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PID Controller Tuning using Genetic Algorithms for uncertain system with delay

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Abstract— **Stabilization being the most basic requirement in any controller design problem. In this paper, we propose two methods for optimizing PID parameters for a discrete system with time delay based on the genetic algorithm.Indeed a method consists in obtaining a continuous optimal regulator and subsequently discretises it, while the second method makes it possible to obtain a discrete optimal regulator.Firstly, time domain measures of the closed loop system such as overshoot and response time are minimized using two methods of genetic algorithms. On another side,frequency domain measures of the closed loop system such as gain margin and phase margin are maximized using genetic algorithms.Finally, an uncertainty in the coefficient and in the delay were introduced to the discrete system with delay to ensure the robustness of the two optimization methods studied. A numerical example is given to demonstrate the capabilities and limitations of each proposed methods of optimization.**

***Keywords*—System with time delay, PID controller, genetic algorithm,time response,frequency response, robust control.**

I. INTRODUCTION

Over the past few decades, time-delay systems have drawn much attention from researchers throughout the world. This is due to their important role in many practical systems [1]. So time delay is frequently encountered in many fields of engineering systems, such us in biology, manufacturing system, teleoperation, mechanics, and economic system. The presence of delay can cause considerable and complex behaviour on thedynamics of the system. Indeed, when introducing a small delay, it is possible to destroy the stability of the system or to have oscillatory movements.

For this reason stabilization and control of system with delay has attracted the attention of several automaticians. In this way PID controllers are today found in all areas where control is used and are one of the most important control structures that are commonly used in 95% of industrial practice[2, 3].

Therefore, many PID controller tuning methods have been introduced. For example, the Ziegler Nichols Horowitz, or Cohen-Coon. Seen that Performance improvement is the main goal of the study of PID control and much research has been conducted for this purpose [4]. Furthermore the whole system's performance strongly depends on the controller's efficiency and hence the tuning process plays a key role in the system's behaviour.

Therefore, the choice of the technique of adjustment of the PID parameters has a major effect on the efficiency of the control and the accuracy of the system as much as in the temporal domain as in the frequency domain. So to get an optimal PID controller, there is some application of genetic algorithm optimization techniques to the tuning of

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PID controllers [5]. In fact, genetic algorithm has shown its superiority to the level of accuracy in tuning the PID controller. Genetic Algorithms (GAs) are a stochastic global search method that mimics the process of natural evolution [6]. Unlike classicaloptimization methods, they are not gradient based which makes GAs suitable to minimize performance measures such as maximum percent overshoot, response time [7]. In fact using genetic algorithms to perform the tuning of the PID controller will result in the optimum controller being evaluated for the system every time [8]. In this sense several research works are based on the optimization of parameters of the PID controller by genetic algorithm.

This paper is organized as follow:

First an overview of genetic algorithm will be presented briefly andfollowed by an explanation of how to implement an optimal PID regulator for controlling a discrete system with delay. Therefore, two valid optimization methods will be proposed for controlling a discrete system with time delay. In the end, to ensure the effectiveness of each method, a numerical example of a teleoperated robot has been studied in the regular case and in the uncertain case. A comparison between the two proposed methods will be detailed and a conclusion will be derived in the end of this paper.

II. OVERVIEW OF GENETIC ALGORITHM

Genetic Algorithms (GA's) are a stochastic global search method that mimics the process of natural evolution. Recently, GA has been recognized as an effective and efficient technique to solve optimization problems, compared with other optimization techniques. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions [9]. There are three main stages of a genetic algorithm; Selection, Crossover and Mutation. The application of these three basic operations allows the creation of new individuals which may be better than their parents. This algorithm is repeated for many generations and finally stops when reaching individuals that represent the optimum solution to the problem [9]. The process of Genetic Algorithm will be summarized in a flowchart.

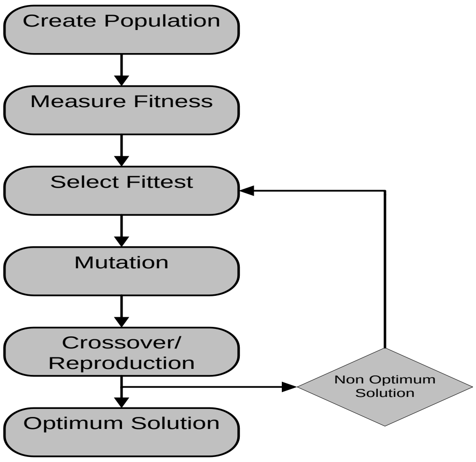

Fig.1. Genetic Algorithm Process Flowchart

III. IMPLEMENTATION OF GA BASED PID CONTROLLER

Your PID control consists of three types of control, Proportional, Integral and Derivative control. The Figure 2 is a simple diagram illustrating the schematic of the PID controller.

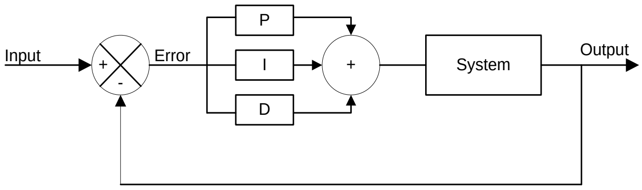

Fig. 2. Schematic of conventional PID controller

The transfer function of a PID controller is described as follows [10]:

$$G(s) = k_p + \frac{k_i}{s} + k_d s \quad (1)$$

Where k_p, k_i and k_d are the proportional, integral and derivative gains, respectively.

Generally, it may be very difficult to adjust the parameters of the PID controllers via analytical methods. To overcome this problem, we can use an intelligent method which is the genetic algorithm [11], [12]. Our goal is to minimize overshoot and response time. To apply the genetic algorithm, it is necessary to define the cost function, which makes it possible to give a measure to objectify the evolution of the overshoot and the response time on the one hand and the phase margin and the gain margin of one somewhere else.

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For the discrete case the digital PID controller is described by the following equation:

$$G(z)=k_p+k_i\frac{z}{z-1}+k_d\frac{z-1}{z} \quad (2)$$

Thus, in order to obtain the optimal parameters of a PID controller with the genetic algorithm of a discrete system with delay, two methods have been proposed: the first consists in optimizing the regulator continuously thendiscretizing the optimal regulator and the process. The second method consists in making the optimization of the parameters in discrete time.It is important to remember that the optimizations of the regulator with both methods are aimed at obtaining a response with minimal response time and overshoot and also in the frequency domain a maximum phase and gain margin. Finally, a comparison between the two proposed methods will be made and then we will ensure the robustness of the two methods by adding uncertainties in the coefficient at the first time then we will add an uncertainty in the delay.

A. *Optimization of the PID parameters with the first method*

In this optimization method we have the equation of the PID regulator described in equation (1) in continuous case and the transfer function of the system with delay in the continuous case described by the following equation:

$$H(s)=\frac{b e^{-\tau s}}{a_2 s^2+a_1 s+a_0} \quad (3)$$

So for designing process, the first step is to determine the total set of stabilizing PID controllers. Once this set of stabilizing PID controllers is found, it is natural to search within this set, controllers that meet extra performance specifications. Two performance measures will be considered:

Response time and overshoot (time domain)

The phase margin and gain margin (frequency domain).This step consists in determining the total parameters of the PID controllers and is very important. It enhances the application of the genetic algorithm by fixing the search space, unlike other works on optimizing PID controllers using GAs [10, 12] where the ranges of (k_p , k_d , k_i) are set arbitrary [7]. In addition, it improves the optimization time and increases the chances of obtaining the overall optimum. The optimization of the PID controllers is done by minimizing each of two cost functions: response time and overshoot, then maximizing the phase margin and gain margin. The parameters and tools used in the implementation of the genetic algorithm are described with details in [7, 13, 14]

For the optimization of the PID parameters with the first method, it consists in obtaining the parameters of the regulator such that the overshoot and the response time are minimum and the frequency response is maximum (phase margin and gain margin) in three steps as follow:

Step 1: Optimizing the parameters of the continuous PID controller with genetic algorithm as described above

Step 2: discretization of the obtained regulator

Step 3: discretization of the system with delay

It is interesting to recall that the discretization technique used in this paper is that of Tustin with a sampling period equal to 0.1s.

B. *Optimization of the PID parameters with the second method*

In this method the optimization of the digital PID regulator with optimal parameters is obtained directly, so it is no longer necessary to go to the discretization of the regulator and the system with delay separately.

IV. SIMULATION RESULTS

This robot is controlled through a communication network whichintroduces delays in the control loop [7]: $H(s)=\frac{11.32\,e^{-s}}{s^2+11.32}$ (4)

The transfer function above represents ateleoperatedrobotic system. The slave part is a model of a mobile robot which can move in one direction [15]. The discrete transfer function of the system with delay defined by equation (4) is given as:

$$\mathrm{H(z)}=\frac{z^{-8}0.0187+0.03614z^{-9}+0.01807z^{-10}}{z^{2}-1.277z+2.771} \quad (5)$$

Fig. 3 shows the step response of the closed-loop system, the system is stable and precise, but there is a significant overshoot of 60% and a response time equal to 10 s.

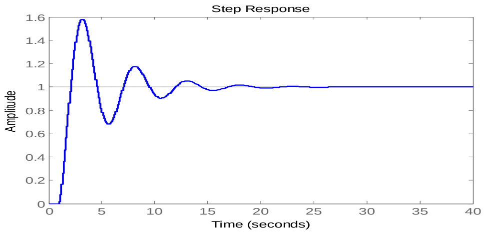

Fig.3. Step response of the closed loop system with delay

A/ PID Controller Design using Genetic Algorithms

To obtain an optimal PID regulator which guarantees a time delay system with minimum time response and overshoot, we compared the results obtained with two methods proposed in the previous section.The first method consists in continuously optimizing the parameters and then moving to discretization, and the second method is based on the optimization of discrete PID parameters.The simulation results of the implementation of the optimal PID controller obtained by the methods proposed above, have shown the superiority of the second method in the temporal domain, as shown in fig.4 and explained in the table.

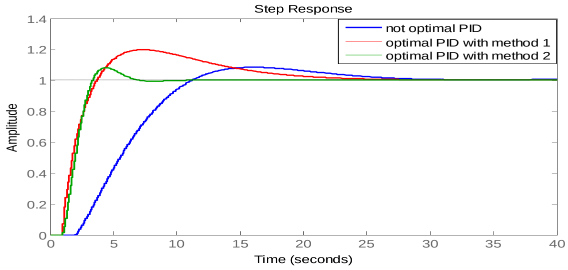

Fig.4. Comparison between the two optimization methods and the not optimal system

Table I shows that Method 2 is the best because it guarantees a 4% overrun with a fast response of 3s.

TABLE I
COMPARISON BETWEEN THE RESPONSE OF THE SYSTEM IN THE TIME DOMAIN AND IN THE FREQUENCYDOMAIN USING THE TWO OPTIMIZATION METHODS

method	**(k_p , k_d , k_i)**	**Response time (s)**	**Over shoot (%)**	**Phase margin (db)**	**Gain margin (°)**
Not optimal PID	(2.436, 0.0039, -4.3612)	14	8	12.3	60
Method 1	(5,0.6,2)	13.4	20	8.79	113
Method 2	(5.9982, 2.9963, 2.2902)	3	4	5.28	-180

Therefore we tried to improve the frequency response of the system given with the proposed methods by forcing the PID corrector to give a maximum phase margin and gain margin.

In this case of optimization condition, the first method gave better results as shown in Fig.5 and 6 as well as detailed in both following tables.

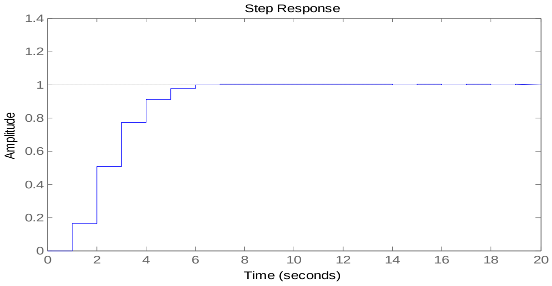

Fig.5. System response to a step after optimization in the frequency domain of the regulator with the first method

TABLE III
RESPONSE OF THE SYSTEM IN THE CASE OF OPTIMIZATION IN THE FREQUENCY DOMAIN USING THE FIRST METHOD

	Time response	**overshoot**	**Phase margin**	**Gain margin**
Optimisation using method 1	0	5 %	11.2	160

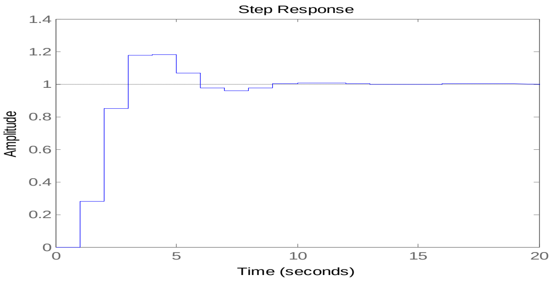

Fig.6. System response to a step after optimization in the frequency domain of the regulator with the second method

TABLE IIIII
RESPONSE OF THE SYSTEM IN THE CASE OF OPTIMIZATION IN THE FREQUENCY DOMAIN USING THE SECOND METHOD

	Time response	**overshoot**	**Phase margin**	**Gain margin**
Optimisation using method 2	6	18 %	14	142.1

B/Study of robustness

To ensure the efficiency and robustness of each optimization method, we added an uncertainty in the first coefficient of the transfer function denominator $a_2 + \Delta a_2$ as follow:

$$H(s) = \frac{11.32\, e^{-s}}{(1+\Delta a_2)s^2 + 11.32} \tag{6}$$

Fig.9 represents the response of the uncertain system with an optimal regulator using the first method of optimization. In this case the systemremains robust until a coefficient of uncertainty equal to 300% as presented in Fig.7.

Also, it was found that the first method remains robust to an uncertainty coefficient of 300% as shown in the following figure and detailed in the following table.

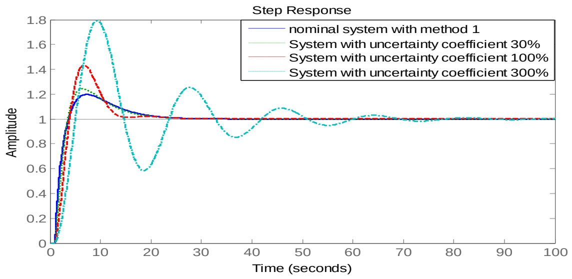

Fig.7. response of the uncertain system with an optimal regulator with 1st method

TABLE IV
EFFECT OF UNCERTAINTY ON THE ROBUSTNESS OF THE FIRST METHOD

Method 1	**Nominal system**	**System with uncertainty coefficient 30%**	**System with uncertainty coefficient 100%**	**System with uncertainty coefficient 300%**
Response time (s)	13.4	12.8	14.1	45.8
Overshoot (%)	20	24	46	80

Therefore, according to this table, the first method remains robust up to an uncertainty value equal to 300%. On the other hand, the system becomes slow and the overshoot is greater.

The Fig.8 shows that the first method loses the robustness from an uncertainty coefficient equal to 450%.

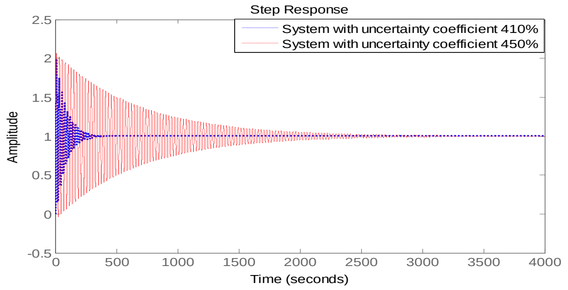

Fig.8. Effect of the uncertainty of the coefficients on the robustness of the system for the first method

Figure.9 represents the step response of the system given in (6) with different values of uncertainties coefficient. It should be noted that the second method yields satisfactory results by comparing with the first method, although there is an uncertainty on the system coefficient of 300%. Indeed the response time is equal to 23s and the overshoot is 43%

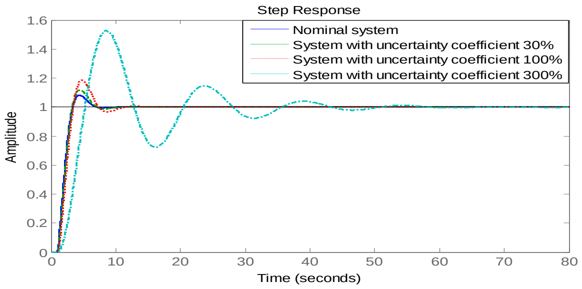

Fig.9. Response of the uncertain system with an optimalregulator with the second method

TABLE V
EFFECT OF UNCERTAINTY ON THE ROBUSTNESS OF THE SECOND METHOD

Method 2	**Nominal system**	**System with uncertainty coefficient 30%**	**System with uncertainty coefficient 100%**	**System with uncertainty coefficient 300%**
Response time (s)	3	5	11	23
Overshoot (%)	3	12	26	43

Similarly, an uncertainty in the coefficient is added to the obtained system with the second method. In this case the system remains robust for an uncertainty coefficient equal to 450%.In this case, the robustness of the system is shown despite the uncertainty of 450% and the system remains stable as shown in Fig.10 but the time response becomes important equal to 650s and the overshoot more than 81%.

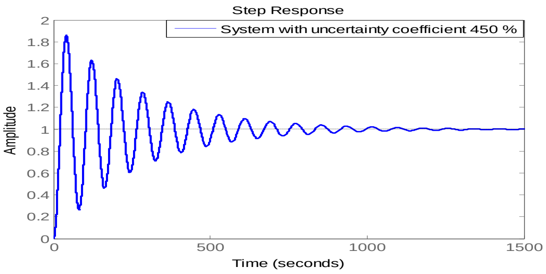

Fig.10. System response with uncertainty coefficient equal to 450% using the secondmethod optimization

Finally, in the case of adding an uncertainty in the delay, Fig.11 shows that the first method is no longer robust from an uncertainty equal to 150%, whereas the second method loses its robustness from an uncertainty in the delay which is equal to 230% as shown in the Fig.12.

$$H(s)=\frac{11.32\;e^{-(1+\Delta\,\tau)\,s}}{s^{2}+11.32} \qquad (7)$$

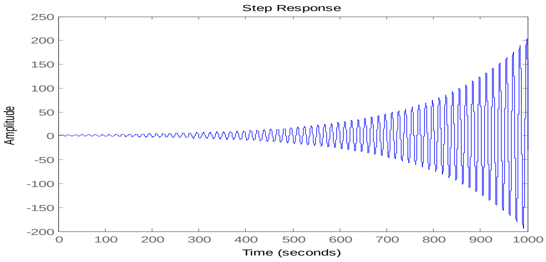

Fig.9. System response with uncertain delay equal to 150% using the 1st optimization method

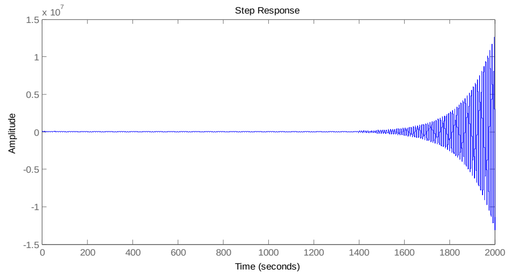

Fig.10. System response with uncertain delay equal to 150% using the 2nd optimization method

V. CONCLUSION

Since the genetic algorithm has proved its efficiency in the optimization of PID parameters in this paper, we are interested in the use of this type of stochastic algorithm in the control of discrete delay systems. Indeed, two methods of optimization with gene algorithm of the PID regulator for a discrete system with delay were presented.The first method consists in obtaining an optimal PID corrector for a continuous system and subsequently discretizing it as well as the system to be controlled.

The second method consists in obtaining an optimal PID controller with AG discrete directly.

A numerical example showed the superiority of the last method when optimizing in the time domain. Indeed the optimization with the second method gave a lower response time and a minimum overrun. On the other hand the first method proved its superiority in the frequency domain. Finally, by adding an uncertainty in the coefficient or in the delay to the transfer function of our system, the optimal PID regulator with the second method remains always more robust. For the prospects it is interesting to conduct our research work with the use of robust H-inf control and compare it with the results obtained in this article.

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