Tuning PID Controllers through Genetic Algorithms

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Abstract: **-** This work 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 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.

Key-Words: - PID controller, PID Tuning, Evolutionary computation, Genetic algorithms, Intelligent technique

1 Introduction

The use of so-called intelligent techniques – fuzzy logic, neural nets, genetic algorithms – in control is well established nowadays. Fuzzy controllers usually implement a control strategy derived from linguistic rules, which are translated into mathematical terms through the concepts of fuzzy sets and fuzzy logic [1]. Neural controllers are capable of learning the system's behaviour based on information about its input and output [2]. Both fuzzy and neural controllers are especially useful in the control of complex systems [2],[3].

Genetic algorithms are inspired in natural evolution and genetic recombination mechanisms. This technique is basically a procedure of adaptive and parallel search for the solution of complex problems and can be used in conjunction with other intelligent techniques [4],[5].

The main objective of this work is to investigate the use of genetic algorithms in the tuning of PID controllers [6]. The algorithm searches for the controller gains K_p (proportional gain) , K_i (integral gain) and K_d (derivative or differential gain) so that specifications for the closed-loop step response are satisfied. Due to their widespread use in industry, tuning procedures for PID controllers are always a topic of interest [7].

In the following section basic concepts and modelling of PID controllers are presented. Section 3 presents the tuning procedure, based on genetic algorithms, that has been used. Experimental results and comparisons with a classical tuning method are shown in section 4. Conclusions follow in section 5.

2 PID Controllers

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). The PID controller is characterized by three gains, as shown in Fig. 2.

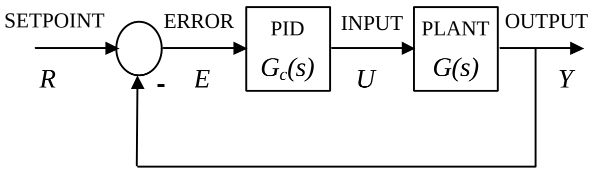

Fig. 1 PID control of a plant

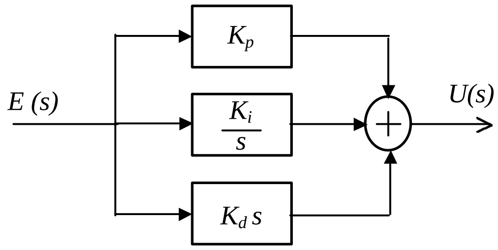

Fig. 2 PID controller internal structure

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:

$$G_c(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

The closed-loop transfer function $G_g(s)$ is given by:

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

The tuning of a PID controller consists of selecting gains K_p, K_i and K_d 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 K_p that results in marginal stability are used as starting points for obtaining gain values that guarantee a satisfactory behaviour. Finer adjustments to the gains may also be carried out.

3 Tuning Procedure

In this section a brief description of the Genetic Algorithms technique is given, followed by its application to the tuning of PID controllers.

3.1 Genetic Algorithms

Genetic Algorithms [9] provide an adaptive searching mechanism inspired on Darwin's principle of reproduction and survival of the fittest. The individuals (solutions) in a population are represented by chromosomes; each of them is associated to a fitness value (problem evaluation). The chromosomes are subjected to an evolutionary process which takes several cycles. Basic operations are selection, reproduction, crossover and mutation. Parent selection gives more reproductive chances to the fittest individuals. During crossover some reproduced individuals cross and exchange their genetic characteristics. Mutations may occur in a small percentage and cause a random change in the genetic material, thus contributing to introduce variety in the population. The evolution process guides the genetic algorithm through more promising regions in the search space.

Some of the advantages of using genetic algorithms are: it is a global search technique, can be applied to the optimization of ill-structured problems and do not require a precise mathematical formulation for the problem. Besides, genetic algorithms are robust, applicable to a number of problems and efficient, in the sense that either a sub-optimal or optimal solution may be found within reasonable time.

3.2 Genetic Algorithm for PID Tuning

The implementation of the tuning procedure through genetic algorithms starts with the definition of the chromosome representation. As illustrated in Fig. 3, the chromosome is formed by three values that correspond to the three gains to be adjusted in order to achieve a satisfactory behaviour. The gains K_p , K_i and K_d are real numbers and characterize the individual to be evaluated.

K_p	K_i	K_d

Fig. 3 Chromosome definition

Since the objective is to minimize the error between the setpoint (desired output) and the plant output (actual output), the fitness function has been defined as:

$$Fitness = S^n\ [desired\ output - actual\ output]^2 \qquad (3)$$

Desired and actual responses for a given system are shown in Fig. 4. The observation interval is divided into n points, or samples; the error for each sample is calculated and entered into (3), which gives the sum of all errors squared as a result. The minimization of (3), performed by the Genetic Algorithm by adjusting the PID gains, will ensure that the actual output is as close as possible to the desired one.

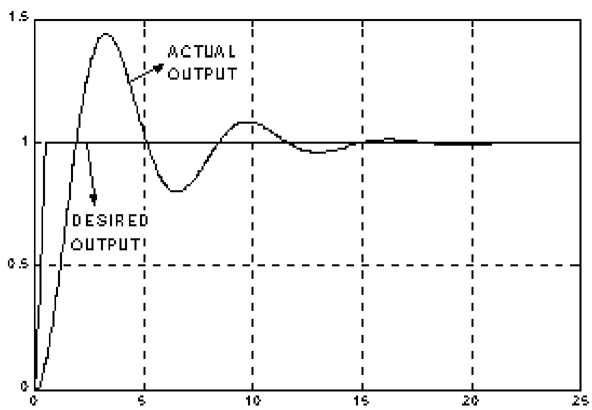

Fig. 4 Example of desired and actual outputs

4 Experimental Results

In the experiments, the Evolver© 4.0 (Palisade Co.) has been used for running the genetic algorithm, while the control system has been implemented on Matlab©, which also provides the *Excellink* for communication between the two softwares.

The genetic algorithm has been configured as follows:

- Population: 50
- Generations: 100
- Crossover (arithmetic and one-point) : 0.8
- Mutation: 0.06

Experiments with four 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 plant 1, described by the following transfer function, is shown in Fig. 5.

$$G_1(s) = \frac{4}{s^2 + 0.5s + 1} \qquad (4)$$

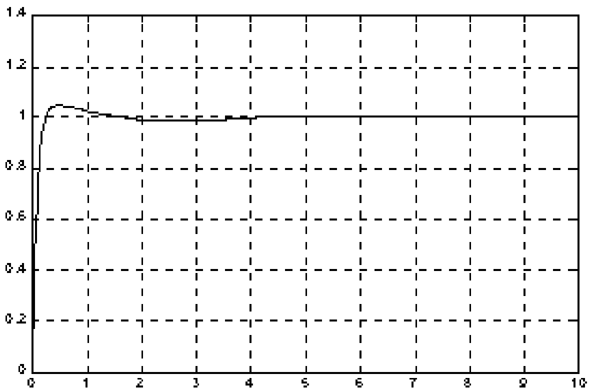

Fig. 5 Closed-loop step response for plant 1

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 experiment was carried out with the plant [8] described by the transfer function expressed by (5). The responses obtained through application of the genetic algorithm, with the same parameters as in the previous experiment, are presented in Fig. 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.

$$G_2(s) = \frac{1}{s(s+1)(s+5)} \qquad (5)$$

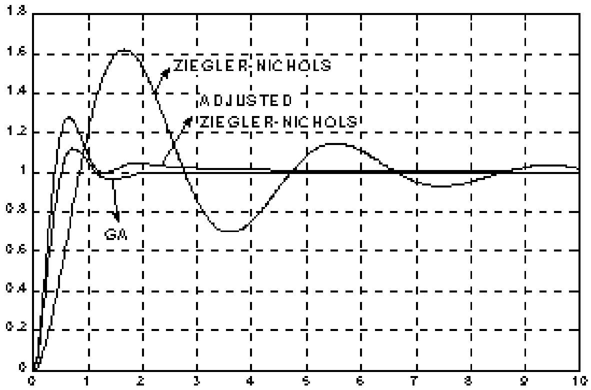

Fig. 6 Closed-loop step response for plant 2

It can be seen in Fig. 6 that the straight application of Ziegler-Nichols rules provided gain values which led to a poor behaviour. 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 1.

Table 1 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 experiment a plant with time-delay was considered; its transfer function [10] is given by (6) and the results are shown in Fig. 7.

$$G_3(s) = \frac{5\exp(-2s)}{(5s+1)(3s+1)} \qquad (6)$$

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.

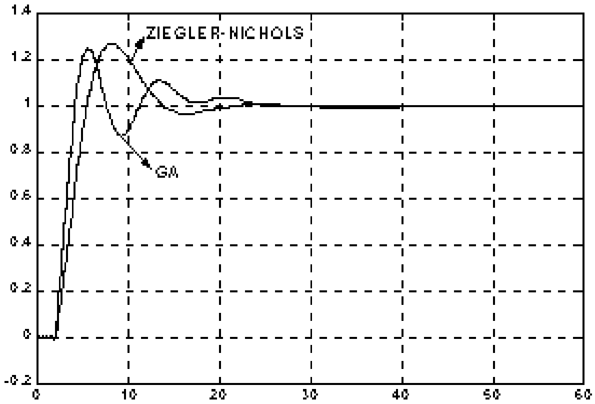

Fig. 7 Closed-loop step response for plant 3

The fourth experiment considered a plant where Ziegler-Nichols's rules could not be applied [9]. Its transfer function is given by (7) and results are shown in Fig. 8.

$$G_4(s) = \frac{(s+2)(s+3)}{s(s+1)(s+5)} \qquad (7)$$

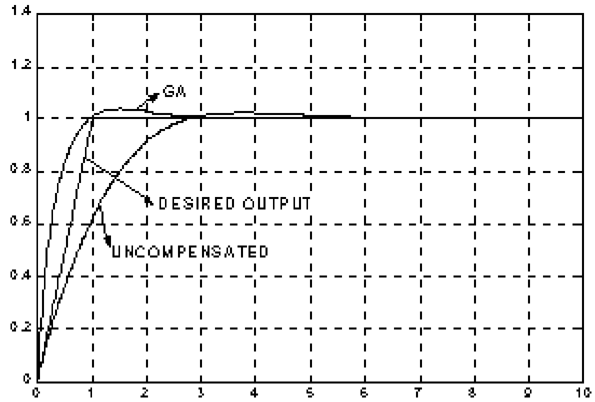

Fig. 8 Closed-loop step responses for plant 4

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.

5 Conclusions

This work consisted of carrying out a series of experiments 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 favourably 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.

Future work will include investigations with more complex and real plants. Genetic algorithms techniques for multi-objective optimization shall also be used in further experiments [11].

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