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Design of Intelligent PID Controller using Particle Swarm Optimization with Different Performance Indices

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Abstract— PID control scheme is still providing simple and effective solutions to the many control engineering problems. Today many real world problems are nonlinear and time varying, control of such problems are very difficult with the conventional designed PID controller. This paper presents a new designing technique of PID controller, which can effectively control the nonlinear optimization problems. The technique which has been introduced in this research is particle swarm optimization. It is population based stochastic optimization algorithm derived from human behavior and animal behavior as well. Conventional gain tuning schemes such as Ziegler Nichols method usually produces big overshoot therefore modern approach has been used in this paper to tune the parameters of PID controller. For designing of PID controller different performance indices have been used here for different plant transfer functions.

Index Terms—Fitness function, Particle Swarm Optimization, PSO parameters, PID tuning, Social behavior,Time varying inertia weight, Ziegler NicholsTuning method.

1 Introduction

PID control is the most ancient and the strongest control method in process industries. With the advancement in technology control systems are becoming more and more complex day by day. Conventional PID control is not able to solve such complex problems. In recent years many intelligent controllers have been introduced such as fuzzy PID controller, neural network and so on. The intelligent PID controllers having the properties such as self adaptability, self learning ability and self organization are able to control complex systems [11].

PID controller is widely used in industrial control systems. PID controller calculates the error between set point value and measured response. The objective of PID controller is to minimize the generating error. PID controller calculation involves three terms proportional, derivative and integral [12]. The purpose of proportional term is to determine the reaction of current error, integrating term determines the reaction of sum of current error and derivative term determines the rate of error generating. The objective of PID controller tuning is to design such a controller which meet the desired closed loop performance. A PID controller improves the transient response of the system by reducing the overshoot in the step response, and by reducing the settling and rise time. Standard methods of PID tuning involve Ziegler Nichols [4], Cohen-coon's [6], Astrom and Hagglund [5] and many other techniques. This paper presents soft computing technique for designing an intelligent PID controller.

Particle swarm optimization has been used here for the tuning of PID controller. PSO is a population based stochastic optimization algorithm which is first proposed by Eberhart and Kennedy in 1995 [3]. This technique is derived from research on biological organism such as bird flocking and fish schooling. Craig Reynolds (1987) [1] showed that flock is simply the result of the interaction between the behaviours of individual birds. To simulate a flock we simulate the behaviour of an individual bird. He concluded that to build a simulated bird flock model following three simple rules must be followed: Velocity Matching, centring of bird flock and avoid collisions. Work of Kennedy and Eberhart was influenced by Heppner and Grenander's (1990) work on simulated behaviour of bird [2].

This section presents introduction about PID controller and proposed scheme of PID tuning, section II presents model of the plant, section III contains model intelligent PID controller, section IV presents particle swarm optimization, section V contains PSO based controller, section VI presents simulation results and comparison and finally section VII contains coclusion.

2 Problem Formulation

Three plants have been used here for the study. Mathematical model of plants are:

1) Mathematical model of DC shunt motor is given by [12]:

$$G_1(s) = \frac{Y(s)}{U(s)} = \frac{0.01}{0.005s^2+0.006s+0.1001} \quad (1)$$

2) Mathematical model of electric DC motor is [13]

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$$G_2(s) = \frac{0.9}{0.00105s^3 + 0.2104s^2 + 0.8913s} \quad (2)$$

3) Mathematical model of time delayed process[14]

$$G_3(s) = \frac{e^{-1s}}{(s+1)} \quad (3)$$

3 DESIGN OF INTELLIGENT PID CONTROLLER

Objective of tuning method is to find a set of controller parameters which gives better results. They provide a control signal which is given by:

$$u(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \quad (4)$$

where 'e' is the error, k_p, k_i and k_d are controller parameters,

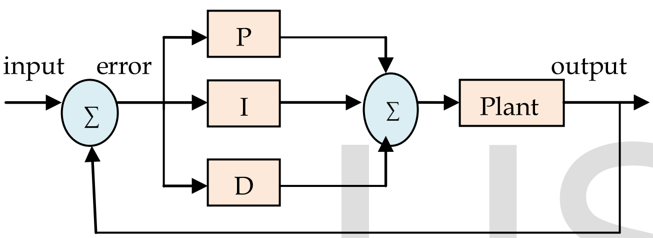

Fig.1. Block diagram of PID controller

and 'u' is controller output. Block diagram of PID controller is shown in fig.1. and block diagram of Intelligent PID controller is shown in fig.2.

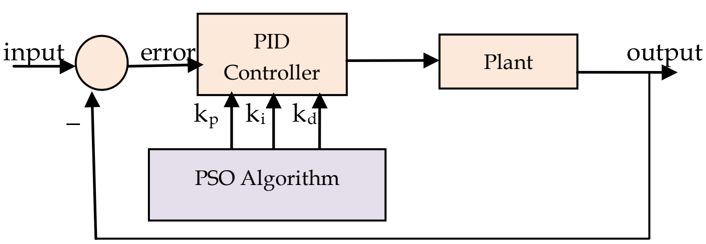

Fig.2. Block diagram of Intelligent PID controller

The objective of PID controller is to adjust parameters like that system perform better in the wide range of operating conditions. PID controller improves the transient as well as steady state response of the system. PSO tuned PID controller is shown in fig.2 in which parameters are adjusted by PSO algorithm [11].

4 PARTICLE SWARM OPTIMIZATION: BASIC CONCEPTS

In 1995 James Kennedy and Russel Eberhart [3] proposed first simulation which was influenced by Heppner and Grenander's (1990) work on simulated behaviour of bird [2].

In PSO a number of particles are placed in the search space of some problem. Each particle in the swarm evaluates the objective function at its current location. Each particle then move through the search space according to the history of its own current and best location of neighbourhood in the swarm on each iteration. The next iteration takes place after all particles have been moved. In PSO swarm moves like a bird flock searching for food. Each individual in the swarm is composed of three d-dimensional vectors, where d is the dimension of the search space. Three vectors are the current position x_i, the previous best position p_i, and the velocity v_i [9].
The PSO algorithm based on the concept that individual member refine their knowledge about the search space by social interaction. In PSO each member is called particle and population is called swarm. The term 'swarm' means irregular movement of particles.

Particle swarm optimization is a member of swarm intelligence family it has some advantages over other intelligent optimization techniques [10]:

1) It is simple to implement
2) There are fewer parameters to adjust
3) It has more effective memory capability
4) It uses a relatively small population
5) It is fast
6) PSO is more effective in maintaining diversity of swarm and lead to fast convergence

These advantages have given it popularity to solve nonlinear optimization problems in the field of evolutionary computation. PSO have been successfully applied in many areas of system design, system modeling, system identification, signal processing, pattern recognition, robotic applications. The algorithm of PSO include following steps [8]:

1) Initialize the swarm by assigning random position and velocity to each particle.
2) Evaluate fitness function for each particle.
3) Compare the current fitness value with the pbest value of the particle in history.
4) If current fitness value is better than the previous best value (pbest), then set this value as current pbest.
5) Now best evaluated value of pbest is set as gbest value.
6) Update the velocity and position of the particles according to the equation (5) and (6).
7) Repeat the steps 2 to 6 until sufficiently good stopping criterion is met such as maximum number of iterations or best fitness value.

Update in particle's velocities and positions are given by following equations:

$$v_{n,d}^{k+1} = w * v_{n,d}^{k} + c1 * r1 * \left(pbest_{n,d} - x_{n,d}^{k}\right) + c2 * r2 * \left(gbest_d - x_{n,d}^{k}\right) \quad (5)$$

$$x_{n,d}^{k+1} = x_{n,d}^{k} + v_{n,d}^{k+1} \quad (6)$$

n=1,2,.....,N , d=1,2,........,D and k=1,2,.....,T

where,

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N	Number of particles
D	Dimension of the problem space
T	Maximum number of iterations
$v_{n,d}^{k+1}$	Velocity of n^{th} particle with dimension d at iteration k+1
if	$v_{i,j}^{(k)} > v_{max}$ then $v_{i,j}^{(k)} = v_{max}$
else if	$v_{i,j}^{(k)} < -v_{max}$ then $v_{i,j}^{(k)} = -v_{max}$
$x_{n,d}^{k}$	Current position of n^{th} particle with dimension
c1,c2	Acceleration factors
r1,r2	Random numbers between [0,1]
$pbest_{n,d}$	Personal best value of n^{th} particle with dimension d
$gbest_{n,d}$	Global best value of swarm
w	Inertia weight

Most of the PSO strategies use time varying inertia weight. This inertia weight may be linear or nonlinear and increasing or decreasing in nature.
Shi and R. Eberhart proposed a new method in 1998 [7]. In this method the value of 'w' starting with the value greater than 1 and decreasing eventually to a value less than 1 so later on it was kept linear from 0.9 to 0.4.Inertia weight 'w' is given by:

$$w(iter) = w_{max} - \left(\frac{w_{max} - w_{min}}{itermax}\right) * iter \quad (7)$$

where $w_{max} = 0.9$ and $w_{min} = 0.4$

5 PSO BASED PID CONTROLLER DESIGN

To design PID controller with PSO some parameters and fitness function are required:

5.1 PSO parameters

Particle swarm optimization algorithm is population based technique so first of all we have to produce initial swarm of particles in search space represented by a matrix of dimension swarm size x 3. Three parameters are there to be tuned where their values are set in the range of 0 to 100. For this three dimensional problem position and velocity are represented by matrices of dimension swarm size x 3. Swarm size is the number of particles, 30 is considered here for the problem. Maximum number of iterations 25 has been used here. However more number of iterations produce better results but for study and comparison between different performance indices 25 iterations have been used in this paper.

5.2 Fitness function

The objective function which has been used here is error criteria. Performance of controller is based on error criterion or performance index. Commonly employed performance indices are [15]:

1) Integral of Absolute Errors, given by

$$J_{IAE} = \int_0^\infty |e(t)|dt \quad (8)$$

2) Integral of Squared Errors, given by

$$J_{ISE} = \int_0^\infty e^2(t)dt \quad (9)$$

3) Integral of Time multiplied by Absolute Errors

$$J_{ITAE} = \int_0^\infty t|e(t)|dt \quad (10)$$

6 STUDY OF SIMULATION RESULTS AND COMPARISON

Simulation results of proposed tuning method for different performance indices in time domain are showm in table 1, 2 and table 3.

TABLE 1
TIME DOMAIN PERFORMANCE SPECIFICATIONS FOR PLANT 1

	Peak Overshoot(%)	Rrise time(sec)	settling time(sec)	PI
ITAE	0	0.22	0.39	0.01046
IAE	2.02	0.03	1.15	0.05948
ISE	0.58	0.008	0.013	0.00585

TABLE 2
TIME DOMAIN PERFORMANCE SPECIFICATIONS FOR PLANT 2

	Peak Overshoot(%)	Rrise time(sec)	settling time(sec)	PI
ITAE	5.63	0.02	0.348	0.00656
IAE	28.3	0.008	0.067	0.01916
ISE	37.2	0.007	0.075	0.0072

TABLE 3
TIME DOMAIN PERFORMANCE SPECIFICATIONS FOR PLANT 3

	Peak Overshoot(%)	Rrise time(sec)	settling time(sec)	PI
ITAE	9.12	0.741	3.62	1.082
IAE	2.518e+028	0.00302	104	83.57
ISE	29.3	0.496	6.02	1.07

Comparison of different performance indices for plant 1, plant 2 and plant 3 are shown in fig3, fig 4 and fig 5. From the results we can see that integral time of absolute error performnace criterion gives better results than other performance criterion. It produces less overshoot in all the three case and optimum value is achieved by it.

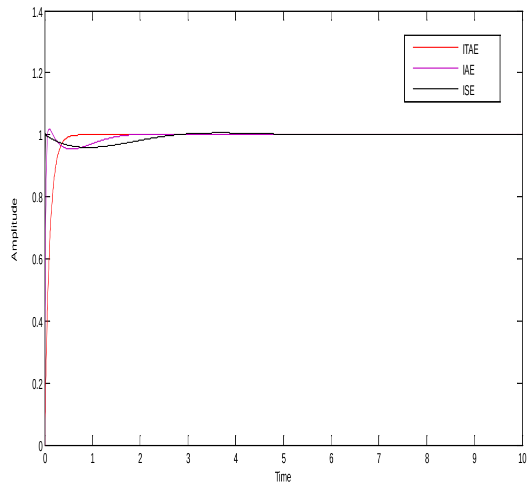

Fig.3. Comparison of different performance indices for plant 1

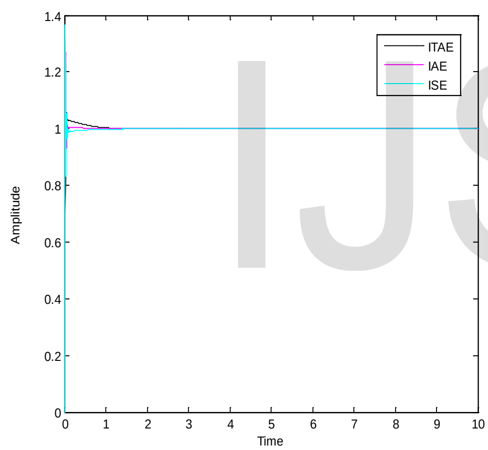

Fig.4. comparison of different performance indices for plant 3

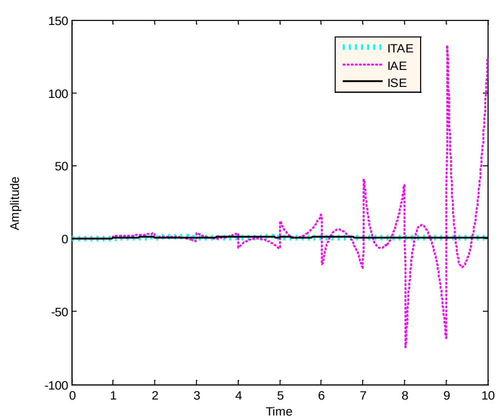

Fig.5. comparison of different performance indices for plant 3

7 CONCLUSION

A new optimization technique has been implemented here on three different plant transfer functions for obtaining the step response of systems for different performance indices. From the results obtained, it is clear that integral time of absolute error gives good results in time domain compare to other performance indices. It does not give big overshoot and also give less settling time and less rise time.

REFERENCES

[1] C.W. Reynolds, "Flocks, herds and schools: a distributed behavioral model", Computer Graphics, 21(4), p.25-34, 1987.

[2] Heppner and Grenander, "A stochastic nonlinear model for coordinated bird flocks", In S. Krasner, Ed., The Ubiquity of Chaos. AAAS Publications, Washington, DC, 1990.

[3] J. Kennedy and R.C.Eberhart, "Particle swarm optimization," in Proceedings of the IEEE International Conference on Neural Networks, vol. 4, pp. 1942–1948, Dec 1995.

[4] Ziegler, G. and Nichols, N. B "Optimum settings for automatic controllers", Trans. ASME, 64,759-768, 1942..

[5] Astrom, K J.;.Hagglund .T, "Automatic tuning of simple regulators with specifications on phase and amplitude margins", Automatica, 20,645-651, 1984.

[6] G.H Cohen and G.A Coon, "Theoretical Consideration of Retarded Contro", Trans ASME 75,pp.827/834,(1953).

[7] Y.Shi and R.Eberhart, "A modified particle swarm optimizer", in Proc. IEEE World Congr. Comput. Intell, pp. 69-73, 1998.

[8] Yamille del Valle, Ganesh Kumar Venayagamoorthy,Salman Mohagheghi, Jean-Carlos Hernandez and Ronald G. Harley, "Particle swarm optimization:Basic concepts,Variants and Applications in power systems", IEEE Transaction on Evolutionary Computation,Vol. 12, No. 2, April 2008.

[9] F. van den Bergh, "An Analysis of Particle Swarm Optimizaers", PhD thesis, Department of Computer Science, University of Pretoria, South Africa 2002.

[10] R. Mendes .Population Topologies and Their Influence in Particle Swarm Performance. PhD thesis, Escola de Engenharia, Universidade do Minho, 2004.

[11] Liguo Qu, Yourui Huang, and Liuyi Ling, "Design of Intelligent PID Controller Based on Adaptive Genetic Algorithm and Implementation of FPGA", F. Sun et al. (Eds.): ISNN 2008, Part II, LNCS 5264, pp. 542–551, 2008.

[12] Mehdi Ghazavi Dozein, "Speed Control of DC Motor using Different Optimization Techniques based PID Controller", Journal of Applied Scientific Research. 2(7) 6488-6494, 2012.

[13] B. Nagraj, S. Subha, and B. Rampriya, "Tuning algorithm for PID controller using soft comuting techniques", IJCSNS International journal of computer science and network security, Vol.8, No. 4, April 2008.

[14] Dan Chen and Dale E.Seborg, "PI/PID controller design based on direct sysnthesis and disturbance rejection", Ind. Eng. Chem. Res., Vol. 41, No. 19, 2002.

[15] S. M. Giriraj Kumar, Deepak Jayaraj, Anoop. R. Kishan, "PSO based tuning of a PID controller for a high performance drilling machine", International Journal of Computer Applications(0975-8887), Volume 1, No. 19, 2010.