Fuzzy Logic based PID Controller Tuning for Speed Control of DC Servo Motor

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August 18, 2020

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Abstract. The principal target of the present examination is to investigate and evaluate the performance of conventional PID and Adaptive Fuzzy-PID controllers for the purpose of controlling speed of separately excited DC motor in MATLAB/SIMULINK. The adaptive Fuzzy- PID controller acts like a gain scheduler that has been designed using twenty five fuzzy set rules which comprises of Gaussian membership function for the input and trapezoidal membership function for the output. The novelty of the work is to examine time domain and frequency domain specifications of controllers under no load and sudden loaded conditions. Performance indices namely ISE and ITAE have been adopted to assess viability of the controllers. The consequences reveal that adaptive Fuzzy-PID controller exhibits superlative attributes during transient and frequency domain analysis.

KeywordsPID Controller • DC Motor • Fuzzy logic • Adaptive Fuzzy-PID

1 Introduction

Electrical drives assume critical job in the usage of assignments for expanding efficiency in different ventures, for robotization and complex automation of creation forms. DC motors are generally utilized, in light of the fact that they have these great exhibitions, for instance, great starting, proper regulation of speed, wide speed run, smooth burden, solid overloading ability, minimal electromagnetic impedance and cheap maintenance, so it is important to examine the speed control of the DC motor. Multitudinous controlling methodologies have been proposed and actualized for speed control of DC motor and to improve the execution of the framework [1-4].Generally, in industries conventional PID controller is widely used because of its simple design and high reliability but tuning of this controller is a tedious task. Numerous studies [5-8] have been performed in designing varoius algorithms to tune the pertinent parameters of PID controller. In another study, performance of three distinct controllers have been analysed for controlling the speed of DC motor which is fed with chopper [9].

The ideal objective of our investigation is to examine the execution of two distinct controllers for speed control of dc servo motor. In designing of conventional PID controller, pole placement strategy has been adopted to acquire the values of pertinent parameters while in structuring of adaptive Fuzzy-PID controller, the gain parameters are self- tuned using fuzzy logic.

2 Mathematical Model

Scientific demonstration of separately excited DC motor is exhibited in this segment. Fig 1 illustrates the block diagram of armature controlled DC motor. The mathematical model of DC motor constitutes of electrical and mechanical equations. The electrical circuit consists of armature resistance R_a connected in series with inductanceL_a. The voltage is induced across the armature coil is denoted V_aA back electromotive force $E_b$is generated which opposes the voltage source. By applying Ohm's law and KVL, the electrical equation can be expressed as:

$$V_a = R_a I + L_a \frac{dI}{dt} + E_b \tag{1}$$

The back emf can be defined as

$$E_b = K_B \omega \tag{2}$$

In the above equation, ω represents rotational speed of rotor and K_B denotes the back electromotive constant.The governing mechanical equation can be descibed by the fundamental torque equation:

$$T_e - T_L = J\frac{d\omega}{dt} + B\omega \tag{3}$$

In the equation (3), T_L stands for load torque applied during working conditions, J represents rotor inertia and B is coefficient of viscous friction. $T_e = K_T I$ is emf torque where K_T denotes torque constant.

Taking Laplace transform of the above equations (1-3) we design our model.

$$V_a(s) = R_a I(s) + I(s)\, L_a s + E_b(s) \tag{4}$$

$$E_b(s) = K_B \omega(s) \tag{5}$$

$$T_e - T_L = Js\omega(s) + B\omega(s) \tag{6}$$

$$T_e = K_T I(s) \tag{7}$$

Using equation (4-7) the open loop transfer function of the plant in expressed as given below:

$$\frac{\omega(s)}{V_a(s)} = \frac{K_T}{(R_a + sL_a)(Js + B) + K_B K_T} \tag{8}$$

By placing the values of the parameters, as mentioned in Table 1, in equation (8), the plant transfer function is acquired as appeared underneath:

$$G_P(s) = \frac{2}{s^2 + 12s + 20.02} \tag{9}$$

Table1DC Motor Parameters

Notation	**Specification Values**
$\boldsymbol{J}$	0.01 kgm^2
$\boldsymbol{B}$	0.1Nms
$\boldsymbol{K_T}$	0.01Nm/A
$\boldsymbol{K_B}$	0.01V/rad/s
$\boldsymbol{R_a}$	1 Ω
$\boldsymbol{L_a}$	0.5henry

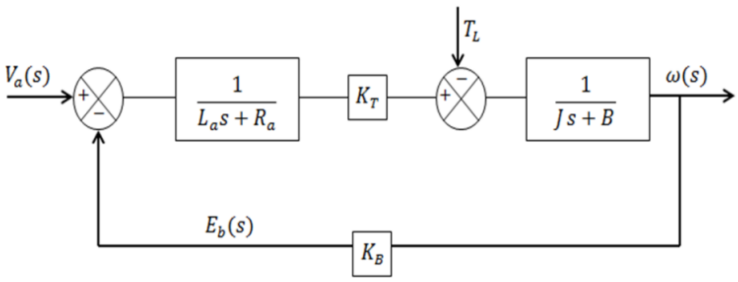

Fig. 1. Block diagram of DC Motor

3 Proposed Controllers

3.1 Conventional PID Controller

The design of PID controller is represented in Fig.2 which consists ofProportional (P), Integral (I) and Derivative (D) gains that are arranged in parallel to each other along the feed forward path of a closed loop system. The function of proportional control is to reduce the rise time and settling time while the function of integral control is to eradicate the steady state error of the system. The derivative control is used to improve the transient response of the framework. The error estimated between the references quantity and the actual quantity is then fed to the PID controller. The expression for the PID controller is stated below:

$$U(t) = K_P e(t) + K_I \int e(t)\ dt + K_D \frac{de(t)}{dt} \tag{10}$$

The transfer function of PID Controller

$$G_c = K_P + \frac{K_I}{s} + K_D s \tag{11}$$

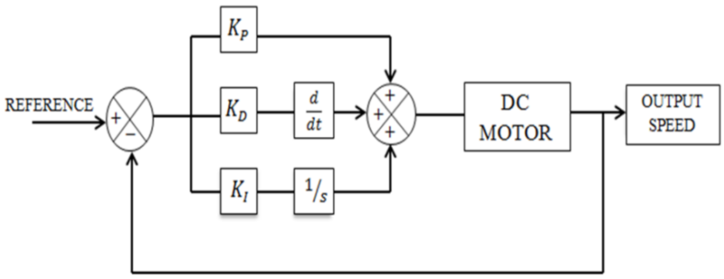

Fig. 2. Block diagram of PID Controller

The overall transfer function for unity feedback system is stated as

$$\frac{Y(s)}{R(s)} = \frac{(G_P(s)*G_C(s))}{1+(G_P(s)*G_C(s))} \tag{12}$$

Thereby, the characteristic equation for the system has been presented as follows:

$$s^3 + (12 + 2K_D)s^2 + (20.02 + 2K_P)s + 2K_I = 0 \tag{13}$$

The pole placement scheme is utilised for tuning the pertinent parameters of PID controller. For this purpose,the desired specifications considered for the stated plant are peak overshoot < 5% and settling time < 2 s.From the mentioned specification, the estimated damping ratio is $\zeta = 0.689$ and the estimated natural frequency is $\omega_n = 2.899$.By placing these values in the standard second order characteristic equations$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$ .We obtain the equation $s^2 + 4s + 8.404 = 0$ from which we acquire dominant poles that are expressed as$s_{1,2} = -2 + j2.0985 , -2 - j2.0985$.Thus by implementing pole placement concept where the third pole is represented as'p', the characteristic polynomial can be obtained as:

$$(s + p)(s^2 + 4s + 8.404) = 0 \tag{14}$$

On comparing the equation (13) and (14) we can obtain the expressions for tuning the pertinent parameters of PID controller

$$K_D = \frac{p - 8.002}{2} \tag{15}$$

$$K_P = \frac{4p - 11.616}{2} \tag{16}$$

$K_I = 4.202\text{p}$ (17)

Thus the value of non-dominant pole is chosen as 23 on the left hand side of s-plane. Table 2 illustrates the respective tuned values of proportional, integral and derivative gain.

Table 2 Tuned values of PID parameters

TUNED VALUES	KP	KD	KI
	40.192	7.499	96.646

3.2 Adaptive Fuzzy- PID Controller

This segment deals with the designing of adaptive fuzzy-PID controller which embodies a fuzzy controller that schedules the value of proportional, integral and derivative gains. Fig. 3 illustrates the block diagram of the postulated controller with the system. It is marked that fuzzy logic controller constitutes three major components namely Fuzzification, knowledge base control rules and Defuzzification. The fuzzy logic controller takes two quantities as input namely error and change in error. For the input quantities, Gaussian membership function has been adopted which is represented in Fig.4 and Fig.5 respectively.At the initial stage, the input parameters are transfigured into linguistic variables and this process is termed as Fuzzification. Mamdani rule base system has been employed in our design of proposed controller. The Mamdani inference involves min-operation as the antecedent pairs in the rule structure are connected by a logical operator 'AND'. All the rules are then aggregated using max-operation. At the final stage, the process of Defuzzification is employed which utilizes center of gravity technique to transform fuzzy set values into crisp set values. The output quantities are the proportional, derivative and integral gain parameters which utilize trapezoidal membership function as depicted in Fig.6, Fig.7 and Fig.8 respectively. The range set for propotional gain in output membership function varies from $[0,\ 80.925]$ Similarly, the range of derivative gain is $[0,\ 2.418]$ and integral gain is $[0,\ 115.2]$.

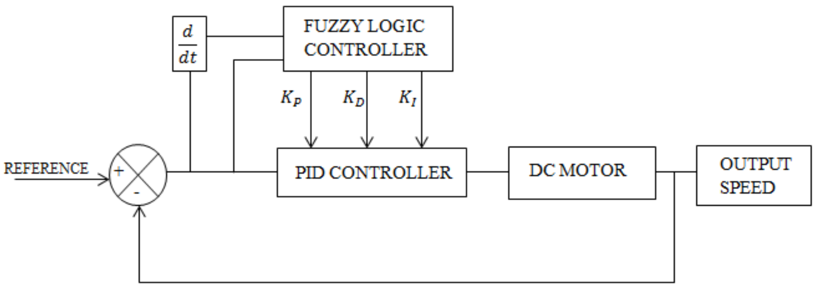

Fig. 3. Block diagram of Adaptive Fuzzy- PID Controller

The linguistic variables which implies input have been categorised as: NL(Negative large),NS (Negative Small), ZE (zero),PS (Positive small) and PL (Positive Large). The liguistic variable which indicates output has been stated as: PES (Positive Extremely Small), PS (Positive Small), PMS (Positive Moderate Small), PM (Positive Moderate), PML (Positive Moderate lagre), PL (Positive Large) and PEL (Positive Extremely Large).The fuzzy rules are extracted from fundamental knowledge and human experience about the process. These rules contain the input /output relationship that define control strategy. In our examination, we have formulated 25 fuzzy set rules represented in Table 3, Table 4 and Table 5 for propotional , derivative and integral gain respectively. For instance, the fuzzy rules are defined as:

*RULE 1: If (**E**is NL)AND(**CE** is NL) then (**kp** is PEL) (**kd** is PES) (**ki** is PM)*

*RULE 2: If (**E**is NL)AND(**CE** is NS) then (**kp** is PEL)(**kd** is PMS) (**ki** is PM)*

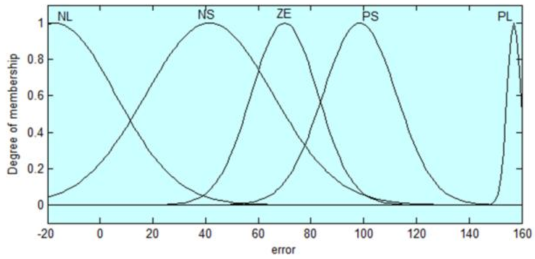

Fig. 4. Membership function for error input

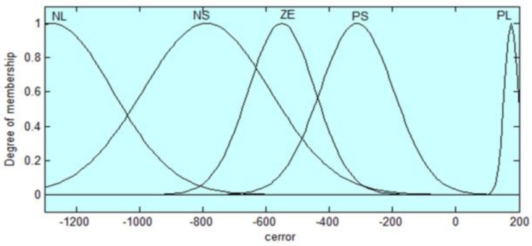

Fig. 5. Membership function for change in error input

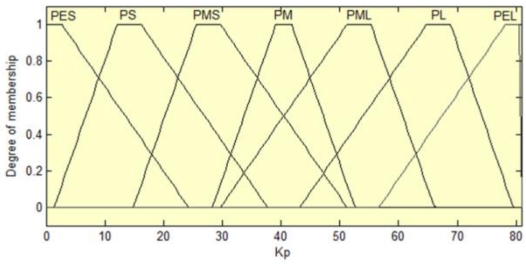

Fig. 6. Membership function for propotional gain output

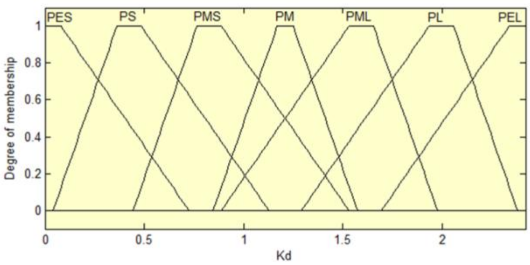

Fig. 7. Membership function for Derivative gain output

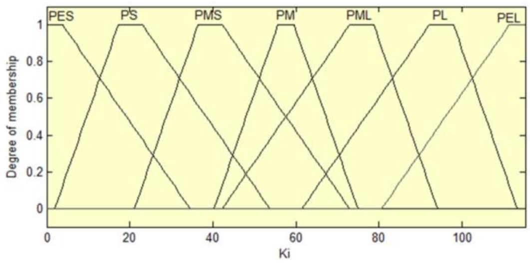

Fig. 8. Membership function for Integral gain output

Table 3 Fuzzy Set Rules for Propotional Gain

E \ CE	NL	NS	ZE	PS	PL
NL	PEL	PEL	PEL	PM	PEL
NS	PML	PML	PML	PL	PEL
ZE	PES	PES	PS	PMS	PMS
PS	PML	PML	PML	PL	PEL
PL	PS	PL	PMS	PEL	PEL

Table 4 Fuzzy Set Rules for Derivative Gain

E \ CE	NL	NS	ZE	PS	PL
NL	PES	PMS	PM	PL	PS
NS	PEL	PML	PL	PEL	PEL
ZE	PML	PL	PL	PES	PM
PS	PML	PEL	PL	PS	PEL
PL	PEL	PEL	PEL	PEL	PMS

Table 5 Fuzzy Rules for Integral Gain

E \ CE	NL	NS	ZE	PS	PL
NL	PM	PM	PMS	PM	PM
NS	PMS	PEL	PMS	PM	PES
ZE	PS	PL	PMS	PS	PS
PS	PMS	PMS	PMS	PMS	PL
PL	PM	PM	PM	PM	PM

4 Simulation Results

In this segment, we evaluate the performance of conventional PID controller and proposed Adaptive Fuzzy-PID in graphical and tabular form. It is observed in Table 6 that Adaptive Fuzzy-PID manifest better attributes during transient and frequency operation. Fig.9 demonstrates the step response of PID and adaptive fuzzy-PID under no load conditions.Fig.10 exhibits the staircase response of controllers in which the speed of the motor is accelerated from 500rpm to 1200rpm. Fig.11 illustrates the performance of these distinct controllers when the motor is suddenly loaded with 25Nm at 2.6sec. It is to be marked that phase margin for Adaptive fuzzy-PID is less compared to conventional PID. Furthermore, ISE and ITAE have been adopted as performance indices to analyze the effectiveness of the designed controllers which is well depicted in Table 7.

Table 6 Time Domain and Frequency Domain Specifications

SPECİFİCATİONS	PID	ADAPTIVE FUZZY-PID
RISE TIME	0.2495	0.0622
SETTLING TIME	1.4306	0.1755
OVERSHOOT	18.4705	2.5664
PEAK TIME	0.6559	0.1400
GAIN MARGIN (DB)	∞	∞
PHASE MARGIN (DEG)	28.3	27.9

Table7 Performance Indices

CONTROLLERS	ISE	ITAE
PID	1.38E+05	145.3
ADAPTIVE FUZZY-PID	2.559E+04	11.22

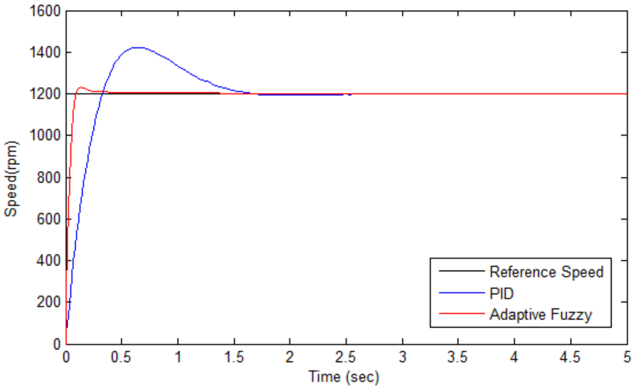

Fig. 9. Step response for controllers under No load condition

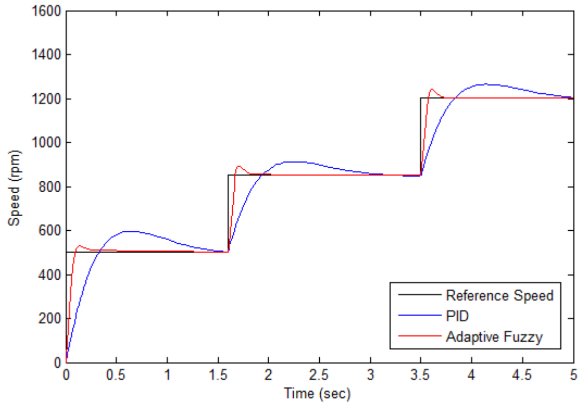

Fig. 10. Staircase Response for Controllers

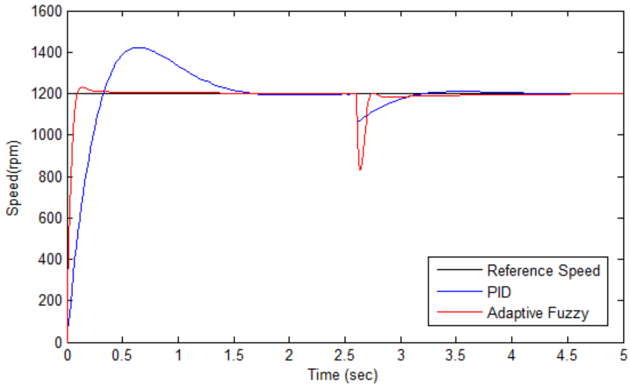

Fig. 11. Step Response for Controllersunder Sudden loaded condition

5 Conclusion

In this article, PID and Adaptive Fuzzy-PID controllers have been designed for speed control of DC MOTOR system and the performance is compared. The result of comparison depicts that Adaptive Fuzzy-PID controller provides better characteristics than PID controller in terms transient and frequency response.It is also demonstrated from performance indices that integral square error and integral time absolute error is least for adaptive Fuzzy-PID controller. From frequency domain analysis it can be concluded that both the controllers have very high gain margin while the phase margin of Adaptive Fuzzy-PID is lesser than conventional PID controller. In addition to it, transient attributes obtained from simulation reveals that Adaptive Fuzzy-PID displays superior outcomes in terms of overshoot, settling time and rise time.

References

1. Flores-Morán E., Yánez-Pazmiño W., Espin-Pazmiño L., Molina-Miranda M., Guzmán-Real C. (2019) PID and Fuzzy Logic Controllers for DC Motor Speed Control. In: Botto-Tobar M., Barzola-Monteses J., Santos-Baquerizo E., Espinoza-Andaluz M., Yánez-Pazmiño W. (eds) Computer and Communication Engineering. ICCCE 2018. Communications in Computer and Information Science, vol 959. Springer, Cham.
2. Baidya D., Roy R.G. (2018) Speed Control of DC Motor Using Fuzzy-Based Intelligent Model Reference Adaptive Control Scheme. In: Bera R., Sarkar S., Chakraborty S. (eds) Advances in Communication, Devices and Networking. Lecture Notes in Electrical Engineering, vol 462. Springer, Singapore.
3. Berrospe E., González-Olvera M.A., Tang Y. (2009) Identification and Speed Control of a DC Motor Using an Input-Output Recurrent Neurofuzzy Network. In: Yu W., Sanchez E.N. (eds) Advances in Computational Intelligence. Advances in Intelligent and Soft Computing, vol 116. Springer, Berlin, Heidelberg.
4. an H., Lei Y., Pang D., Han X. (2016) Research of Speed Control System for DC Motor Based on Fuzzy PID. In: Qi E. (eds) Proceedings of the 6th International Asia Conference on Industrial Engineering and Management Innovation. Atlantis Press, Paris.
5. Cozma A. (2008) DC Motor Monitoring and Control System. In: Sobh T., Elleithy K., Mahmood A., Karim M.A. (eds) Novel Algorithms and Techniques In Telecommunications, Automation and Industrial Electronics. Springer, Dordrecht.
6. Delavari H., RanjbarNoiey A., Minagar S. (2008) Artificial Intelligent Controller for a DC Motor. In: Sarbazi-Azad H., Parhami B., Miremadi SG., Hessabi S. (eds) Advances in Computer Science and Engineering. CSICC 2008. Communications in Computer and Information Science, vol 6. Springer, Berlin, Heidelberg.
7. D. Puangdownreong, A. Nawikavatan, C. Thammarat, Optimal Design of I-PD Controller for DC Motor Speed Control System by Cuckoo Search, Procedia Computer Science, Volume 86, 2016, Pages 83-86.
8. Sun, H., Wang, X., Lin, Q., Wang, X. and Su, S.: The design of the DC servo motor controller based on fuzzy immune PID algorithm. In: 2017 36th Chinese Control Conference pp. 4724-4729, IEEE, Dalian,(2017).
9. Das, C.K. and Swain, S.K.: Closed loop speed control of chopper fed DC motor for industrial drive application.In:2017 International Conference on Power and Embedded Drive Controlpp. 478-483, IEEE,Chennai, (2017)