PID tuning for position control of DC servo-motor using TLBO

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Abstract

In this paper, an optimal proportional–integral–derivative (PID) controller is suggested for position control of DC servo-motor system. The performance index considered is integral-square-error (ISE) of unit step response. The ISE is designed with the help of alpha and beta tables. The teaching-learning-based optimization (TLBO) algorithm is utilized for minimizing the performance index. The proposed results are compared with other existing well-known methods. It is found that the TLBO based tuning provided better results.

Keywords

ISE, Optimization, PID controller, Position control, Servo-motor, TLBO.

1.Introduction

Being simple and reliable, the proportional-integral-derivative (PID) controllers are still used in various engineering applications. One of the most respected methods is Ziegler-Nichols (ZN) tuning rule [1]. Some other tuning rules include 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].

Although rule based tuning criteria provide good dynamic response however they are not best suited for optimal control. Due to this various evolutionary and swarm intelligence based tuning methods have been proposed in literature. Luus-Jaakola optimization procedure for PID controller tuning [3], evolutionary computation based PID tuning [4], PID controller tuning based on particle swarm optimization [5], PID tuning using soft computing techniques [6], PID controller tuning based on genetic algorithm [7], etc. are some examples of evolutionary and swarm intelligence based tuning methods. This paper proposes swarm intelligence based tuning method which utilizes teaching-learning-based optimization (TLBO) algorithm. The TLBO is applied for optimizing various engineering problems [8-11].

The advantages of TLBO algorithm are simplicity, efficiency and no algorithm-specific parameters. The design criterion considered in this work is integral-square-error (ISE) of unit step response. The ISE is constructed in terms of alpha and beta parameters.

The brief layout of this paper is as follows. Section 2 describes the DC servo-motor and its model. Section 3 gives the structure of PID controller. The proposed method of tuning is discussed in section 4. The teacher learner based optimization algorithm is detailed in section 5. Section 6 discusses the simulation parameters and results obtained. The conclusion is provided in section 7.

2.The servo-motor

The block diagram shown in *Figure 1* shows the closed loop position control of DC servo-motor.

Figure 1 Closed loop position control of DC servo-motor

The transfer function of plant i.e. DC servo-motor [12] is given as

$$G(s) = \frac{K}{s(L_a s + R_a)(J_0 s + B_0) + KK_1 s} \quad (1)$$

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where, K is electromotive force constant, K_1 is back EMF constant, J_0 is moment of inertia of motor, B_0 is viscous friction coefficient, R_a is armature resistance and L_a is armature inductance. The $C(s)$ in block diagram represents the controller.

3. The controller

The transfer function of proportional-integral-derivative (PID) controller considered in this work is described as

$$C(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad (2)$$

where, K_p , T_i and T_d are, respectively, the proportional gain, integral time constant and derivative time constant. Other controller settings [2] due to Ziegler-Nichols (ZN) criterion, 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 are given in Table 1. The parameters K_u and T_u represent, respectively, the ultimate gain and corresponding period T_u .

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	$0.2K_u$	$0.5T_u$	$0.33T_u$

Table 2 Alpha table

	$c_0^0 = a_0$ $c_0^1 = a_1$	$c_2^0 = a_2$ $c_2^1 = a_3$	$c_4^0 = a_4$ $c_4^1 = a_5$	$c_6^0 = a_6$...
$\alpha_1 = c_0^0 / c_0^1$	$c_0^2 = c_0^0 - \alpha_1 c_2^1$	$c_2^2 = c_2^0 - \alpha_1 c_4^1$	$c_4^2 = c_4^0 - \alpha_1 c_6^1$	...
$\alpha_2 = c_0^1 / c_0^2$	$c_0^3 = c_0^1 - \alpha_2 c_2^2$	$c_2^3 = c_2^1 - \alpha_2 c_4^2$	$c_4^3 = c_4^1 - \alpha_2 c_6^2$	...
$\alpha_3 = c_0^2 / c_0^3$	$c_0^4 = c_0^2 - \alpha_3 c_2^3$	$c_2^4 = c_2^2 - \alpha_3 c_4^3$	$\vdots$	
$\alpha_4 = c_0^3 / c_0^4$	$c_0^5 = c_0^3 - \alpha_4 c_2^4$	$\vdots$		
$\alpha_5 = c_0^4 / c_0^5$	$\vdots$			
$\vdots$				

Table 3 Beta table

	$d_0^1 = b_1$ $d_0^2 = b_2$	$d_2^1 = b_3$ $d_2^2 = b_4$	$d_4^1 = b_5$ $d_4^2 = b_6$	$d_6^1 = b_7$...
$\beta_1 = d_0^1 / c_0^1$	$d_0^3 = d_0^1 - \beta_1 c_2^1$	$d_2^3 = d_2^1 - \beta_1 c_4^1$	$d_4^3 = d_4^1 - \beta_1 c_6^1$	...
$\beta_2 = d_0^2 / c_0^2$	$d_0^4 = d_0^2 - \beta_2 c_2^2$	$d_2^4 = d_2^2 - \beta_2 c_4^2$	$d_4^4 = d_4^2 - \beta_2 c_6^2$	...
$\beta_3 = d_0^3 / c_0^3$	$d_0^5 = d_0^3 - \beta_3 c_2^3$	$d_2^5 = d_2^3 - \beta_3 c_4^3$	$\vdots$	
$\beta_4 = d_0^4 / c_0^4$	$d_0^6 = d_0^4 - \beta_4 c_2^4$	$\vdots$		
$\beta_5 = d_0^5 / c_0^5$	$\vdots$			
$\vdots$				

5	MT-ZN	$0.6K_u$	$0.5T_u$	$0.125T_u$
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4. The proposed tuning method

The integral-square-error (ISE) of unit step input is minimized in this work. The error in s -domain for system given in Figure 1 can be written as

$$E(s) = R(s) - Y(s) = \frac{R(s)}{1 + G(s)C(s)} \quad (3)$$

where $R(s)$ and $Y(s)$ denotes respectively the desired input and actual output. The input is taken as

$$R(s) = \frac{1}{s} \quad (4)$$

In general, the error can be denoted as

$$E(s) = \frac{b_1 s^{n-1} + \dots + b_n}{a_0 s^n + a_1 s^{n-1} + \dots + a_n} \quad (5)$$

where n is the order of error $E(s)$.

The ISE

$$J = \int_{t=0}^{t=\infty} e^2(t) dt \quad (6)$$

for (5) in terms of alpha and beta parameters [13] is given as

$$J = \frac{1}{2} \sum_{i=1}^n \frac{\beta_i^2}{\alpha_i} \quad (7)$$

The parameters α_i and β_i for $i=1, 2, \dots, n$ are obtained from alpha table and beta table as given in Table 2 and Table 3.

5. Teacher learner based optimization

The teacher learner based optimization (TLBO) is recently proposed by Rao et al. [14]. It consists two phases: teacher phase and learner phase. In former phase, the teacher tries to improve the performance of class to his level. In latter phase, students interact to each other to improve their performance in various subjects offered to them.

Suppose, there is a total R learners in the class and the subjects offered are C . The performance of i th learner, $i = 1, 2, \dots, R$, in j th subject, $j = 1, 2, \dots, C$ is $X_{i,j}$.

In teacher phase, teacher (i.e. best learner of the class) tries to improve the performance of students as:

$$newX_{i,j} = X_{i,j} + r(X_{best,j} - T_f \bar{X}_{i,j}) \quad (8)$$

where $newX_{i,j}$ is updated performance and r is a random number such that $r = (0,1)$. $X_{best,j}$ and $\bar{X}_{i,j}$ represent respectively the performance of best student and average performance of the class. The parameter T_f is known as teacher factor which is given as

$$T_f = \{1, 2\} \quad (9)$$

At the end of teacher phase, $newX_{i,j}$ is updated if it is a better solution otherwise old solution is retained. The solution at the end of teacher becomes input to the learner phase. In learner phase, each learner interact to other as given by

$$newX_{i,j} = X_{i,j} + r(X_{p,j} - X_{q,j}) \quad (10)$$

where p and q are two randomly selected learners such that $p \neq q$, $f(X_{p,j}) < f(X_{q,j})$ and $r = (0,1)$.

At the end of learner phase, the solution $newX_{i,j}$ is updated in X if it is better otherwise $X_{i,j}$ is retained. This completes one iteration of TLBO algorithm. This process continues until desired criterion meets.

6. Results and discussion

The parameters of DC servo-motor [12] are given as $K = 0.01$, $K_1 = 0.01$, $R_a = 1$, $L_a = 0.5$, $J_0 = 0.01$ and $B_0 = 0.1$. For these values, (5) becomes

$$E(s) = \frac{b_1 s^3 + b_2 s^2 + b_3 s + b_4}{a_0 s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4} \quad (11)$$

Where,

$$a_0 = T_i L_a J_0 \quad (12)$$

$$a_1 = T_i (L_a B_0 + R_a J_0) \quad (13)$$

$$a_2 = T_i (B_0 R_a + K K_1 + K_p K T_d) \quad (14)$$

$$a_3 = T_i K K_p \quad (15)$$

$$a_4 = K K_p \quad (16)$$

$$b_1 = T_i L_a J_0 \quad (17)$$

$$b_2 = T_i (L_a B_0 + R_a J_0) \quad (18)$$

$$b_3 = T_i (B_0 R_a + K K_1) \quad (19)$$

$$b_4 = 0 \quad (20)$$

The alpha and beta tables (Table 2 and Table 3) for (11) becomes, respectively, Table 4 and Table 5.

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

	$d_0^1 = b_1$	$d_2^1 = b_3$
	$d_0^2 = b_2$	$d_2^2 = 0$
$\beta_1 = d_0^1 / c_0^1$	$d_0^3 = d_2^1 - \beta_1 c_2^1$	
$\beta_2 = d_0^2 / c_0^2$	$d_0^4 = -\beta_2 c_2^2$	
$\beta_3 = d_0^3 / c_0^3$		
$\beta_4 = d_0^4 / c_0^4$		

The performance index, given by (7), takes place

$$J = \frac{1}{2} \sum_{i=1}^4 \frac{\beta_i^2}{\alpha_i} = \frac{1}{2} \left\{ \frac{\beta_1^2}{\alpha_1} + \frac{\beta_2^2}{\alpha_2} + \frac{\beta_3^2}{\alpha_3} + \frac{\beta_4^2}{\alpha_4} \right\} \quad (21)$$

$$J = \frac{1}{2} \left\{ \frac{\left(\frac{b_1}{a_1} \right)^2}{a_0 / a_1} + \frac{\left(\frac{b_2}{a_1} \right)^2}{a_1 / (a_2 - \alpha_1 a_3)} + \frac{\left(\frac{(b_3 - \beta_1 a_3)}{(a_2 - \alpha_1 a_3)} \right)^2}{(a_3 - \alpha_2 a_4)} + \frac{\left(\frac{(b_4 - \beta_2 a_4)}{a_4} \right)^2}{(a_3 - \alpha_2 a_4) / a_4} \right\} \quad (22)$$

The optimal results obtained by minimizing (22) using TLBO are provided in Table 6. Table 6 also tabulates the controller parameters obtained due to ZN, PIAE, SO-OV, NO-OV and MT-ZN rules.

Figure 2 shows the unit step responses for proposed method and other existing settings. The settling time is provided in Table 7.

Table 6 Controller parameters

S.N.	Rule	K_p	T_i	T_d
1	Proposed	999.99	127.84	999.99
2	ZN	72.07	0.70	0.17
3	PIAE	84.08	0.56	0.21
4	SO-OV	39.63	0.70	0.46
5	NO-OV	24.02	0.70	0.46
6	MT-ZN	72.07	0.70	0.17

Table 7 Settling time

S.N.	Rule	T_s (Sec.)
1	Proposed	0.65
2	ZN	5.77
3	PIAE	4.56
4	SO-OV	5.59
5	NO-OV	8.90
6	MT-ZN	5.77

Figure 2 Step response of the system

From response plotted in *Figure 2* and settling time provided in *Table 7*, it is clear that the proposed method gives better results compared to other methods.

7. Conclusion

In this paper, an optimal PID controller for position control of DC servo-motor is proposed. For optimal settings, an ISE of unit step response is considered as design criterion. The ISE is obtained with the help of alpha and beta parameters. The teacher learner based optimization algorithm is employed for minimizing the ISE. The obtained controller parameters provide 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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