Tuning of PID Controller Using GA for Ball and Hoop System

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Abstract The PID controller is one of the control strategies having simple structure was understood by plant operator, which is comparatively easy to tune. Irrespective of the attractiveness, the tuning characteristic of PID controllers is a task for engineers and scientists. Numerous procedures for tuning PID-controllers are recommended such as: Ziegler Nichols tuning method auto-tuning, artificial intelligence and optimization techniques. Evolutionary optimization techniques (EOTs) as emergent techniques, an efficient GA-based tuning approach aiming at enhancing PID control for complex processes is proposed. The test and simulation results demonstrate that the GA-based proposed scheme is capable and can be used to overcome the flaws of traditional fixed gain controller. The main role of the article is to appraise the algorithm for tuning of PID-controller gains along with minimization of cost function and argue about the capability, computational efficiency of GA to solve the problems in control systems.

Keywords PID-controller, Tuning Methods, Performance and Optimization

1. Introduction

A PID control is universal feedback control apparatus and it makes up 90% of controllers in commercial control systems. The PID controller was first employed in the marketplace in the year 1939 and has continued the most widely used controller in industrial applications [1].

The PID controllers are popular because of their practical easiness and reliability. They offer robust and stable performance for most of the control systems. PID gains are tuned to ensure the acceptable performance of the control system [2]. An appropriately tuned PID controller improves the transient response of a system by decreasing the overshoot, and by reducing the settling time of a control system [3].

Standard methods for tuning include Ziegler-Nichols Ultimate-cycle tuning [4] and many other customary

procedures. Although new approaches are proposed for tuning the PID controller, their usage is inadequate due to complications arising at the time of implementation.

Irrespective of the attractiveness, the tuning characteristic of PID controllers tuning characteristic is a task for engineers and scientists. Numerous procedures for tuning PID-controllers are recommended such as Ziegler Nichols tuning method auto-tuning, artificial intelligence, and optimization techniques. Evolutionary optimization techniques (EOTs) as emergent techniques [5]

The use of nature inspired algorithms in solving control systems problems has been increased during last decades. In comparison to traditional optimization techniques, the EAs can be regarded as robust and more distinct to apply in the situations where less knowledge regarding the process has to be controlled is not desirable in a priori [6]

Copious techniques have been proposed to simplify the PIDs tuning process. Currently, according to the most admired tuning methods are: tuning, frequency domain tuning and optimal tuning. The traditional Ziegler-Nichols method [Ziegler-Nichols (1942)] is still widely used in industry.

The main role of the article is to appraise the algorithm for tuning of PID-controller gains along with minimization of cost function and argue about the capability, computational efficiency of GA to solve the problems in control systems. All simulation work has been performed using a MATLAB. The overall results suggest that GA normally can stumble on improved solutions.

The manuscript has been organized as: an overview of PID controller is given in section 2, section 3 briefly introduces GA, Main steps for designing and tuning the PID using GA has been placed in Section 4, section 5, present test and simulation results and the conclusion remarks are given in Section 6.

2. PID Controller an Over View

A PID controller tuning means to locale the PID gain values to get the best possible control for a particular process.

The adjusted controller gains have to satisfy the time domain performance specifications such as stability margin, transient response and bandwidth. The PID controller in its standard form is written as:

$$u = K_p \cdot e + k_1 \int e \cdot dt + k_D \cdot \frac{de}{dt} \quad (1)$$

The PID control is a linear control methodology. The structure of PID controllers is very simple. They operate on the error signal. This is the difference between the desired output and the actual output, and generates the actuating signal that drives the plant

3. An Overview of GA

The GA was initiated by J. Holland in the year 1970. The GA is a nature inspired algorithm that follows the principles of genetics and natural evolution. The evolutionary algorithms GA use “survival of the fittest” principle in its process of search for generation and selection of individuals that are used in design objectives. Hence, number of generations will grow and continue in the composition of the population [7].

GA is a search technique in which process starts with initialization of population of individuals randomly. Then, the fitness of each individual is computed. The transmission of the population takes place by using genetic operators such as selection, crossover and mutation. The procedure chooses the fittest individuals from the population to go on with the next generation [8].

4. Design of GA-PID Controller

A plant given in Eq. (2) has been borrowed from literature. It demonstrates a fourth order system dynamics of a ball that is free to roll inside the rotating circular hoop.

$$P(s) = \frac{1}{(1s^4 + 6.0s^3 + 11.0s + 6.0s)} \quad (2)$$

The $K(\alpha)$ is assumed as a specific structure of controller to be designed. The controller structure can be specified before the start of optimization process. Here, α is vector of controller gains $\alpha = [K_P \ K_I \ K_D]$. The vector of controller gains α is used to optimize gains. Details are given in [2].

The shaped plant (PS) is formulated as $K_\infty(s)$ controller which stabilizes the closed loop system and minimizes γ

$$\gamma = \inf_k \left\| \begin{bmatrix} I \\ K_\infty \end{bmatrix} (I + P_s K_\infty)^{-1} M^{-1} \right\|_\infty \quad (3)$$

Where, γ is the H_∞ -norm and $(I + G_s K_\infty)^{-1}$ is the sensitivity function, the lowly attainable value of γ and corresponding stability margin is calculated by the equation given:

$$\gamma = \varepsilon_{\max}^{-1} = \sqrt{1 + \lambda_{\max}(XZ)} \quad (4)$$

$$\begin{aligned} (A - BS^{-1}D^T C) + Z(A - BS^{-1}D^T C)^T - ZC^T R^{-1}CZ + BS^{-1}B^T &= 0 \\ (A - BS^{-1}D^T C)^T + X(A - BS^{-1}D^T C) - XBS^{-1}B^T X + C^T R^{-1}C &= 0 \end{aligned} \quad (5)$$

Where, A, B, C, and D are state space matrices of G, $S = I + D^T D$ and $\bar{S} = I + D D^T$

$$\|T_{zw}\|_\infty = \left\| \begin{bmatrix} I \\ W_1^{-1}K(\alpha) \end{bmatrix} (I + P_s W_1^{-1}K(\alpha)(I \ P_s)) \right\|_\infty \quad (6)$$

4.1. Step-wise Procedure for proposed approach

Following are the steps for tuning the GA-based PID controller:

Step-1 sets several initial parameters of α generated randomly, where α is vector of controller gains.

Step-2 Select pre-specific the controller structure and compute the CF of each chromosome.

Step-3 the chromosomes with lowly CF may be selected as solution in existing generation, apply operators of GA, selection, cross over and mutation.

Step-4 after applying GA operator a new population is produced if present generation is less than the maximum generations repeat to step 3.

Step-5 if present generation is maximum generation then, stops.

5. Test and Simulation Results

The weighting functions are selected for the nominal plant transfer function as given in Eq. (7).

$$W_1 = \frac{0.44S + 1}{S + 0.001} \quad (7)$$

Choose W_2 as an identity matrix, with these chosen weights the plant is shaped as given in Eq. (8)

$$P_s(s) = \frac{0.3s + 1}{1s^4 + 11.81s^3 + 6s^2 + 0.07s} \quad (8)$$

The $K_\infty(s)$ is obtained by using MATLAB code as given in Eq. (9)

$$K_\infty(s) = \frac{2.6e^{-0.15}s^4 + 5.41e^{-0.15}s^3 - 7.9e^{-0.16}s^2 + 0.5s + 1}{1s^5 + 6.2s^4 + 12.2s^3 + 7.11s^2 + 0.06s} \quad (9)$$

With the help of loop-shaping procedure a 9th order complex controller is computed as given in Eq. (10)

$$K(s) = \frac{8e^{-0.16}s^5 + 4.26e^{-0.15}s^4 + s^3 + 0.09s^2 + 0.63s + 1}{12s^9 + 59s^8 + 146s^7 + 196s^6 + 136s^5 + 39s^4 + 0.7s^3 + 0.3s^2 + 6s + 1} \quad (10)$$

The designed controller's transfer function is shown in Eq. (10) is of 9th order it has complex structure and it is thorny to put into practice.

A PID controller is tuned, K_P , K_I , K_D as the controller gains that are tuned by GA. The structure of specific controller is given in Eq. (11)

$$K(\alpha) = K_P + \frac{K_I}{S} + K_D \quad (11)$$

The MATLAB based simulations were started by using specification of algorithm as shown in table.1 at the 49th generation the optimum values of PID gains are accomplished.

Table 1. Specification for the GA

Parameters	G A
Initial Population	100
Type of Selection	Rootle wheel
Crossover	Single point
Crossover Probability	0.87
Mutation	One bit mutation

The algorithm converged in 49th generation, and gave minimal value of CF 1.340. The Fig.1 shows the plot of CF convergence against generations of GA.

The optimal solutions of GA-PID gains were achieved having satisfactory stability margin that is 0.747. The calculated optimal gains of controller are as given in Eq. (12)

$$K(\alpha)^* = 0.987 + \frac{0.769}{S} + 0.98 \quad (12)$$

Figure 1. CF Convergence plot Vs. Generations of GA

The step response of the control system with GA –PID controller is shown in Fig. 2. The computed optimal values are tabulated in table 2

Table 2. Computed Optimal Values

Proportional gin	0.987
Integral Gain	0.769
Derivative gain	0.980
Cost Function (CF)	1.340
Stability Margin	0.747

Figure 2. Shows response with GA-PID controller

6. Conclusions

This paper proposes the GA-based scheme to find out the best possible PID controller gains and find out minimal cost function value hence the maximum stability margin. Test and simulation analysis results demonstrate that the proposed PID tuning approach can be used to enhance the performance of complex system. Consequently, while a GA is applied to control system problems, their typical characteristic proves that GA-based controller has faster and smoother response in term of performance in time domain. The suggested method for GA-PID controller tuning has good performance as proved after implementation of GA-controller.

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