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PI-Controller Adjustment Using PSO for a Laboratory Scale Continuous Stirred Tank Heater

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ABSTRACT

In this paper, a PI type controller is tuned to control the level and temperature of a Continuous Stirred Tank Heater (CSTH). The PI parameters are adjusted by using Particle Swarm Optimization (PSO) method. A laboratory scale CSTH is considered as pilot to show the proposed method. The effectiveness of the proposed method illustrates by a comparison between the PSO-PI controller and two other PI controllers which are designed and optimized by Ziegler-Nichols (Z-N) and Genetic Algorithms (GA). The simulation results confirm the validity of the PSO as the proposed method to adjust the PID type controller in compare with the ZN-PI and GA-PI controllers.
KEY WORDS: Particle Swarm Optimization, Genetic Algorithm, Ziegler-Nichols, PI Controller, CSTH, Interacting System.

1. INTRODUCTION

Interacting systems are used more commonly than no interacting systems in the industry. These systems are utilized to have a constant temperature, perfect mixture and plain density. A laboratory size Continuous Stirred Tank Heater (CSTH) in series with a Feeding Tank and a circulation pump can be defined as an interacting system for educational purposes. By using a system which consists of these three elements a wide variety of control problems and issues such as nonlinearity, linearization, coupled and decoupled loops, time delay and others, can be studied and solved. Hence interacting systems have high significance in process control systems for theoretical and practical studies and analysis [1- 2].

PID controller is a mechanism which efforts to reduce the difference between measured variable and reference value of a process by calculating and doing desired action that can modify the performance. This regulation is done by changing in three parameters which are known as K_P, K_I and K_D respectively. PI controller in comparison with the other control devices and algorithms plays a key role in the industry and control purposes [3, 4, 5, 6]. It is known as the first and sometimes the best solution for the control problems and overcomes all other advanced controllers. In spite of so many advantages such as the capability to be used in most processes control systems, straightforward and uncomplicated in use and simple implementation, sometimes the other controllers can be more useful than PI controllers [6].In most cases the main problem originates from the PI parameters design. Traditionally, this problem has been solved by a relatively simple trial and error method. During the previous decades more systematic approaches such as Ziegler-Nichols and Cohen-Coon have been presented [6]. Control practitioners show much more interest to Ziegler-Nichols tuning formula in compare with the other tuning rules. Some researchers use Evolutionary Computation (EC) methods to design a PID controller. [7,8,9] applies GA to adjust a PID controller. In [10] a fuzzy-genetic method is applied for auto tuning of a PID controller.

This paper is aimed to show an application of Particle Swarm Optimization (PSO), by tuning a PI-controller for a laboratory scale CSTH such that the output illustrates the preferred properties. PSO can converge to the optimum values much faster than the other optimization methods. Moreover, the optimum values which are found by PSO have the less cost in compare to the other optimization methods. Simulation results prove these facts and indicate that the PSO-PI controller has an improved performance index in compare to the GA and ZN methods.

The scientific contributions of this paper are: 1) the fast convergence of PSO in order to find the optimum values in compare to the other algorithm. 2) Show the less cost of function 3) repeatability of the PSO for optimization process.

Apart from this introductory section, this paper is organized as follows. The plant under study is described in section 2. The tuning methodology is explained in section 3 and PI controller adjustment is developed in section 4. As a final section, the simulation results are presented and discussed in section 5.

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2. PLANT MODEL:

A two tanks CSTH control rig is considered as the pilot system and shown in Figure 1. The liquid flows in a loop from upper to the lower tank by effect of gravity and from the lower to the upper tank using the pump [11].

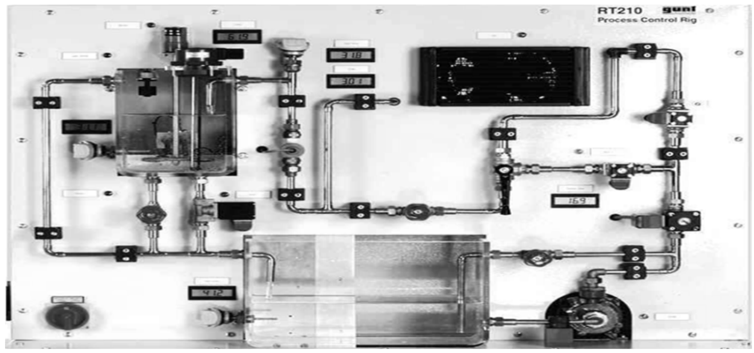

Figure 1. Process control rig [11]

The schematic diagram of the process control rig is shown in figure 2. The amount of liquid flows in and of tank 1 is controlled by valve 1 and valve 2 respectively [11] .

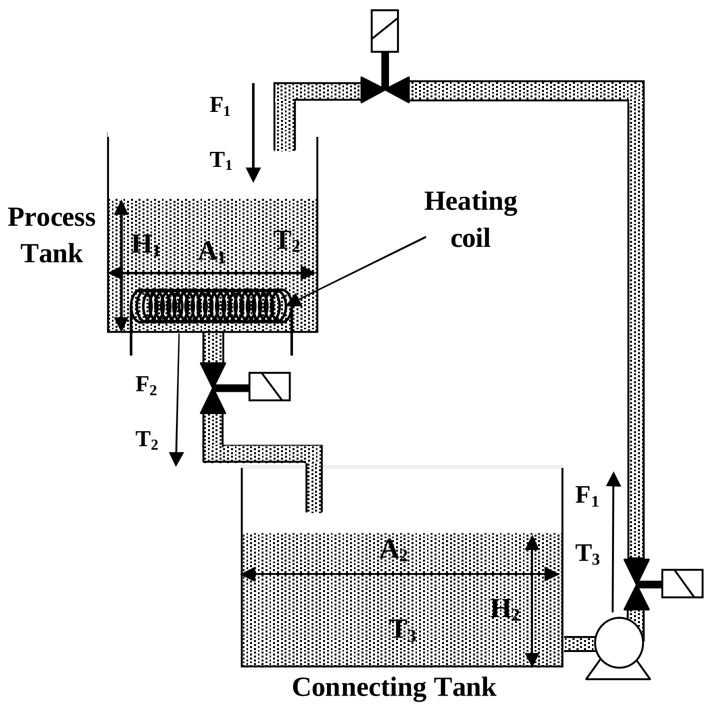

Figure 2.Process control rig diagram [11]

Tank 1 has an electric heater which controls the liquid temperature. The main aim is to control the level and temperature of the liquid (distilled water) in tank 1 by controlling the liquid inlet flow and the heating power. The block diagram of the CSTH which consists of the transfer functions of the systemis shown in figure 3 [11].

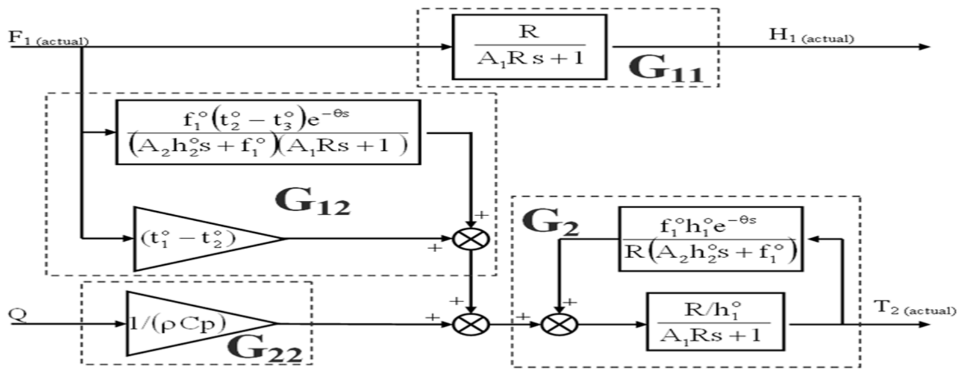

Figure 3.Process block diagram [12]

The system constants and initial conditions and also the symbol are given in the appendix. [11].By using the decoupling blocks the CSTH has been considered as a system with two blocks which formed a non-interacting system .In fact, system has been changed from a MIMO to two SISO to remove the coupling effects among the two systems which are level system and temperature system[11]. The level system transfer function is:

$$G_p(\mathrm{s}) = \frac{4577}{122.8\,\mathrm{s} + 1} \tag{1}$$

And the temperature system transfer function is defined as:

$$G_P(\mathrm{s}) = \frac{810.712\,\mathrm{s} + 1.000314}{1.52272\ \mathrm{s}^2 + 0.01427\,\mathrm{s} + (1.53\ \times 10^{-5})(1 - \mathrm{e}^{-8.6\,\mathrm{s}})} \tag{2}$$

3. DESIGN METHODOLOGY:

As mentioned in the first section, a PI controller is aimed to control the CSTH system. PSO is used to obtain the parameters of this PI controller. The structure of the PID controllers which is defined in (3) is formed by three parameters.

$$\text{PI Controller} = \mathrm{K_p} + \frac{\mathrm{K_I}}{\mathrm{S}} \tag{3}$$

A. Particle Swarm Optimization (PSO):

PSO was proposed by Eberhart and Kennedy in 1995. The social behavior a group of birds, and also the decision making procedure of human beings are the main thought behind this algorithm. PSO is similar to the GA in the initialization's step which has to start with a population; but, PSO works without evolution operators such as crossover or mutation. The population in PSO is called particles which includes the values of variables and also is not encoded in the form of binary. The particles moveover the objective surface with an initial velocity and then try to update their velocities and positions after each iteration based on their local and global best positions as mentioned in (4) and (5) [12]:

$$v_i^{k+1} = v_i^k + c_1 rand_1 \times \left(pbest_i - s_i^k\right) + c_2 rand_2 \times \left(gbest_i - s_i^k\right) \tag{4}$$

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{5}$$

where:

v_i^k = present velocity of agent i at iteration k, v_i^{k+1} = new velocity of agent i at iteration k,

C_1 = adjustable cognitive acceleration constants,C_2= adjustable social acceleration constant ,

s_i^k = present position of agent i at iteration k, *pbest* = personal best of agent i,

$gbest$ = global best of the population.
For (5):
s_i^{k+1} denotes the position of agent i at the next iteration k +1,

The velocity vector is updated by the PSO for each particle then the new velocity adds the positions or values of the particle. Velocity updates procedures are affected by two factors: one is the best global position which is defined as the lowest cost found by a particle and the other is the best local position which is defined as the lowest cost in the current population. The main advantages of PSO are the ease of implementation and also the minimum amount of parameters which are needed to tune. The PSO is capable to find the best solutions for the cost functions which have many local minimum [12].Figure 4.illustrates the general flowchart for the PSO technique.

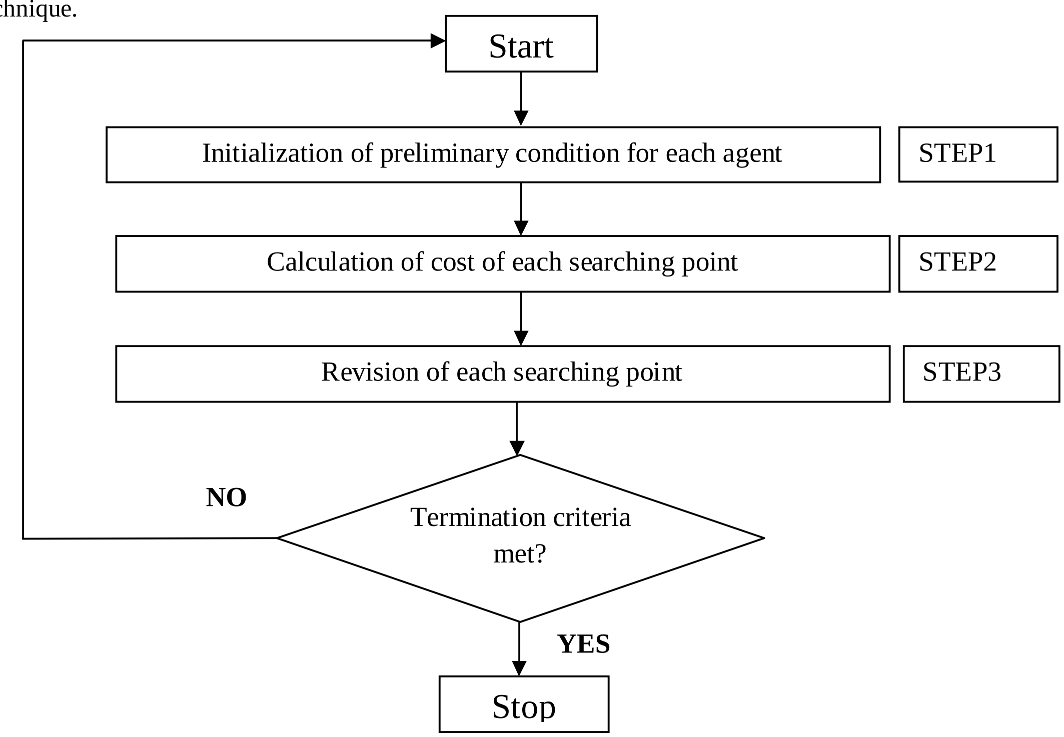

Figure 4. Steps in PSO [12]

B. Description of the PSO Tuning Methodology:

The SISO system and its related PSO tuning algorithm which is used in this paper is shown in figure 5. The steps for PSO tuning were mentioned in previous section. The velocity and positional algorithms define the search within the solution space. Following each iteration, the impact of each agent's position within the search space is evaluated according to the cost function.

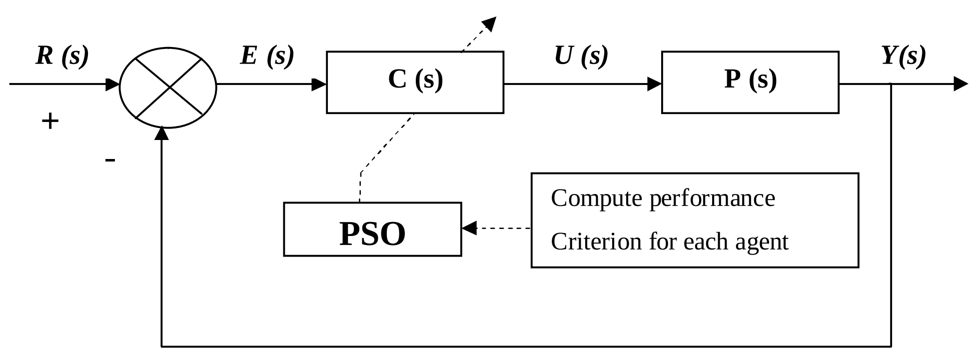

Figure 5.Positioning of the PSO with in a SISO system

The minimization of the cost function provides a global quantification of overall system performance. The parameters used for the all simulations using the PSO are given in Table.1.

Table 1. PSO Parameters

Parameter	Value
Maximum Iterations	50
Maximum Velocity (Vmax)	1
Cognitive Acceleration (c1)	2
Social Acceleration (c2)	2
Weight (W)	0.9

4. PI-CONTROLLER TUNING USING PSO:

In this section, the PSO algorithm is used to tune the parameters of the proposed PI controllers. The PI-controller has two parameters which are symbolized by K_P and K_i. Because of the order of the CSTH system, two PI controllers are sufficient for the control purposes. Therefore in two control loops with two PI - controllers, there are four parameters which need to be tuned and found by using the PSO. The optimum values of K_P and K_i are perfectly calculated using PSO. In optimization methods, it is essential to define a performance index to find the optimum values. In this paper, the performance index is defined as (6) which is known as the Integral of the Absolute Error (*IAE*).

$$IAE = \int_0^{\infty} |e(t)| dt \tag{6}$$

In IAE, "t" is defined as the simulation time. It is clear that a controller which shows the lowest IAE value would be selected as the most efficient controller. To find the optimum values for the parameters, the PSO tries to minimize the performance index which is the IAE. In order to attain better performance, the optimum number of iteration, the amount of particles and also the particle size are chosen as 24, 50 and 12 respectively. These parameters have been determined by a trial and error method to find the optimum values for this particular problem. It should be mentioned that for this study, the PSO algorithm is run 50 times and then the optimum values are selected. The optimum values presented in the Table 2.

Table 2. PSO-PI Optimum Values

PSO	PI Parameters			
	K_p	K_i	*Iteration*	*Cost*
Level	2.73	2.1	24	8.59
Temperature	4.25	2.33	34	20.28

5. RESULT AND DISCUSSION:

In this section, the results from the proposed PSO-PI controller which is applied to the CSTH are presented and discussed. In order to compare and illustrate the efficiency of the PSO based scheme, two other PI- controllers which are adjusted by ZN and GA are designed and tuned for CSTH. Table 3, summarizes the optimum values of the parameters for both the ZN-PI and GA-PI controllers.

Table 3. ZN-PI Controller Optimum Values

		PI Parameters			
		K_p	K_i	*Iteration*	*Cost*
ZN	Level	2.5	1.9	-	9.31
	Temperature	4.78	1.08	-	25.07
GA	Level	2.92	2.24	43	8.83
	Temperature	4.53	1.4	45	23.18

The level system step response is shown in Figure 6.

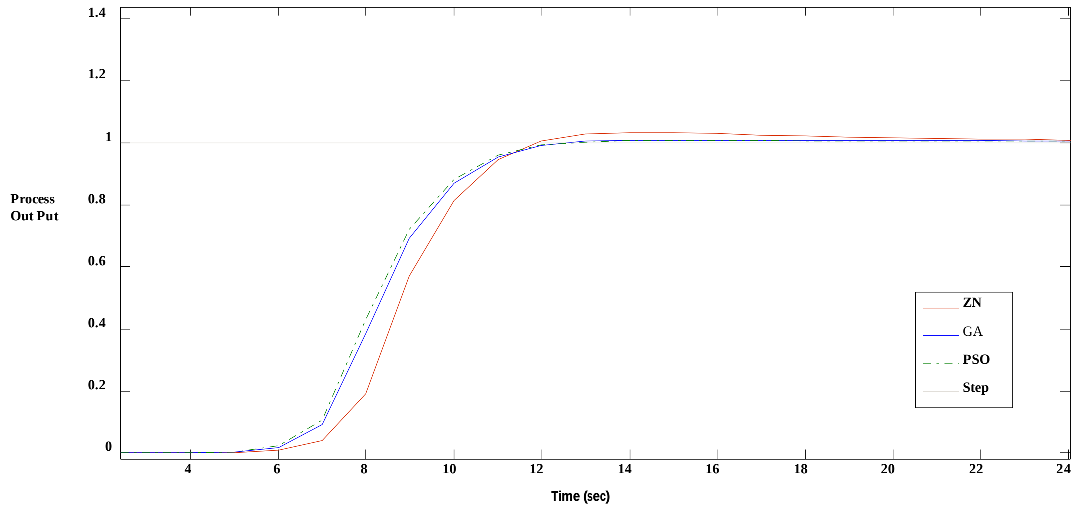

Figure 6.Level System Response

The temperature system step response in shown in Figure 7.

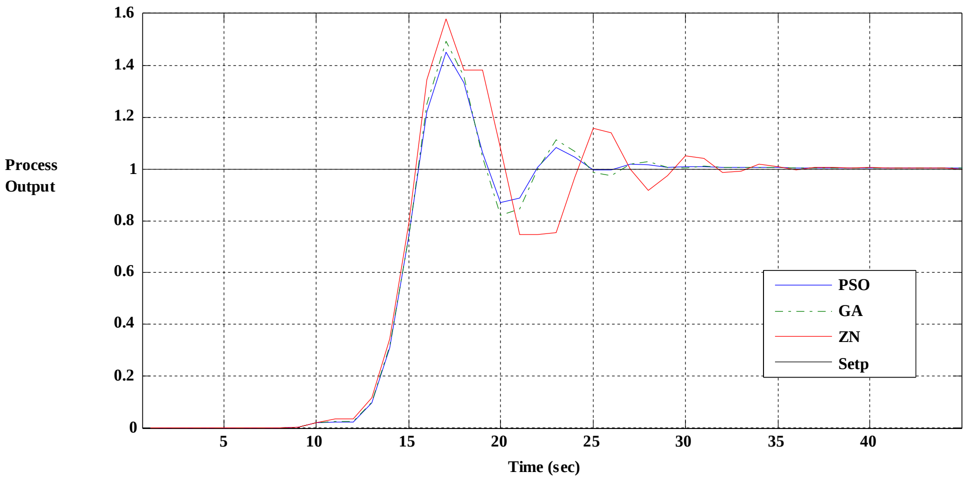

Figure 7.Temperature System Response

The results indicate that PSO generates better responses in compare to the GA and ZN. From Table 2and3 it is clear that the PSO is able to tune the PI parameters not only in lower cost which is 8.59 for level system and 20.28 for the temperature system but also in fewer amounts of iterations 24 and 38. The cost values for the GA are 8.83 and 23.18 which are greater than the PSO ones. The ZN tuning methods show the worst responses in compare to the other ones. The cost values for the ZN method are 9.31 for the level system and 25.07 for the temperature system. From figures 5 and 6 it can be concluded that system shows better response to the controller which is tuned by PSO rather than the GA or ZN methods.The results are summarized in Table 4.

Table 4. PI-Controller Optimum Values

		PI Parameters			
		K_p	K_i	*Iteration*	*Cost*
ZN	Level	2.5	1.9	-	9.31
	Temperature	4.78	1.08	-	25.07
GA	Level	2.92	2.24	43	8.83
	Temperature	4.53	1.4	45	23.18
PSO	Level	2.73	2.1	24	8.59
	Temperature	4.25	2.33	34	20.28

6. CONCLUSION

In this paper, two PI controllers has been successfully tuned to control a laboratory continues stirred tank heater by using particle swarm optimization algorithm. The simulation results verified that the PSO-PI-controllers are able to display the stability and robust performance with a minimum of the cost. Moreover, the results indicated that the performance of the PSO-PID controller is much better than the ZN and GA-PI type controllers for both level and temperature systems. The PI controllers are one of the most used controllers in the engineering and applied systems; hence the paper's results can be used for the CSTH systems in industry and practical matters.

APPENDIX:

System parameters and values [10]

Symbol	Definition	Initial Values
A_1	Tank 1 cross-sectional area.	0.185×0.145 m^2
A_2	Tank 1 cross-sectional area.	0.185×0.335 m^2
A_{Pipe}	Pipe cross-sectional area.	0.034159 m^2
L_{Pipe}	Pipe length.	1.67 m
ρ	Liquid (water) density.	100 kg/m^3
Cp	Liquid heat capacity.	4186 J/kg/C
h_1	Tank 1 liquid level.	0.07 m
h_2	Tank 2 liquid level.	0.18 m
$m_{1,2,3}$	Tank 1,2,3 inlet and out let liquid mass flow rate.	-
f_1	Tank 1 inlet liquid volumetric flow rate.	0.000131 m^3
$f_{2,3}$	Tank 1,2 outlet liquid volumetric flow rate.	-
t_1	Tank 1 inlet liquid temperature.	32° C
t_2	Tank 1 outlet liquid temperature.	30 ° C
t_3	Tank 2 outlet liquid temperature.	27 ° C

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