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Optimal Tuning of PID Controller Using Genetic Algorithm and Swarm Techniques

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Abstract

In order to control the systems, a few control strategies must deal with the effects of non-linearties or uncertainties. As earlier utilized control techniques based on mathematical models have been primarily concentrated on stability robustness against the ill-effects of control mechanism, they are limited in their ability to amend the transient responses. These conventional techniques failed to tune the non-linear and non-minimum phase systems. Therefore, a few modern algorithms have been introduced here such as; Bacteria Foraging Optimization, Particle Swarm Optimization and Genetic Algorithm which have been proved an appropriate aid to improve the transient responses of systems perturbed by non-linearties or unknown mathematical characteristics. This Paper presents designing a PID controller by selection of PID parameters using Bacterial Foraging Optimization, Particle Swarm Optimization (PSO) and Genetic Algorithm. Here, the closed loop step response of the PID controller has been compared for the above mentioned three optimization algorithms.

Keywords: PSO, BFO, GA, PID Controller, Matlab, Ball and Hoop system.

1. Introduction

The Proportional-Integral-Derivative (PID) controller has been proved the most popular controller of this century for its remarkable effectiveness, easiness of implementation and vast applicability. But it is also hard to tune the PID controller. A number of tuning methods are done manually which are difficult and time consuming. For using PID controller efficiently, the optimal tuning of its parameters has become a significant research area. Optimization problems have been resolved with the aid of numerous techniques. Todays, an alternative approach to the traditional methods for operations research, meta-heuristic methods are implanted to simplify optimization difficulties.

Nature Inspired strategies are those, which are inspired by natural and biological events for example, immune system, foraging behaviour of ants and other insects. Swarms can be considered as any collection of interacting agents or individuals and implemented strategy is inspired by intelligent behaviour of insects [2].Swarm intelligence algorithm promotes to develop modern meta-heuristics which can utilize insect's problem solution strengths [3]. to find optimal solutions to the complex and difficult optimization problems.

Particle Swarm Optimization (PSO) algorithm imposing swarm-intelligence is which was introduced by Eberhart and Kennedy in 1995 [4]. PSO has been found simple, quite easy to realize and has immense intelligence of swarms. In accordance with deployed researches, PSO has been a population-based stochastic optimization technique and proved to be appropriate for the optimization of nonlinear functions in multidimensional space. PSO algorithm follows the principles of natural selection and search algorithm.

Bacteria Foraging Optimization (BFO) Algorithm has been applied for tuning the subjected parameters of PID controller [5]. This tuning method based on research of foraging behaviour of E.colli bacteria proposed by Kevin M.Passino and Liu exploits a bacterial foraging and swarming behaviour. It exhibits linked social foraging process along with distributed non-gradient optimization.

Stochastic optimization approaches are needed to deal with more complicated open loop unstable systems .Genetic Algorithm [6] for instance is a powerful search algorithm to optimize the multi-objective PID controller. In the multi-objective optimization, the time specification can be directly formulated as objective function in the optimization process. Hence the tuning objectives and parameter variations can be directly incorporated to find the optimum PID controller parameter values.

Experimental evaluation on tuning the parameters of PID controller for the ball and hoop problem shows that GA performs superior to the standard BFO and PSO based on global best particle search technique. The obtained results have higher fitness and faster convergence.

2. Problem Formulation

PID controller consists of Proportional, Integral and derivative gains. The feedback control system is illustrated in Fig.1 where *r*, *e*, *y* are respectively the reference, error and controlled variables.

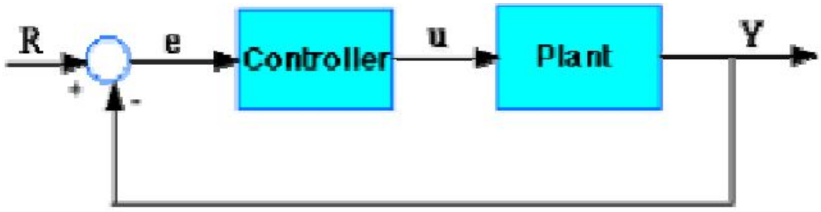

Fig. 1: Unity Feedback control system.

In the diagram of Fig.1, G(s) is the plant transfer function and C(s) is the PID controller transfer function that is given as:

$$C(s) = K_p + \frac{K_i}{S} + K_d S \qquad (1)$$

Where K_p, K_i, K_d are respectively the proportional, integral, derivative gains/parameters of the PID controllers that are going to be tuned. The plant used here is a Ball and Hoop system [1] which is a fourth order system written as:

$$G(s) = \frac{1}{s^4+6s^3+11s^2+6s} \qquad (2)$$

3. Tuning of PID Using BFO-based Optimization

Bacteria Foraging Optimization (BFO) algorithm exploits a variety of bacterial foraging and swarming behavior, including a discussion of connecting social foraging process along with distributed non-gradient optimization strategy. In the bacterial foraging optimization four motile behaviors are mimicked:

Chemotaxis: Chemotaxis process is achieved through swimming and tumbling. With the aid of rotation of the flagella in each bacterium, it decides that bacteria should move in a predefined direction (swimming) or in a diverse direction (tumbling), in the whole life span of the bacterium. To signify a tumble, a unit length random direction, ϴ (j) is generated which will be used to label the direction of progress after a tumble.

$$\Theta^i(j+1,k,1) = \Theta^i(j,k,1) + C(i) * \Theta(j) \qquad (3)$$

Where Θ^i(j,k,l) represents the ith bacterium at jth chemo tactic kth reproductive and lth elimination and dispersal step. C (i) is the size of the step used in the random direction precised by the tumble. “C” is termed as the “run length unit”.

Swarming:-A bacterium should search the optimum pathway of food searching and should try to magnetize other bacteria so that they can reach the desired place more swiftly. Swarming makes the bacteria assemble into groups and hence move as concentric patterns of groups with peak bacterial density.

Reproduction: - The least fit bacteria depart its life and each-other fittest bacteria split into two bacteria. Such bacteria are located in the similar site which makes the population of bacteria constant.

Elimination and dispersal: - The existence of a population of bacteria changes either gradually by spending of nutrients or abruptly due to some other influence in a local environment. Events can eradicate or spread out all the bacteria in a section. Actually, they have the impact of destroying the chemo-tactic progress, but in disparity, they also support it. Since dispersal may consign bacteria near excellent food sources. Elimination and dispersal helps in dropping the conduct of stagnation (i.e., being trapped in a untimely solution position or local optima).

4. Tuning of PID Using PSO-Based Optimization:-

The basic Particle Swarm Optimization (PSO) was developed by researching on swarm behaviour as fish schooling and bird flocking which has been proved an evolutionary optimization algorithm.PSO utilizes the individuals called as particles which get “evolved” by two processes such as cooperation and competition among themselves through generations. A particle denotes a potential solution to a problem that adjusts its flying manner according to its own flying experience and companion flying experience. Each particle is assumed as a position in a D-dimensional space.Over the number of iterations, a group of variables have their value adjusted closer to the particle who is nearest to the food source.Imagine a flock of birds circling hovering over an area where they can smell food.The bird that is closest to the food source chirps loudest and other birds swing along in its direction.If any other bird comes closest to the food source ,it chirps even louder letting other birds know the location and the flock veer towards that direction.This orbital pattern of the birds continue until one of the bird finds the food . The particles are updated according to the following equations:

$$V_{i,m}^{(t+1)} = W.V_{i,m}^{(t)}+C_1*rand()*(Pbest_{i.m}-X_{i,m}^{(t)}) +C_2*rand()*(gbest_m - X_{i,m}^{(t)}) \qquad (4)$$

5. Tuning Of PID Using GA-Based Optimization

A genetic algorithm (GA) is a local search technique used to find approximate solutions to optimization and search problems. Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as *inheritance, mutation, selection, and crossover* (also called recombination).Genetic algorithms are typically implemented as a computer simulation, in which a population of abstract representations (called *chromosomes*) of candidate solutions (called individuals) to an optimization problem evolves toward better solutions. The evolution starts from a population of completely random individuals and occurs in generations. In each generation, the fitness of the whole population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (mutated or recombined) to form a new population. The new population is then used in the next iteration of the algorithm.

6. Simulation Results

able 1 Table 2

Parameters	BFO	PSO	GA
Rise Time	2.0419	1.7013	0.8102
Settling Time	23.4616	11.505	9.3936
Overshoot (%)	15.9717	44.821	28.7017

Comparison of Optimized PID parameters Step response performance for PID controller

Parameter	BFO	PSO	GA
Kp	3.6116	4.4972	15.1179
Ki	0.3112	0.8142	8.0621
Kd	3.7334	2.9035	0.2429

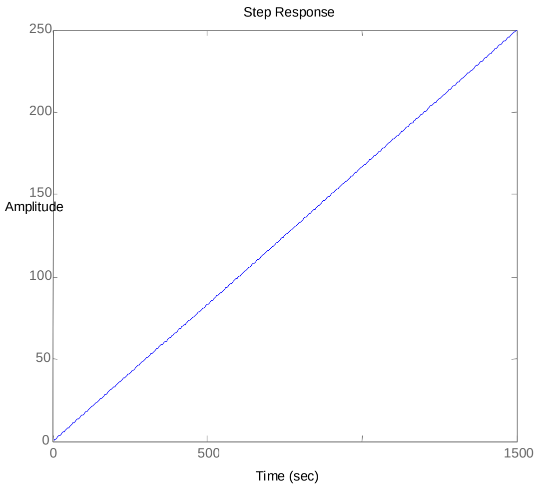

Fig. 3: Step response of open loop plant

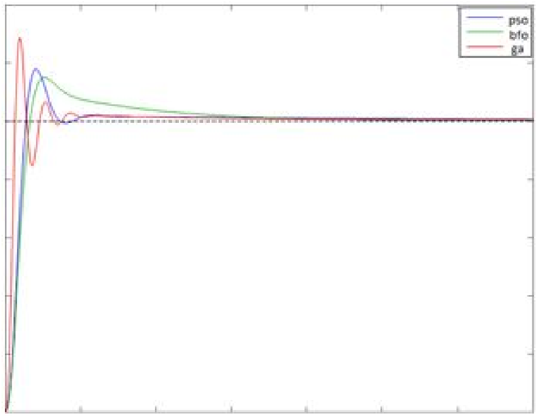

Fig. 4: Comparative Results of GA and Swarm Techniques

7. Conclusion

From the results, the designed PID controllers using BFO based optimization have less overshoot compared to other applied tuning algorithms. GA based optimization offers least rise time and settling time among all the introduced techniques. The obtained results have higher fitness and faster convergence. Results show that meta-heuristic algorithms are even efficient enough to optimize the non-linear and unstable systems which cannot be optimized at all by conventional methods like Ziegler-Nichols.

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