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Simulation and Tuning of PID Controllers using Evolutionary Algorithms For different systems

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Abstract: *PID controllers are used for decades in controlling processes in linear feedback control systems. Their use requires accurate and effective tuning to satisfy an acceptable performance for the control system. This paper presents an automatic procedure for adjusting the gains of a Proportional-Integral-Derivative (PID) controller. Genetic Algorithms are used for tuning this controller so that closed-loop step response specifications are satisfied. By using this procedure, designers need only specify the desired closed-loop response. Experiments with different processes application indicate that the gains obtained through genetic algorithms may provide better responses than those obtained by the classical Ziegler-Nichols method. Moreover, the genetic algorithm is capable of generating adequate gains for systems where classical rules are not applicable. The algorithms are simulated with MATLAB programming.The simulation result showing a better dynamic performance than those based on traditional (Ziegler-Nichols) method.*
Keywords -*PID controllers, Genetic Algorithm (GA), Ziegler-Nichols*

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I. INTRODUCTION

The genetic algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection. GA have been successfully implemented in the area of industrial electronics, for instance, parameter and system identification, control, robotics, pattern recognition, planning and scheduling and classifier system. For its use in control engineering, GA can be applied to a number of control methodologies for the improvement of the overall system performance. GA-based method has been considered as a useful and promising technique for deriving global optimization solutions of complex functions in recent years, and also has been applied to solve difficult problems in the field of control engineering. Generally, the GA for global optimization contains four parts: initialization, mutation, competition, and reproduction [1].

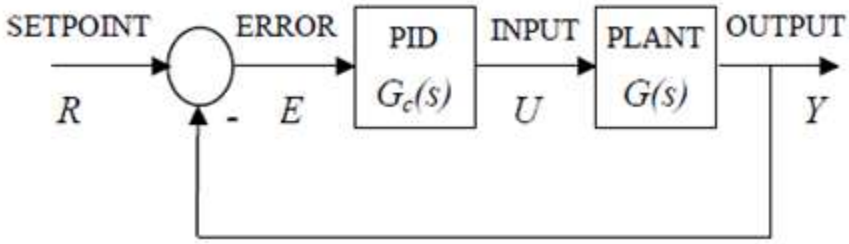
Proportional Integral Derivative (PID) control is one of the earlier control strategies. Its early implementation was in pneumatic devices, followed by vacuum and solid state analog electronics, before arriving at today's digital implementation of microprocessors. It has a simple control structure which was understood by plant operators and which they found relatively easy to tune [2,3]. It can be used to solve even very complex control problems, especially when combined with different functional blocks, such as, filters compensators or correction blocks, selectors etc. According to a survey for process control systems conducted in 1989, more than 90 of the control loops were of the PID type [4].

Traditional Ziegler-Nichols method of tuning PID controllers although commands substantial acceptance in control engineering community [1,4]. To enhance the capabilities of traditional PID tuning methods,. Nowadays, several new methods from an artificial intelligent approach, such as, neural networks, GA, fuzzy logic, the applications of GAs have expanded into various fields. With the abilities for global optimization and good robustness, and without knowing anything about the underlying mathematics, GAs are expected to overcome the weakness of traditional PID tuning techniques and to be more acceptable for industrial practice. In the previous work, it has been shown that GAs gives a better performance in tuning the parameters of PID controllers than the Z-N method does.[5,6].

II. Characteristics of PID controller

The block diagram shown in Fig. (1) Illustrates a closed-loop system with a PID controller in the direct path, which is the usual connection. The system's output should follow as closely as possible the reference signal (set point)[1,2]. The PID controller is characterized by three gains, as shown in Fig. (2)

Fig. 1 PID control of a plant



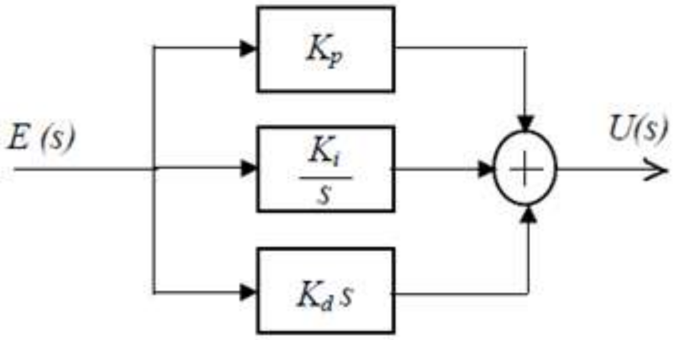


Fig. 2 PID controller internal structure

In the frequency domain, the relation between the PID controller input E (error signal) and output U (input to the plant) can be expressed by the following transfer function:

$$\frac{U(s)}{E(s)} = K_p + \frac{K_I}{s} + K_d\, s = \frac{K_d\, s^2 + K_p s + K_I}{s} \quad ....(1)$$

The closed –loop transfer function is given by:

$$G_g(s) = \frac{Y(s)}{R(s)} = \frac{G_c(s)G(S)}{1+G_c(s)G(S)} ....(2)$$

The tuning of a PID controller consists of selecting gains Kp, Ki and Kd so that performance specifications are satisfied. By employing Ziegler- Nichols's method for PID tuning [8] those gains are obtained through experiments with the process under control. The step response and the value of Kp that results in marginal stability are used as starting points for obtaining gain values that guarantee a satisfactory behavior. Finer adjustments to the gains may also be carried out.[2,3,4]

III. Traditional Tuning of PID controller

In order to use a controller, it must first be tuned to the system. This tuning synchronizes the controller with the controlled variable, thus allowing the process to be kept at its desired operating condition. Ziegler-Nichols method is the most common one and will be adopted here in the present work as a traditional method of tuning PID parameters [4,7].

3.1. Ziegler–Nichols Tuning Formula

The tuning formula is based on the approximation that the plant model is given by a first-order plus dead time (FOPDT) which can be expressed by [9]

$$G(s) = \frac{K}{1+Ts} e^{-Ls} \quad .... \quad (3)$$

In real-time process control systems, a large variety of plants can be approximately modeled by (8). If the system model cannot be physically derived, experiments can be performed to extract the parameters for the approximate model.[1]

VI. Genetic algorithm

Genetic algorithm is a powerful search algorithm that performs an exploration of the search space that evolves similar to the evolution in nature. GAs use probabilistic transition rules instead of deterministic rules, and handle a population of potential solutions known as individuals or chromosomes that evolve iteratively (Fig 3). Each iteration of the algorithm is termed as a generation. The evolution of solutions is simulated through a fitness function and genetic operators such as reproduction, crossover and mutation. The fittest individual will survive generation after generation; while also reproducing and generating offspring‘s that might be stronger. At the same time, the weakest individuals disappear from each generation.[9,10].

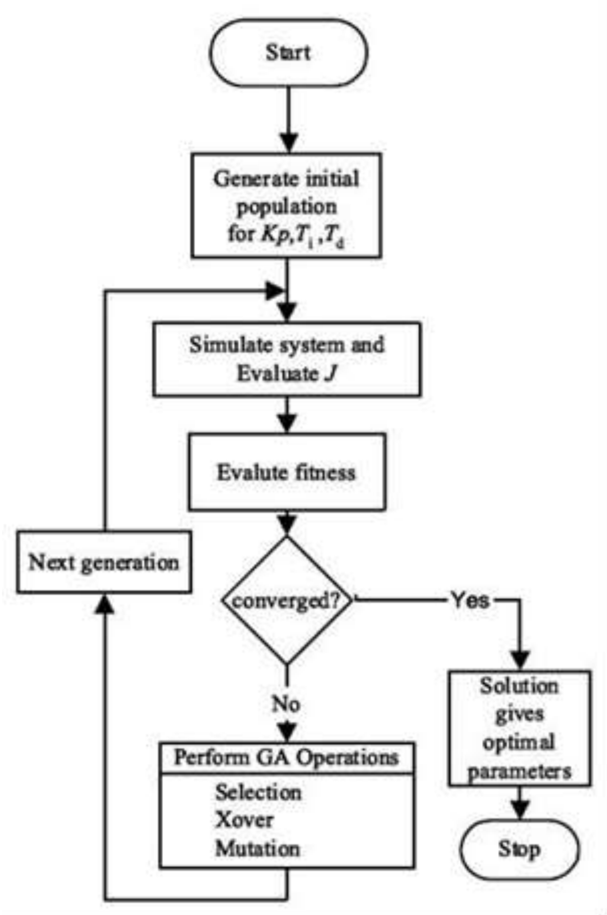


Fig.3 A simple genetic algorithm Implementation

A genetic algorithm is typically initialized with a random population consisting of between 20 and 100 individuals. This population (mating pool) is usually represented by a real-valued number or a binary string called a chromosome. Fitness value is a measure of response of the chromosomes to the objective function. The fitness of each chromosome is assessed and a survival of the fittest strategy is applied. In this paper, the magnitude of the error is used to assess the fitness of each chromosome. There are three main operators for a genetic algorithm – Selection, crossover and mutation.

4.1 Selection

The fitness value of the chromosomes is used in the selection process to provide bias towards fitter individuals. Just like in natural evolution, a fit chromosome has a higher probability of being selected for reproduction. The probability of an individual being selected is, thus, related to its fitness, ensuring that fitter individuals are more likely to leave offspring.

An example of a common selection technique is the .Roulette Wheel. Selection method, as shown in Fig.(4).[11]

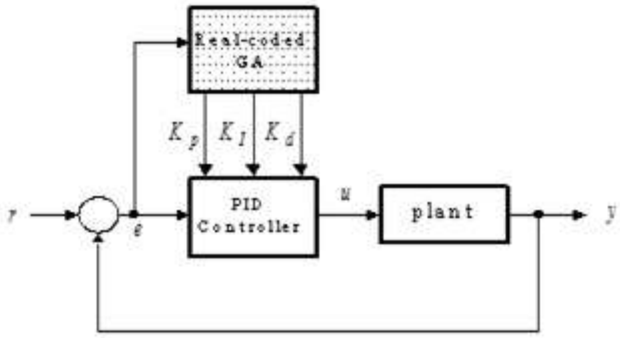


Fig.(4): depiction of roulette wheGel selection

4.2 Crossover

Once the selection process is complete, the crossover algorithm is initiated. The crossover operations swap certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. The crossover probability indicates how often crossover is performed. The different crossover techniques are the Single Point Crossover, Two Point Crossover, Uniform Crossover etc are defined for different types of chromosome encoding.[12]

4.3 mutation & Elitism

Mutation is the occasional random alteration of a value of a string position. It is considered a background operator in the GA. The probability of mutation is normally low because a high mutation rate would destroy fit strings and degenerate the GA into a random search. Once a string is selected for mutation, a randomly chosen element of the string is changed or _mutated. However, when creating a new population by crossover & mutation, then best chromosome might be lost. Hence, Elitism is method which first copies the best chromosomes to the new population. Elitism rapidly increases the performance of the GA, by preventing loss of the best found solution.[13]

V. Genetic algorithm based design method

The structure of GA-based PID controller is shown in Fig.(5)

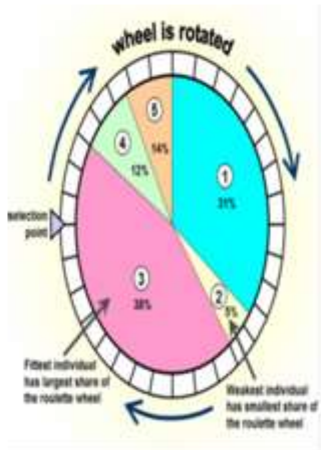


Fig.5 Block diagram of PID controller tuner

The most crucial step in applying GA is to choose the objective functions that are used to evaluate fitness of each chromosome.

The PID controller is used to minimize the error signals, or we can define more rigorously, in the term of error criteria: to minimize the value of performance indices mentioned above. Because the smaller the value of performance indices of the corresponding chromosomes the fitter the chromosomes will be, the fitness of the chromosomes is defines as [1,14]:

$$Fitness value = \frac{1}{Performance index} \qquad (4)$$

Each chromosome represents a solution of the problem and hence it consists of three genes: the first one is the k_p value, the second one is the k_d value and the third one is k_I. Then the Chromosome vector is given by

Chromosome = [k_p k_d k_I].

It must be noted here that the range of each gain must be specified, i.e.,

$$k_{p\,min} \le k_p \le k_{I\,max}$$
$$k_{d\,min} \le k_d \le k_{d\,max}$$
$$k_{Imin} \le k_I \le k_{I\,max}$$

VI. Initialization of Experimental system Parameters Results.

In this application method, the GA is used to search for the optimal PID parameters that minimize the error when the process is in steady state. Therefore, the parameter tuning problem of PID controller using GA can be considered by selecting the three parameters such that the response of the system is desired. In the application, the Evolver has been used for running the genetic algorithm, while the control system has been implemented on Matlab .

Initialization of certain parameters, like the Population size, Number genes in a chromosome, Crossover probability, Mutation probability, Selection probability, Number of generations, is done at the first stage of GA implementation.

The GA parameters are summarized in Table (1). Generally, the requirements for any controlled system are fast tracking of set point changes without overshoot and the maximum dip at the response due to step disturbance must be kept small as much as possible.

Table (1) Genetic Algorithm Parameters

No. of generations	100
Population size	50
No. of variables in each chromosome	3
Selection method	Ranking selection
Crossover method	Single point crossover
CROSSOVER PROBABILITY	0.8
Mutation rate	0.06
Bounds of K_p	$0 \le K_p \le 100$
Bounds of K_I	$0 \le K_I \le 100$
Bounds of K_D	$0 \le K_D \le 100$

Experiments application with three different plants have been performed for the evaluation of the tuning procedure. A simple second order system was initially used as a primary test for the proposed method. In the second experiment, results were compared with the original values obtained through the classical Ziegler-Nichols method. The third plant has a time-delay and again results were compared to classical ones. Finally, the fourth plant was chosen because its characteristics render it unsuitable for the application of Ziegler-Nichols rules.

The step response for application plant 1, described by the following transfer function, is shown in Fig. 5.

$$\mathrm{G1(s)} = \frac{4}{s^2 + 0.5s + 1} \quad \ldots\ldots\ldots\ldots\ldots..(5)$$

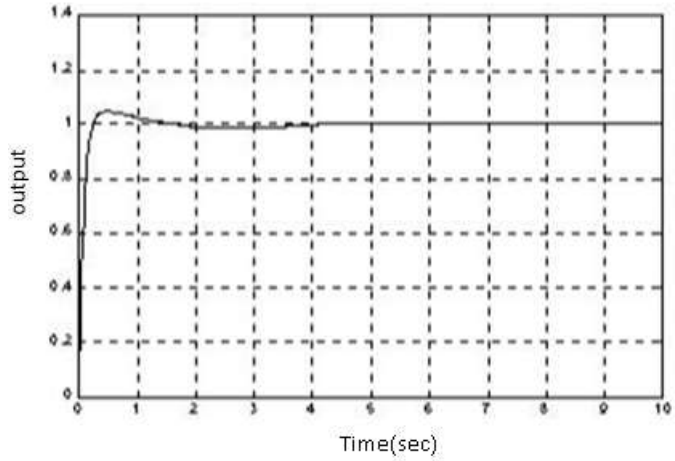


Fig. (5) Closed-loop step response for plant 1

The gains K_p = 4.0, K_i = 5.0 and K_d = 3.11 have been obtained after 100 generations of a population of 50 individuals. The gains were allowed to take values in the range from 0 to 100.
The second application plant was carried out with the plant [8] described by the transfer function expressed by equation (6). The responses obtained through application of the genetic algorithm, with the same parameters as in the previous experiment, are presented in Fig. 6,

$$G2(s) = \frac{4}{s(s+1)(s+5)} \quad \dots \dots \dots \dots \dots (6)$$

Which also shows results obtained with the straight and with an "adjusted" Ziegler-Nichols technique. In this, Ziegler-Nichols rules provide initial values for the gains; based on operator's experience, adjustments to those gains are performed thereafter.

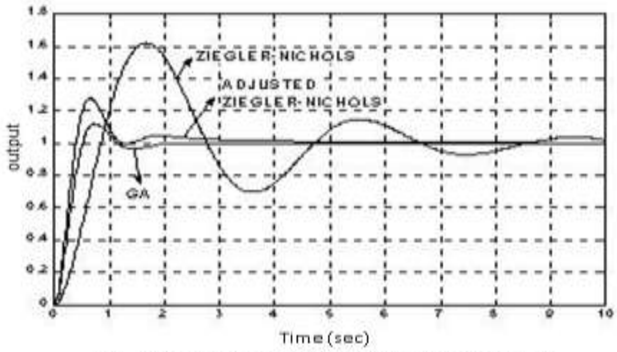


Fig. (6) Closed-loop step response for plant

It can be seen in Fig.(6) that the straight application of Ziegler-Nichols rules provided gain values which led to a poor behavior. By adjusting those gains manually, the system's response improved significantly, but remained poorer than that obtained with the genetic algorithm as a gain tuner. Gain values obtained with each of the techniques for the control of plant 2 are shown in Table 2.
Table (2) PID controller gains for plant 2

Gains	Straight Z-N	Adjusted Z-N	GA
K_p	18	39,42	20,17
K_i	12,81	12,81	0
K_d	6,32	30,32	24,53

In the third application a plant with time-delay was considered; its transfer function is given by equation (7) and the results are shown in Fig. 7.

$$G3(s) = \frac{5\exp(-2s)}{s(5s+1)(3s+5)} \quad \dots \dots \dots \dots \dots (7)$$

It can be seen in Fig. (7) that the use of Genetic Algorithms provides a faster response, with similar overshoot and settling time to those obtained through the Ziegler-Nichols's method.

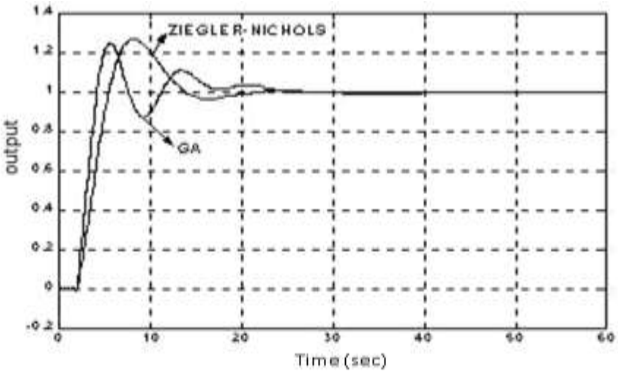


Fig. 7 Closed-loop step response for plant 3

It can be observed that the response provided by the PID controller tuned through genetic algorithms is rather close to the desired one. It is much faster than the closed-loop step response without compensation, with a minimal overshoot.

VII. CONCLUSION

This work shows how simple and powerful a GA application for controller tuning can be. Because the GA is a very good optimization technique. The work consisted of carrying out a series of experiments application to investigate the applicability of genetic algorithms to the automatic tuning of PID controllers. The method searches for a combination of gains so that the error between actual and desired responses is minimized.

Tuning through genetic algorithms led to satisfactory closed-loop step responses for all plants tested. Results compared favorably to those obtained through the classical Ziegler-Nichols's tuning method. As sometimes is the case with this method, there was no need for further manual adjustments to the PID gains when automatic tuning was employed. The automatic procedure was even capable of providing gain values where the classical method could not be applied.

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