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A Comparative Study of Genetic Algorithm and Particle Swarm Optimization based Optimizations of PID Controller Parameters

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Abstract— Proportional-Integral-Derivative (PID) control is the most commonly used algorithm for industrial control. The process of computing and setting the optimal gains for P, I and D to get an ideal response from a control system, called as tuning, is a very difficult task. In this paper, two types of nature inspired algorithms genetic algorithm (GA) and particle swarm optimization (PSO) techniques are used for optimizing the PID parameters. These techniques have been observed to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optima. Hard disk drive read/write head servo control system and DC motor control are used in the simulation study for depicting the efficacy of the proposed methods. PID controllers optimized using GA and PSO are observed to provide better time domain performance in comparison with conventionally used tuning method of Ziegler-Nichols.

Index Terms— Genetic Algorithm, Particle Swarm Optimization, Tuning of PID Controller, Ziegler-Nichols.

I. INTRODUCTION

Despite the popularity of PID controllers as the most practical controller for control engineers, reports shows that 30% of the installed PID controllers are operating in manual mode and 65% of the automatic controllers are poorly tuned [1]. The remaining 5% of the PID controllers are operating under default settings which means that these controllers are not tuned at all. These situations imply that tuning the PID controllers are the vexing problems to the control engineers. Most commonly used tuning methods are Ziegler-Nichols and Cohen-Coon methods and they have many inherent disadvantages.

This paper tries to provide an alternative approach for tuning the PID controllers. The nature inspired algorithms, especially genetic algorithm (GA) [2] and particle swarm optimisation (PSO) [3] discussed in this paper can generate a high quality solutions and stable convergence characteristics and they will provide the designers with the optimized PID parameters with less rules of tuning. A comparative study on the performances of GA and PSO tuned PID controller parameters, on the basis of application on simulated models of hard disk drive control and dc motor control, is presented in this paper. The GA tuned and PSO tuned PID controllers give better time response characteristics in comparison with PID controllers tuned with conventional methods.

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II. MATHEMATICAL MODELLING OF SYSTEMS

Hard disk drive control and armature controlled dc motor control systems are used to depict the efficacy of the GA and PSO based PID controllers.

A. Hard Disk Drive system

The objective of the disk drive reader device is to position the reader head accurately at the desired track and to move from one track to another within minimum time possible. A basic diagram of disk drive control is shown in Fig. 1 [4].

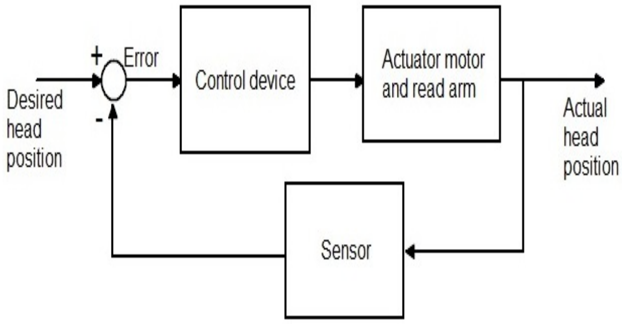

Fig. 1 Closed-Loop Control System for Hard Disk Drive

The variable to accurately control is the position of the reader head through actuator motor. The block diagram indicating the individual sections of the system with transfer functions is shown in Fig. 2. The typical parameters depicted in the figure along with their assumed values are listed in Table 1 [4]. It can be seen that the overall transfer function of the hard disk drive as [4]

$$G(s) = \frac{5000}{s(s+20)(s+1000)} \quad (1)$$

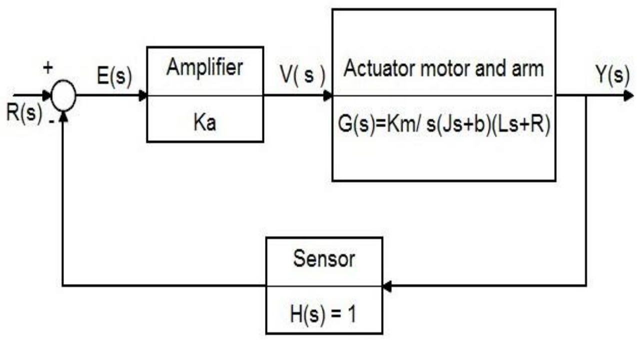

Fig. 2 Block Diagram Model of Hard Disk Drive System

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Table 1: Typical Parameters of Disk Drive Reader

Parameter	Value
Armature resistance (R)	1Ω
Motor constant (K_m)	5 N-m/A
Armature inductance (L)	1 mH
Inertia of arm and read head (J)	1 N-m.s^2/rad
Friction (b)	20 kg/m/s
Amplifier (K_a)	10 - 1000

A. Modelling of DC Motor

In armature controlled motor, the field current, I_f is held constant, and the armature current is controlled through the armature voltage, V. In this case, the motor torque increases linearly with the armature current [4]. The dynamic behavior of the DC motor is well described by the following equations;

$$V = R_a i_a + L\frac{di_a}{dt} + e_b \tag{2}$$

$$T_m = J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt} \tag{3}$$

$$T_m = K_b i(t) \tag{4}$$

$$e_b(t) = K_b\frac{d\theta(t)}{dt} \tag{5}$$

Where ia is the armature current, eb is the back e.m.f, Tm is the motor torque, and θ is the angular displacement. Typical parameters of the DC motor under consideration with their assumed values are listed in Table 2. The transfer function from the input armature voltage to the resulting angular position change can be obtained as [4]

$$\frac{\theta(s)}{V(s)} = \frac{K_b}{(JL_a S^3 + (R_a J + BL_a)S^2 + (K_b^{\,2} + R_a B)S} \tag{6}$$

The overall transfer function of the DC motor system is

$$\frac{\theta(s)}{V(s)} = \frac{1.2}{(0.00077S^3 + 0.0539S^2 + 1.441S} \tag{7}$$

Table 2: Typical Parameters of DC Motor

Parameters	Values
Armature resistance (R_a)	2.45 Ω
Armature inductance (L_a)	0.035 H
Inertia of rotor (J)	0.022 Kg-m ^{2} /rad
Viscous friction coefficient (B)	0.5*10^{-3} N-m/(rad/sec)
Back emf constant (K_b)	1.2 volt/(rad/sec)

III. TUNING PID CONTROLLER

It is a challenging task to obtain the optimum values of PID controller, suited for each plant. Of the various types of tuning rules reported in literature, one of the most preferred tuning method used in industries is Ziegler-Nichols technique.

A. Ziegler-Nichols Tuning Rule

Ziegler and Nichols proposed rules for determining the values of proportional gain Kp, integral time Ti and derivative time Td are based on the transient response characteristics of a given plant [5]. Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. These procedures are accepted as standard in control systems practice.

B. Genetic Algorithm based Tuning

Genetic Algorithms (GAs) are adaptive methods which may be used to solve search and optimization problems [2, 6]. It is one of the modern heuristic algorithms based on a principle of Darwinian theory of evolution. Genetic algorithms use biologically inspired mechanisms and survival of the fittest theory in order to refine a set of solution iteratively. GAs belongs to the class of probabilistic algorithms, but they are very different from random algorithms as they combine elements of directed and stochastic search. Because of this, GAs is also more robust than directed search methods. Another important property of such genetic based search methods is that they maintain a population of potential solutions. A block diagram showing the different steps involved in the optimization process using GA is given in Fig. 4. Main steps involved are selection, crossover, mutation and evaluation.

C. Particle Swarm Optimization based Tuning

Particle swarm optimization (PSO) is a population based search optimization technique inspired by the social behavior of bird flocking or fish schooling. The PSO algorithm works by simultaneously maintaining several candidate solutions in the search space [3, 7-8]. During each iteration, the candidate solution is evaluated by the objective function to determine the fitness of that solution. It uses the fitness function to evaluate its candidate solutions.

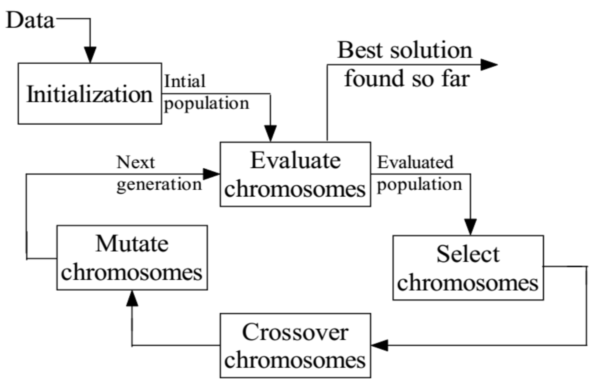

Fig. 4 Optimization using GA

The PSO algorithm mainly consists of three steps:

1. Evaluating the fitness of each particle.
2. Updating individual and global best fitness and positions.
3. Updating velocity and position of each particle.

These steps are repeated until some stopping conditions are met such as maximum number of iterations or a predefined fitness value. The optimization ability of the PSO algorithm is caused by the velocity and position update step. The velocity of each particle in the

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swarm is updated by using the following equation;

$$v_i(t+1) = wv_i(t) + c_1 r_1 \left[\overline{x_i}(t) - x_i(t) \right] + c_2 r_2 \left[g(t) - x_i(t) \right] \tag{8}$$

The index of the particle is represented by i. Thus, $v_i(t)$ is the velocity of particle, i at time t and $x_i(t)$ is the position of particle i at time t. The parameters w, c_1, and c_2 ($0 \leq w \leq 1.2, 0 \leq c_1, c_2 \leq 2$) are user-supplied coefficients. The values r_1 and r_2 ($0 \leq r_1, r_2 \leq 1$) are random values regenerated for each velocity update. The value $\overline{x_i}(t)$ is the individual best candidate solution and $g(t)$ is the swarm's global best candidate solution. Once the velocity for each particle is updated, position of each particle is updated by applying the new velocity to the particle's previous position:

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{9}$$

IV. RESULTS

In this paper, GA and PSO have been used to obtain the optimized P, I, D values for effective control of two plants, as shown in Fig. 5. An objective function or fitness function is required to evaluate the best PID controller for the system. Any function that would be a measure of proper control of the system can be used as an objective function. In this paper, mean of the squared error (MSE), as given in (10), is selected as the objective function.

$$MSE = \frac{1}{t} \int_0^{\tau} \left(e(t) \right)^2 dt \tag{10}$$

where *e(t)* is the error signal in time domain.

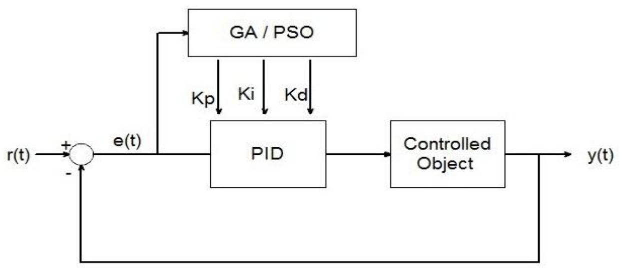

Fig. 5 Optimization of PID Controller based on GA/PSO

Genetic algorithm and particle swarm optimization techniques were applied for optimisation of PID values with parameters shown in Tables 2 and 3 respectively. These parameters are observed to give the best results. It was observed that both the optimisation procedures converge within reasonable time and yield good results.

Table 3: GA Parameters used in Simulation

GA property	Value/method
Fitness function	Mean squared error
Population size	50
Maximum no. of generations	300
Selection	Roulette wheel
Crossover	Multipoint
Mutation	Uniform

Table 4: PSO Parameters used in Simulation

PSO property	Value/method
Objective function	Mean squared error
Population size	50
Maximum no. of generations	100
Cognitive Attraction	.4
Social Attraction	1.2

Optimum PID values are computed manually with Ziegler-Nichols (Z-N) method. Unit step response of the hard disk drive read system using the PID controller tuned with Z-N method is shown in Fig. 6. Unit step responses of the same system with GA and PSO tuned PID controllers [9 – 10] is shown in Fig. 7 and Fig. 8 respectively. The unit step responses of the dc motor system using the PID controllers tuned with Z-N, GA and PSO method are compared in Fig. 9.

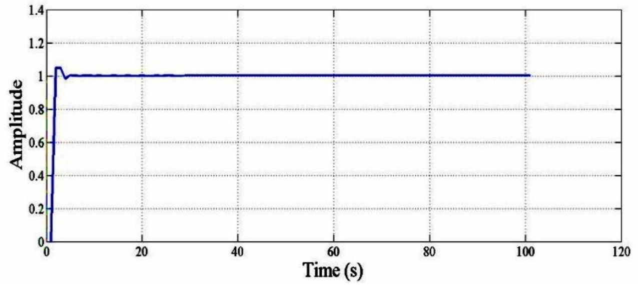

Fig. 6 Unit Step Response with Z-N Tuned PID Controller for Hard Disk Drive Control

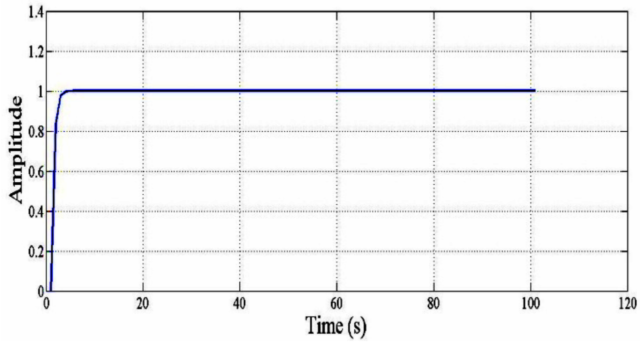

Fig. 7 Unit Step Response with GA based PID Controller for Hard Disk Drive Control

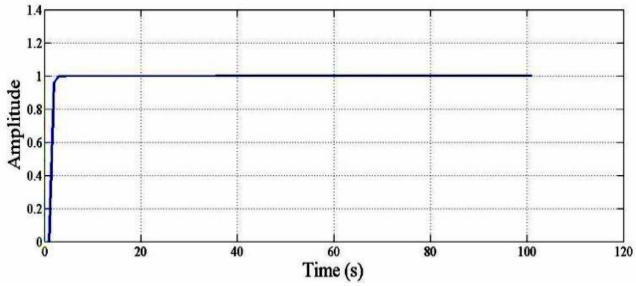

Fig. 8 Unit Step Response with PSO based PID Controller for Hard Disk Drive Control

From the comparison of the step responses of both the plants, it is observed that GA based and PSO based PID controllers yields much better results in comparison with Z-N based PID controller. Performances of these three methods are depicted using performance measures such as rise time, settling time, and maximum overshoot in Table 5. Although GA and PSO based method has deteriorated in terms of rise time, it has a much better performance considering settling time and maximum overshoot.

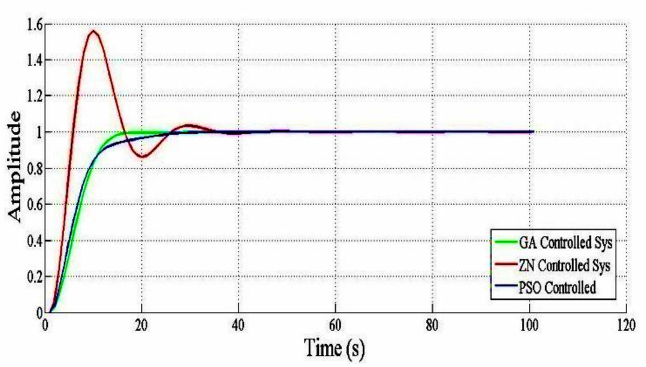

Fig. 9 Comparative Unit Step Responses with Z-N, GA and PSO based PID Controller for a DC Motor

Table 5: Comparison of PID Controller Responses

PLANT	Tuning method	Rise time(s)	Settling time(s)	Maximum overshoot (%)
HDD	Z-N	0.076	0.2427	4.8
	GA	0.075	0.0975	0.5
	PSO	0.08	0.0981	0.0063
DC MOTOR	Z-N	0.0329	0.8601	56
	GA	0.085	0.1386	0.46
	PSO	0.0935	0.2244	0.011

V. CONCLUSIONS

Effectiveness of nature inspired algorithms, genetic algorithm and particle swarm optimization in tuning PID controllers is demonstrated. GA based and PSO based PID controllers are designed for hard disk drive and DC motor systems. As per performance criteria computed from unit step responses, the proposed controllers show better characteristics than the most popular classical tuning method of Ziegler-Nichols rule.

REFERENCES

[1] D. B. Ender, "Process control performance not as good as you think", control engineering, 40 (10), 1993, pp. 173-186.

[2] D. E. Goldberg, "*Genetic Algorithms in Search, Optimization, and Machine Learning*", MA: Addison-Wesley, 1989.

[3] R. C. Eberhart, Y. Shi, "Particle swarm optimization: developments, applications and resources," *Proc. 2001 Congress on Evolutionary Computation*, 2001, 81-86.

[4] R. C. Dorf and R. H. Bishop, *Modern Control Systems*, 10^{th} ed., 2004, Upper Saddle River, NJ: Pearson Education.

[5] K. J. Astrom and T. Hagglund, "*Automatic Tuning of PID Controllers*", Instrument Society of America, North Carolina, USA, 1988.

[6] N. Thomas and P. Poongodi, "Position Control of DC Motor using Genetic Algorithm Based PID Controller," *Proc. World Congress on Eng.*, vol II, WCE 2009, London, U.K.

[7] J. Kennedy and R. C. Eberhart, "Particle Swarm Optimization", *IEEE International Conf. on Neural Networks*, 1995, pp.1942-1948.

[8] Z. Gaing, "A particle swarm optimization approach for optimum design of PID controller in AVR system," *IEEE trans. energy conversion*, Nov. 2002

[9] GAOT - A Genetic algorithm Optimization Toolbox for use with MATLAB, *http://www.daimi.au.dk/~pmn/Matlab/dochome/toolbox/GAOT/gaotindex.html*

[10] PSOT - a Particle Swarm Optimization Toolbox for use with MATLAB, *http://www.mathworks.com/matlabcentral/fileexchange/7506-particle-swarm-optimization-toolbox*

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