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Parameter Estimation of a PID Controller using Particle Swarm Optimization Algorithm

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Abstract: The Proportional Integral Derivative (PID) structure is mainly used to achieve the desired output in case of closed loop control systems in most of the industry applications. In PID controller it is difficult to obtain the proper values of the controlling parameters K_p, K_i and K_d. The paper describes the design of dynamic control system model with PID controller and the values of the controlling parameters K_p, K_i and K_d are computed by using stochastic global search method i.e. Particle Swarm Optimization (PSO). The approach is based on the search for global optimum value for the PID control parameters with the help of cost functions using Integral Control performance criterion like "Integral Absolute Error" (IAE). The optimum solution generally converges to a solution having minimum error which affects the control parameters thereby influencing rise time, maximum overshoot, settling time, gain margin and phase margin of the system. The proposed methods are demonstrated by tuning all the parameters of PID controllers for single input – single output (SISO) system.

Keywords: Particle Swarm Optimization (PSO), Particle, Swarm Intelligence, PID Controller

I. INTRODUCTION

The aim of control systems is to obtain desired static and dynamic characteristics of closed loop systems. PID (Proportional Integral Derivative) control is one of the earlier control strategies which are used for controlling any plant transfer function. Now to get better efficiency, the actual output should be matched with the set output. Hence some control action should be carried out. Since many control systems using PID controller gives satisfactory result and it helps to tune the control parameters to the optimum values, it is used in industrial control. Now there are various methods to obtain optimum values of the parameters of PID controller for the purpose of tuning. The classical methods are Ziegler Nichols method, Ziegler Nichols reaction curve method [13], Cohen Coon reaction curve method etc. But recently the use of Evolutionary algorithm for tuning the parameters has increased drastically.

Genetic Algorithm (GA), Biogeography Based Optimization (BBO) , Particle Swarm Optimization (PSO), Differential Evolutionary (DE) Algorithm, Ant Colony Optimization (ACO) etc are generally used to tune the unknown parameters. In this paper three types of transfer functions (Type 0, Type 1 and Type 2) are taken and the PID controller block is attached before these transfer function blocks. The tuning of parameters of the PID controller is carried out by using Particle Swarm Optimization (PSO) [1-3].

Finally the time domain and frequency domain responses are generated after fitting all the tuned parameters and comparison is made. The main objective of this paper is to show that a system can be optimized by using Evolutionary algorithm like Particle Swarm Optimization. Different types of close loop control systems and the general idea of a PID controller are described in Section 2. Brief reviews of Particle Swarm Optimization (PSO) algorithm is discussed in Section 3. The PID parameter estimation process using these algorithms is explained in Section 4 and all the responses corresponding to the specific system after simulation are given and compared. In Section 5 and Section 6, the conclusions and references are given.

II. SYSTEM MODELLING OF CONTROL SYSTEM

In Control Engineering, any model is represented by transfer function for single input and single output and linear time invariant dynamical system. In this paper three types of transfer functions (Type 0, Type 1 and Type 2) are taken and the PID controller block is attached before these transfer function blocks. The popularity of PID controllers in industry has increased due to their applicability, functional simplicity and reliability in performance. In general, the synthesis of PID can be described by,

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \text{ ------ } (1)$$

where e(t) is the error and e(t) = r(t) – y(t) , r(t) is the reference input, u(t) is the controller output, and K_p, K_i, and K_d are the proportional, Integral and derivative gains. For a simple feedback control system with PID controller, the transfer function of the PID controller is described by,

$$G_{pid}(s) = K_p + \frac{Ki}{s} + sK_d \text{ ------------ } (2)$$

The control system is designed at SIMULINK toolbox and represented in **Figure 1**.

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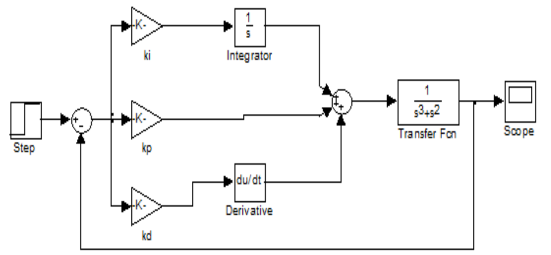


Figure 1: Simulink model of a PID Controller for a system

The optimization methods are introduced for the purpose of tuning the parameters to search for the best solution by minimizing the objective function. To obtain the objective the associated characteristics like rise time, maximum overshoot, settling time, gain margin, phase margin are measured and compared for different optimization methods. A set of performance indicators may be used as a design tool to evaluate tuning method. In this paper Integral Absolute Error (IAE) is taken as performance indicator [8, 10, 14] and it is denoted by,

$$J_{IAE} = \int_0^t |e(t)|dt - - - - - - (3)$$

III. BRIEF REVIEW OF PARTICLE SWARM OPTIMIZATION ALGORITHM

In this section the evolutionary algorithm like Particle Swarm Optimization (PSO) is discussed briefly.

Particle Swarm Optimization

Particle swarms was first described by Eberhart and Kennedy in 1995. The basic operational principle of the particle swarm is applicable for the flock of birds or fish or for a group of people. While searching for food, the birds are either scattered or go together before they locate the place where they can find the food. While the birds are searching for food from one place to another, there is always a bird that can smell the food very well, that is, the bird can observe the place where the food can be found. Because they are transmitting the information, especially the good information at any time while searching the food from one place to another, getting the good information, the birds will eventually flock to the place where food can be found [5-6].

A swarm consist of several particles. Each particle keeps track of its own attributes. The most important attribute is their current positions which are represented by n-dimensional vectors. The position of the particles corresponds to potential solutions of the cost function which is to be minimized. Another attribute of the particle is current velocity which keeps track of the current speed and direction of travel by the particles. Each particle has a current fitness value which is obtained by evaluating the error function of the particle's current position.

Each particle has to remember its own personal best position so that it can be used to guide the construction of new solutions. The best overall positions among all particles are recorded. This position is used for termination of the algorithm.

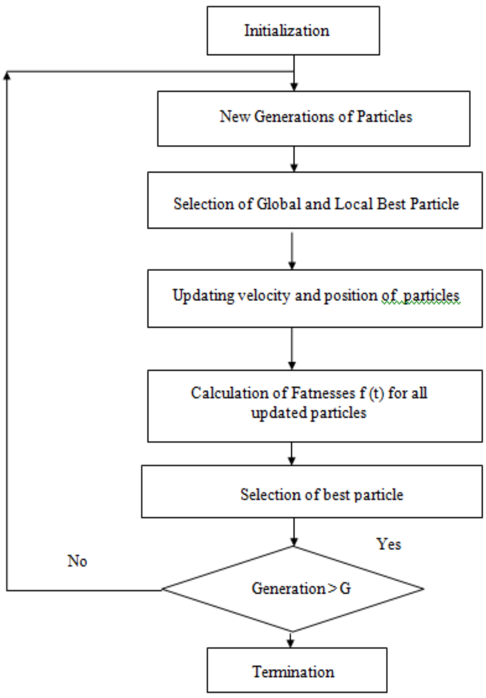
PSO is a multi-agent parallel search technique. Particles are entitles with fly through the multi-dimensional search space. At any particular instant each particle has a position and velocity. The position vector of a particle with respect to the origin of the search space represents a trail solution of the search problem. At the beginning a population of particles is initialized with random positions marked by the vectors $\overrightarrow{X_i}$ and random velocities $\overrightarrow{V_i}$. The population of such particles is called 'swarm' S. A neighborhood relation N is defined in the swarm. N determines whether two particles P_i and P_j are neighbor or not. The equations are presented for the d-th dimension of the position and velocity of the i-th particle.

$$V_{id}(t+1) = \omega V_{id}(t) + C_1\phi_1(P_d(t) - X_{id}(t)) + C_2\phi_2(g_d(t) - X_{id}(t)) - - - - - (4)$$

$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1) - (5)$$

The first term in the velocity updating formula represents the inertial velocity of the particle. The second term involving $\vec{p}$ (t) represents the personal experience of each particle and is referred to as "cognitive part". The last term is interpreted as the "social term" which represents how an individual particle is influenced by the other members of the society. V_{max} or maximum velocity which restricts $\vec{v}$ (t) within the interval [$-V_{max}$, $+V_{max}$] ; ω is an inertial weight factor ; Two uniformly distributed random numbers φ_1 and φ_2 which respectively determine the influence of $\vec{p}$ (t) and $\vec{g}$ (t) on the velocity update formula; C_1 and C_2 are two constant and popularly known as "self-confidence" and "swarm confidence" respectively [7].

Flow chart of PSO Algorithm:



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IV. PARAMETER ESTIMATION OF PID CONTROLLER USING EVOLUTIONARY ALGORITHMS

The initial population for choosing PID parameters are derived from the trial and error method where the following specifications are maintained for all algorithms: Population Size=50, Chromosome Length=20, Crossover Rate=0.5 and Mutation Rate=0.05.The different values of PID parameters and the evaluated transfer functions of the PID controller are shown in the following table.
After simulation, the following values are obtained:
$K_p = 7.9953$, $K_i = 0.00709$, $K_d = 0.05923$
Hence the transfer function of PID Controller corresponds to the tuned parameters are:

$$G_{pid}(s) = 7.9953 + \frac{0.00709}{s} + 0.059233s \text{ -----(6)}$$

IV. SIMULATION RESULTS

Fitness distributions are plotted after minimizing the cost functions for different parameters of the PID controller.

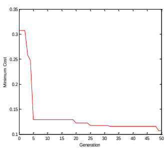
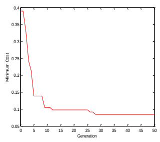
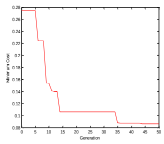
Parameters	Using PSO
K_p	
K_i	
K_d	

Figure 2: Plotting of optimized fitness values w.r.t. no. of generation

The Fitness value for each optimization w.r.t. no of generation is plotted in Figure 2.

The time domain and frequency domain responses for Type 0 to Type 2 systems are shown in the Figure 3.

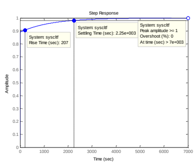
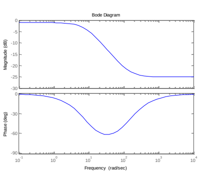
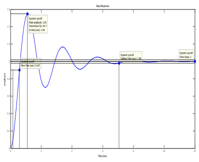
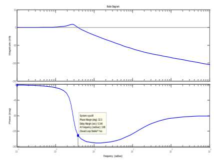
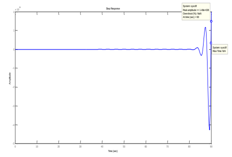
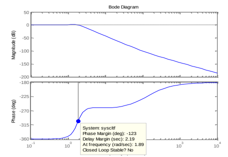
System	Responses	Using PSO
Type 0	Step Responses	
	Frequency Responses	
Type 1	Step Responses	
	Frequency Responses	
Type 2	Step Responses	
	Frequency Responses	

Figure 3

Table 1
Time domain parameters and frequency domain parameters after tuning PID parameters using PSO for Type 0, Type 1 and Type 2 systems:

Parameters	Type 0 System	Type 1 System	Type 2 System
Rise time	207	0.427	N.A.
Settling time	2250	7.06	N.A.
Peak amplitude	>1	1.55	$1.48*10^{26}$
Percentage Overshoot	0%	54.7	Very high
Gain Margin	Infinity	Infinity	Infinity
Phase Margin	-180˚	32.3197	-122.74˚
Stability of the system	Stable	Stable	Unstable

The comparison of the results obtained from the step responses and frequency responses of the systems is shown in Table 2. It is clear that rise time and settling time are better when Type 1 system is used. Hence the system response will be faster. The performance in case of Type 1 system is good because most of the parameters have small values and phase margin is also less. The percentage overshoot is 0 when Type 0 system is used. But if the type of the system is increased i.e. for Type 2 system, all the parameters have large values and hence it is becoming unstable.

V. CONCLUSION

This paper presents the application of evolutionary algorithms used as optimization methods for the purpose of parameter estimation of a PID controller rather than using classical method of tuning the parameters. GA, PSO and BBO are used as search techniques to find the optimum values of the parameters K_p, K_d and K_i by minimizing the cost function. From the obtained results, it is obvious that the performance of BBO is better than the performance of GA and PSO when Type 0 system is used. As soon as the type of the system is increased, the performance of GA improves than the performance of PSO and BBO because of less percentage overshoot and phase margin. It is observed that with the increase of type of the transfer function, the system stability is decreased which is the major disadvantage of this approach. It seems to be easy to adapt the methods presented here to tune other controller types where optimization is involved.

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