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Design of PSO based I-PD Controller and PID Controller for a Spherical Tank System

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Abstract

Objective: The objective is to design PSO based I-PD Controller and PID Controller for a nonlinear system. The nonlinear system selected is Interacting Spherical Tank System. **Methods:** Controlling of a nonlinear system is an important process. The PID Controller and PSO based I-PD controller are designed for the non linear systems selected and the error values are calculated. The comparison of performance between these two controllers is done and result is produced. **Findings:** From the simulation result it is inferred that PSO based I-PD controller gives smooth response when compared to PID controller whereas error indices are less in PID controller. **Applications:** The spherical Tank is widely used in petrochemical industries, paper making industry, water treatment industries.

Keywords: Nonlinear System, PID Controller, PSO-Particle Swarm Optimization, Spherical Tank

1. Introduction

Nonlinear systems cannot be broken down into parts and reassembled in the same thing and do not change in proportion to a change in an input. Most monetary and social (and numerous modern) procedures are nonlinear where numerical examination (with couple of special cases) is not able to give general results. The nonlinear problems are troublesome (if conceivable) to solve and they are very less understandable when compared to the linear problems[1]. Regardless of the fact that not precisely resolvable. The result of a linear problem is fairly unsurprising, while the result of a nonlinear is intrinsically not. The controlling the level of the liquid in Tanks and the flow lies between two Tanks is a very basic problem faced in process industries. In these process industries the liquids that are to be pumped and stored in Tanks, and thereafter are pumped to another Tank. Many of the times these liquids will be treated by a chemical treatment or by blending in the Tanks, but always the level of the liquid in the Tanks must be checked[2]. The basic control issue in the process industries is that the control of the liquid level in the storage Tanks and reaction vessels. The rate of change of the flow from one tank to that of another tank as well as the level of fluid are the two important operational factors seen. The level controls of the liquid in Tanks have a challenging issue because of its constant changes in the cross section and non linearity of the Tank. Hence, controlling of liquid level is very important and the common task in the process industries. Spherical Tank is efficient washing and inexpensive, loss of product is less. The spherical Tank is widely used in petrochemical, paper making and water treatment industries[3].

2. Spherical Tank System

The setup contains two spherical Tanks. Tank 1, Tank 2 the two identical Spherical Tanks. The height H of the tank is 50 cm and the radius R of the tank is 25 cm. Restriction R_1 interconnects the two Spherical Tanks. $F2_{in}$ and $F1_{in}$ are

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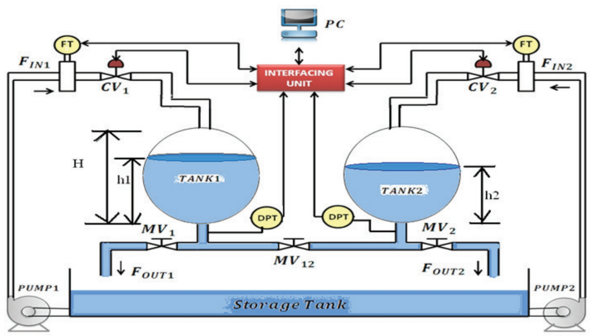

Figure 1. Schematic of TTSIS

the input streams to Tank 2 and Tank 1 respectively. The output stream of the Tank 2 is F_{out} which flows through the restriction R_2 to the sump and h_1, h_2 are the fluid height of Tank 1 and Tank 2. The fluid heights are measured by the differential Pressure transmitters and they are transmitted in the form of standard 4 – 20 mA current signals to the interfacing unit of the Personal Computer. Here the liquid level in Tank 2 would be controlled. The input flows $F1_{in}$ and $F2_{in}$ are measured by the Magnetic Flow transmitters are then transmitted in the standard form of 4 –20 mA current signals to the interfacing unit[4, 5]. After implementation of the concerned propelled control schemes in the Personal Computer, then the control signal will be produced in the form of 4-20 mA standard current signals and are then transmitted to the individual SMART control valves that is to produce a required flow to the Tank 1 and Tank 2. The schematic of TTSIS is shown in Figure 1.

The model of Tank 1 can be represented as,

$$A_1(h_1)\frac{dh_1}{dt} = Fin1 - \beta_{12}\sqrt{h1-h2} \tag{7}$$

Taking Linearization above equation becomes

$$A_1(h_1)\frac{d(\partial h_1)}{dt} = f_1(Fin1) - f_1(h_1-h_2) \tag{8}$$

Applying partial differentiation to above equation,

$$A_1(h_1)\frac{d(\partial h_1)}{dt} = \left(\frac{\partial f_1}{\partial Fin1}\right)\cdot\partial Fin1 - \left(\frac{\partial f_2}{\partial h_2}\right)\cdot\partial h_1 - \left(\frac{\partial f_2}{\partial h_2}\right)\cdot\partial h_2 \tag{9}$$

On rearranging above equation,

$$A_1(h_1)\frac{d(\partial h_1)}{dt} = \partial Fin1 - \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_1 + \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_2$$

Applying Laplace transformations to above Equation,

$$\partial h_1 = \frac{\partial Fin1 + \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_2}{A_1(h_1)s + \frac{\beta_{12}}{2\sqrt{h_1-h_2}}} \tag{10}$$

The model Tank 2 can be represented as,

$$A_1(h_1)\frac{dh_2}{dt} = \beta_{12}\sqrt{h_1-h_2} - \beta_2\sqrt{h_2} \tag{11}$$

Taking linearization,

$$A_2(h_2)\frac{d(\partial h_2)}{dt} = f_1(h_1,h_2) - f_2(h_2) \tag{12}$$

Applying partial differentiation to above Equation,

$$A_2(h_2)\frac{d(\partial h_2)}{dt} = \left(\frac{\partial f_1}{\partial h_1}\right)\cdot\partial h_1 - \left(\frac{\partial f_1}{\partial h_2}\right)\cdot\partial h_2 - \left(\frac{\partial f_2}{\partial h_2}\right)\cdot\partial h_2$$

$$A_2(h_2)\frac{d(\partial h_2)}{dt} = \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_1 - \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_2 - \frac{\beta_2}{2\sqrt{h_2}}\partial h_2 \tag{13}$$

Applying Laplace transformation,

$$\left[A_2(h_2)s + \frac{\beta_{12}}{2\sqrt{h_1-h_2}} + \frac{\beta_2}{2\sqrt{h_2}}\right]\partial h_2 - \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_1 \tag{14}$$

Substituting (4.4) in (4.8) we get,

$$\left[A_2(h_2)s + \frac{\beta_{12}}{2\sqrt{h_1-h_2}} + \frac{\beta_2}{2\sqrt{h_2}}\right]\partial h_2 = \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\left[\frac{\partial Fin1 + \frac{\beta_{12}}{2\sqrt{h_1-h_2}}\partial h_2}{A_1(h_1)s + \frac{\beta_{12}}{2\sqrt{h_1-h_2}}}\right] \tag{15}$$

Let us assume,

$$C_1 = \frac{1}{2\sqrt{h_1-h_2}} \qquad C_2 = \frac{1}{2\sqrt{h_2}}$$

$$R_1 = \frac{1}{\beta_{12}C_1} \qquad R_2 = \frac{1}{\beta_2 C_2}$$

$$\tau_1 = A(h_1)R_1 \qquad \tau_2 = A(h_2)R_2$$

On substituting the above variables in (15), we get the transfer function of the TTSIS that is relating h_2 and Fin1

Table 1. Parameters of spherical Tank

Parameters	Values
Fin	107.25
β1	78.28
β2	19.690
h1	31.90
h2	30
θ	0.20
C1	0.3627
R1	0.03522
C2	0.091280
R2	0.55640
τ1	63.85
τ2	1048.2575

$$\frac{\partial h_2}{\partial Fin1} = \frac{R_2}{\tau_1\tau_2 s^2 + \left[\tau_1 + \tau_2 + A(h_1)R_2\right]s + 1} \quad (16)$$

Table 1 represents the parameters of the spherical tank.

On substituting these values from the Table 1 in the Equation (16), we get a transfer function,

$$\frac{\partial h_2}{\partial Fin1} = \frac{0.5564}{66931.25s^2 + 2120.87s + 1}$$

3. PSO based I-PD Controller

The I-PD is another kind of PID structure and is generally most popularly used in industries, wherever a sleek point chase is needed. Here the desired steady state response is zero. It is used for temperature, speed, position, level control system etc[6]. Particle Swarm Optimization (PSO) is a method with regard to a given measure of quality optimizes a problem and improves the solution. PSO optimizes a problem by moving the particles around in the search space according to simple formula over velocity and Position of particle[7-10]. It gives the local, best, global position and the better positions are updated. PSO moves the swarm towards the best solutions.

There are two PID block in first block K_p and K_d are kept as 0. And in second PID block K_i value is kept 0. Now the PSO algorithm is used to run the block. This gives the appropriate values which are entered in the block. Now

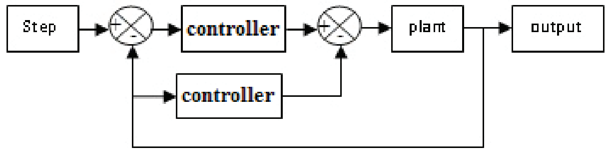

Figure 2. Block diagram of PSO based I-PD controller.

Table 2. The Tuning Parameter of the controller

System	Parameter	I	PD
Spherical Tank	K_p	0	87
	K_i	0.87	0
	K_d	0	34

the system settles smoothly. Figure 2 shows the block diagram of the PSO based I-PD controller.

The tuning parameters of the controller are given in the Table 2.

4. PID Controller

The PID controller is a combination of P controller, I controller and D controller. It gives quick response and stability due to Proportional gain value K_p and it has the ability to eliminate the offset due to Integral gain value K_i. It also has the ability to reduce peak error and provide faster recovery due to Derivative gain value K_d. The advantage of using this controller is that it gives a control action which is very close to an expert human operator[11-13]. The tuning parameter of the controller is given in Table 3.

Block diagram of the PID controller is shown in Figure 3.

Table 3. Tuning Parameter of PID Controller

System	K_p	K_i	K_d
Spherical Tank	87.08	0.71	35.02

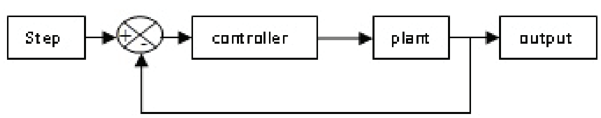

Figure 3. Block diagram of the PID controller.

5. Simulation Result

The Simulation is done for the non linear system. PID and PSO based I-PD controllers are compared and the result is shown. The simulation result of Spherical Tank is shown in the Figure 4. And the Time domain specification and Error indices of PID Controller and I-PD Controller is listed in the Table 4 and Table 5 respectively.

The regulatory response of spherical tank is shown in Figure 5.

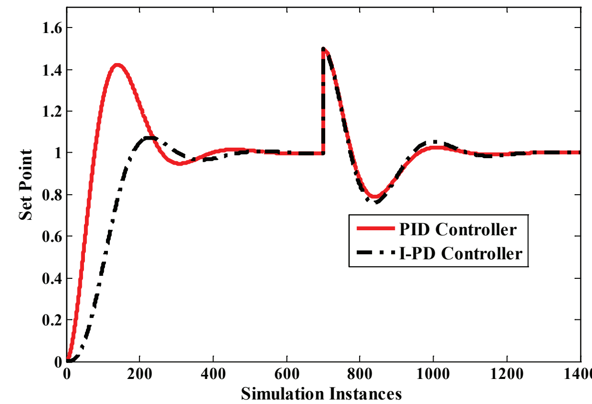

Figure 5. Regulatory Response of controllers.

6. Conclusion

On comparing with PID controller, PSO based I-PD controller has less oscillation which is very important for the spherical Tank system. In spherical Tank system the settling time of the system by I-PD and PID controllers are 415.4s and 420.87s respectively. By using the I-PD controller there is less peak overshoot. On analyzing the errors Integral Absolute Error (IAE) and Integral Square Error (ISE) of PID controller is less when compared to I-PD controller. But Integral Time weighted Absolute Error (ITAE) is less for I-PD controller.

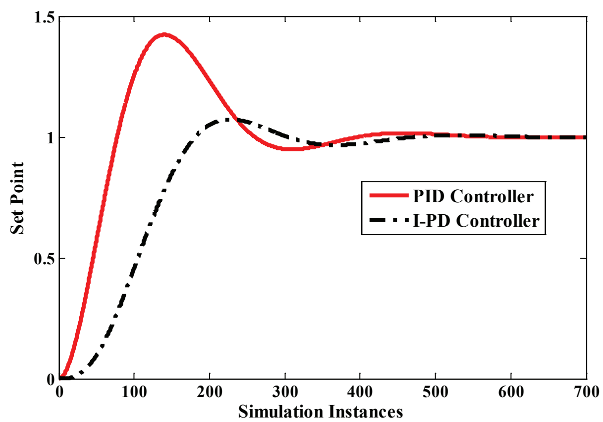

Figure 4. Servo Response of Spherical Tank System.

Table 4. Time domain specification

System	Rise time	Settling time	Peak overshoot
PID controller	45.35	420.87	0.28
I-PD controller	126.7	415.4	0

Table 5. Error Indices

System	IAE	ISE	ITAE
PID controller	98.23	49.38	1009.23
I-PD controller	117.3	86.42	8653.1

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