Research Article

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Elephant herding optimization based PID controller tuning

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Abstract
In this paper, an elephant herding optimization (EHO) based optimal proportional-integral-derivative (PID) controller is proposed for level control of three tank system. The integral-square-error (ISE) of unit step response is minimized for obtaining optimal controller parameters. The ISE is obtained with the help of alpha and beta tables. The EHO algorithm is utilized for minimizing the ISE. The results obtained using proposed methods are compared with other techniques. It is found that the proposed technique performs better in comparison to others.

Keywords
Elephant herding optimization, ISE, Optimization, PID controller, Tuning.

1.Introduction
Being reliable, the proportional-integral-derivative (PID) controllers are still popular in industry. Some methods of tuning of PID controller include Ziegler-Nichols (ZN) settings [1], integral of square time weighted error (ISTE), Pessen integral of absolute error (PIAE), Kessler Landau Voda (KLV), some overshoot rule (SO-OV), no overshoot rule (NO-OV), Mantz-Tacconi Ziegler-Nichols (MT-ZN) and refined Ziegler-Nichols (R-ZN) [2] which fall into the category of rule based design criteria. Various evolutionary and swarm intelligence based methods are also available in the literature such as PID controller tuning based on particle swarm optimization [3, 4], Luus-Jaakola optimization procedure for PID controller tuning [5], PID controller tuning based on genetic algorithm [6, 7], evolutionary computation based PID tuning [8], colonial competitive algorithm based PID tuning [9], PID tuning using soft computing techniques [10], etc. This work proposes an elephant herding optimization (EHO) [11] based tuning approach for obtaining desired parameters of PID controller. The performance index is integral-square-error (ISE) of unit step response. The ISE is obtained from alpha and beta parameters. This type of performance index requires some number of alpha and beta parameters only unlike other methods in which integration with respect to time is necessary. The layout of this paper is as follows. Section 2 describes preliminaries and techniques available for tuning of PID controller. Section 3 discusses the three tank system and its model. The EHO based tuning method is described in section 4. The details of EHO are provided in section 5. Section 6 presents the simulation parameters and discusses the quantitative and qualitative results obtained. The paper is concluded in section 7.

2.PID controller
The transfer function of PID controller in terms of proportional gain, integral time constant and derivative time constant is given as

$$C(s) = K_p\left\{1+\frac{1}{T_i s}+T_d s\right\} \quad (1)$$

where, K_p, T_i and T_d are, respectively, the proportional gain, integral time constant and derivative time constant. The values of three controller parameters [2] are given in *Table 1* due to Ziegler-Nichols (ZN) tuning rule, Pessen integral of absolute error (PIAE) criterion, some overshoot rule (SO-OV), no overshoot rule (NO-OV) and Mantz-Tacconi Ziegler-Nichols (MT-ZN) criterion. The parameters K_u and T_u are ultimate gain and corresponding time period, respectively.

Table 1 Controller parameters

S.N.	Rule	K_p	T_i	T_d
1	ZN	$0.6K_u$	$0.5T_u$	$0.125T_u$
2	PIAE	$0.7K_u$	$0.4T_u$	$0.15T_u$
3	SO-OV	$0.33K_u$	$0.5T_u$	$0.33T_u$
4	NO-OV	$0.2K_u$	$0.5T_u$	$0.33T_u$
5	MT-ZN	$0.6K_u$	$0.5T_u$	$0.125T_u$

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3.Three tank system

The closed loop control of three tank system [12] is given in *Figure 1*. The transfer functions $C(s)$ and $G(s)$, respectively, denote controller and plant.

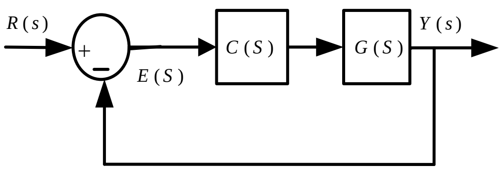

Figure 1 Three tank system

The transfer function three tank system is

$$G(s)=\frac{K}{(\tau_a s+1)(\tau_b s+1)(\tau_c s+1)} \tag{2}$$

where, K is gain and τ_a, τ_b and τ_c are time constants of three tanks.

4.The proposed approach

The ISE of unit step response is considered as tuning criterion in this work. The ISE can be written as

$$J=\int_{t=0}^{t=\infty} e^2(t)dt \tag{3}$$

which further can be obtained with the help of alpha and beta parameters [13] as given below

$$J=\frac{1}{2}\sum_{i=1}^{n}\frac{\beta_i^2}{\alpha_i} \tag{4}$$

Where n is the order of error in s-domain . The error in s-domain for system given in *Figure 1* can be obtained as

$$E(s)=R(s)-Y(s)=\frac{R(s)}{1+G(s)C(s)} \tag{5}$$

Where, $R(s)=1/s$. The transfer function of error, in general can be denoted as

$$E(s)=\frac{B_1 s^{n-1}+\cdots+B_n}{A_0 s^n+A_1 s^{n-1}+\cdots+A_n} \tag{6}$$

Where n is the order of $E(s)$. The alpha and beta parameters are derived from alpha and beta tables (*Table 2* and *Table 3*) constructed for numerator and denominator coefficients of $E(s)$.

Table 2 Alpha table

	$c_0^0=A_0$	$c_2^0=A_2$	$c_4^0=A_4$	$c_6^0=A_6$	$\cdots$
	$c_0^1=A_1$	$c_2^1=A_3$	$c_4^1=A_5$	$\cdots$	
$\alpha_1=c_0^0/c_0^1$	$c_0^2=c_2^0-\alpha_1 c_2^1$	$c_2^2=c_4^0-\alpha_1 c_4^1$	$c_4^2=c_6^0-\alpha_1 c_6^1$	$\cdots$	
$\alpha_2=c_0^1/c_0^2$	$c_0^3=c_2^1-\alpha_2 c_2^2$	$c_2^3=c_4^1-\alpha_2 c_4^2$	$c_4^3=c_6^1-\alpha_2 c_6^2$	$\ddots$	
$\alpha_3=c_0^2/c_0^3$	$c_0^4=c_2^2-\alpha_3 c_2^3$	$c_2^4=c_4^2-\alpha_3 c_4^3$	$\vdots$		
$\alpha_4=c_0^3/c_0^4$	$c_0^5=c_2^3-\alpha_4 c_2^4$	$\vdots$			
$\alpha_5=c_0^4/c_0^5$	$\vdots$				
$\vdots$					

Table 3 Beta table

	$d_0^1=B_1$	$d_2^1=B_3$	$d_4^1=B_5$	$d_6^1=B_7$	$\cdots$
	$d_0^2=B_2$	$d_2^2=B_4$	$d_4^2=B_6$	$\cdots$	
$\beta_1=d_0^1/c_0^1$	$d_0^3=d_2^1-\beta_1 c_2^1$	$d_2^3=d_4^1-\beta_1 c_4^1$	$d_4^3=d_6^1-\beta_1 c_6^1$	$\cdots$	
$\beta_2=d_0^2/c_0^2$	$d_0^4=d_2^2-\beta_2 c_2^2$	$d_2^4=d_4^2-\beta_2 c_4^2$	$d_4^4=d_6^2-\beta_2 c_6^2$	$\ddots$	
$\beta_3=d_0^3/c_0^3$	$d_0^5=d_2^3-\beta_3 c_2^3$	$d_2^5=d_4^3-\beta_3 c_4^3$	$\vdots$		
$\beta_4=d_0^4/c_0^4$	$d_0^6=d_2^4-\beta_4 c_2^4$	$\vdots$			
$\beta_5=d_0^5/c_0^5$	$\vdots$				
$\vdots$					

5.Elephant herding optimization (EHO)

Wang et al. [11] proposed elephant herding optimization (EHO) in 2015. This algorithm is based on herding behavior of elephants. In EHO, following assumptions are considered for herding:

1.The whole population of elephants contains some fixed number of subgroups known as clans and each clan contains fixed number of elephants.

2.A fixed number of elephants leave their clan and live alone.

3.Each clan moves under the leadership of a matriarch.

Each clan is headed by matriarch who represents the best solution of clan. Suppose, there is a total C clans of elephants and each clan have R elephants. The position of ith elephant, $i = 1, 2, \cdots, R$, in jth clan, $j = 1, 2, \cdots, C$ is represented as $X_{i,j}$. The current position of all elephants are updated as given below:

$$newX_{i,j} = X_{i,j} + \alpha \left(X_{best,j} - X_{i,j} \right) r \tag{7}$$

Where $newX_{i,j}$ is updated position and α is a scale factor which determines the influence of matriarch on clan such that $\alpha = [0,1]$. $X_{best,j}$ and $X_{i,j}$ denote, respectively, the best position (i.e. matriarch) of jth clan for $j = 1, 2, \cdots, C$ and positions of all elephants in jth clan for $j = 1, 2, \cdots, C$. The parameter r is a random number in the range $r = [0,1]$.

The best position which represents the matriarch cannot be updated by(7). The matriarch movement is updated by

$$X_{\text{best},j} = \beta X_{\text{center},j} \tag{8}$$

Where β is a factor such that $\beta = [0,1]$ and

$$X_{\text{center},j} = \frac{1}{R} \sum_{j=1}^{R} X_{i,j} \tag{9}$$

The worst position of each clan denotes the male elephant leaving the clan. The worst position is updated as

$$X_{\text{worst},j} = X_{\min} + r \left(X_{\max} - X_{\min} + 1 \right) \tag{10}$$

Where $X_{\text{worst},j}$ is updated position of worst elephant of jth clan for $j = 1, 2, \cdots, C$. $X_{\min}$ and $X_{\max}$ represent, respectively, the minimum and maximum positions. The parameter r is random number such that $r = [0,1]$.

This completes one iteration of EHO. The same process continues until termination criterion meets.

6.Results and discussion

In this work, the parameters [12] of plants considered are $K = 6$, $\tau_a = 2$, $\tau_b = 4$ and $\tau_c = 6$.

For above values, (6) becomes

$$E(s) = \frac{B_1 s^3 + B_2 s^2 + B_3 s + B_4}{A_0 s^4 + A_1 s^3 + A_2 s^2 + A_3 s + A_4} \tag{11}$$

where,

$$A_0 = T_i \ \tau_a \ \tau_b \ \tau_c \tag{12}$$

$$A_1 = T_i \left(\ \tau_b \ \tau_c + \tau_a \ \tau_c \right) \tag{13}$$

$$A_2 = T_i \left(K \ K_p \ T_d + \tau_c \right) \tag{14}$$

$$A_3 = T_i \left(1 + K \ K_p \right) \tag{15}$$

$$A_4 = K \ K_p \tag{16}$$

$$B_1 = T_i \ \tau_a \ \tau_b \ \tau_c \tag{17}$$

$$B_2 = T_i \left(\ \tau_b \ \tau_c + \tau_a \ \tau_c \right) \tag{18}$$

$$B_3 = T_i \ \tau_c \tag{19}$$

$$B_4 = T_i \tag{20}$$

The alpha and beta tables (*Table 2* and *Table 3*) modifies to *Table 4* and *Table 5*, respectively.

Table 4 Alpha table

	$c_0^0 = A_0$	$c_2^0 = A_2$	$c_4^0 = A_4$
	$c_0^1 = A_1$	$c_2^1 = A_3$	$c_4^1 = 0$
$\alpha_1 = c_0^0 / c_0^1$	$c_0^2 = c_2^0 - \alpha_1 c_2^1$	$c_2^2 = c_4^0$	
$\alpha_2 = c_0^1 / c_0^2$	$c_0^3 = c_2^1 - \alpha_2 c_2^2$	$c_2^3 = 0$	
$\alpha_3 = c_0^2 / c_0^3$	$c_0^4 = c_2^2$		
$\alpha_4 = c_0^3 / c_0^4$			

Table 5 Beta table

	$d_0^1 = B_1$	$d_2^1 = B_3$
	$d_0^2 = B_2$	$d_2^2 = B_4$
$\beta_1 = d_0^1 / c_0^1$	$d_0^3 = d_2^1 - \beta_1 c_2^1$	
$\beta_2 = d_0^2 / c_0^2$	$d_0^4 = d_2^2 - \beta_2 c_2^2$	
$\beta_3 = d_0^3 / c_0^3$		
$\beta_4 = d_0^4 / c_0^4$		

The performance index, given by (4) turn out to be

$$J = \frac{1}{2} \sum_{i=1}^{4} \frac{\beta_i^2}{\alpha_i} \tag{21}$$

$$J=\frac{1}{2}\left\{\begin{array}{l}\frac{B_1^2}{A_0A_1}+\frac{B_2^2}{A_1\left(A_2-\alpha_1A_3\right)}+\\ \frac{\left(B_3-\beta_1A_3\right)^2}{\left(A_2-\alpha_1A_3\right)\left(A_3-\alpha_2A_4\right)}+\\ \frac{\left(B_4-\beta_2A_4\right)^2}{\left(A_3-\alpha_2A_4\right)A_4}\end{array}\right\} \quad (22)$$

Minimizing (22) using EHO, the obtained results are tabulated in *Table 6*. *Table 6* also provides the settings obtained due to ZN, PIAE, SO-OV, NO-OV and MT-ZN rules.

Table 6 Controller parameters

S.N.	Rule	K_p	T_i	T_d
1	Proposed	891.26	666.21	999.62
2	ZN	1	6.28	1.57
3	PIAE	1.17	5.03	1.89
4	SO-OV	0.55	6.28	4.15
5	NO-OV	0.33	6.28	4.15
6	MT-ZN	1	6.28	1.57

Figure 2 shows the unit step responses obtained for different settings. The time domain specifications (settling time and peak over shoot) are tabulated in *Table 7*.

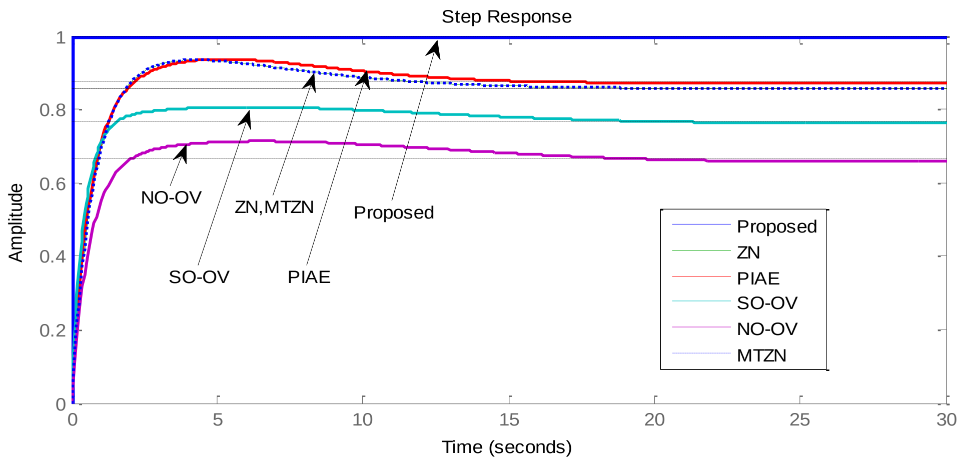

Figure 2 Step response of the system

Table 7 Settling time and peak overshoot

S.N.	Rule	T_s (Sec.)	M_p (%)
1	Proposed	5.26e-8	0.00
2	ZN	11.90	8.96
3	PIAE	11.50	6.97
4	SO-OV	13.90	5.00
5	NO-OV	15.60	7.29
6	MT-ZN	11.90	8.96

From the qualitative and quantitative results provided in this section, it can easily be concluded that EHO based tuning provides better controller settings compared to other methods.

7.Conclusion

An optimal PID controller based on evolutionary computation is proposed in this work for liquid level control of three tank system. The controller settings are obtained by minimizing the ISE of unit step response. The ISE is obtained in terms of alpha and beta parameters. Recently proposed optimization technique, elephant herding optimization, is used for minimizing the ISE. The EHO based tuning method shows better performance in terms of qualitative and quantitative results.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

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