when using genetic algorithm less than the peak over shot when using ITAE. The GA's are carried out in six runs of 25 iterations using MATLAB software.

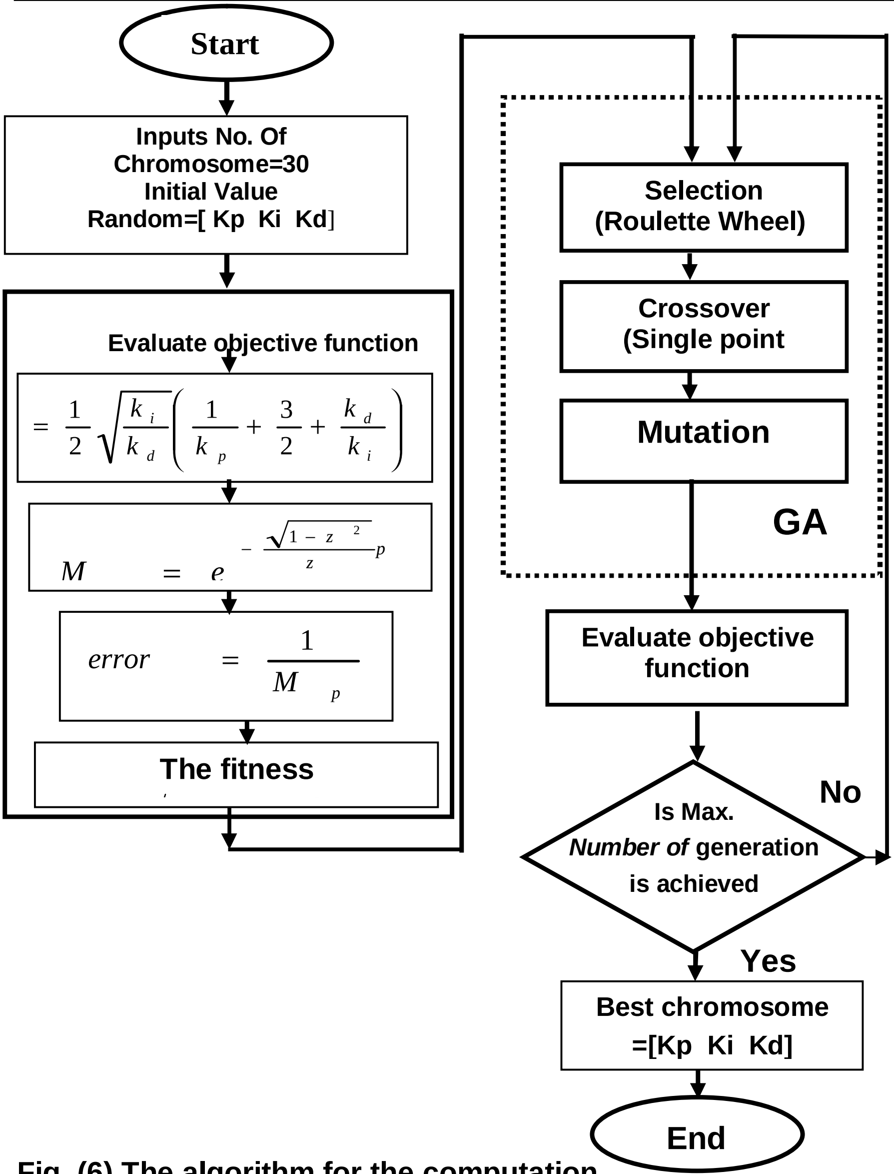


Fig. (6) The algorithm for the computation of PID parameters using genetic algorithm.

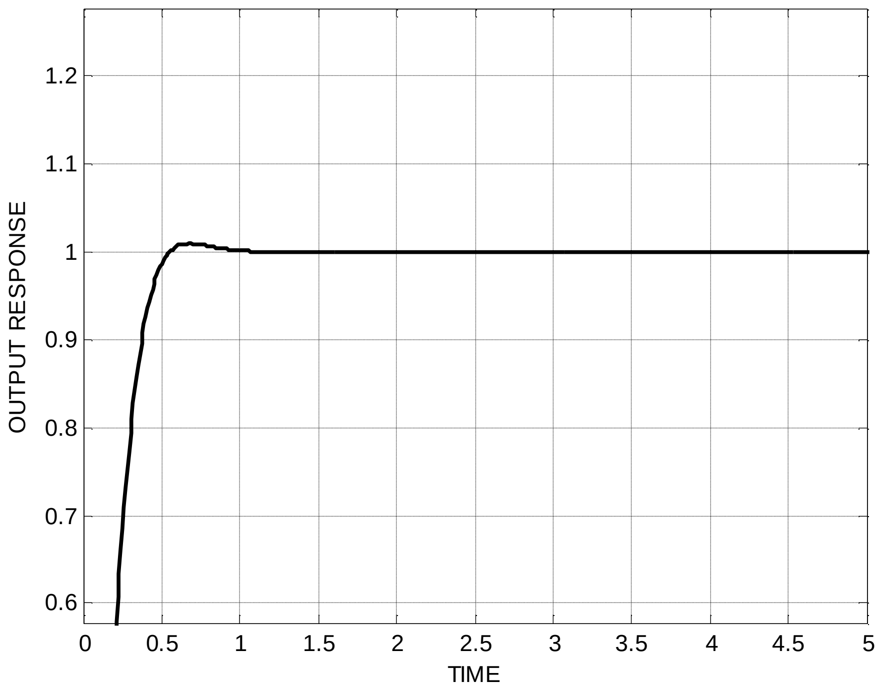


Fig. (7) The response of PID controller using genetic al first run.

Zeta=0.8311		
wn =8.314		
mp =0.01		
Kp	**Ki**	**Kd**
15.1898	**0.7443**	**1.9421**

Table (1) The parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)) for first run.

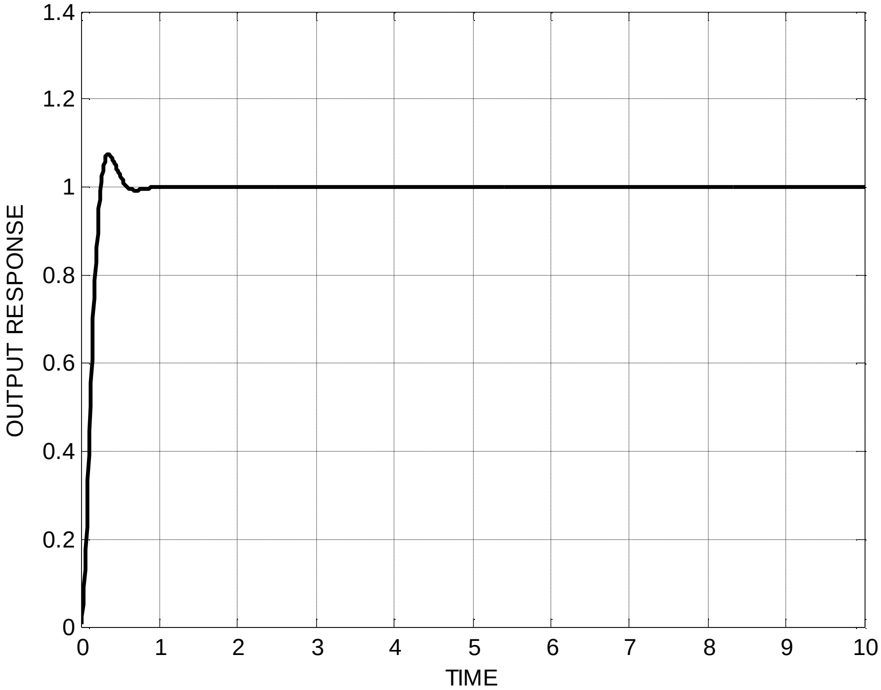


Fig. (8) The response of PID controller using genetic algorithm for second run.

Zeta=0.6347		
wn =11.5332		
mp =0.0757		
Kp	**Ki**	**Kd**
15.32	**0.7183**	**1.0466**

Table (2) The parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)) for second run.

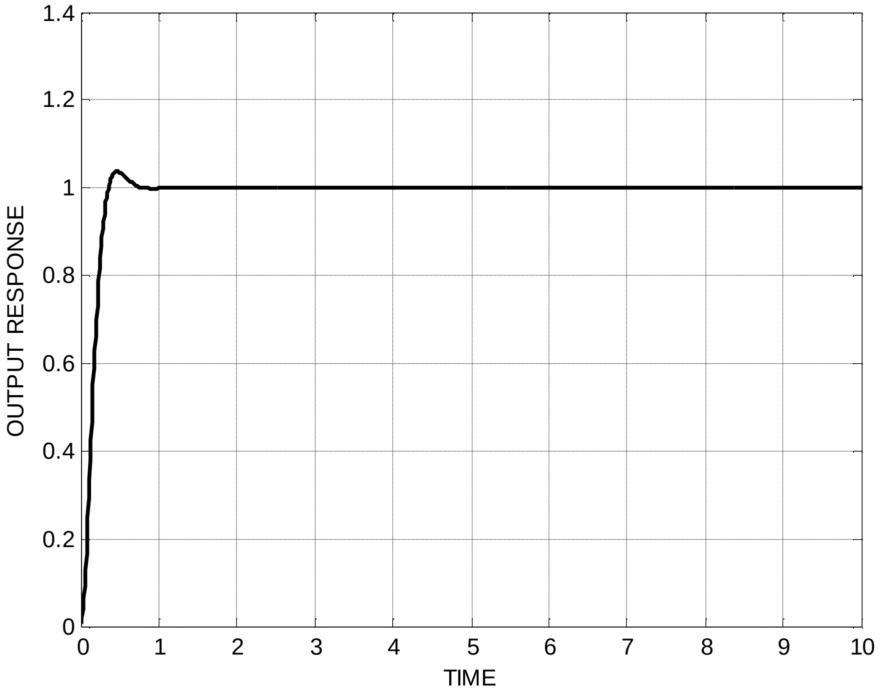


Fig. (9) The response of PID controller using genetic algorithm for third run.

Zeta=0.7234		
wn =9.7647		
mp =0.0372		
Kp	**Ki**	**Kd**
15.1775	**0.7356**	**1.4258**

Table (3) The parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)) for third run.

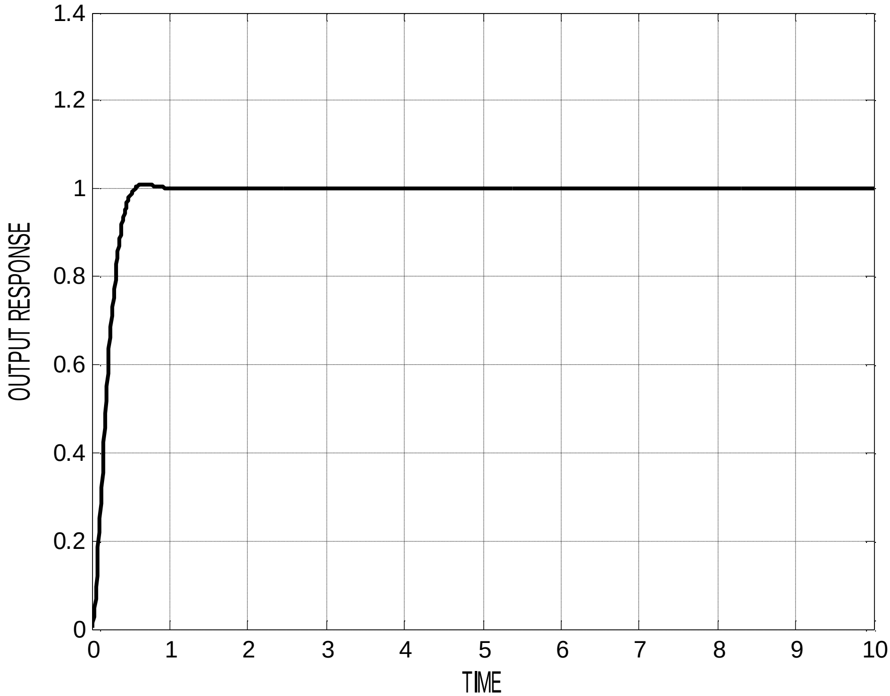


Fig. (10) The response of PID controller using genetic algorithm for fourth run.

Zeta=0.8311		
wn =8.3174		
mp =0.01		
Kp	**Ki**	**Kd**
15.1898	**0.7443**	**1.9421**

Table (4) The parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)) for fourth run.

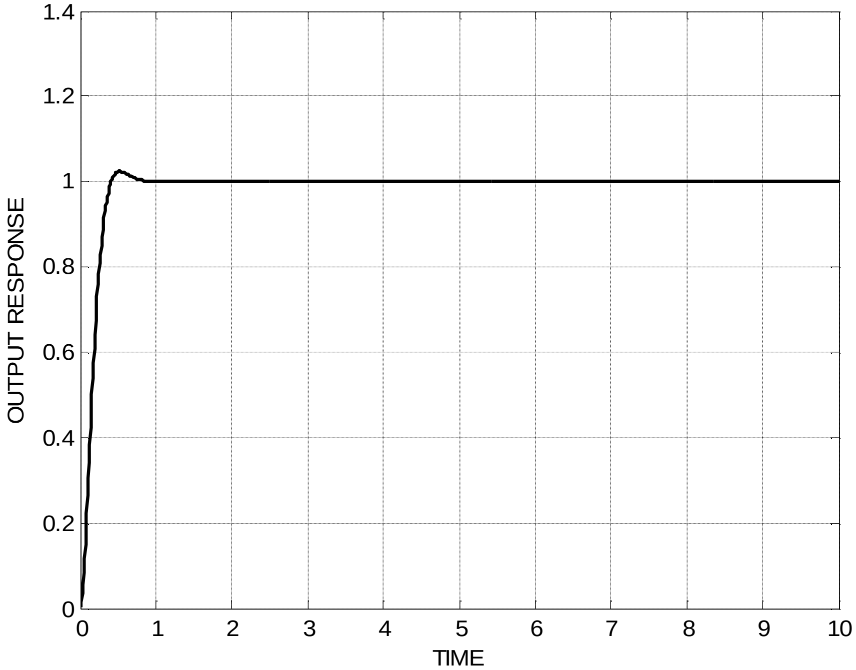


Fig. (11) The response of PID controller using genetic algorithm for fifth run.

Zeta=0.7666		
wn =9.2467		
mp =0.0235		
Kp	**Ki**	**Kd**
15.4201	**0.7294**	**1.6036**

Table (5) The parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)) for fifth run.

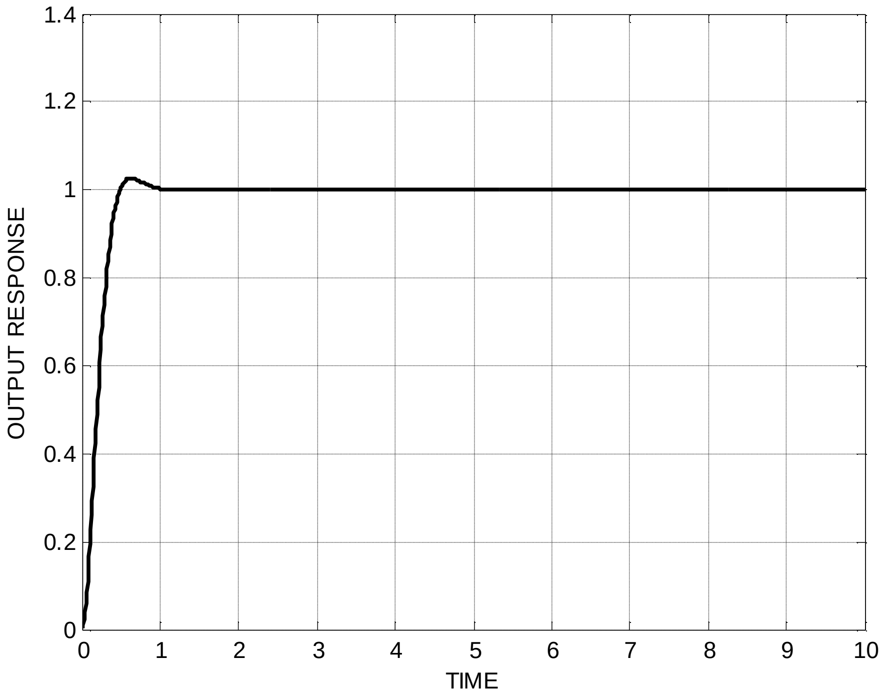


Fig. (12) The response of PID controller using genetic algorithm for sixth run.

Zeta=0.7546		
wn =7.6017		
mp =0.027		
Kp	**Ki**	**Kd**
15.1896	**0.9028**	**1.9168**

Table (6) The parameters (Zeta, angular frequency (wn), peak over shoot (mp), and the parameters of PID controller (Kp Ki Kd)) for sixth run

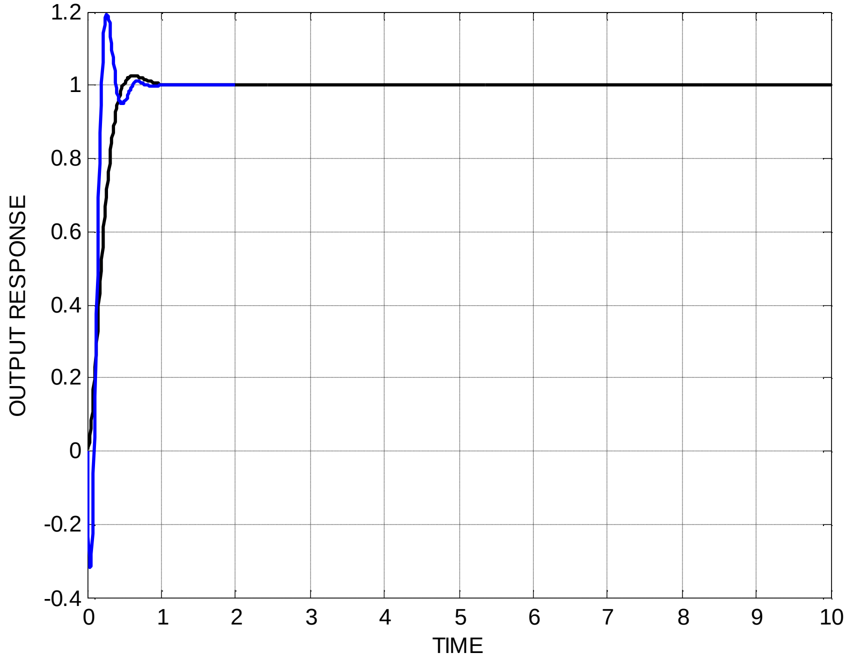


Fig. (13) The responses of PID controller using genetic algorithm and ITAE(blue line for ITAE and black for GA).

Conclusion:-

1- Simple and flexible GA's is proposed as a general purposed tool for electronic PID controller design. Genetic algorithm may be used as alternative method to achieve the same objective, which other methods can do. Genetic algorithm can solve the problem of tuning of PID parameters.

2- By comparing with classical method (ITAE), the response of PID controller when using genetic algorithm is better than when using (ITAE) (Peak overshot is less when using genetic algorithm).

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تصميم مسيطر الكتروني متناسب خطي – مكامل – مفاضل (PID) باستخدام الخوارزمية الجينية

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المستخلص

يقدم في هذا البحث تصميم مسيطر الكتروني متناسب خطي – مكامل – مفاضل (PID) باستخدام الخوارزمية الجينية . إن عملية التنغيم تستند على إيجاد أكبر قيمة لدالة الملائمة المبنية على أساس مقلوب دالة القمة . إن هذه الطريقة تمتلك عدة فوائد منها: إنها تعطي تمثيل واضح وبسيط للمسألة، وإنها تقوم ببناء كروموسوم بسيط وإنها تجنب استخدام الأرقام الثنائية لكي تكون البرمجة بسيطة.

يوجه هذا البحث لتوضيح قابلية الخوارزمية الجينية لحل مسائل المفاضلة المعقدة والمقيدة بواسطة الانتفاع بالخوارزميات الجينية كأداة مفاضلة عامة لحل مختلف مسائل تصميم أنظمة السيطرة.

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