Control of a Dc Motor using Sensorless Observer Based Sliding Mode Control Method

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Abstract

Sensorless control methods are one of the control methods that continue to develop in recent years.In these control types, the target rotor is to obtain the speed and position information from the measured quantities such as voltage and current. There are several methods for sensorless control. These methods are usually affected by the dc motor's parameter changes, uncertainties and disturbing factors, which leads to a reduction in the quality of the control. In this study, an observer-based sliding mode control method is proposed for position and speed-free control of a DC motor. Luenberger and Kalman filter observer methods were used as observers for control of DC motor. The saturation function is used for the cracking problem of the sliding mode control method. Both the process noise and the measurement noise were applied to control the DC motor system in conditions close to the actual ambient conditions. A second-order low-pass filter design has been designed to improve the performance of the controllers in the noise environment. As a result of these studies, the controller was designed and graphical results were obtained in order to be used in a real physical environment. The control methods applied according to the results of the simulation environment were compared and the results were examined.

Keywords — *Sliding Mode Control Method, Luenberger observer, Kalman Filter, Sensorless, DC motor*

I. INTRODUCTION

Direct current (DC) motors are used frequently because of their features such as cost, ease of control, long life and quiet operation. DC motors for robotics, defense industry and automotive applications etc. are used in many fields [1-10]. In recent years, sensorless control methods have been used in the control of dc motors [11-15]. During the control of most systems, there is only parameter information and partial status over the measured outputs, which usually limits the performance of the system.In order to recover unknown situations and parameters, powerful observers with high estimation accuracy are required. Many effective technologies and methods have been developed to solve case and parameter estimation problems.

Control studies using observer-based control methods (Kalman filter, adaptive, sliding-mode observations, Luenberger, etc.) have been done in the literature [16-22]. The sliding mode control was the result of the studies carried out in the 1950s. In 1976, Itkis [23] and Utkin [124-25] in 1977 with the work of this control method is the basis. The sliding mode control is a special case of the variable structure control. First, a surface is selected and the surface is referred to as the sliding surface. This surface is selected in the state space. First, state variables are forced to go over the slip-surface. After the state variables reach the slip surface, the control signals that are directed to the origin on this surface are determined. In this method, first the state variables are forced to go onto the sliding surface and are then shifted on the surface and then shifted towards the origin. It is therefore also referred to as the sliding surface, also called the switching surface. Due to the nature of this method has a non-continuous control structure. This discontinuous control sign leads to cracking. This damages the physical system elements.

One way to prevent this is to replace the discontinuous signum function in the sliding-mode control signal with the saturation function, a continuous approach of this function [26-27]. Many methods are usually affected by dc motor parameter changes, uncertainties and disturbing factors, which leads to a decrease in the quality of the control. Due to model uncertainties and resistance to external factors and nonlinear structure, sliding mode control method is preferred for controlling DC motor. In this study, an observer-based sliding-mode control method is proposed for position and speed-free control of a DC motor. For the control of the DC motor, the observer type Luenberger and Kalman filter observer methods were used. The saturation function is used for the cracking problem of the sliding mode control method. Both the process noise and the measurement noise were applied to control the DC motor system in conditions close to the actual ambient conditions. A second-order low-pass filter design has been designed to improve the performance of the controllers in the noise environment. The control methods applied according to the results of the simulation environment were compared and their results were examined.

II. STATE STACE MODEL OF DC MOTOR

Direct current motor are the most commonly used motors in the control systems. They may provide rotation and offset movement. DC motor model is shown in Figure 1.

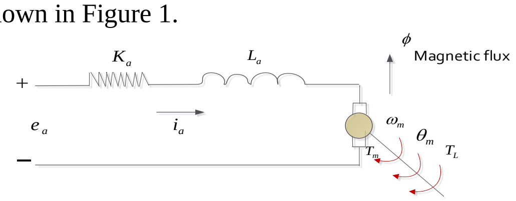

Fig. 1 Dc motor model

Moment received from the electric motor;

$$T_m(t) = K_m.\Phi.i_a(t) = K_i.i_a(t) \quad (1)$$

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

$$T_m = K_i.I_a \quad (3)$$

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

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

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.

$$\dot{\underline{x}} = A.\underline{x} + b.u \quad (6)$$

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

$$y = Cx + Du \quad (8)$$

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

TABLE I
PARAMETERS OF DC MOTOR

Sembol	Description	Units	Value
m	Body Mass	*kg*	10
J	Body Inertia	*kgm^2*	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	Damping ratio of the system friction constant	*Nm.*	0.097

III.THE CONTROLLER DESIGN

Control performances were performed by using different observers in control of DC motor. In the control systems used, the purpose is that the output value of the system follows the targeted value. This error is minimized by the controller applied to the system.

A. Sliding Mode Control

The sliding-mode control (SMC) method was used to control this system[28-33]. The control variable of the system is the position angle of the motor. The position angle of the system has been checked in the presence of disturbing effects. Figure 2 shows the block diagram of the sliding-mode control (SMC) method.

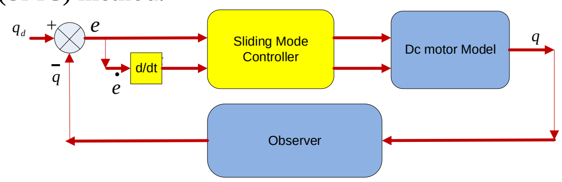

Fig. 2 Block diagram of the control structure system

$$e(t) = q_d(t) - q(t) \quad (9)$$

$$\dot{e}(t) = \omega_d(t) - \omega(t) \quad (10)$$

In the above equation, q_d denotes the desired joint trajectory and q shows the true trajectory. The first and second-degree derivatives were used for equation 9.

$$S = \dot{e} - \lambda e \quad (11)$$

$$\dot{S} = \ddot{e} - \lambda \dot{e} \quad (12)$$

S shows the sliding surface. Equations 11 and 12 were obtained. λ is a positive defined symmetric matrix. k is the constant parameter with the equation 13. Signum is a signal function and s functions as a switch. Figure 3 shows the concept of the sliding surface.

$$u = -k * sign(S) \quad (13)$$

$$sat(s/\phi) = \begin{cases} \frac{s}{\phi} & if \left|\frac{s}{\phi}\right| \le 1 \\ \mathrm{sgn}(s/\phi) & if \left|\frac{s}{\phi}\right| > 1 \end{cases} \quad (14)$$

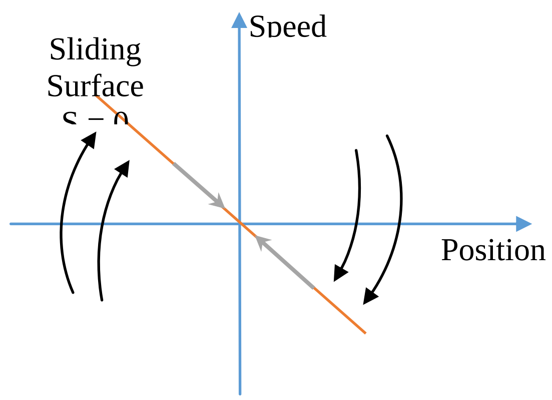

Fig. 3 The concept of the sliding surface.

Lyapunov criteria were used for the stability of the system. Saturation function is used to solve the chattering problem. ϕ shows the thickness of the boundary layer.

$$V = \frac{1}{2} S^T S \qquad (15)$$

S ≠0 for V>0. The derivative of the equation 15 was obtained to obtain the number 11. $\dot{V}$ is <0.

$$\dot{V} = S^T \dot{S} + \frac{1}{2} S^T S \qquad (16)$$

B. Sensorless Control

The traditional method for measuring the speed of DC motors uses a tacho-generator that converts the speed to the corresponding voltage. The output voltage can be used as feedback to control the speed of the DC motors. In this study, motor speed measurement system is applied without mechanical components. The transfer function or status area analysis is one of the popular methods of controlling the speed of DC motors without speed sensor [34]. The method converts the DC motor's continuous-time system parameters to state space form. The system inputs are armature voltage and armature current and the system output is the speed of the DC motor. The position can be estimated by integrating the speed. In this study, Luenberger and Kalman filters were used for the estimation of speed.

C. Luenberger Observer

A system is generally used as an information in the system's state feedback control by making it measurable by measuring with sensors. However, it is sometimes necessary to estimate the non-measurable state variables such as the cost of the sensors and in some cases, there is no sensor to provide that measurement. It is called state observation that these variables can be measured by using measurable state variables and measurable outputs of the system. and the tools used for this process are also called status monitors or briefly observers. The most well-known and most frequently used observer is the Luenberger observer [35-38]. The problem in this study is the estimation of the angular velocity of the dc motor. Using the dc motor state space model, the engine was estimated using the angular velocity observer. State space model equations of the observer can be given as follows:

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - C\hat{x}) \qquad (17)$$

$$y = C\hat{x} + v \qquad (18)$$

The $\hat{x}$ values given in the above equations show the predicted states, the inputs u, the outputs y, the observer gain matrix L, the measurement noise v. The block diagram of the system and the observer is given in Figure 4.

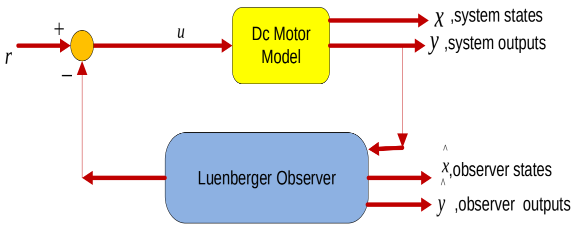

Fig. 4 Block diagram of the Leuenberger observer and system

While the observer gain matrix L is found, the monitor's poles are selected to the left of the system poles at least 10 times faster than the system poles so that the observer's estimation error converges to the zero quickly and the effect of the monitor on the system response is minimized. To be able to design a system for a system, it must be observable. The system has been found to be fully observable for all velocity and motor friction coefficients in the dc motor model. In this study, the Luenberger observer was used in the first studies and then the Kalman filter which is an advanced observer was used for speed estimation.

D. Kalman Filter Design

Kalman filter is a filter estimating the status of the systems using the input and output information [39-42]. It has become one of the popular control methods for the DC motors without the transfer function or the state-space speed sensor. The inputs of the system are the armature voltage and armature current, system output is the speed of the dc motor in this system. Kalman filter is a kind of filter that can conduct optimally filter the operation and computation noise as long as the covariance of the noise is known. Estimation with this filter results in minimizing the covariance matrix of the fault for the systems exposed to Gauss computation or operation noise. State space model equations of Kalman estimator can be given as follows:

$$\dot{x} = Ax + Bu + w \qquad (14)$$

$$y = Cx + v \qquad (15)$$

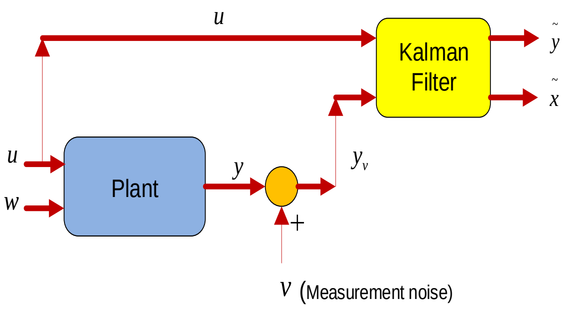

Fig. 5 Block diagram of the Kalman estimator

Respectively, w represents the operation noise given to the system randomly, and v represents the commutation noise. In general, the following are the equations of Kalman estimator.

$$\dot{x} = Ax + Bu + w \tag{16}$$

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - C\hat{x}) \tag{17}$$

$\dot{\hat{x}}$ it is the estimated x value.

$$AP + PA^{T} - PC^{T}R^{-1}CP + Q \tag{18}$$

Q must be positively defined and R must be positive semi-defined and the system must be observable. Operation noise is expressed as w~N(0, Q) and measurement noise is expressed as v~N(0, Q). Here, Q is the input covariance matrix and R is the output covariance matrix. P algebraic invariant minimizing the cost function is calculated with the Riccati equation. Filter gain, L, is calculated as shown with the Riccati equation.

$$L = PC^{T}R^{-1} \tag{19}$$

IV. NUMERICAL SIMULATION

In this section, the sliding-mode control method based on the Luenberger and Kalman filter monitors given above is used. The design, calculations, and simulations of the methods were made. The observer-based control of the Dc motor was simulated using the parameters shown in Table 1. In simulation studies, sensorless speed control was performed by using observer-based control methods. The most important point in this study is that the controllers are stable and the system performs the desired task with minimum error rate. The following figures show the motor speed graphs according to the reference speed change. The Luenberger observer-based sliding-mode control method has generally followed the reference with more amplitude. According to observer method, settling time, overshoot etc. parameters differ from each other. Figure 6,7 and 8 shows every control techniques in one graphic, Kalman filter based sliding mode control has the best settling time over Luenberger observer sliding mode control. Kalman filter-based sliding mode control method gave the best results.

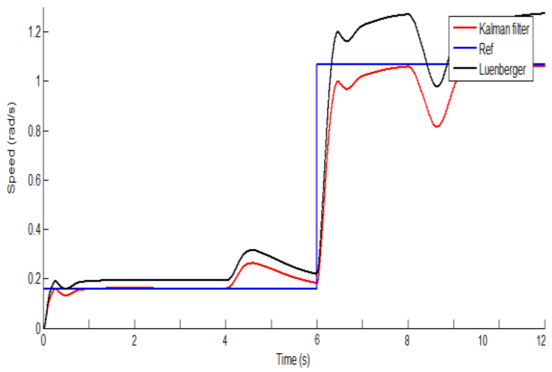

Fig. 6 The speed results of numerical simulation for square input

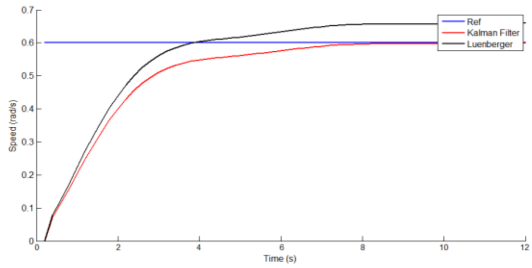

Fig. 7 The speed results of numerical simulation for constant input

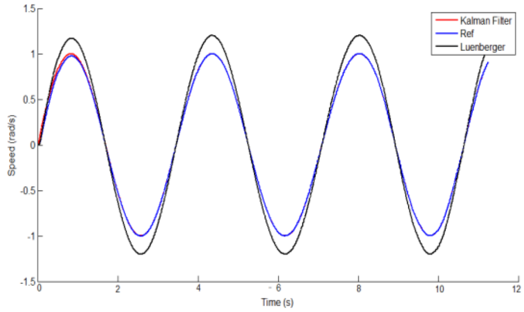

Fig. 8 The speed results of numerical simulation for sinus input

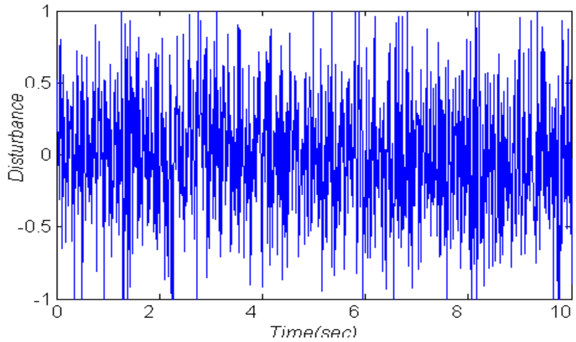

Fig. 9 Disturbance input signal affecting the motor

V. CONCLUSIONS

In this study, the design and simulation of Luenberger and Kalman filter-based sliding-mode control are performed for dc motor speed control. It has been seen that the chattering problem of the sliding mode control method is solved by the saturation function. In order to control the DC motor under conditions close to the actual ambient conditions, both noise and measurement noise was applied. A second order low pass filter design has been applied to increase the performance of the controllers in the noise environment. The Kalman filter-based observer gave the best results. As a result of the comparison of observer-based control methods, it was observed that the controllers gave satisfactory results. In future studies, the proposed observers are intended to be developed and implemented on a real system.

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APPENDIX

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	The angular velocity of the rotor