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Tuning of PID Controller using Bio-Geography based Optimization

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***Abstract*— In this paper we represent a novel technique for tuning PID controller using a well-known global optimization technique known as Bio-Geography Based Optimization. This technique is used for obtaining the optimum parameters of the PID such that output response of the plant is fast. Simulation is performed using MATLAB® and the results are presented. The results show that the optimization based PID performs better than the conventional tuning technique such as Ziegler Nichols tuning method.**

Keywords—PID controller; Bio-Geography Based Optimization; PID Tuning

I. INTRODUCTION

PID Controller is a very powerful method and it is widely used in industrial applications [1] because of its simplicity, reliability and robust performance. PID controller has been used for control of diverse dynamical systems ranging from industrial processes to aircraft control and ship dynamics. The main advantages of PID Controller are higher stability, no offset, reduced overshoot, reduced steady state error, reliability, etc. However the PID controller has to be tuned in order to achieve satisfactory performance. In this paper, we present Bio-geography Based Optimization [2] for tuning of PID controller.

The organization of the paper is as follows: second section describes about the PID controller Bio-geography Based Optimization (BBO) technique is presented in the third section. In the fourth section an objective function is formulated for optimizing the closed loop response of the plant (system) and the simulation result are presented. Finally, conclusions are presented in the last section.

II. PID CONTROLLER

PID controller is the most widely used controller in the industry. A PID controller has three parameters- proportional constant 'K_P', integral constant 'K_I' and the derivative constant 'K_D'. These three parameters are meant to take care of the present, future and the past errors. A PID controlled process having system transfer function 'G_s' and unity feedback is shown in Fig. 1.

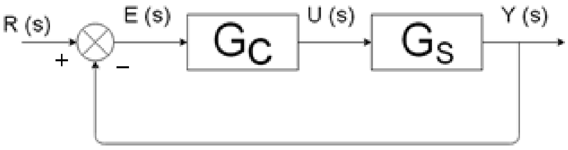

Fig.1. PID Controller

'G_c' is the transfer function of the PID controller and is given by equation (1) and closed loop transfer function of the PID controlled process is given by equation (2)

$$G_c = K_P + \frac{K_I}{s} + K_D s \quad (1)$$

$$G = \frac{G_c G_s}{1 + G_c G_s}$$

$$G = \frac{\left(K_P + \frac{K_I}{s} + K_D s\right) G_s}{1 + \left(K_P + \frac{K_I}{s} + K_D s\right) G_s} \quad (2)$$

Proportional action is meant to minimize the instantaneous errors. However, by itself it cannot make the error zero and provides a limited performance. The integral action forces the steady state error to zero, but has two disadvantages: due to the presence of a pole at the origin, it may result in system instability and the integral action may create an undesirable effect known as wind-up in the presence of actuator saturation. The derivative action acts on the rate of change of error and it may result in large control signals when the error signal is of high frequency.

III. BIO-GEOGRAPHY BASED OPTIMIZATION

BBO [3] is a new evolutionary global optimization technique. In nature, animal and plant species generally migrate to habitats which are highly suitable for living. In BBO, each solution is characterized by an island. Each island has certain features which characterize its habitability and are known as suitability index variables (SIV). Each island also has a sustainability index (SI), which characterizes how suitable is the island for the animals and plants to live. Islands with high SI values have a high density of populations and those with low SI values are sparsely populated. Also islands which have good SI values have low immigration rates (λ) and high emigration rates (μ) and those with low SI values have high value of λ and low value of μ. Islands with low SI values can accept more population and so there have more chance to improve their SI values. In BBO, an island H is a vector of N (SIVs) which are initialized randomly and then these features are migrated from one island to another followed by mutation to reach the global minima. Features are shared based on immigration and emigration rates of the solution. Each solution is modified based on a probability (P_a) which is defined by the user. Each island has its own λ and μ given by (3) and (4)

$$\lambda_k = (EK/P) \quad (3)$$

$$\mu_k = I\,(1-(K/P)) \quad (4)$$

Where K is the number of species on the island
E= maximum λ
I=maximum μ
P = population size

Generate an initial population of the islands, then apply migration between islands, to exchange features between the islands. To apply the migration operator emigration and immigration rates are calculated for every solution. Each feature in an island has a probability of immigration proportional to λ. Emigrating island is selected with a probability proportional to its emigration rate μ.

After migration takes place, mutation is applied to increase the diversity of the population. This is applied probabilistically and is given by

$$\text{Mutation rate (m)} = P_a\,(1- P_i/P_{max}) \quad (5)$$

Where P_{max} =argmax(P_i),, i = 1,…,p.

BBO Algorithm:

Initial Parameters:
N = population size
MAX = Maximum number of generations
P =Elitism parameter
P_a =Island modification probability

Step 1: Generate initial solutions randomly and assign species count probabilities for each solution;
Step 2: Calculate the fitness value of each solution;
Step 3: While a termination criterion is not met
  Save the best solutions in a temporary array;
  For each solution map the SI value to K, λ and μ;
  Perform migration operations;
  Perform mutation operation on the worst half of the population;
  Calculate the fitness of each solution;
  Sort the population from worst to best;
  N=N+1
End while

IV. SIMULATION RESULTS

Consider a plant with the model given by:

$$G_s = \frac{1}{(s+1)^4}$$

A PID controller is designed for this plant model using the Ziegler Nicolas tuning rules. The parameters of the PID controller are K_P = 2.4, K_I = 0.734 and K_D = 1.885. These parameters were obtained using the SISOTOOL of MATLAB®Now, the proposed technique is used for obtaining the parameters of the PID. An objective function is formulated which is given by equation (6).

$$f = \left(T_r^2 + T_s^2 + M^2\right) \quad (6)$$

Where T_r is the rise time, T_s is the settling time and M is the maximum overshoot of the step response of the closed loop system. The BBO algorithm is implemented using MATLAB® and the parameters are taken to be:

No of generations: 20
Population size: 20
No of variables: 3
Mutation probability: 0.04
Habitat modification probability: 1
Elitism: 2

The parameters of the PID obtained after the completion of the optimization are K_P = 1.5369, K_I = 0.6175and K_D = 2.2404. The comparison of the step response of unity feedback closed loop system with the PID controller tuned using the Ziegler Nicholas method and the proposed method is shown in Fig. 2. The parameters of the unit step response are shown in Table. 1.

Table. 1. Step response parameters for first example

	Settling Time (sec)	Rise Time (sec)	Overshoot (%)
Ziegler-Nicolas Tuning	11.64	1.63	25.5
Proposed Tuning	3.5	2.14	0.69

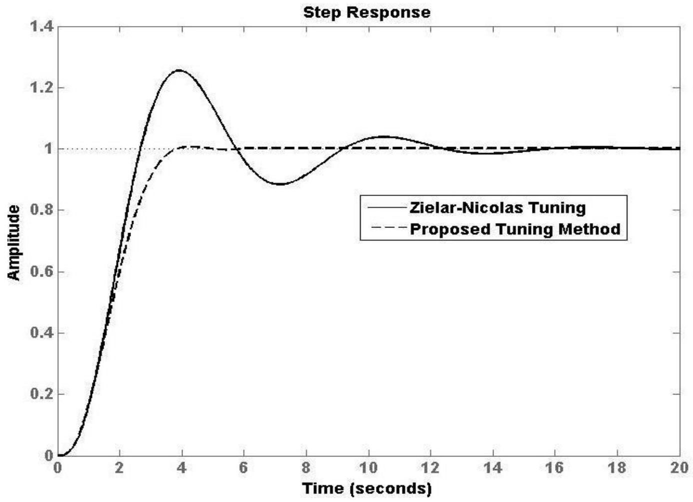

Fig .2. Step response comparison for the first example

Consider another plant with the model given by:

$$G_s = \frac{e^{-s}}{(s+1)^2}$$

PID controller is designed using the proposed method its step response is compared with that obtained using Ziegler-Nicolas method. The step response is shown in Fig. 3. The parameters of the PID are shown in Table 2 and the comparison of the step response parameters is shown in Table 3.

Table. 2. Parameters of PID controller

	K_P	K_I	K_D
Ziegler-Nicolas Tuning	1.63	0.68	0.98
Proposed Tuning	1.19	0.55	0.75

Table. 3. Step response parameters for second example

	Settling Time (sec)	Rise Time (sec)	Overshoot (%)
Ziegler-Nicolas Tuning	7.65	.95	19.89
Proposed Tuning	3.0	1.5	1.21

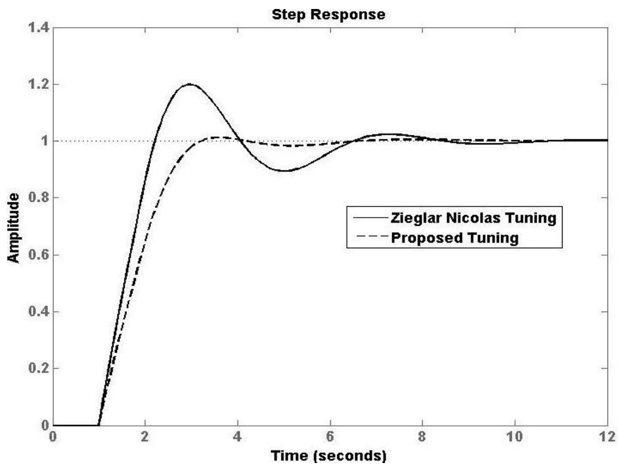

Fig .2. Step response comparison for the second example

V. CONCLUSIONS

A Bio-Geography Based Optimization technique for tuning of the PID controllers has been presented. An objective function has been formulated for minimizing the rise time, settling time and the maximum overshoot of the closed loop response of the system. The PID controller parameters were obtained by using the BBO for minimizing the fitness function values. The comparison of the step response of the PID controller obtained using the Ziegler-Nicolas tuning method and that of the proposed method shows the superior performance of the proposed method.

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