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RESEARCH ARTICLE

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# Optimization design for tuning PID controller by using Genetic Algorithms

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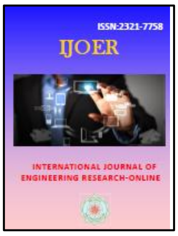


**ABSTRACT**

Tuning method for a PID controller based of a Genetic Algorithm (*GA*) is proposed to achieve the desired requirements that Ziegler-Nichols method cannot and showed some drawback. This algorithm is used to generate a huge number of possible solutions for the three gains of the controller, which is then evaluated and selected by minimization of a fitness function. A fitness function is constructed as inverse of three criteria: ISE, ITAE and IAE. The algorithms are simulated with MATLAB programming. The simulation result shows that The GA–based tuner is used to compensate the delay with high oscillation systems and showed a better dynamic performance than those based on traditional (Ziegler-Nichols) method.

## 1. Introduction

Proportional-integral-derivative (PID) control is a very popular control strategy in industry due to its simple architecture and easy tuning. For many simple processes, PID control can usually obtain satisfactory control performance. However, many industrial processes possess some complex properties such as nonlinearity, and time varying properties etc.. A conventional PID controller with fixed parameters may usually derive poor control performance. An alternative to deal with the control of such complex processes is to use adaptive control schemes used self-tuning technique to adjust PID parameters on-line [1]. However this was based on the assumption that the process to be controlled is linear.

If severe nonlinearity is involved in the controlled process, a nonlinear control scheme will be more useful. In practice the theoretical tuning methods are frequently substitute for empirical methods such: trial and error, continuous cycling method (Ziegler Nichols method), process reaction curve methods (Ziegler-Nichols and Cohen-Coon methods), and ITAE criteria.[2]

Traditional Ziegler-Nichols method of tuning PID controllers although commands substantial acceptance in control engineering community [3,4]. 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]

**2. 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 (setpoint)[1,2]. The PID controller is characterized by three gains, as shown in Fig.(2)

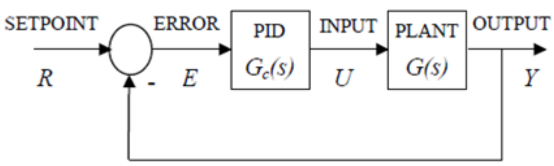


Fig. 1 PID control of a plant

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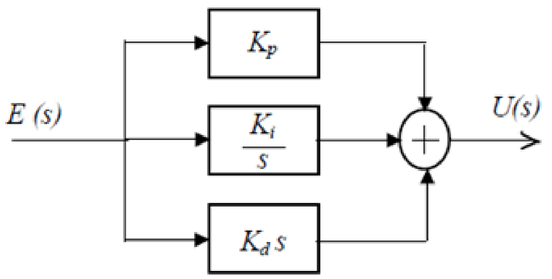


Fig. 2 PID controller internal structure

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:

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

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]

### 3. 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]

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

In real-time process control systems, a large variety of plants can be approximately modeled by (11). If the system model cannot be physically derived, experiments can be performed to extract the parameters for the approximate model.[8]

### 4. 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]

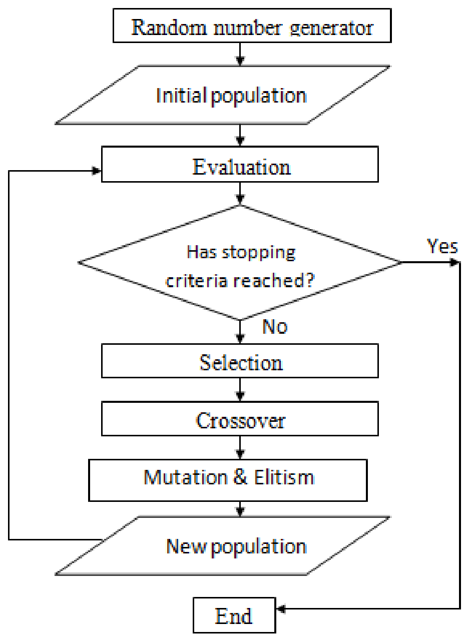


Figure 3 A simple genetic algorithm Implementation

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.

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There are three main operators for a genetic algorithm – Selection, crossover and mutation.

### 4.1 Selection

During the reproduction phase the fitness value of each chromosome is assessed. This value 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. An example of a common selection technique is the .Roulette Wheel. Selection method, as shown in Fig.(4).[11]

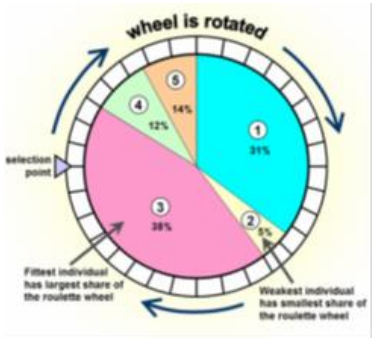


Fig.(4): depiction of *roulette wheGel selection*

### 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]

## 5. Genetic algorithm based design method

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

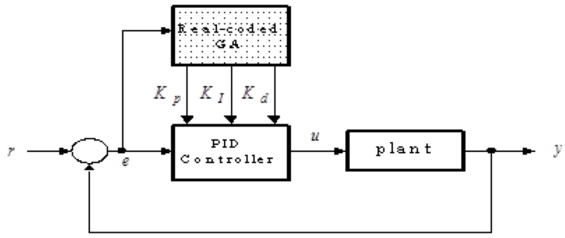


**Figure 5** Block diagram of PID controller tuner

The most crucial step in applying GA is to choose the objective functions that are used to evaluate fitness of each chromosome. Some works use *performance indices* as the objective functions. Other works uses Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE), while in use ISE, IAE, and ITAE to minimize the error signal suitable one. The performance indices are defined as follow [14,15]:

$$MSE = \frac{1}{t}\int_0^{\tau} (e(t))^2\, dt;$$

$$ITAE = \int_0^{\tau} t\,|e(t)|\,dt;$$

$$IAE = \int_0^{\tau} |e(t)|\; dt$$

$$ISE = \int_0^{\tau} e(t)^2\; dt;$$ and

$$ITSE = \int_0^{\tau} t\, e(t)^2\; dt$$

Where $e(t)$ is the error signal in time domain.

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 [16]:

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

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.,

$$k_{p\min} \le k_p \le k_{I\max}$$

$$k_{d\min} \le k_d \le k_{d\max}$$

$$k_{\mathrm{I}min} \le k_I \le k_{I\max}$$

**6. Initialization of system Parameters:**

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 | 20 |
| No. of variables in each chromosome | 3 |
| Selection method | roulette wheel selection |
| Crossover method | Single point crossover |
| Crossover probability | 0.8 |
| Mutation rate | 0.02 |
| Bounds of $K_p$ | $0 \le K_p \le 100$ |
| Bounds of $K_I$ | $0 \le K_I \le 100$ |
| Bounds of $K_D$ | $0 \le K_D \le 100$ |

**7. Third-order with high oscillation:**

The third plant can be described by the following transfer function:

$$G(s) = \frac{1}{54s^3 + 44s^2 + 3s + 1}$$

Firstly, Ziegler-Nichols method is used to find the values of PID controller gains. Then, the genetic algorithm is executed to find the best terms for PID controller, or to find the values of PID gains which yield the minima for the criteria ISE, IAE and ITAE. At the end of specified generation, the optimized gains are set to the PID controller and these are considered as the best or optimal gains.

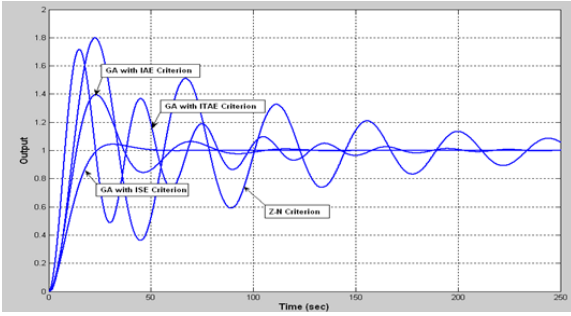


**Figure (6)** Step responses of third order oscillatory system with traditional and GA-tuned PID controller

It is easy to see from Fig.(6) that the response obtained from Z-N method is oscillatory and has poor stability characteristics. The GA shows a better dynamic performance than traditional method. However, the GA with IAE and ITAE still shows bad response characteristics due to high oscillation and high peak-overshoot. The response based on GA with ISE shows best characteristics; as it is oscillation-free and has relatively small peak-overshoot.

The behavior of PID controller gains as a function to generation number is shown in Fig.(7). The variations of gains are only found for the response of GA with ISE criterion. The values of gains at the end of generation are the optimal values of PID controller and will be set to the controller for controlling purpose.

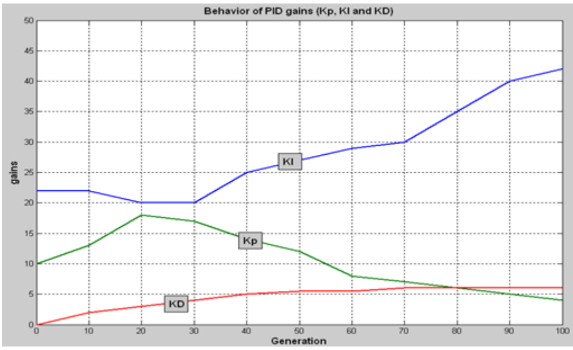


Figure (7) Change of PID controller terms with generation number

The transient parameters of all responses of Fig.(6) are listed in Table (2). Also the gain values of PID controller are given in the table. It is worth to say that these are the optimal gains which obtained at the end of generation loop.

**Table 2.** Transient Parameters for different responses of traditional *and GA methods*

| Transient Parameters and PID controller terms | Optimization Method | | | |
|---|---|---|---|---|
| | Traditional Method (Z-N) | Genetic Algorithm | | |
| | | ISE | IAE | ITAE |
| Rise Time ($T_r$) | 16.66 | 28.87 | 19.78 | 12.54 |
| Peak Overshoot ($M_p$) | 0.8 | 0.133 | 0.432 | 0.732 |
| Settling time ($T_{ss}$) | 310.33 | 49.87 | 110.78 | 190.78 |
| Proportional Gain ($K_p$) | 56.855 | 4.34 | 34 | 15.55 |
| Integral Gain ($K_I$) | 32.886 | 43.23 | 11.98 | 75.12 |
| Derivative Gain ($K_D$) | 4.553 | 6.557 | 0.02 | 1.212 |

## 8. CONCLUSIONS

This work shows how simple and powerful a GA application for controller tuning can be. Because the GA is a very good optimization technique, all control specifications that can be translated to a cost index can be applied.

The step response of closed-loop system with GA-tuned PID controller generally outperforms those with Ziegler-Nichols-tuned controller, and the responses of GA with IAE and ITAE are rather promising for high oscillation third order systems.

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