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Position Control of a DC Motor under Different Loads Using SMC and PID Control Methods

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Abstract

Various methods are proposed and applied for the control of Direct current (DC) motors used in many systems from past to present. These motors are operated under various loads in real life and loads cause a decrease in the running performance of the motor. In this study, modeling of dc motor and position control under different loads were performed using Sliding Mode Control (SMC) and Proportional-Integral-Derivative (PID) control methods. Also, the position results of the motor were evaluated using the Mean-Square-Error (ISE) performance criterion. The obtained results were given in the form of graphics and tables and analyzed.

Keywords: Modeling; Sliding Mode Control(SMC); Proportional-Integral-Derivative(PID); Different Loads

1. INTRODUCTION

Cost, ease of control, long life and silent operation, etc. Direct current (DC) motors have been used frequently from past to present due to their characteristics. Since these motors have a wide area of use in the literature, control studies have been actively researched and continue to be investigated. Ohishi et al. He worked on microprocessor-controlled DC motor control for non-load sensitive position servo system [1]. Weerasooriya and El-Sharkawi worked on the identification and control of a DC motor using neural networks using a backpropagation algorithm [2]. Baek and Kuc proposed the control of DC motors with adaptive PID learning [3]. Mehta and Chiasson [4] have done theory and experimental work on the nonlinear control of a series of DC motors. Tang realized the speed and position control of real-time DC motor by using a PID control method with TMS320C31 DSK with on-line parameter setting [5]. Ruderman et al. optimum control of the DC motor has been realized in the state space [6]. Position control of the DC motor was carried out by using Thomas and Poongodi genetic algorithm based PID controller [7]. Adhikari et al. realized the control of the DC motor using the PID control method. They found the control coefficients of the method by using the Ziegler Nichols and the genetic algorithm [8].

Anandaraju et al. He has performed the speed control of a DC motor by obtaining the control coefficients of the PID method with a genetic algorithm [9]. Yousef carried out the experimental setup and verification of servo DC motor position control based on the integral sliding mode control approach [10]. Wang and Suh performed precise synchronous speed and position tracking of brushed dc motors using nonlinear time-frequency control [11]. In another study, the Kalman filter was used to estimate DC motor speed and both PID and LQR controllers were used to control the motor [12]. Chaudhary et al. ANFIS based speed control of DC motor. It has been recommended and implemented [13]. Khubalkar et al. modeled and controlled permanent magnet brushless DC motor drive using a fractional proportional-integral-derivative controller [14]. Qader made a study to determine the most appropriate controller strategy for DC motors [15]. Usman et al. performed an estimation of permanent magnet DC motor parameters via universal adaptive stabilization [16]. DC motors are operated under various loads in real life and loads cause a decrease in the running performance of the motor. In this study, the modeling of DC motor and position control under different loads were performed using Sliding Mode Control (SMC) and Proportional-Integral-Derivative (PID) control methods. Also, the angular position results of the motor were evaluated using the Mean-Square-Error (MSE) performance criterion. The obtained results were given in the form of graphics and tables and analyzed.

2. MATHEMATICAL MODEL OF DC MOTOR

Direct current (DC) motors are widely used in a variety of industrial and electronic equipment where high accuracy position control is required. The model of the dc motor is given in the equations below. Figure 1 shows the direct current (DC) motor.

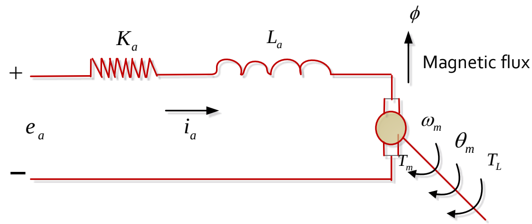

Fig.1. Direct current (DC) motor model

The moment received from the electric motor;

$$T_m(t) = K_m.\Phi.i_a(t) = K_i.i_a(t) \tag{1}$$

$$\frac{di_a}{dt} = \frac{1}{L_a}.e_a - \frac{R_a}{L_a}.i_a - \frac{1}{L_a}.e_b \tag{2}$$

$$T_m = K_i.I_a \tag{3}$$

$$e_b = K_b.\frac{d\theta_m}{dt} = K_b.\omega_m(t) \tag{4}$$

$$J_m\frac{d^2\theta_m}{dt^2} = T_m - T_L - B_m.\frac{d\theta_m}{dt} \tag{5}$$

If we take our variables as i_a, θ_m and ω_m, the equations of state from the first order can be written as follows.

$$\dot{x} = Ax + Bu \tag{6}$$

$$\begin{bmatrix} \frac{di_a}{dt} \\ \frac{d\omega_m}{dt} \\ \frac{d\theta_m}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{K_b}{L_a} & 0 \\ \frac{K_i}{J_m} & -\frac{B_m}{J_m} & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_a \\ \omega_m \\ \theta_m \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} \\ 0 \\ 0 \end{bmatrix} .e_a - \begin{bmatrix} 0 \\ \frac{1}{J_m} \\ 0 \end{bmatrix} .T_L(t) \tag{7}$$

$$\frac{\theta_m(s)}{E_a(s)} \quad \frac{\theta_m(s)}{E_a(s)} = \frac{K_i}{L_aJ_ms^3 + (R_aJ_m + B_mL_a)s^2 + (K_bK_i + R_aB_m)s} \tag{8}$$

The parameters of the dc motor are shown in Table 1.

Table 1. Parameters of Dc motor

Symbol	*Description*	*Units*	*Value*
m	Body Mass	*kg*	10
J	Body Inertia	*kgm²*	0.171
K_m	Motor Constant	*Nm/A*	3520
R_a	Motor Resistance	*Ohm*	55
l_o	Leg Length	*m*	0.323
L_m	Motor electric inductance	*H*	0.3
B_m	The damping ratio of the system friction constant	*Nm.*	0.097

3. CONTROLLER DESIGN

Using two different control methods under different loads, a controller has been designed to reach the desired position of the DC motor and obtain the minimum error in position control. It is aimed here that θ (actual motor angle) follows θd (desired motor angle) with minimum error. DC motor was controlled under different loads using PID and Sliding Mode Control (SMC) control methods.

3.1. PROPORTIONAL-INTEGRAL DERIVATIVE (PID) CONTROL

The Proportional-Integral-Derivative (PID) control method is a method used in many applications. The basic mathematical equation of the PID control method is given in equation 9 [17]. Ziegler-Nichols method was used to find the PID control coefficients and closed-loop control type was used in this method [18]. θ_d Reference input angle signal, θ the output angle of the real system, $e=\theta_d-\theta$ error signal, Kp proportional gain, Ki integral gain, and Kd derivative gain.

$$u(t)=K_p e(t)+K_I\int_0^{\tau} e(t)\,dt+K_D\frac{d}{dt}e(t) \qquad (9)$$

3.2. SLIDING MODE CONTROL (SMC) METHOD

Sliding mode control is a special case of variable structured control. SMC is a special form of variable structured control. This method initially forces state variables to go on the sliding surface and then, they are kept on such surface and afterward, are shifted towards the origin

[19]. Therefore, it is called the sliding surface as well as the switching surface. Due to the nature of this method, it has a non-continuous control structure. This discontinuous check mark causes chattering. This harms the physical system elements. One of the ways to prevent this is to replace the discontinuous signum function in the sliding mode control with the saturation function, which is a continuous approximation of this function [20-21]. The angular position of the motor is the control variable. The block diagram of the sliding mode control (SMC) method is given in Figure 2. Equations containing the error and its derivative are given in equations 10 and 11.

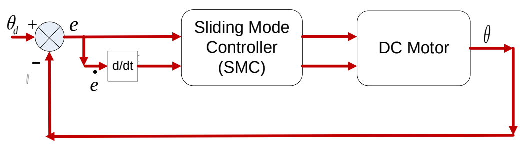

Fig.2. The control structure of the SMC method.

$$e(t) = \theta_d(t) - \theta(t) \tag{10}$$

$$\dot{e} = \dot{\theta}_d - \dot{\theta} \tag{11}$$

In the expressions given in the equations given above, θ_d the reference input angle signal θ is called the output angle of the real system, e and $\dot{e}$ the error signal respectively. The sliding surface (s) is given in equations 12 and 13. λ is a positively defined symmetric matrix and k is a constant parameter. Signum is the sign function and s functions as switching. The Lyapunov criterion was used for the stability of the system. The saturation function is used to solve the cracking problem. ϕ shows the thickness of the boundary layer.

$$s = \dot{e} - \lambda e \tag{12}$$

$$\dot{s} = \ddot{e} - \lambda \dot{e} \tag{13}$$

$$u = -k * sign(s) \tag{14}$$

$$sat(s/\phi) = \begin{cases} \dfrac{s}{\phi} & if \left|\dfrac{s}{\phi}\right| \le 1 \\ \operatorname{sgn}(s/\phi) & if \left|\dfrac{s}{\phi}\right| > 1 \end{cases} \tag{15}$$

4. SIMULATION RESULTS

In this section, simulation studies obtained by using mathematical model equations of dc motor are given. PID and sliding mode control algorithms are used in the control of the DC motor. The control variable is the motor angular position. A fixed value and sine wave input are applied to the motor model. Also, the motor was controlled under 10, 100, and 1000 N load, respectively, without load. The results of the control methods recommended under different loads were obtained according to the performance criteria (Mean Square Error (MSE)) and the methods were examined. The simulation time was set as 10 seconds. Figure 3 shows a constant value of the motor without load and the angular motor position and error graph obtained by using the PID control method. Figure 4 shows a constant value of the motor under 10 N load and the angular motor position and error graph obtained by using the PID control method. Figure 5 shows a fixed value of the motor under 100 N load and angular motor position and error graph obtained by using the PID control method.

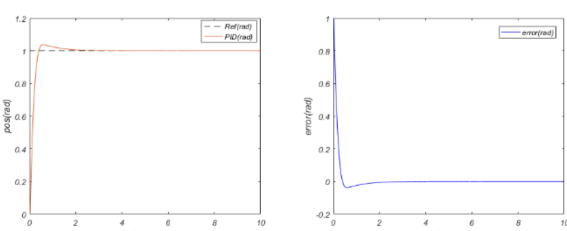

Fig.3. The angular position and error graph obtained by applying a constant input and PID control method (load TL = 0 N)

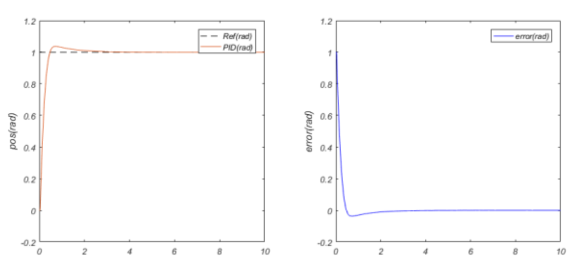

Fig. 4. The angular position and error graph obtained by applying a constant input and PID control method (load TL = 10 N)

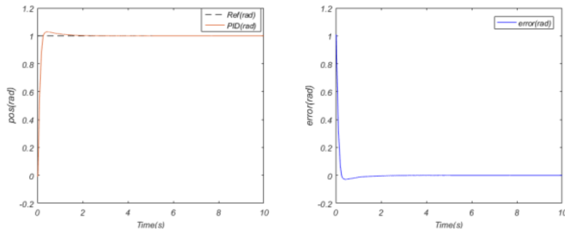

Fig. 5. The angular position and error graph obtained by applying a constant input and PID control method (load TL = 100 N)

In Figure 3, it was seen that the maximum overshoot occurred in the graph obtained as a result of using the PID control method against a constant input value of the motor with no load. Looking at the angular motor error graph, it was seen that the motor reached the settling time in about 7 seconds. In Figure 4, it was seen that the maximum overshoot occurred in the graph obtained as a result of the use of the PID control method against a constant input value of the motor under 10 N load. Looking at the angular motor error graph, it was seen that the motor reached settling time in about 5 seconds. In Figure 5, it is seen that the maximum overshoot occurs but the amplitude decreases in the graph obtained as a result of using the PID control method against a constant input value of the motor under 100 N load. Looking at the angular motor error graph, the motor's 2.2. It was observed that it reached the settlement time per second. In Figure 6, the angular motor position and error graph obtained by using a fixed input and SMC control method of the motor without load is given. Figure 7 shows the angular motor position and error graph obtained by using a fixed input and SMC control method of the motor under 10 N load. Figure 8 shows the angular motor position and error graph obtained by using a fixed input and SMC control method of the motor under 100 N load.

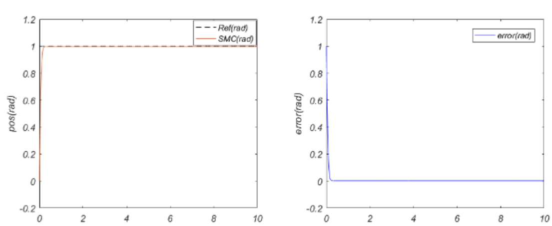

Fig.6. The angular position and error graph obtained by applying a constant input and SMC control method (load TL = 0 N)

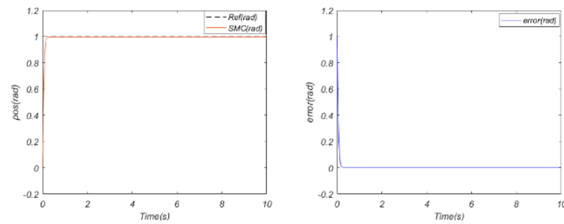

Fig. 7. The angular position and error graph obtained by applying a constant input and SMC control method (load TL = 10 N)

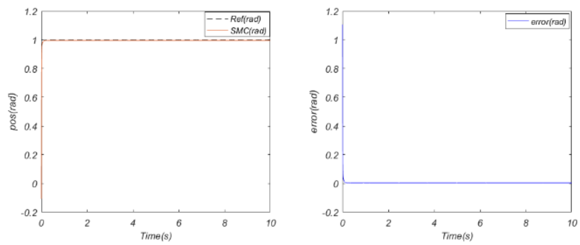

Fig.8. The angular position and error graph obtained by applying a constant input and SMC control method (load TL = 100 N)

In Figure 6, it is seen that maximum overshoot does not occur in the graph obtained as a result of using the SMC control method against a fixed input value of the motor without load. Looking at the angular motor error graph, the motor is about 0.3. It was observed that it reached the settlement time per second. In Figure 7, it was seen that the maximum overshoot did not occur in the graph obtained as a result of using the SMC control method against a fixed input value of the motor under 10 N load. Looking at the angular motor error graph, the motor is about 0.15. It was observed that it reached the settlement time per second. In Figure 8, it was seen that the maximum overshoot did not occur in the graph obtained as a result of using the SMC control method against a fixed input value of the motor under 100 N load. Looking at the angular motor error graph, the motor is about 0.01. It was observed that it reached the settlement time per second. Error results were obtained according to Mean Absolute Error (MSE) performance criteria in Table 1. The equation of the performance criterion for MSE is given below.

$$MSE = \frac{1}{N}(\sum_{j}^{N} y_{m_j} - y_{s_j})^2 \quad (16)$$

y_{dj} robot requested j. If the value is y_j, the robot j. shows its true value. y represents the angular position (θ) of the motor. j = 1,2,3,4… .N. Table 1 shows the error results obtained by using the performance criteria of the PID and SMC control methods against a fixed input value, which is the MSE.

Table 1. The error results according to performance criteria.

MSE	PID Control	SMC
TL=0	0.0097	0.0030
TL=10	0.0118	0.0031
TL=100	0.0072	0.0007

According to the no-load angular position results of the motor given in Table 1, the best error rate for a fixed input value was obtained by the SMC control method and the result was 0.0030 radians. The value obtained using the PID control method is 0.0097 radians. When under 10 N load given in the table, the best error rate was again obtained by SMC control method and the result was 0.0118 radians. The value obtained using the PID control method is 0.0031 radians. The best error rate obtained under 100 N load, another load value given in the table, was also obtained by the SMC control method and the result was 0.0072 radians. The value obtained using the PID control method is 0.0007 radians. Considering the results obtained, it is seen that the best error rate is obtained with the SMC method. In general, it is seen that the SMC method shows superior performance.

5. DISCUSSION AND CONCLUSION

In this study, modeling of DC motor and angular position control was performed using Proportional-Integral-Derivative (PID) and Sliding Mode Control (SMC) control methods. The control performance of the system was evaluated using the MSE criteria. When the results obtained with the SMC method are observed, the best performance result has been obtained in terms of both maxima exceeding and settling time. The values obtained by using PID, another control method given in the table, did not give as good results as the SMC method. Considering the results obtained, the lowest error rate was obtained using the SMC method under 100 N load and its value is 0.0007 radians. In general, it is seen that the SMC method shows superior performance. The method can be applied in a real-time laboratory environment in future studies.

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APPENDİX

Nomenclature	
i_a	Motor current
R_a	Motor resistance
e_b	emf
T_L	Load torque
ϕ	Magnetic flux
J_m	Moment of inertia
B_m	Viscous damping coefficient
L_a	Motor inductance
e_a	Motor voltage
K_b	emf constant
θ_m	Angular rotation of the rotor
K_i	Torque constant
w_m	Angular velocity of the rotor