PID Parameter Optimisation using Genetic Algorithm for ball and beam system

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Abstract - *Almost half of the industrial processes world wide makes use of PID control for their processes. The most challenging part in designing PID controller is the control parameter tuning. The paper presents the tuning of PID parameters using Genetic Algorithm for the ball position control of ball and beam system. The parameters obtained are compared with those obtained from computational optimisation.*

Key Words: ***PID Tuning, Ball and Beam, Genetic Algorithm, Computational Optimization***

1. INTRODUCTION

Control engineering has witnessed the evolution of a number of control algorithms and strategies over the years. Still thousands of industries worldwide make use of PID controllers for their processes. Generally the PID controllers are applicable to most of the control systems especially when the mathematical model of the plant is not known [4]. The simple structure and ease of implementation makes it the most preferred one. One biggest challenge with the use of PID controller is the tuning of controller parameters. Tuning is the process of selecting the controller parameters so that the performance specifications are satisfied. Overtuned or undertuned controllers may not give the desired results. Performance of the entire control system is dependent on the control parameters. Several empirical and analytical tuning methods are used for parameter tuning. Zeigler Nichols, Cohen Coon methods fall in the first category and they are best suited for simple process models. Frequency response method, Root locus method [4] etc fall under the second category and these are suitable for tuning controllers for higher order systems.

The PID tuning problem still continues to be an area of active research. Evolutionary techniques like Genetic Algorithm, Particle Swarm Optimisation etc are widely used for solving optimisation problems. The paper presents Genetic Algorithm as an effective algorithm in tuning PID parameters.

The process under study is the position control of a ball and beam system. The ball and beam system is used extensively for demonstrating modern as well as classical control techniques. The system consists of a long beam mounted on the output shaft of a servomotor. A ball moves freely on top of the beam. The control problem is to regulate the position of the ball on the beam. Feedback control is required to achieve this as the system is unstable in open loop.

For comparative study PID tuning is also done using computational optimisation [4] method. The rest of the paper is organised as follows. Section 2 presents an overview of PID controller structure followed by a note on Genetic Algorithm. Section 4 presents plant modelling and Section V explains the tuning of PID parameters followed by simulation results and conclusion.

2. PID CONTROLLER

The general structure of a PID controller is as shown in Fig.1.

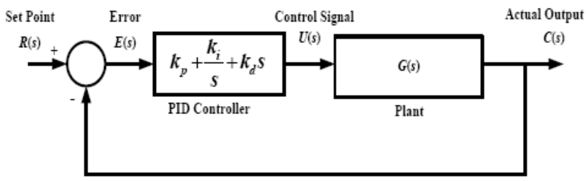

Fig -1: Structure of PID controller

The controller input is the difference between the process output and the setpoint. Suitably designed control parameters Kp, Ki and Kd acts on the error signal and generates the control signal [3].The control signal is then applied to the plant and new process output is generated. The process continues till steady state is reached. The controller transfer function is represented as $\frac{U(s)}{E(s)} = Kp + \frac{Ki}{s} + sKd$

3. GENETIC ALGORITHM

Genetic Algorithm (GA) is a stochastic evolutionary algorithm which is based on the principles and concepts of biological evolution[5]. It was first proposed by Holland.

Genetic Algorithm is found to be effective in solving complex optimization problems. The flowchart for the algorithm is shown in Fig.2. GA is initialised with a randomly generated population typically consisting of 20-100 individuals. Each individual that represents the PID parameters are encoded into binary strings. Length of the string depends on the precision required. The most important part in GA is the objective function. The performance of each individual is assessed by the objective function. Each individual is assigned a corresponding number called fitness value. This value forms the basis for the selection of individuals for reproduction. New generation of individuals are created using the operators selection, crossover and mutation.
Selection-Each chromosome or individual undergoes a selection process and the one with higher fitness values has more chances of getting selected.
Crossover-This is the basic operator that produces new chromosomes. The assumption is that the offspring will be superior to the parents if it takes the beast characteristics from both parents.

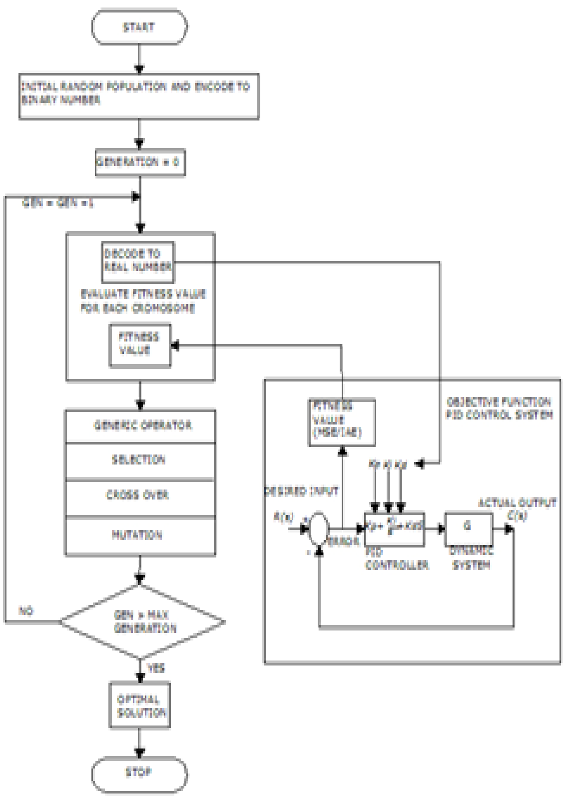

Fig -2: Flowchart for Genetic Algorithm

Mutation-This operator helps to maintain genetic diversity from one generation to the next. Mutation acts as a safety mechanism to recover good genetic material that may be lost due to crossover and selection.
One major drawback while optimising using Genetic Algorithm is the premature convergence of result. This happens when the diversity in the population is lost. Use of Elitism helps to maintain population diversity. The population size should also be selected appropriately.

4. MODELLING OF BALL AND BEAM SYSTEM

The Fig.3 shows the schematic representation of the ball and beam system. The system under study consists of a beam supported at one end. The other end is coupled to the output gear system which is driven by a DC Servomotor.

Modelling of ball and beam system is done by using Euler Lagrange equations. It is assumed that the ball rolls without slipping. The equations are obtained as follows.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\alpha}}\right)-\frac{\partial L}{\partial \alpha}=\tau \qquad (1)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right)-\frac{\partial L}{\partial x}=0 \qquad (2)$$

α – beam angle

x – position of ball on beam

$$\ddot{\alpha}\left(J_b+m_b x^2\right)+2m_b x\dot{x}\dot{\alpha}+m_b gxCos\alpha = \qquad (3)$$

$$\ddot{x}+\frac{5}{7}\left(gSin\alpha - x\left(\dot{\alpha}\right)^2\right)=0 \qquad (4)$$

The equation can be linearised around the operating point as,

$$\ddot{x}+\frac{5}{7}gSin\alpha=0 \qquad (5)$$

The motor gear angle and the beam angle can be related.

Equating the arc distances from Figure 3,

$$\alpha L_{beam}=\theta r_{arm} \qquad (6)$$

θ -servo angle

Rewriting (5) using (6) and taking Laplace Transforms, the ball and beam transfer function can be obtained as

$$\frac{X(s)}{\theta(s)}=\frac{0.4182}{s^2} \qquad (7)$$

The ball and beam system specifications are given in Table1.

Figure 3 shows the schematic diagram [6].

Table -1: Ball and Beam system specifications

	Parameter	Value
1.	Beam Length	0.4255m
2.	Distance between servo output gear shaft and coupled joint	0.0254m
3.	Radius of ball	0.0127m
4.	Mass of ball	0.064kg

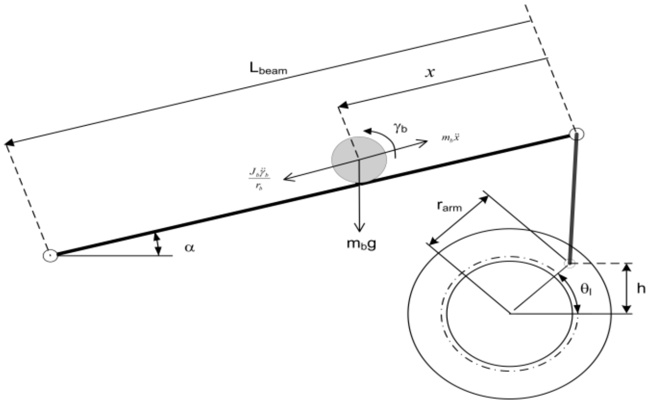

Fig -3 Schematic diagram of ball and system

5. TUNING OF PID CONTROLLER PARAMETERS

The ball and beam system is an open loop unstable system. Feedback control is required to bring the ball position to a desired one. The open loop response of the system is as shown in Figure 4. The paper presents a PID controller for the system with parameters tuned using computational optimization and Genetic Algorithm.

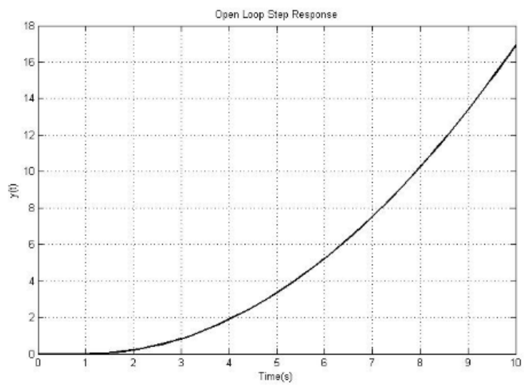

Fig -4: Open loop response of ball and beam system

5.1 Tuning with computational Optimisation

In computational optimization method of tuning, optimal sets of controller parameters are searched to satisfy the given transient specifications. From the obtained sets of parameter values, the best is chosen that satisfies the specifications. The PID parameters obtained using the method is shown in Table 2.

Table -2: Parameters from computational optimization

Kp	Ki	Kd
14.4	2.88	18

5.2 Tuning with Genetic Algorithm

GA is initialized with a random population consisting of 30 individuals. Number of iterations required is 120.The GA parameters used for tuning are given in Table 3.

Table -3: GA Parameters for tuning ball position controller

Parameter	Value
Population Size	20
Number of generations	250
Crossover	Arithmetic
Selection	Tournament
Mutation Rate	0.01
Crossover Fraction	0.8

The tuned controller parameters are as shown in Table 4.

Table -4: PID Parameters for ball and beam system from GA

Kp	Ki	Kd
9.1404	0.4553	16.1010

Simulation Results

A comparison of the ball position response using PID controller with GA tuned parameters and with those obtained from computational optimization is given in Fig.5. Simulation with GA tuned parameters clearly shows better performance with lesser overshoot and better settling time.

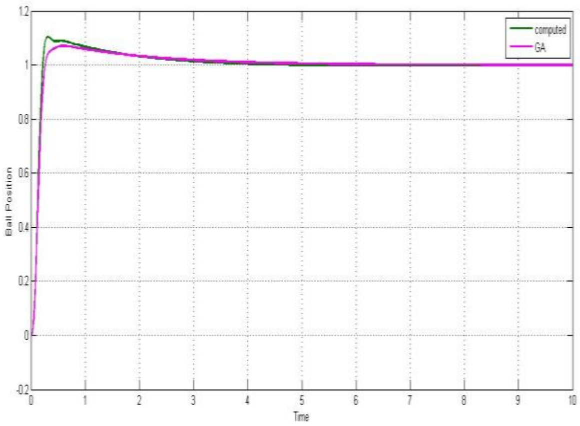

Fig -5: Comparison of ball position response with controller parameters tuned using GA and computational optimisation

A comparison of the transient response specifications with the two tuning methods are given in Table 5.Overshoot is very little with GA tuned PID controller. A reduction in settling time has also been achieved.

Table -5: Comparison of transient response specifications

	Settling Time(4%)	Max overshoot
Computational optimisation	1.7s	1.105
Genetic Algorithm	1.63s	1.069

6. CONCLUSION

PID controllers are the most commonly used controllers in industries worldwide due to their simple structure and realatively easier implementation. The paper presents Genetic Algorithm based tuning strategy for the ball and beam system. The tuning method succeeded in attaining a controller which reduces the system overshoot and improves settling time

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