



Optimal Fuzzy Sliding Mode Control Design for Practical DC Motor by Utilizing Jaya Algorithm

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Abstract

In this study, an optimal fuzzy sliding mode control (OFSMC) is proposed for the speed and position of a DC motor. For robustness against external disturbance and parameter uncertainty, sliding mode control (SMC) is offered. To improve the effectiveness of the SMC and to decrease the chattering effects, fuzzy logic systems are combined with the proposed sliding mode controller. Moreover, by utilizing of Jaya Optimization Algorithm, the parameters of the suggested controller are optimized. By using Jaya Algorithm, the sliding surface of controller is tuning online that has more benefits in verse of constant gains. As expecting OFSMC is the best control performance (lower error values) among other suggested controllers that merits of applying the Jaya optimization algorithm for the optimization of the sliding surface gains system are apparent. In following, by utilizing the Lyapunov stability theorem closed-loop system stability is proved. Finally, the experimental results have denoted the merits of the suggested controller.

Keywords: DC Motor, Fuzzy logic system, Sliding mode control, Jaya Optimization Algorithm.

1. Introduction

Direct current (DC) motor is one of the common electrical machines that has been utilized in laboratories and industrial applications. In recent years DC motors have been used in electric winches, robotic industries, electric cars, home applications and etc (Arof et al., 2019; Barkas et al., 2020; Yunardi et al., 2021). Position and speed control of DC motors are two main factors in their applications. Two main issues that be considered in DC motor controls are time-varying motor parameters and the noise in the system loop. The PID controller is the one of popular methods that have been suggested widely in industrial control systems. In (Hammoodi et al., 2020) some experiments have been performed to tune the parameters of PID controller and determine the best mathematical model. It worth be mentioning, PID does not work effectively in applications of nonlinear, and complex systems (Nouri et

al., 2008). To resolve these issues, the sliding mode control (SMC) technique can be suggested. The sliding mode controller is an attractive method for researchers in recent studies. The main merit of the sliding mode is low sensitivity in the presence of changes in plant parameters and disturbances. The SMC has many benefits such as simplicity, robustness against disturbances and uncertainties (Esmail & Fathi, 2022; Maghfiroh et al., 2020; Rauf et al., 2020). It is worth mentioning that the switching gains of the control signal terms have large values to decrease the results of uncertainties and warranty of the system stability. On the other hand, the high-value gain can be caused chattering issues that are a destructive factor for the control systems. In recent years, various recommendations for the mentioned problem are offering such as fuzzy sliding mode control (Aghaseyedabdollah et al., 2022a; Alaviyan & Afzalian, 2020; Zaghrat et al., 2022), type 2

fuzzy sliding mode control (Dilmi et al., 2021), fuzzy fractional sliding mode control (Aghaseyedabdollah et al., 2021a) and neural network-based sliding mode control (Aribowo et al., 2021). In recent studies, the mixing of fuzzy systems with sliding mode controllers has on of the favorite methods. Fuzzy sliding mode control (FSMC) has the advantage of both methods to improve the efficiency of the control and remove chattering effects. It is worth mentioning that a proper selection for membership functions and control rules of an FLS needs expert knowledge. Hence optimization tools can be suggested to adjust the parameters of the FLSs. In recent years Genetic optimization algorithm (Lotfy et al., 2020), Whale Optimization Algorithm (WOA) (Razmjoo et al., 2020), Gray Wolf Optimization Algorithm (GWO) (Dutta & Nayak, 2021), Grasshopper Optimization Algorithm (GOA) (Dutta & Nayak, 2021), Artificial Bee Colony (ABC) (Venu et al., 2021), and Jaya Algorithm (Rao, 2016) are major popular optimization algorithms. The Jaya algorithm is a new metaheuristic methodology that does not need specific parameters to attain the desired performance. In (Aghaseyedabdollah et al., 2021b) Jaya optimization algorithm has been utilized for optimization of the membership function of the fuzzy sliding surface system. In this paper, an OFSMC is offered for the speed and position of a DC motor that by utilizing a fuzzy logic system the chattering values have decreased. Moreover, the controller parameters have been optimized by the Jaya algorithm. The suggested controller attains removes chattering and decreases error in uncertainty conditions. Also, the Lyapunov stability theorem is used for stability analysis. The rest of this article is structured as follows: In Section 2 DC motor mathematic model is expressed and in Section 3 design of offered controllers is presented. Also, Jaya and optimizing its parameters are represented in mentioned section. In Section 4, the experiments and results of the suggested control techniques for DC motor are displayed. Finally, the paper is concluded in Section 5.

2. DC motor model

DC motors are proper to offer wide-range speed control and position adjustment. In the armature control of DC motors, the voltage has been applied to the field winding that motor is

tuned without changing the voltage applied to field. The DC Motor schematic is denoted in Fig.1. The armature circuit has differential equation as follows:

$$v(t) = R_a \cdot i_a(t) + L_a \cdot \frac{di_a(t)}{dt} + e_b(t) \quad (1)$$

$$e_b(t) = K_b \cdot w(t) \quad (2)$$

where $v(t)$ is the input voltage, R_a denotes the armature resistance, L_a shows the armature inductance, $i_a(t)$ is the armature current, $e_b(t)$ is the back electromotive force (EMF), $w(t)$ is angular velocity of rotor, K_b is back EMF coefficient. The torque equation can be written as:

$$T_m(t) = K_T \cdot i_a(t) \quad (3)$$

$$T_m(t) = J_m \cdot \frac{dw(t)}{dt} + B_m \cdot w(t) \quad (4)$$

By combining the upper equations together:

$$v_a(t) = R_a \cdot i_a(t) + L_a \cdot \frac{di_a(t)}{dt} + K_b \cdot w(t) \quad (5)$$

$$K_T \cdot i_a(t) = J_m \cdot \frac{dw(t)}{dt} + B_m \cdot w(t) \quad (6)$$

Applying Laplace transforms to (5) and (6) can be expressed as:

$$V_a(s) = R_a \cdot I_a(s) + L_a \cdot I_a(s) \cdot s + K_b \cdot w(s) \quad (7)$$

$$K_T \cdot I_a(s) = J_m \cdot w(s) \cdot s + B_m \cdot w(s) \quad (8)$$

The voltage of armature can be presented as:

$$V_a(s) = w(s) \cdot \frac{1}{K_T} + [L_a \cdot J_m s^2 + (R_a \cdot J_m + L_a \cdot B_m) \cdot s + (R_a \cdot B_m + K_b \cdot K_T)] \quad (9)$$

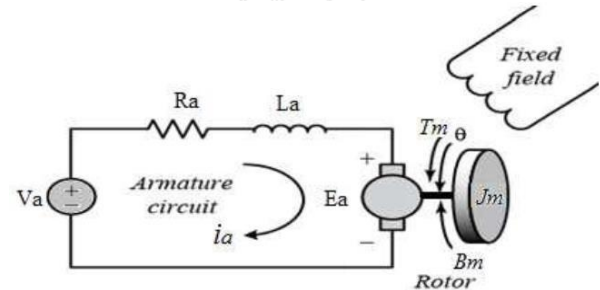


Fig. 1. The DC Motor schematic

The following transfer function is the relation between armature voltage and shaft angular speed:

$$\frac{w(s)}{V_a(s)} = \frac{K_T}{[L_a J_m s^2 + (R_a J_m + L_a B_m) \cdot s + (R_a B_m + K_b K_T)]} \quad (10)$$

Also, the position equation can be given as:

$$\theta(s) = \frac{w(s)}{s} \quad (11)$$

The transfer function between armature voltage as input and the position of the shaft as output when the motor without load is:

$$\theta(s) = \frac{\theta(s)}{V_a(s)} = \frac{K_T}{[L_a J_m s^3 + (R_a J_m + L_a B_m) \cdot s^2 + (R_a B_m + K_b K_T)]s} \quad (12)$$

3. Controller design

3.1. Sliding mode control

The main aim of this section design of sliding mode control (SMC) method for the present DC motor. (SMC) is a non-linear controller that much popular in control of non-linear dynamic systems. One of main benefits of suggested method has been robusting system against uncertainties and external disturbances. The block diagram of the suggested sliding mode controller for DC motor is denoted in Fig. 2. First, by considering nth order plant with scalar control following as:

$$\dot{x} = Ax(t) + Bu(t) \quad (13)$$

In which, vector B as input vector with size $n \times 1$ and the system transformation matrix is denoted by A with size $n \times n$. In the following the suggested sliding surface can be given as follows:

$$s = [c_1 c_2 c_3][x_1 x_2 x_3] \quad (14)$$

where the vector C, is positive coefficients that explain the sliding surface in terms of the state vector x. By derivation of Eq. (14) and replacing equation (13) in it, we have:

$$\dot{s} = CAx(t) + CBu(t) \quad (15)$$

By putting $\dot{s} = 0$, the equivalent term can be calculated as:

$$u_{eq} = (CB)^T CAx(t) \quad (16)$$

Now by simplifying the above equation and considering equation (5,6):

$$\dot{X} = \{I - B(CB)^{-1}\}Ax(t) \quad (17)$$

Also, to obtain the asymptotic stability of Eq. (12) about the equilibrium point $s=0$, the second Lyapunov method is utilized for the stability analysis of the system.

$$V(t) = \frac{1}{2} s(t)^2 \quad (18)$$

Also, other conditions are essential to satisfy stability: (a) $\dot{V} < 0$ & (b) $m|s| \rightarrow \infty$ It is obvious that condition (b) can be satisfying and to achieve finite time convergence condition (a) is improved to the following equation:

$$\dot{V} \leq -\alpha V^{\frac{1}{2}}, \alpha > 0 \quad (19)$$

Now, by Integrating of above inequality in $0 \leq \tau \leq t$:

$$V^{\frac{1}{2}}(t) \leq -\frac{1}{2} \alpha t + V^{\frac{1}{2}}(0), \alpha > 0 \quad (20)$$

So, $V(t)$ in finite time (tr) reaches zero as:

$$t \leq -\frac{1}{\alpha} \frac{2V^{\frac{1}{2}}(0)}{r} \quad (21)$$

where, derivative of V is calculated as:

$$\dot{V} = \dot{s}s = S(Cx_2 + f(x_1, x_2, t) + u) \quad (22)$$

Supposing $u = -Cx_2 + v$, and using it into above equation, we have:

$$\dot{V} = S(f(x_1, x_2, t) + v) = Sf(x_1, x_2, t) + Sv \leq SL + Sv \quad (23)$$

By choosing $v = -\rho si(s)$, $\rho > 0$ and placing into Eq.

$$\dot{V} \leq |s|L|s|\rho = -|s|(\rho - L) \quad (24)$$

Putting Eq. (24) in Eq. (19), condition Eq. (22) has been written as follows:

$$\dot{V} \leq -\frac{1}{\sqrt{2}} \alpha |s|, \alpha > 0 \quad (25)$$

Eq. (25) is combined with Eq. (24) as follows:

$$\dot{V} \leq -|s|(\rho - L) = -\frac{\alpha}{\sqrt{2}} |s| \quad (26)$$

Hence, the control gain ρ is calculated as:

$$\rho = L + \frac{\alpha}{\sqrt{2}} \quad (27)$$

In which reach s to zero in finite time. Also, $\dot{s} \leq -\frac{\alpha}{\sqrt{2}} |s|$ is called as reaching condition that has been utilized for the sliding mode controller.

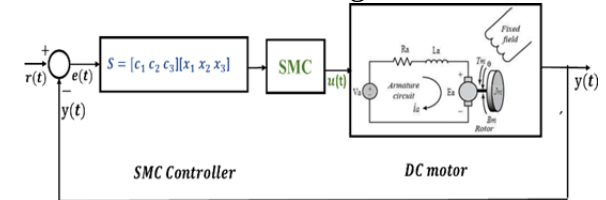


Fig. 2. The control scheme of the sliding mode controller for DC motor

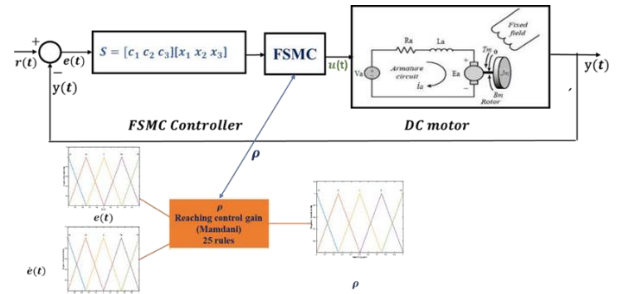


Fig. 3. The control scheme of the fuzzy sliding mode controller for DC motor

3.2.Fuzzy sliding mode control

In the new studies, the chattering phenomenon can be removed by utilizing the fuzzy logic systems to obtain the proper reaching control law. The main merit of the suggested method is guaranteed robust behavior of the system. The structure of offered fuzzy sliding mode control (FSMC) schematic is denoted in Fig. 2. This study uses the general structure of a fuzzy system is presented in Fig.4. Mamdani-based fuzzy inference engine, two- input, and single-output fuzzy logic system. The reaching control law can be calculated following as:

$$\rho = FSMC(e, \dot{e}) \quad (28)$$

In which ρ presents the FSMC output obtained by the normalized e and $\dot{e}$. The general fuzzy control rules can be trained as follows:

$$R^{(l)} :: \text{If } e(t) \text{ is } A^l \text{ and } \dot{e}(t) \text{ is } B^l \text{ then } \rho \text{ is } B^l \quad (29)$$

$l = 1, \dots, m$

Here, A^l and B^l are the fuzzy inputs and output sets label.

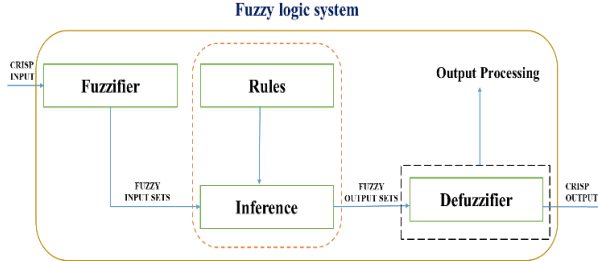


Fig. 4. The general structure of a fuzzy system

Table 1. Fuzzy rules

$\dot{e}$	e					
		NB	N	ZE	P	PB
	NB	M	S	VS	S	M
	N	B	M	S	M	B
	ZE	VB	B	M	B	VB
	P	B	M	S	M	B
	PB	M	S	VS	S	M

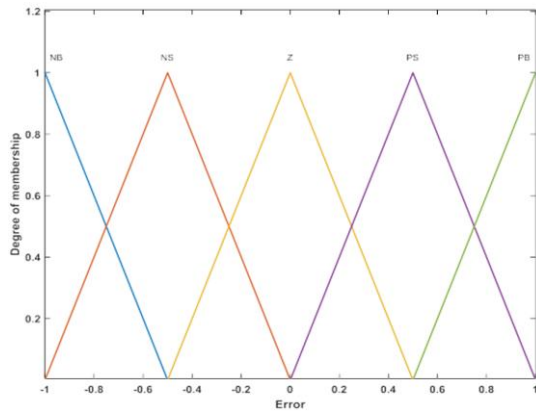


Fig. 5. The membership function of error

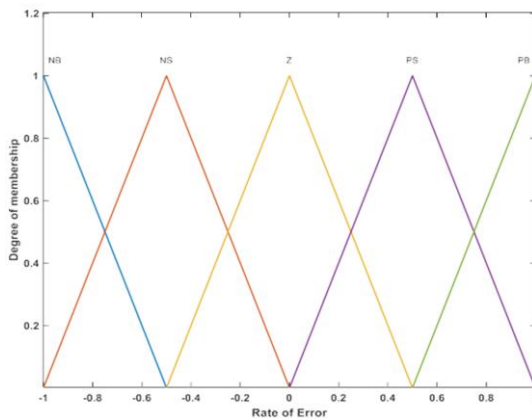


Fig. 6. The membership function of rate of error

In membership functions, ZE is (Zero), P denotes (Positive), PB shows (Positive Big),

NB presents (Negative Big), N is (Negative), VS denotes (Very Small), VB is (Very Big), S shows (Small), M is (Medium), S presents (Small) and B is (Big).

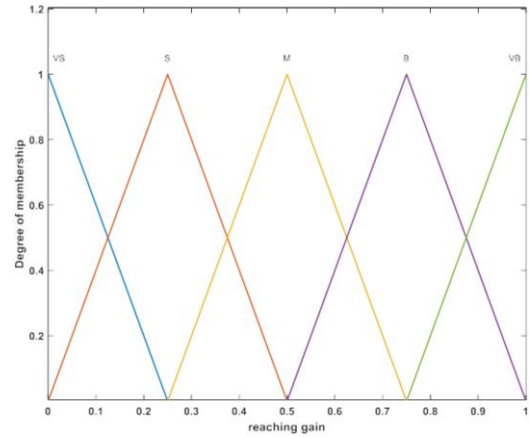


Fig. 7. The membership function of reaching gain

3.3. Optimal fuzzy sliding mode control

In this part, to improve control efficiency, a Jaya optimization algorithm for online tuning of sliding surface gains is proposed. The block diagram scheme of optimal fuzzy sliding mode control is shown in Fig.7. By utilizing this property, the trial and error required for tuning the sliding surface gains are removed. Jaya algorithm is one appropriate selection for unconstrained and constrained optimization applications. The principal goal of this methodology is brief computational and fewer iterations time for reaching globally optimal values. The flowchart depicted in Fig. 10 denotes the several steps utilized by the Jaya optimization algorithm.

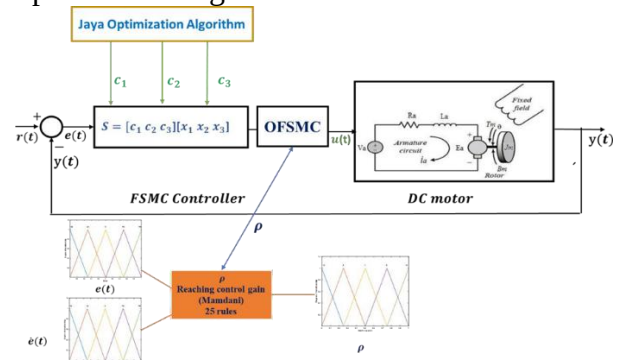


Fig. 8. The Optimal type 2 fuzzy sliding mode control structures

It is assumed that $f(x)$ is the objective function that is to be minimized or maximized. In any iteration i , 'n' illustrates the candidate solutions (population size, $k=1, \dots, n$) and m is the design variables number ($j=1, \dots, m$). The best and the worst candidate values for $f(x)$ are shown as $f(x)$ best and $f(x)$ worst. If $X_{j,,}$

presents the j^{th} variable value for k^{th} candidate, then this value is edited as:

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} (X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i} (X_{j,worst,i} - |X_{j,k,i}|) \quad (30)$$

In which $X_{j,rst,i}$ is the variable j value for the worst candidate and $X_{j,best,i}$ is the variable j value for the best candidate. Also $X_{j,k,i}$ is the updated value of $X_{j,k,i}$ and $r_{1,j,i}$ and $r_{2,j,i}$ are random number in the range $[0, 1]$. The term $r_{1,j,i}(X_{j,best,i} - |X_{j,k,i}|)$ is offered to approaching solution to the best solution and the term $(X_{j,worst,i} - |X_{j,k,i}|)$ is suggested to keeping out solution from the worst solution. Adjustable parameters that should be optimized by the Jaya algorithm are: c_1, c_2, c_3

The above parameters are sliding surface gains that were constant but now are changeable online with the Jaya algorithm. In this research suggested objective function can be given as:

$$f(x) = \sqrt{\int_0^{44} e^2} \quad (31)$$

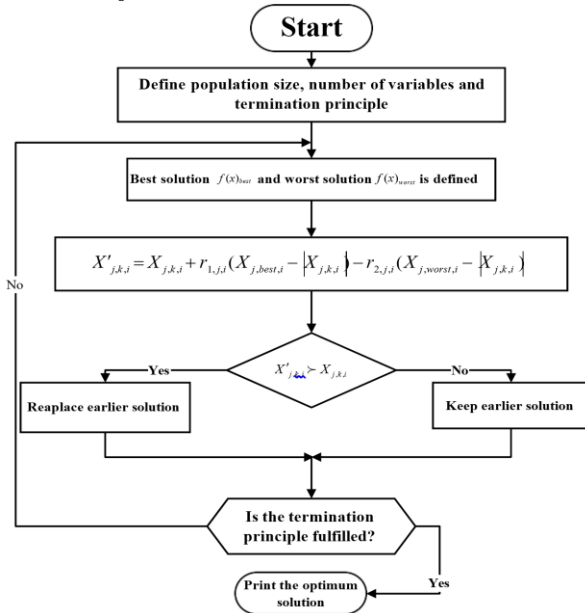


Fig. 9. Flowchart of the Jaya algorithm [20]



Fig. 10. The practical DC motor

4. Experiments and results

At first, the results of the speed control performance of DC motor are represented. Fig.11 presents the performance of tracking the reference velocity for PID, SMC, FSMC, and OFSMC.

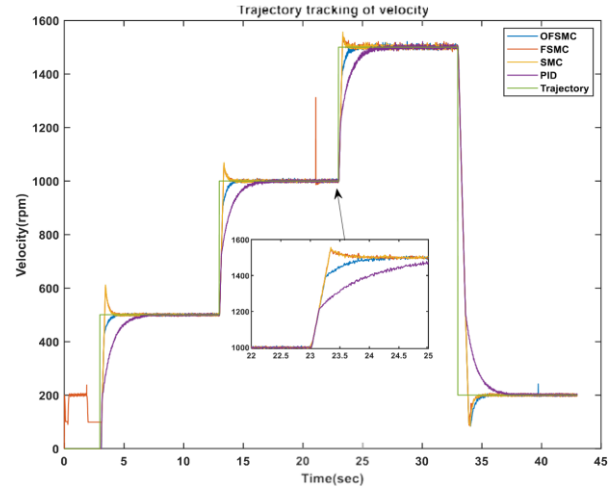


Fig. 11. Trajectory tracking of velocity

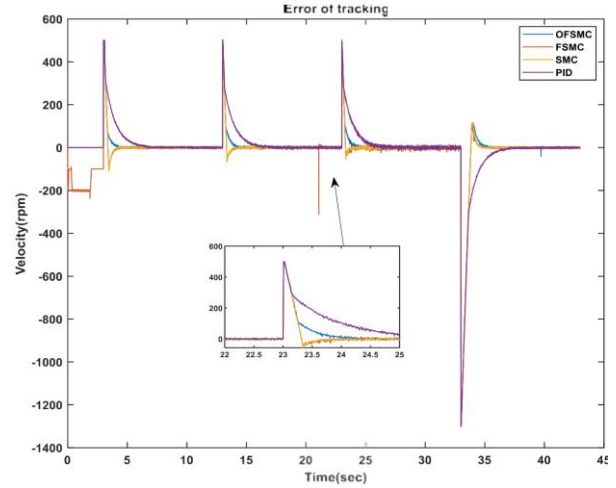


Fig. 12. Error of tracking in velocity control

Also, in Fig.12 the tracking errors comparison of the proposed controllers have been shown.

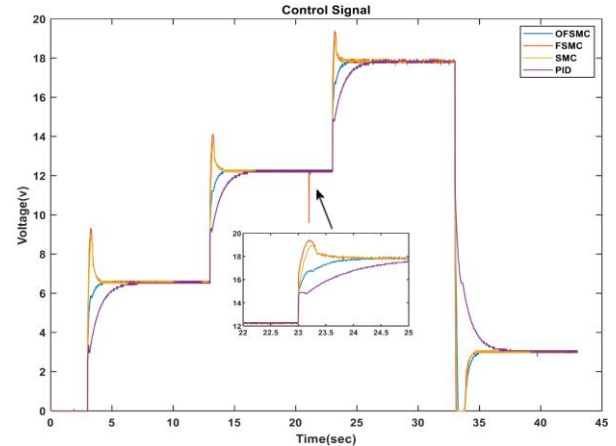


Fig. 13. Control signal of velocity control

As expected, OFSMC is the best control performance (lower error values) among other

suggested controllers that merits of applying the Jaya optimization algorithm for the optimization of the sliding surface gains system are apparent. Fig. 13 denotes the control signal of the DC motor. This figure represents that the chattering effects in the SMC can be decreased by utilizing features of the fuzzy system with SMC without decreasing of system's robustness. Secondly, the results of the position control efficiency of DC motor are presented.

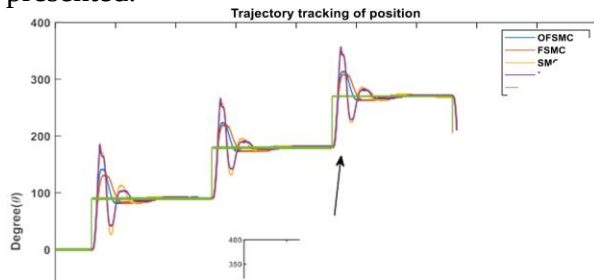


Fig. 14. Trajectory tracking of Position

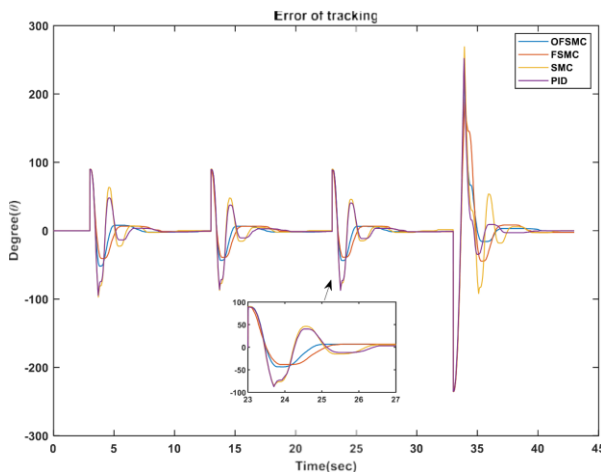


Fig. 15. Error of tracking in position control

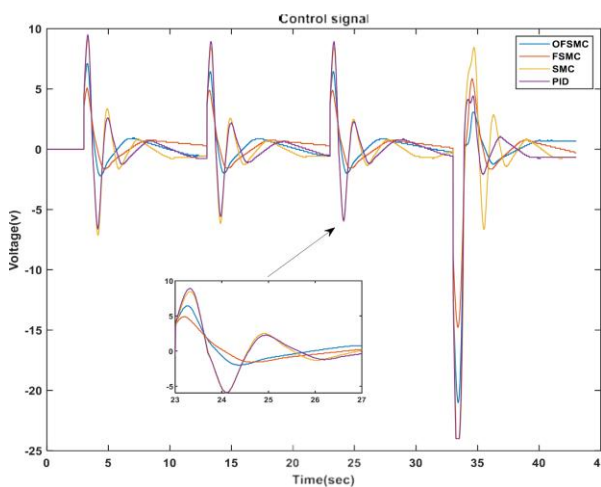


Fig. 16. Control signal of position control

In Fig.14, the efficiency of tracking the reference positions for PID, SMC, FSMC, and OFSMC has been illustrated. Also, in Fig.15 the comparison of tracking errors in the offered controllers has been denoted. It should be noted, the benefits of utilizing the Jaya optimization algorithm in controller design are apparent. Moreover, the control signal comparison is presented in Fig16. It is evident chattering results can be removed by utilizing the benefits of fuzzy system.

5. Conclusion

In the presented research, an OFSMC is utilized for the speed and position control of a DC motor that by applying a fuzzy logic system can chattering effects can be eliminated. The parameters of the proposed controller are adjusted by using the Jaya optimization algorithm. Due to experimental results can be founded the benefits of the suggested controller compared to other considered controllers in speed and position control and reducing chattering, and robust behavior.

6. References

- Aghaseyedabdollah, M., Abedi, M., & Pourgholi, M. (2022). Supervisory adaptive fuzzy sliding mode control with optimal Jaya-based fuzzy PID sliding surface for a planar cable robot. *Soft Computing*, 26(17), 8441–8458.
- Aghaseyedabdollah, M., Abedi, M., & Pourgholi, M. (2022). Supervisory adaptive interval type-2 fuzzy sliding mode control for planar cable-driven parallel robots using Grasshopper optimization. *Iranian Journal of Fuzzy Systems*, 19(5), 111–129. <https://doi.org/10.22111/ijfs.2022.7160>
- Aghaseyedabdollah, M., Alaviyan, Y., Azmi, H., & Yazdizadeh, A. (2021). Fuzzy fractional-order sliding mode controller design for a wind turbine with DFIG. In 2021 29th Iranian Conference on Electrical Engineering (ICEE) (pp. 637–642). IEEE.
- Aghaseyedabdollah, M., Alaviyan, Y., & Yazdizadeh, A. (2021). IoT-based smart greenhouse design with an intelligent supervisory fuzzy optimized controller. In 2021 7th International Conference on Web Research (ICWR) (pp. 311–317). IEEE. <https://doi.org/10.1109/ICWR51868.2021.9443022>
- Alaviyan, Y., & Afzalain, A. A. (2020). Decentralized fuzzy sliding mode control using Jaya algorithm. In 2020 6th Iranian Conference on

Signal Processing and Intelligent Systems (ICSPIS) (pp. 1–5). IEEE.

Arof, S., Diyanah, N. H., Yaakop, N. M., Mawby, P. A., & Arof, H. (2019). Processor in the loop for testing series motor four quadrants drive direct current chopper for series motor driven electric car: Part 1: Chopper operation modes testing. *Advanced Engineering for Processes and Technologies*, 59–76.

Aribowo, W., Muslim, S., Achmad, F., & Hermawan, A. C. (2021). Improving neural network based on Seagull Optimization Algorithm for controlling DC motor. *Jurnal Elektronika dan Telekomunikasi*, 21(1), 48–54.

Barkas, D. A., Ioannidis, G. C., Psomopoulos, C. S., Kaminaris, S. D., & Vokas, G. A. (2020). Brushed DC motor drives for industrial and automobile applications with emphasis on control techniques: A comprehensive review. *Electronics*, 9(6), Article 887.

Dilmi, I., Abderrahmen, A., Djrioui, A., & Chrifi-Alaoui, L. (2021). Interval type-2 fuzzy logic–second order sliding mode based fault detection and active fault-tolerant control of brushless DC motor. *Journal Européen des Systèmes Automatisés*, 54, 475–485.

Dutta, P., & Nayak, S. K. (2021). Grey wolf optimizer based PID controller for speed control of BLDC motor. *Journal of Electrical Engineering & Technology*, 16, 955–961.

Esmail, S. M., & Fathi, S. H. (2022). DC-motor motion control (speed & position) using sliding mode control (SMC). *Journal of Modern Engineering Research*, (2).

Hammoodi, S. J., Flayyih, K. S., & Hamad, A. R. (2020). Design and implementation speed control system of DC motor based on PID control and MATLAB Simulink. *International Journal of Power Electronics and Drive Systems*, 11(1), 127–134.

Lotfy, A., Kaveh, M., Mosavi, M. R., & Rahmati, A. R. (2020). An enhanced fuzzy controller based on improved genetic algorithm for

speed control of DC motors. *Analog Integrated Circuits and Signal Processing*, 105, 141–155.

Maghfiroh, H., Sujono, A., & Aribowo, C. H. B. (2020). Basic tutorial on sliding mode control in speed control of DC-motor. *Journal of Electrical, Electronic, Information, and Communication Technology*, 2(1), 1–4.

Nouri, K., Dhaouadi, R., & Braiek, N. B. (2008). Adaptive control of a nonlinear DC motor drive using recurrent neural networks. *Applied Soft Computing*.

Rao, R. V. (2016). Jaya: A simple and new optimization algorithm for solving constrained and unconstrained optimization problems. *International Journal of Industrial Engineering Computations*, 7(1), 19–34.

Rauf, A., Li, S., Madonski, R., & Yang, J. (2020). Continuous dynamic sliding mode control of converter-fed DC motor system with high order mismatched disturbance compensation. *Transactions of the Institute of Measurement and Control*, 42(14), 2812–2821.

Razmjoooy, N., Vahedi, Z., Estrela, V. V., Padilha, R., & Monteiro, A. C. B. (2020). Speed control of a DC motor using PID controller based on improved whale optimization algorithm. In *Metaheuristics and optimization in computer and electrical engineering* (pp. 153–167). Springer International Publishing.

Venu, Y., Hari Priya, T., & Gnanendar, R. (2021). ABC-based optimal tuning of PID controller for speed control of DC motor. In *Advances in automation, signal processing, instrumentation, and control: Select proceedings of i-CASIC 2020* (pp. 2399–2408). Springer.

Yunardi, R. T., Arifianto, D., Bachtiar, F., & Prananingrum, J. I. (2021). Holonomic implementation of three wheels omnidirectional mobile robot using DC motors. *Journal of Robotics and Control*, 2(2), 65–71.

Zaghrat, F., Gasbaoui, B., Bouchiba, B., Bousserhane, I., & Chaoufi, I. (2022). Robust fuzzy sliding mode control implementation for DC motor. *Przegląd Elektrotechniczny*.



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