Position control of DC Servomotor with Nonlinearity Using ICA Based on FLC

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Abstract—DC Servomotors are used in wide variety fields such as robotics, industry, and mechatronics systems that precise positioning is considerable. Nonlinearities such as Backlash, Dead Zone and load changes limit the performance of precise position control of DC servomotors. Using multi-loop control systems based on principles of cascade control, this paper deals with position control of DC servomotor with non-linear parameters such as backlash, dead zone and load change. To eliminate the effects of Nonlinearities Fuzzy Logic Controllers (FLCs) are proposed in position and speed control loops. In order to achieve better control performance, the Imperialist Competitive Algorithm (ICA) is applied to optimize the parameters of the FLCs consisting of fuzzy control rules and normalization factors. Simulation results show the better performance of proposed ICA-optimized FLC based drive in comparison with FLC and ICA-optimized PI.

Keywords—DC Servomotor; Nonlinearities; Fuzzy Logic Controller (FLC); Imperialist Competitive Algorithm (ICA)

I. INTRODUCTION

The DC servomotors are utilized in applications such as robotic arms, industrial machine tools, and medical applications. For such applications position control of DC servomotors are more important but nonlinearities such as backlash, dead zone, and load changes cause undesirable effects on the system efficiency [1].

Generally, conventional controllers like PI, PID are applied to control the position of a DC servomotor. But, the performance of conventional controllers is dependent on the exact machine model and accurate gains [2]. Moreover, non-linear factors such as backlash, dead zone, load disturbance, and thermal change machine parameters and accordingly disrupt the performance of the conventional controllers. So, these control schemes are not able to eliminate the effects of the nonlinearities appropriately [1].

To overcome the effect of these nonlinearities, advantage can be made of artificial intelligence techniques such neural networks, genetic algorithm, and Fuzzy Logic Controller (FLC) [1, 3-5].

FLC is an intelligent but computationally simple controller [6, 7]. The advantages of FLC over conventional controllers are that it is able to handle nonlinearities and that its design is independent of system parameters [8].

However, there is no systematic procedure for designing and tuning the FLC. It is takes time and requires the designer to be particularly experienced and skillful for the tedious task of fuzzy tuning [8-10].

In this paper, at first cascade PI controllers using cascade control structure, optimized by Imperialist Competitive Algorithm (ICA) are developed to control the position of DC servomotor with and without nonlinearities. After that, in order to eliminate the nonlinearities effects, two FLCs are proposed as position and speed controllers. To avoid the lengthy computation and to achieve a better control performance, the ICA is employed to tune the parameters of the FLC consisting of fuzzy control rules and normalization factors. Also presented is assessment of simulation results obtained using the proposed technique in comparison with FLC and ICA-optimized PI.

II. MODEL OF DC SERVOMOTOR

Fig. 1 gives the block diagram of DC servomotor. A model of a DC servomotor basis of this block diagram can be represented by below equation as follow:

\[ \frac{\omega(s)}{\frac{1}{s}} = \begin{bmatrix} F_1(s) & F_2(s) \end{bmatrix} \begin{bmatrix} V_a(s) \\ T_L(s) \end{bmatrix} \]

\[ F_1(s) = \frac{K}{J_s + B} \left[ I_a + R_a s \right] + K^2 \]

\[ F_2(s) = \frac{\left[ R_a + L_a s \right]}{\left[ J_s + B \right]} \left[ I_a + R_a s \right] + K^2 \]

where \( V_a(s) \) is armature voltage as equation 2. \( T_L(s) \) is load torque and \( K \) is servomotor constant those can be expressed as equation 3 and equation 4, respectively. Also, Equation 5 shows the relationship between the angular position and the angular speed [11].

\[ V_a(s) = L_a I_a s + R_a I_a + E(s) \]
\[ T_M - T_e = J \omega(s).s + B \omega(s) \]  
(3)

\[ K = k_p \phi \]  
(4)

\[ \theta(s) = \frac{1}{s} \omega(s) \]  
(5)

where

- \( \omega(s) \) servomotor angular velocity
- \( \theta(s) \) servomotor angular position
- \( I_a \) armature current
- \( R_a \) armature resistance
- \( L_a \) armature inductance
- \( T_{em} \) electromagnetic torque
- \( J \) moment of inertia
- \( B \) coefficient of friction
- \( k_c, k_t \) servomotor constant.

### III. THE PROPOSED CONTROL SCHEME

The schematic representation of the proposed controller is shown in Fig. 2. This controller is based on principles of cascade control and consists of three control loops named position control loop, speed control loop, and current control loop[12].

In this paper, the controllers of the position and the speed control loops are PI or fuzzy logic types. Also, the controller of current control loop is PI-type.

As it is illustrated in the figure the ICA is utilized to optimize the parameters of controllers in order to satisfy the design criteria.

#### A. Nonlinear Dc Servomotor

The block diagram of the DC servomotor model with nonlinearities is shown in Figure 3. The nonlinearity such as backlash, dead zone, and load change were added to the DC servomotor model to make the model relatively act the same way as the real DC servomotor.

#### B. Fuzzy Logic Controller (FLC)

Fig. 4 depicts proposed configuration of the FLC that is applied as position and speed controllers. The inputs of FLC are the error signal \( e \) and the derivative of the error signal \( e \). Then these have to be fuzzified. The fuzzy control algorithm includes a set of fuzzy control rules that are related through the concept of MFs and the composition rule of inference. Fuzzy control sets have to be defuzzified because the plant cannot respond directly to these control sets. On the other hand, the controller output \( \Delta U \) is summed or integrated in order to generate the actual control signal \( U \) as speed \( \omega' \) in position control loop or current \( I_{as} \) in speed control loop. Moreover, \( G_e, G_{de}, \) and \( G_{du} \) are normalization factors. Input variables of FLC have to be normalized over a range specified for MFs and also, output variable of FLC has to be normalized over a range specified for plant. An appropriate normalization has a direct impact on efficiency of the controller. Also, the performance of a FLC depends on the selection of the control rules, MFs, and normalization factors. In line with this, the ICA is used to optimize the fuzzy control rules and the normalization factors [13].

#### C. Imperilist Competitive Algorithm (ICA)

- **Start**
- Initialize the empires
- Move the colonies toward their relevant imperialist
- Is there a colony in an empire which has lower cost than that of imperialist?
- Yes
- Exchange the positions of that imperialist and colony
- Compute the total cost of all colonies
- Pick the weakest colony from the weakest empire and give it to the empire that has the most likelihood to possess it
- Is there an empire with no colonies?
- Yes
- Eliminate this empire
- Stop condition satisfied?
- Yes

**Done**

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Figure 2. Cascade controller optimized by ICA

Figure 3. Block diagram of nonlinear DC servomotor

Figure 4. Block diagram of FLC

Figure 5. Flowchart of Imperialist Competitive Algorithm
ICA is a recently introduced optimization algorithm. Optimization through this algorithm has basis on the concept of imperialistic competition. Fig. 5 portrays the flowchart of ICA. ICA takes advantage of the assimilation policy adopted by imperialistic countries since the 19th century. According to this policy, the imperialists seek to improve the economical, cultural, and political situation of their respective colonies so as to win their loyalty. This theory uses the term “empire” to refer an imperialist and its colonies. The power of an empire depends on the power of its imperialist and its colonies. In imperialistic competitions, weaker imperialists lose their colonies to more powerful empires. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist state. This movement is a simple model of assimilation policy that was pursued by some imperialist states.

Fig. 6 shows the movement of a colony towards the imperialist. In this movement, x and θ are random numbers with uniform distribution as shown in equations (4) and (5) respectively and d is the distance between colony and the imperialist.

x ~ U(0, β × d)  
θ ~ U(−γ, γ)  

where β and γ are arbitrary numbers that modify the area where colonies randomly search around the imperialist.

The weak empires, once they lose all their colonies, will be the colonies of other empires. Eventually, all the weak empires will collapse, leaving only one powerful empire [14].

The proportional and integral gains of the position PI controller are specified by P1 and P2, respectively. P3 is proportional gain and P4 is integral gain of the speed PI controller. Also, P5 and P6 are proportional and integral gains of the current PI controller, respectively. The six points (Pi, 1 ≤ i ≤ 6) are set together to form the array country.

Cost Function = ∫₀^t |de|dt  

In ICA, the initial number of colonies is set at 100, seven of which are chosen as the initial imperialists. Also β and γ are set at 2 and 0.6 (Rad) respectively. The maximum iterations of the ICA set at 80.

B. Optimizing FLCs Using ICA

Depending on the operation of the system, twenty five control rules and nine control rules can be written in fuzzy logic for position and speed controllers, respectively. To design such controllers, in the position control loop the input variables of position error e and derivative of position error Δe and also, output variables ωe are considered to have five MFs: NB (Negative Big), N (Negative), ZE (Zero), P (Positive), and PB (Positive Big) as shown in Fig. 7. Table I shows the twenty five fuzzy if-then rules of position FLC.

Additionally, in the speed control loop the input variables of speed error e and derivative of speed error Ae are considered to have three MFs: N, ZE, and P as shown in Fig. 8. The MFs of the output (I*) are NB, N, ZE, P, and PB is shown in Fig. 9. Table II shows the nine fuzzy if-then rules of speed FLC.
To utilize the ICA in optimizing the position and speed FLCs, the parameters of the FLCs consist of fuzzy control rules and normalization factors, in the ICA are coded in the form of the array Country. Also, a cost function is defined so that it is minimized in order to satisfy the design criteria.

To optimize the parameters of FLCs using ICA the parameters are coded as follow:

The fuzzy control rules of position FLC can be specified by means of twenty five individual points P1 to P25 as shown in Table III. Similarly, the fuzzy control rules of speed FLC can be represented by means of nine individual points P26 to P34 as shown in Table IV.

Also, the normalization factors of position FLC $G_e$, $G_{de}$, and $G_{deu}$ can be specified by P35, P36, P37. Eventually, three points P38, P39, P40 are used for the normalization factors of speed FLC $G_{ew}$, $G_{dew}$, and $G_{deu}$.

Hence, the problem of finding the parameters of FLCs are reduced to the problem of determining 40 points (P1, 1 ≤ i ≤ 40). The 40 points are put together to form the array Country.

$$Country = [P_1, P_2, P_3, ..., P_{40}]$$

Also, the performances of the designed FLCs are evaluated on the basis of the cost function $IAE$.

In ICA, the initial number of colonies is set at 150, eighteen of which are chosen as the initial imperialists. Also $\beta$ and $\gamma$ are set at 2 and 0.6 (Rad) respectively. The maximum iterations of the ICA set at 100.

V. SIMULATION RESULTS

The fuzzy control rules optimized by ICA are shown in Table V and VI.

For evaluation purposes, first a comparison is drawn in MATLAB toolbox for the DC servomotor which use PI controllers and are optimized through ICA. This comparison is between the two states of “with nonlinearities” and “without nonlinearities” in order to study the position response of the servomotor in each case.

The performance of the DC servomotor was evaluated for a period of 1s against a reference position of 0.5 Rad. Also, the validity of the system has been examined with load torque.
change TL=0.38 N.m at t=0.4s. The simulation results of the both optimized controllers with and without nonlinearities are plotted as shown in Fig. 10. As is shown in this figure, nonlinearities cause oscillation in the position tracking control system.

At the next stage, the position response of the DC servomotor with ICA-optimized PI (ICA-PI) controllers is compared with FLCs at the present of nonlinearities as shown in Fig. 11. Also, the comparison of output current of DC servomotor with ICA-PI controllers and FLCs is shown in Fig. 12. As are shown in Fig. 11 and Fig. 12 DC servomotor with FLCs can overcome the nonlinearities and eliminate the oscillation.

Eventually, the position response of the DC servomotor with the FLCs and with the proposed ICA-optimized FLCs (ICA-FLCs) is plotted as shown in Fig. 13. This figure depicts that the response of the DC servomotor with ICA-FLCs is relatively better than FLCs in terms of the accuracy of position tracking.

The cost functions IAE are compared in Table VII. It is obvious from this table that ICA-FLCs based drive has a better performance in comparison with FLCs and ICA-optimized PI controllers.

TABLE VII. COMPARISON OF COST FUNCTIONS

<table>
<thead>
<tr>
<th>Method</th>
<th>IAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICA-PI controllers</td>
<td>0.00024</td>
</tr>
<tr>
<td>FLCs</td>
<td>0.00020</td>
</tr>
<tr>
<td>ICA-FLCs</td>
<td>0.00012</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In this paper, a method of optimizing FLCs using ICA was proposed for the position control of a DC servomotor with non-linear parameters such as backlash, dead done, and load change using multi-loop control systems based on principles of cascade control. In order to prove the superiority of the proposed controller scheme, it was compared with FLCs and ICA-optimized PI controllers in terms of performance. Comparative simulation results indicate that the ICA-optimized FLCs based drive is more efficient than FLC and ICA-optimized PI.

APPENDIX

Following are the specification of the DC motor chosen for the simulation.

Armature resistance: $R_a = 2\Omega$
Armature inductance: $L_a = 0.012H$
Servomotor constant: $k_t = 0.1N.m/\alpha$
Servomotor constant: $k_t = 0.1V.s/\alpha$\r
Moment of inertia: $J = 1Kg.m^2$
Coefficient of friction: $B = 0.001N.m.s$
Width of dead zone: $2V=4V$
Dead-band width of backlash: $2D=1$

REFERENCES


