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Optimization of PID Parameters Based on Genetic Algorithm Optimization for Ball and Beam System

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Abstract:

This paper applies Genetics Algorithms (GA) for tuning PID controller of ball and beam system. PID controller is used to control the output position of the system. A process model of the ball and beam system is defined based on its mathematical model. Using this model, an offline PID parameters optimization based on GA is done. The chromosome in GA represents PID parameters namely proportional gain (Kp), integral gain (Ki), and derivative gain (Kd). The objective functions are settling time and overshoot. The experimental results show that the step response of this GA-based PID controller has superior performance than it using PSO and trial and error.

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Keywords: Genetic Algorithm, Control System, PID, PSO, Ball and Beam

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Introduction

one of the most popular laboratory controls design experiments are the ball and beam balance system because it can be used to study the implementation of classical and modern control techniques and very simple to understand. PID controllers are most widely controller are used in automatic industrial. most of the control loops in process industries are PID type. Tuning is the determination of corresponding PID parameter values for getting the optimum performance from the process. This is clearly are important part in case of all closed loop control systems. There are number of tuning methods have been introduced to obtain acceptable and fast performance. A ball is placed on a beam, in figure 1.1, where it is allowed to roll freely with 1 degree along the beam length. one end of beam is attached to the lever arm at and in the other servo gear. As the servo gear turns by an angle θ, the lever changes the angle of the beam by α. The gravity causes the ball to roll along the beam When the angle is changed from the vertical position. A controller is designed for the ball and beam system so that the ball's position can be controlled [1].

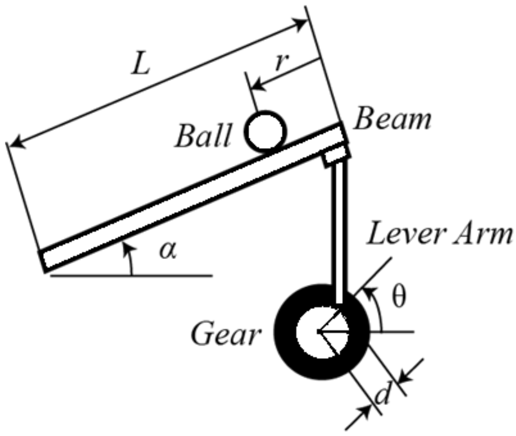

Figure 1: Ball and Beam Configuration

The ball and beam system are a system having instabilities and nonlinearities. The ball and beam with own are an open loop unstable system that is the ball will be rolling continuously on a beam until a controller is used. The challenge is to keep the position of the ball on the beam along while the ball rolls freely. The control goal is to automatically regulate the position of the ball on the beam by changing the angle θ of the beam. The beam angle will control the acceleration of the ball. so, by controlling the acceleration of the ball, the position can be control. In control technology the system is open loop unstable because the system output (the ball position) increases without limit for a fixed input (beam angle). Feedback control signal must be used to maintain the ball in a desired position on the beam. So, a suitable controller to be designed based on the dynamics of ball and beam system [2].

PID controllers are most widely controller are used in automatic industrial. most of the control loops in process industries are PID type. Tuning is the determination of corresponding PID parameter values for getting the optimum performance from the process. This is clearly are important part in case of all closed loop control systems. There are number of tuning methods have been introduced to obtain acceptable and fast performance. The steps implicated in these methods include experimental determination of the dynamic characteristics of the control loop and estimating the controller tuning parameters that produce a desired performance for the dynamic characteristics determined [3].

The steps implicated in these methods include experimental determination of the dynamic characteristics of the control loop and estimating the controller tuning parameters that produce a desired performance for the dynamic characteristics determined. This paper presents development of an optimal PID controller for a composition control system using GA technique. This paper also compares the transient performance of the system using GA technique with PSO technique and trial and error technique.

The basic principle of the genetic algorithms is that they generate and maintain a population of individuals represented by chromosomes. Chromosomes are a character string practically equivalent to the chromosomes appearing in DNA. These chromosomes are usually encoded solutions to a problem. It undergoes a process of evolution as per rules of selection, reproduction, and mutation. Each individual in the environment (represented by chromosome) gets a measure of its fitness in the environment. Reproduction chooses individuals with high fitness values in the population. Through crossover and mutation of such individuals, a new population is determined in which individuals might be an even better fit for their environment. The process of crossover includes two chromosomes swapping chunks of data and is analogous to the process of reproduction. Mutation introduces slight changes into a little extant of the population, and it is representative of an evolutionary.

Mathematical Model of The System

The system consists of two separated systems, the first one is the DC servo motor which is an electromechanical system that receives electrical signal from controller and gives output as a rotational displacement (angle). The second is ball and beam model that converts the rotational displacement (angle) from motor into a linear displacement.

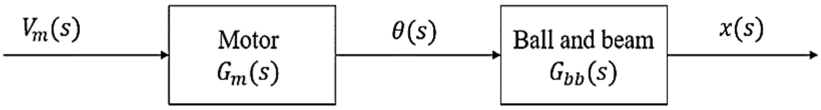

Figure 2: Transfer Function of Ball and Beam System

Based on the system parameters in the table 1, motor model can be written as

$$G_m\ (s) = \frac{\theta(s)}{V_a(s)} = \frac{0.7}{s(0.014\ s+1)}$$

Table 1: The system parameters

Time constant (τ)	0.014 sec
Motor Constant (K)	0.7/rev/sec/volts
Moment of inertia J	1.4 * 106 kg-m2
Beam Length (L)	16.75 cm
Lever arm offset (r)	2.54 cm
Gravitational acceleration (g)	9.8 $m/s2$

Second transfer function describes the relation between ball position (x) and beam angle (θ) and was obtained as:

$$G_{bb}(s) = \frac{x(s)}{\theta(s)} = \frac{1.06}{s^2}$$

the overall open loop transfer function ($G(s)$) of the ball and beam system can obtained as shown in figure 1 by combining the transfer functions($G_m(s)\ and\ G_{bb}(s)$).

$$G(s) = \frac{x(s)}{V_a(s)} = \frac{0.7}{s(0.014\ s+1)}\frac{1.06}{s^2} = \frac{0.742}{s^3(0.014\ s+1)}$$

PID Controller

Proportional-Integral-Derivative (PID) control is the most used control algorithm in industries and has been depending in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple, straightforward manner., PID algorithm consists of three basic parameters; proportional KP, integral KI and derivative KD which are varied to get optimal response.

The block diagram in figure 2 shows the principles of how the terms of PID generated and applied. It shows a PID controller, its continuously calculates an error value e(t) as the difference between a desired setpoint SP = r(t) and output signal (measured process variable PV=y(t)). e(t)=r(t)-y(t) and sitting a correction based on proportional, integral, and derivative terms. The controller is to minimize the error over time by adjustment of a control variable u(t), such as the opening and closing of a control valve, to a new value determined by the summation of the control terms.

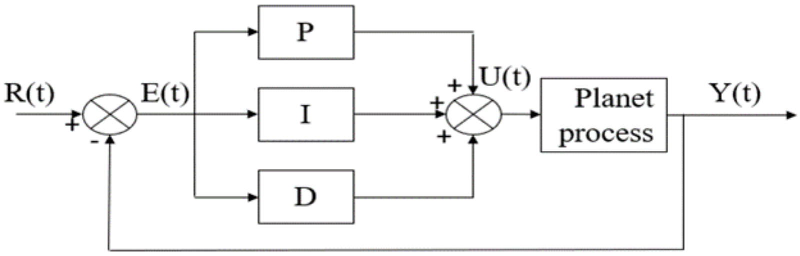

Figure 3: block diagram of a PID controller

The formula of the PID controller is:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{d}{dt} e(t)$$

Genetic Algorithm GA

a genetic algorithm (GA) is inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA). Genetic algorithms are used to generate high-quality solutions to optimization and search problems by depending on biologically inspired operators such as crossover, mutation and selection. Genetic algorithm flow chart describes the steps of how the genetic algorithm based on the initial conditions and throe the selection, crossover and mutation. Figure 4 show the genetic algorithm flow chart [4].

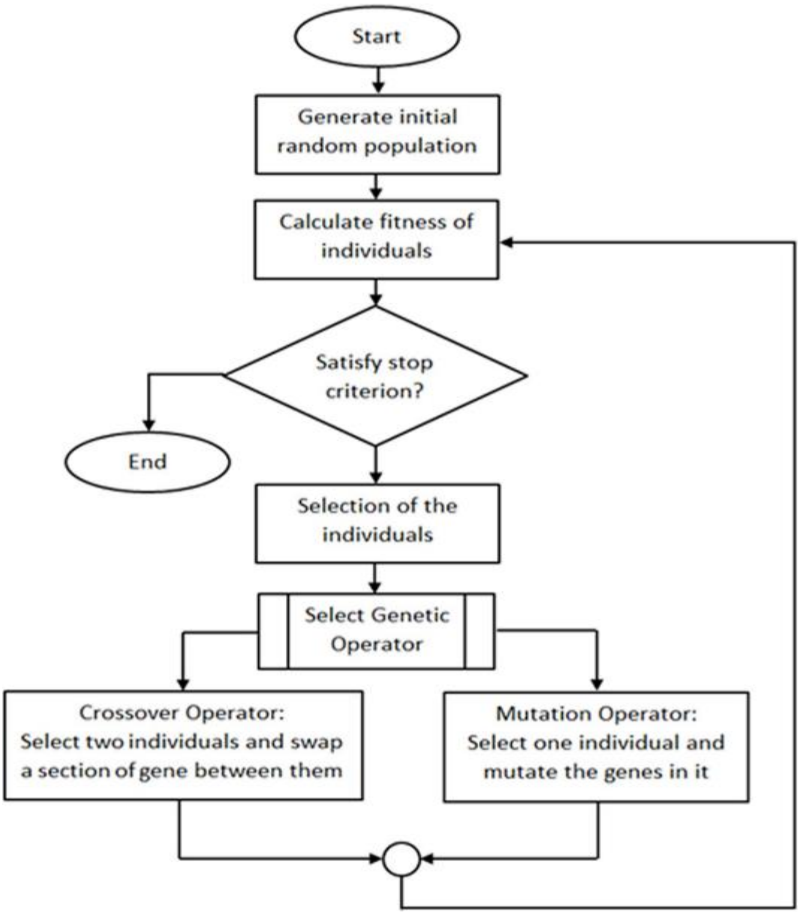

Figure 4: Genetic Algorithm Flowchart

Ball And Beam System Based on PID Controller

The overall open loop transfer function of the system is a fourth order system and it is difficult to design a controller to control a third order and higher order system. Thus, to make the controller design become easier and realizable, the whole system is separated into two feedbacks loops as shown in figure 4.2. The design strategy is to first tunning the parameters of the inner PID controller which will stabilize the inner loop then by the outer loop; the purpose of the inner loop is to control the motor angle position. Inner controller should be designed so that the motor angle tracks the reference signal. The outer loop uses the inner feedback loop to control the ball position. Therefore, the inner loop definitely must be designed before the outer loop.

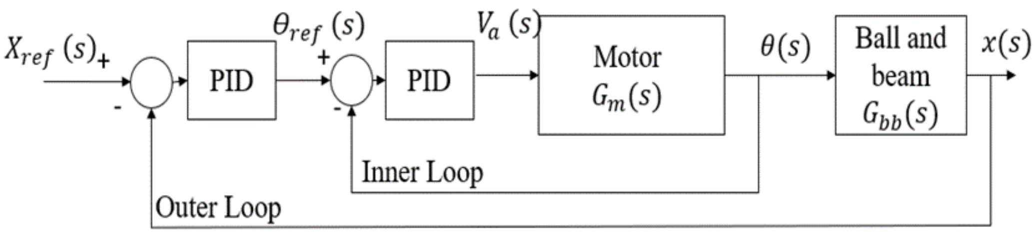

Figure 5: Block diagram of the ball and beam PID control system

1. PID Controller Tunning Parameters Using Trail-And-Error Method

The ball position response of PID controller tuned by trial-and-error method with model given in figure 5.6. The PID parameters (Kp = 8, Ki =3 and Kd = 1 for inner loop) and (Kp = 1, Ki =1 and Kd = 9 for outer loop). The figure shows that it takes around 6 second to settle the ball for given the input reference. This method for tuning PID controller produces 14.6% of overshoot, and zero steady state error.

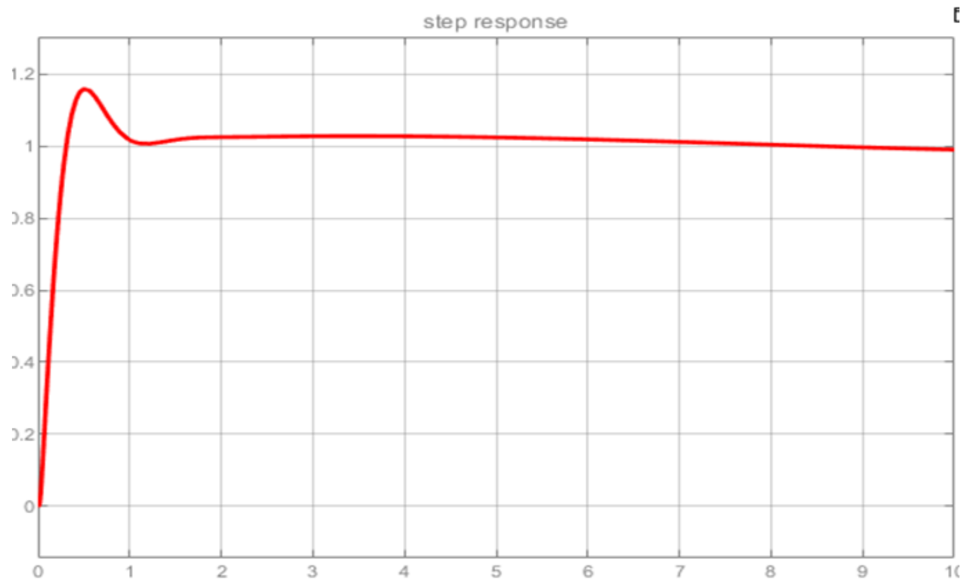

Figure 6: Final System Response with the PID parameters tuned by trial-and-error method

2. PID Tuning Parameters Using Particle Swarm Optimization

The ball position response of PID controller tuned by PSO algorithm method with simplified model, obtained with the help of MATLAB m-file code simulation is shown in figure 5.9. The PID parameters used in simulation are given in tables 5.4 and 5.5. The figure shows that it takes around 3.7 second to settle the ball for given the input reference. This method for tuning PID controller produces 3.67% of overshoot, and zero steady state error. Table 5.7 shows the output response's characteristic.

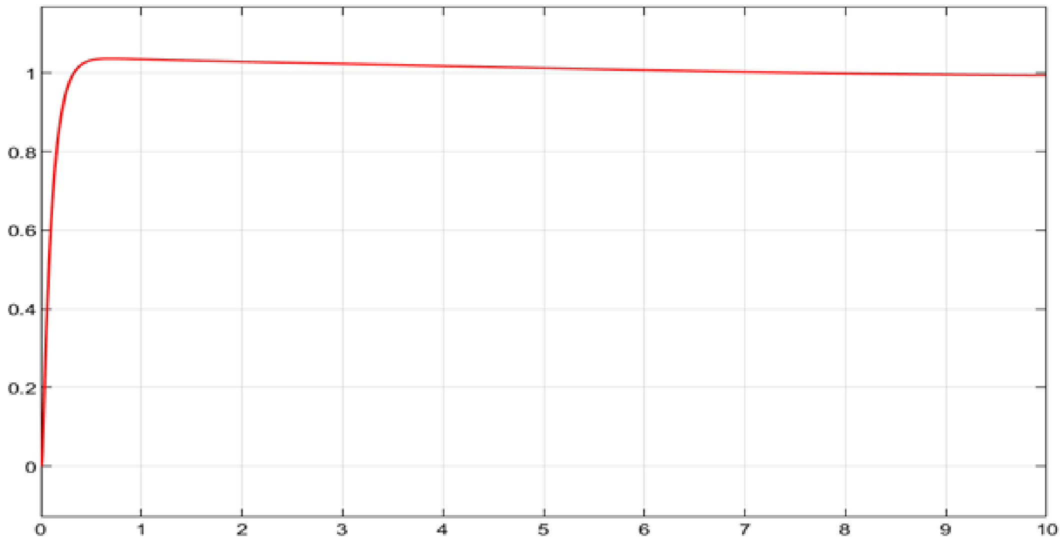

Figure 7: The step response of the system with the PID parameters tuned by PSO method

3. PID Controller Tunning Parameters Using Genetic Algorithm Method

the final result for ball and beam system after setting the parameters of both inner loop and outer loop is shown in the figure 6. This will test the degree that the system optimized. The graph 6 shows that it takes about 1.08 second to settle the ball for given input reference. And 0.225 sec rise time with 3.68% overshoot and steady state error 0.

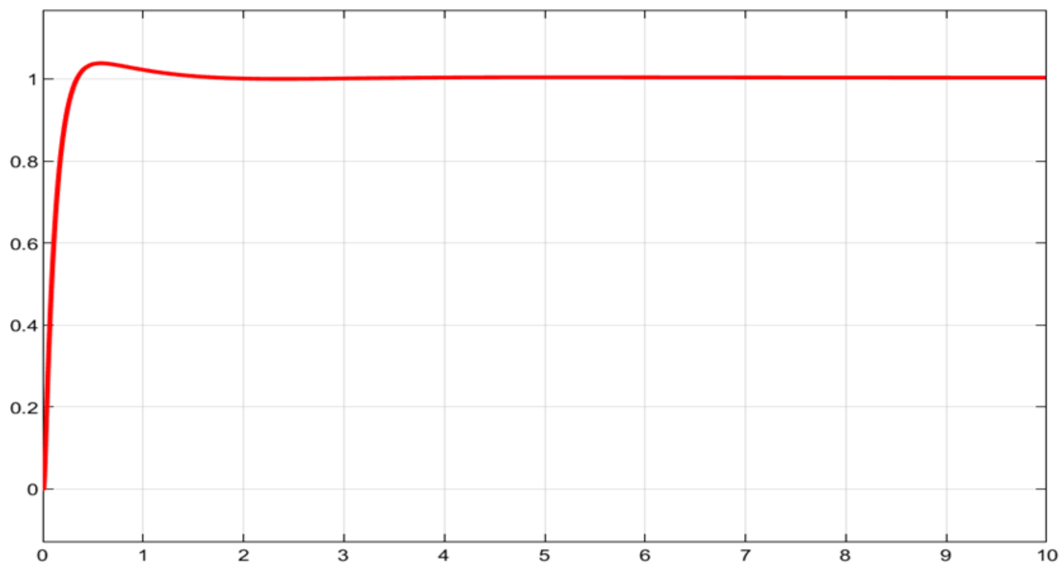

Figure 8: overall step response of the system with PID controller tunned by GA method

System Response for Set-Point Tracking

The setpoint tracking response of PID controller tuned by the GA algorithm method, PSO algorithm and Trial and Error method and, obtained with the help of MATLAB/Simulink. The block diagram in MATLAB/Simulink and setpoint tracking response are shown in figure 9.

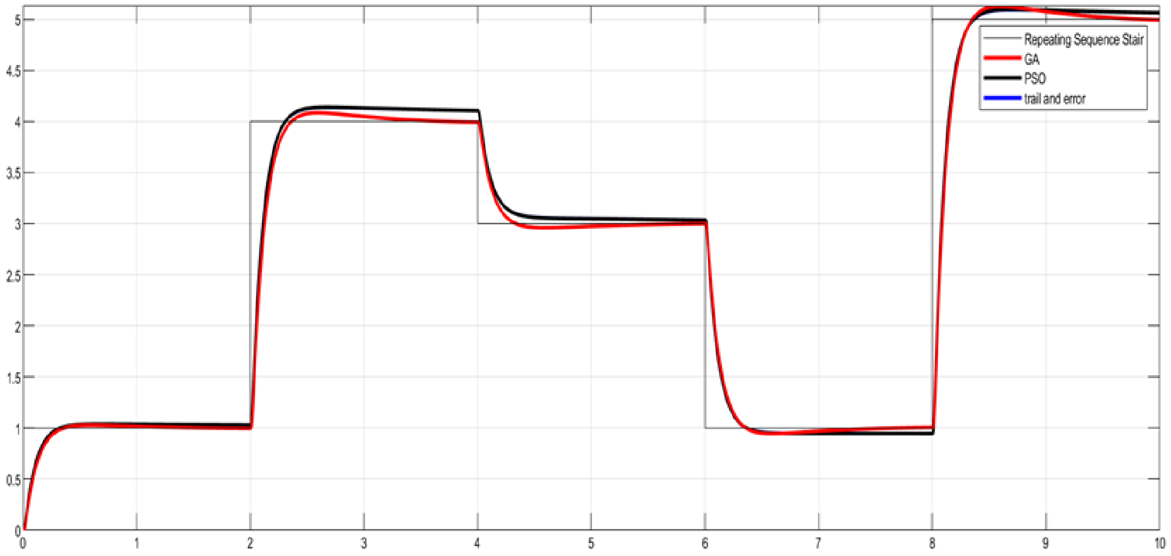

Figure 9: overall methods with step-tracking input signal

System Response with External Disturbance

The external disturbance is added to the system to study how much the system characteristics will change when the disturbance is applied on the system first the disturbance is applied when the input is step input with set point 1 then replacing the input with step change and test it to.

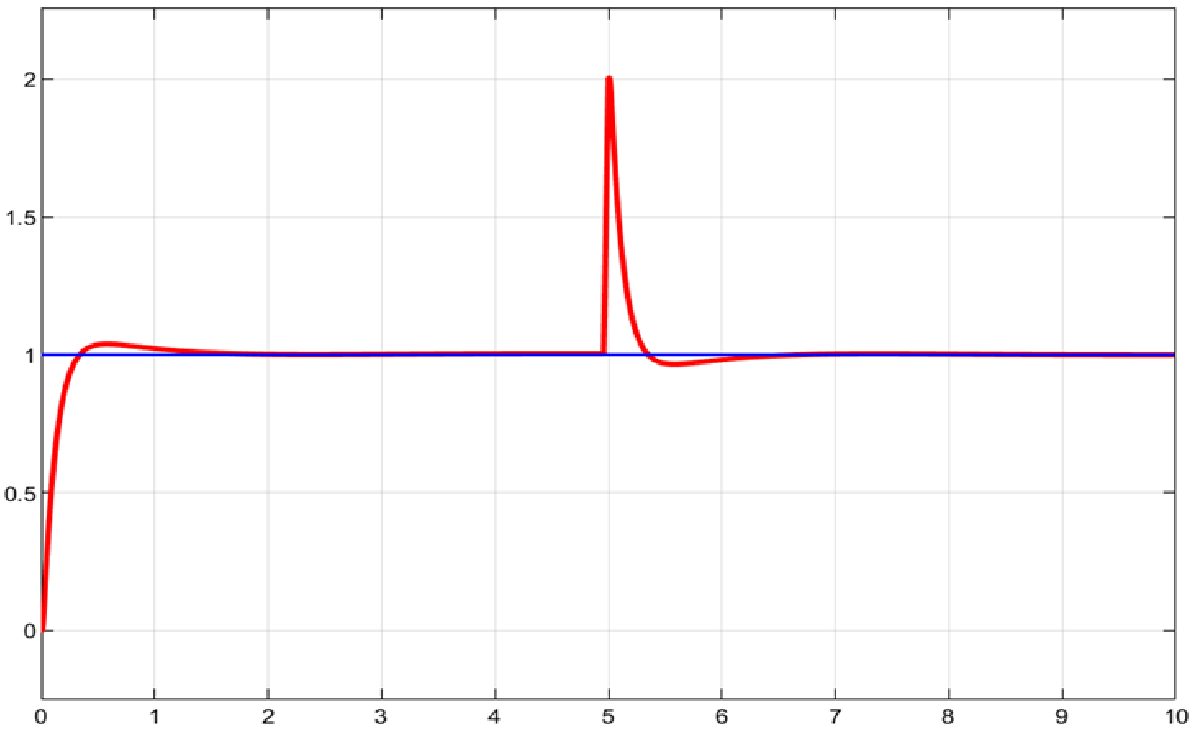

Figure 10: the effect of external disturbance with step input

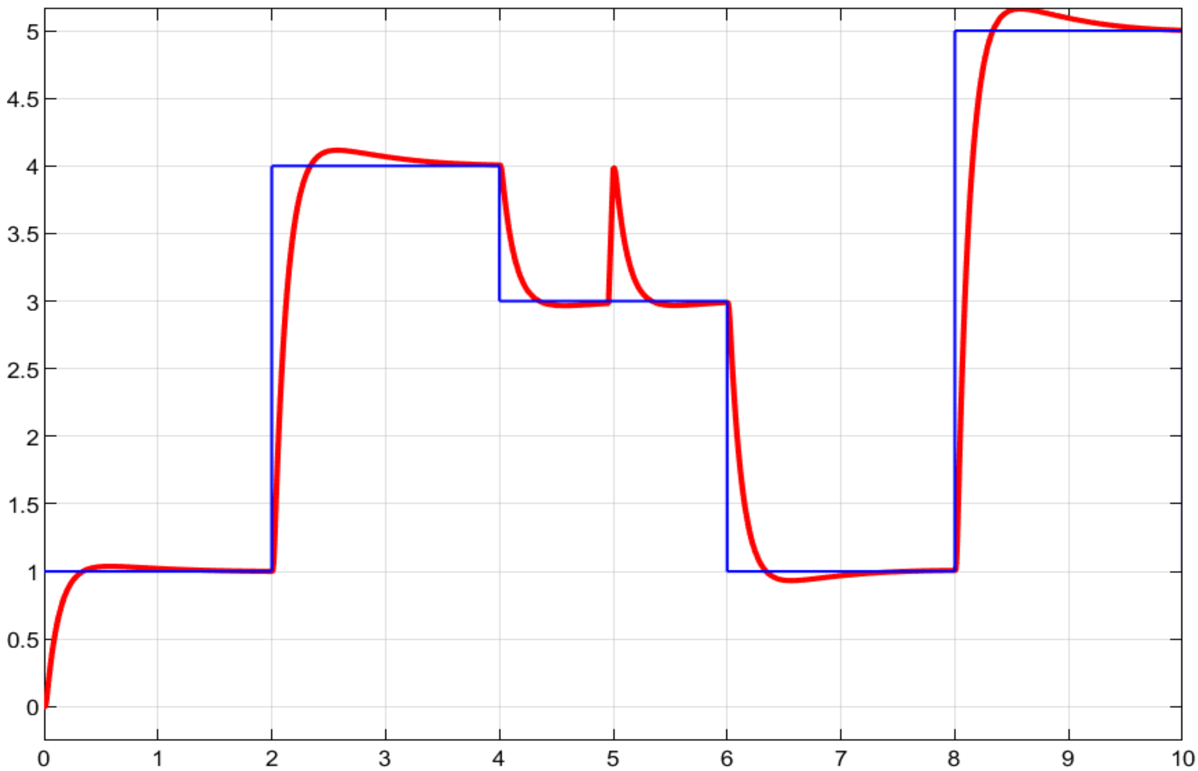

Figure 11: the effect of external disturbance with step change input

Results and discussion

The output responses of different tuning methods designed and simulated in m-file of MATLAB for tuning the parameters of the PID controller are compared. figure 7 and table 1 shows the comparison between genetic algorithm optimization, Particle Swarm Optimization and Trial and Error methods in response's characteristics. GA and PSO method give promising results better than the Trial-and-Error method; genetic algorithm gives settling time approximately 1 second whereas Practical Swarm Optimization gives 3.7 second and trial and error method gives 5.88 second. For the overshoot, the genetic algorithm and Practical Swarm Optimization gives approximately the same percentage about 3.68% and 3.67% respectively. All methods give the same steady state error value that means the final value is the same as the setpoint. Generally, the three methods give a stable system. the GA and PSO methods relatively better than trail-and-error method. GA method is better than PSO method to reach the settling time faster. Hance, the GA method performance is the best between the three methods.

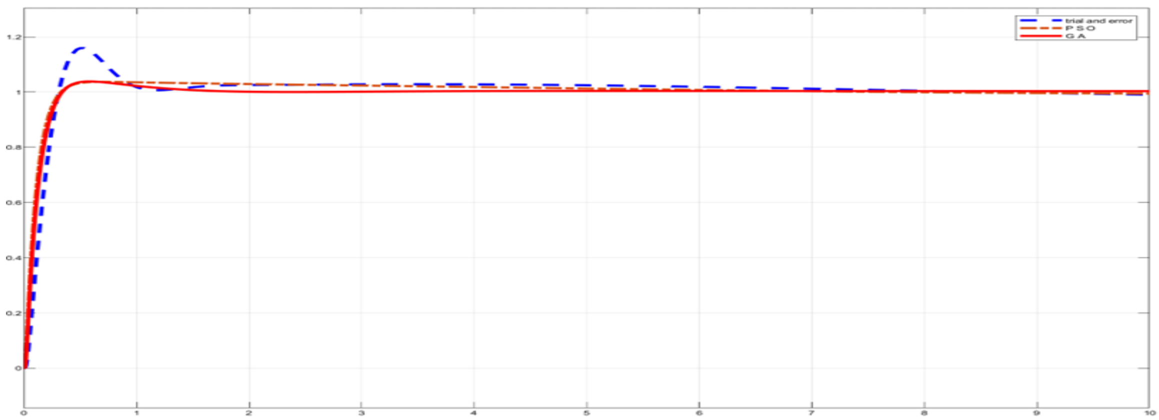

Figure 9: Final Comparison Between Different Tunning Methods

Table 2: final comparison between methods

Specification/method	Trail-and-error	PSO algorithm	GA algorithm
Settling time Ts	5.88 sec	3.7 sec	1.08 sec
Peak time Tp	0.534 sec	0.77 sec	1.04 sec
Overshoot OS%	14.6 %	3.67 %	3.68 %
Rise time Tr	0.235 sec	0.209 sec	0.225 sec
Steady state error ESS	0	0	0

Conclusion

In this research, the mathematical model for a ball and beam system has been presented. The genetic algorithm is used to optimize the PID parameters in which to perform high and accurate response. This optimization is enhancing the ball to balance at the particular position on the beam as prescribed the user. The efficiency of the genetic algorithm for tunning parameters have been compared with the PDO method and trial and error method. In the final results, the genetic algorithm and PSO gives a response a little better than the trial-and-error method. In the characteristic response, the PSO has achieved a peak time batter than GA while the overshoot is approximately the same. However, the GA produced a settling time far better than PSO. Generally, GA needs a little input information than PSO. But the PSO is faster in tunning the parameters due to the possibility of limiting the iteration number. Meanwhile, in GA the iteration number is automatically set. This will result a parameter that more accurate than PSO. Thus, the final conclusion is that the GA is considered to be the best optimization technique compared to the two other methods.

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