Optimal Tuning of PID Controller Using Meta Heuristic Approach

Meenakshi Kishnani[1], Shubham Pareek[2] and Dr. Rajeev Gupta[3]

[1]*Department of Electronics, University College of Engineering,*
RTU, KOTA, Rajasthan, India
[2]*Department of Electronics, University College of Engineering,*
RTU, KOTA, Rajasthan, India
[3]*Professor, Department of Electronics, (UCE), RTU, KOTA, Rajasthan, India*
E-mail: [1]meenakshi__18@hotmail.com, [2]pareek.shubhamengg2011@gmail.com
[3]rajeev_eck@yahoo.com

Abstract

PID controllers have become very popular among the control engineers for its robustness, cost-effectiveness and simple structure. But tuning the PID parameters could be a complex task in some systems. Hence, several conventional and intelligent algorithms have been proposed to achieve the desired specification .Among the intelligent algorithms, widely popular and accepted algorithms are metaheuristic algorithms. In this paper, we have introduced three such algorithms i.e. GA (Genetic Algorithm), PSO (Particle Swarm Optimization) and SA (Simulated Annealing).These algorithms are used to set the parameters for PID controller for the dc motor plant .Performance of the controller is compared for these algorithms with the conventional method and it is shown that these meta-heuristic algorithms have each proven to be an efficient optimization algorithm.

Keywords: PID controller, DC MOTOR, Genetic Algorithm, Particle Swarm Optimization, Simulated Annealing.

1. Introduction

Proportional-Integral-Derivative (PID) controller is one of the earliest control techniques that is still used widely in industries because of its easy implementation, robust performance, simple construction and cost effectiveness. PID controller can be

tuned with conventional and intelligent methods. Conventional methods such as Ziegler and Nichols [2] and Simplex method can tune the optimal PID parameters for only linear and stable systems. Moreover, they tend to produce big surge and large overshoot. The main drawback of this tuning method is that it is limited merely to certain operational zones and has an unsatisfactory design robustness property. Intelligent methods include meta-heuristic algorithms, fuzzy logic etc. This paper proposes to tune the parameters of PID with three of the intelligent algorithms named as Genetic Algorithm, Particle Swarm Optimization and Simulated Annealing.

Genetic Algorithm [3] is an optimization methodology. It was developed in 1970. Genetic Algorithm is a stochastic and evolutionary algorithm that mimics the principles of natural selection and genetics. This is done by the creation within the population of individuals represented by chromosomes. These individuals then undergo a process of evolution.

Particle swarm optimization (PSO)[4] is a novel emerging intelligence which was flexible optimization algorithm proposed in 1995. There are many common characteristics of PSO. First, they are flexible optimization technologies. Second, they all have strong universal property independent of any gradient information.

Simulated Annealing was introduced by Kirkpatrick et al in 1982.it is a technique to solve combinatorial optimization problems by minimizing the functions of many variables.[6]Using the cooling schedules to select the optimal parameters, this method repeatedly generates, judges and accepts/rejects the control parameters .[5]

In this paper, a comparative study is done on PID controllers tuned with the well-known meta-heuristic algorithms GA , PSO ,SA and conventional method i.e. Ziegler-Nichols.

2. Problem Formulation

Proportional, Integral and Derivative gains are combined to form the basis of PID controller. The feedback control system is illustrated in Fig.1.
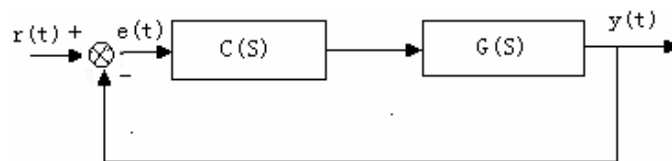

Fig. 1

Here, e is the error variable which is the difference between output(y) and reference variable(r). G(s) is the plant transfer function and C(s) is the PID controller transfer function that is given as:

$$C(S) = Kp + \frac{Ki}{s} + K_d s \qquad\qquad (1)$$

Where Kp, Ki and Kd are respectively the Proportional, Integral, Derivative gains/parameters of the PID controllers that are going to be tuned. The plant used here is a DC motor model [1] which is a third order system given as:

$$G(S) = \frac{1}{S^3 + 9S^2 + 23S + 15} \qquad (2)$$

3. Genetic Algorithm

Genetic algorithms are computerized search and optimization methods that work very similar to the principles of natural evolution. Genetic algorithms have become a viable solution to strategically perform a global search by means of many local searches. A genetic algorithm works by building a population of chromosomes which is a set of possible solutions to the optimization problem. Within a generation of a population, the chromosomes are randomly altered in hopes of creating new chromosomes that have better evaluation scores. The next generation population of chromosomes is randomly selected from the current generation with selection probability based on the evaluation score of each chromosome. Genetic Algorithm starts with evaluating the fitness of all individuals in the population. Then a new population is created by performing the operations such as crossover, fitness proportionate reproduction and mutation on the chromosomes represented by array of bits. Old population is discarded and iteration is started with new defined population. A few parts of Genetic Algorithm work parallel including the crossover and mutation sections. Even the evaluation section works parallel. Only exception being the selection and reproduction section, as a view of the entire population is necessary. Many modifications are possible that can enhance the performance for a given application.

4. Particle Swarm Optimization

PSO is an optimization algorithm based on evolutionary computation technique. The basic PSO is developed from research on swarm such as fish schooling and bird flocking. In PSO, instead of using genetic operators, individuals called as particles are "evolved" by cooperation and competition among themselves through generations. A particle represents a potential solution to a problem. Each particle adjusts its flying according to its own flying experience and its companion flying experience. Each particle is treated as a point in a D-dimensional space. The *i*th particle is represented as XI=(xi1,xi2,…,xiD). The best previous position (giving the minimum fitness value) of any particle is recorded and represented as PI=(pi1,pi2,…,piD), this is called pbest. The index of the best particle among all particles in the population is represented by the symbol *g*, called as gbest. The velocity for the particle *i* is represented as VI= (vi1,vi2,…,viD). The particles are updated according to the following equations:

$$V_{i,m}^{(t+1)} = W.V_{i,m}^{(t)} + C_1 * rand() * (Pbest_{i,m} -$$

$$X_{i,m}^{(t)}) + C_2 * rand() * (gbest_m - X_{i,m}^{(t)}). \qquad .(3)$$

$$X_{i,m}^{(t+1)} = X_{i,m}^{(t)} + V_{i,m}^{(t+1)} \dots \qquad\qquad .(4)$$

where c1 and c2 are two positive constant. As recommended in Clerc's PSO, the constants are c1=c2=15. While rand() is random function between 0 and 1, and m represents iteration. Eq.3 is used to calculate particle's new velocity according to its previous velocity and the distances of its current position from its own best experience (position) and the group's best experience. Then the particle flies toward a new position according to Eq.4.

5. Simulated Annealing

Simulated annealing (SA) is a generic probabilistic metaheuristic algorithm which exploits an analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure, known as annealing process and the search for a global optimum of a given function in a large space. It forms the basis of an optimization technique for combinatorial and other problems.

Simulated annealing was developed in 1982 when Kirkpatrick took the idea of Metropolis and applied SA to optimization algorithms. It transforms poor unordered solution into a highly optimized and desirable solution. SA approaches the global maximization problem similarly to using a bouncing ball that can bounce over mountains from valley to valley. It begins at a high "temperature" which enables the ball to make very high bounces, which enables it to bounce over any mountain to access any valley, given enough bounces. As the temperature declines the ball cannot bounce so high and it can also settle to become trapped in relatively small ranges of valleys. A generating distribution generates possible valleys or states to be explored. An acceptance distribution is also defined, which depends on the difference between the function value of the present generated valley to be explored and the last saved lowest valley. The acceptance distribution decides probabilistically whether to stay in a new lower valley or to bounce out of it. All the generating and acceptance distributions depend on the temperature .It has been proved that by carefully controlling the rate of cooling of the temperature, SA can find the global optimum. [6]

6. Simulation Results

In the conventionally PID controller, the plant response produces high overshoot, but a better performance is obtained with the implementation of SI-based PID controller tuning.

Table 1: Optimized PID parameters.

Tuning Method	Kp	Ki	Kd
ZN	115.364	175.86	9.454
GA	99.94866	74.8835	44.86935
PSO	463.37	205.3177	265.0035
SA	63.5712	46.5308	21.2787

Table 2: Step response performance for PID controllers.

Tuning Method	Overshoot(%)	Settling Time	Rise Time	Peak Time
ZN-PID	70	10.8666	0.3136	0.9014
GA-PID	6	1.2765	0.2662	0.5206
PSO-PID	44	1.2414	0.0777	0.1895
SA-PID	0.9	0.7172	0.4722	0.8996

Comparative results for the PID controllers is given above in Table 2 where the step response performance is evaluated based on the overshoot, settling time, rise time and peak time.
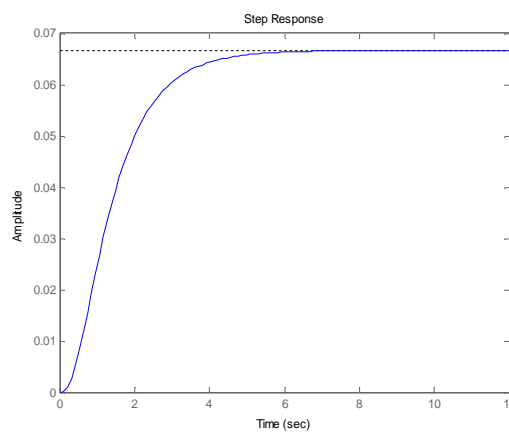

Fig. 2: Step response of the open loop plant.

In order to stabilize this response of DC motor , PID controller is tuned with conventional method i.e. ZN and swarm algorithms i.e. GA,PSO and SA.And their closed loop response are compared.
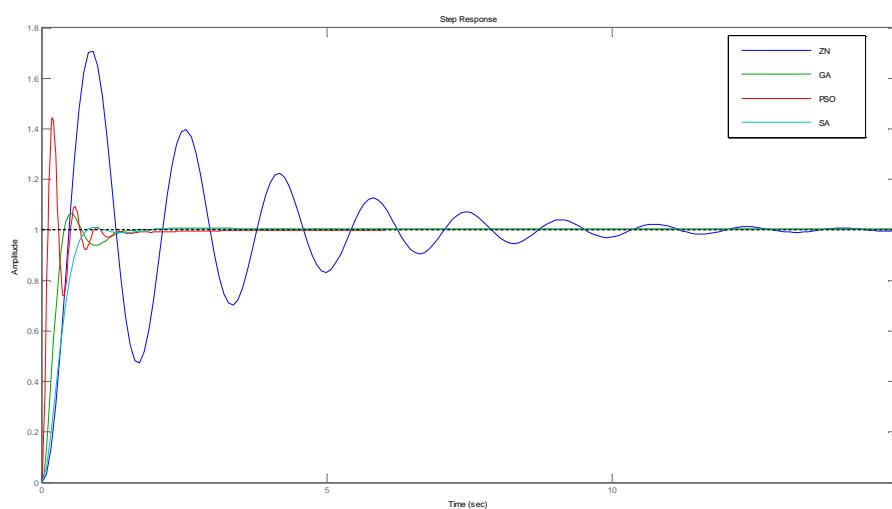

Fig. 3: Comparative Result of PID controllers tuned by metaheuristic algorithms.

7. Conclusion

From the results, the designed PID controllers using Swarm Intelligence algorithms have lesser overshoot and settling time compared to that of the classical method. However, the classical method is good for giving us as the starting point of what are the PID values. The benefit of using a modern optimization approach is observed as a complement solution to improve the performance of the PID controller designed by conventional method. Out of the three algorithms applied for the optimization of PID, SA has been observed to have better response in comparison with GA and PSO.

References

[1] Mahmud Iwan Solihin, Lee Fook Tack and Moey Leap Kean" Tuning of PID Controller Using Particle Swarm Optimization (PSO)" Proceeding of the International Conference on Advanced Science, Engineering and Information Technology 2011.

[2] K Ogata, Modern Control Systems, University of Minnesota, Prentice Hall, 1987

[3] D.E. Goldberg, Genetic Algorithms in search, optimization and machine learning.Addison-wesley, 1989

[4] Zwe-lee gaing, member, IEEE" a particle swarm optimization approach for optimum design

[5] RUTENBAR R A. Simulated Annealing Algorithms: An overview [J]. IEEE Circuits and Devices Magazine, 1989 5(1):19-26.

[6] Yogendra Kumar Soni and Rajesh Bhatt Simulated Annealing optimized PID Controller design using ISE, IAE, IATE and MSE error criteria ISSN: 2278 – 1323.