

Simulation and Arduino Hardware Implementation of DC Motor Control Using Sliding Mode Controller

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Abstract—The research proposed an alternative controller to control the Direct Current (DC) Motor using a sliding mode controller (SMC) in Matlab Simulink simulation and Arduino hardware implementation. The proposed controller, SMC, was designed using the system model (equivalent control) and Lyapunov control design (also to prove the stability). The sliding mode controller had a better response than PID Controller, with no overshoot response in the simulation result. In the Arduino hardware implementation result, the augmented system could reach the reference but has an oscillation and chattering effect in the control signal. The chattering could be reduced by modifying the switching control. Comparing with PID, SMC had a better response with no overshoot. Thus, the SMC could be used as an alternative controller for the DC Motor.

Keywords—DC Motor, Sliding Mode Controller, Arduino, PID Control, Matlab

I. INTRODUCTION

Direct Current (DC) motors play an important role in vehicles [1][2], robotics [3][4][5], aircraft [6], and industrial [7][8][9]. The common controller used in DC motor is Proportional Integral Derivative (PID) Controller [10]. The main weakness of the PID controller is inconsistent performance [11][12]. The parameter of the controller only has good performance in one set point. In other set points, the given response would be different [13].

The other controller is the Fuzzy Logic Controller (FLC) [14][15][16][17][18][19]. It is not easy to be designed, especially if it has many inputs. It requires experience, as in experimental data, to be able to design a suitable controller. It also needs more memory if it has many rules. Thus, we need an alternative controller for DC Motor. Another controller is the state feedback controller [20][21][22]. However, the controller needs all of the state must be measurable in hardware implementation. Thus it cannot work only using one sensor.

The alternative controller for DC Motor is the Sliding Mode Controller (SMC) that has the advantage of avoiding uncertainties and disturbance [23][24]. It is similar to the Variable Structure System (VSS) and is included in the nonlinear controller [25]. It has been applied to many systems, such as Magnetic Levitation System [26][27], Buck Converter [28][29], Quadcopter [30][31], Quadrotor [32], Unmanned Surface Vehicle [33], DC/DC Converters [34]

and robot Manipulator [35][36][37]. Nevertheless, all mentioned researches were limited to simulation purpose only.

The simulation about sliding mode controller had been done before [38][39][40][41][42]. They resulted in a good performance, but we need the hardware implementation to observe more. This research would do not only the simulation but also the hardware implementation. For a simple implementation, it would use the Arduino microcontroller. The advantage of using the Arduino is low-cost [43][44][45], small [46], and has many applications [47][48][49][50]. Thus, it will good for the education purpose [51] and the hardware implementation.

The paper will be structured as follows. The first section of the paper is the introduction. Next, the second section is the modeling of DC Motor. Then, the next section is the sliding mode controller design. The following section is the result and discussion that consist of numerical simulation and hardware implementation. The last section is the conclusions and the future work.

II. MODEL OF DC MOTOR

The DC Motor diagram is shown in Figure 1. The variable v_{DC} is the DC power supply, v_{Emf} is the back electromotive force voltage, R is the armature resistance, L is the armature inductance, f_k is the friction torque, J is the inertia, ω is the angular speed, T is the motor torque, i is the armature current.

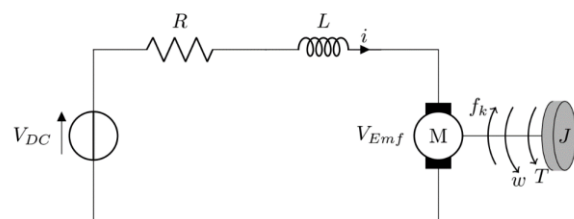


Fig. 1. DC Motor Diagram

The equations with Kirchhoff voltage law analysis is obtained as

$$Ri + L \frac{di}{dt} = v - K_e \omega \quad (1)$$

where variable K_e is the electromotive force constant.

The equation with Newton second law for rotation is obtained as

$$J\dot{\omega} + b\omega = K_t i \quad (2)$$

where K_t is the motor torque constant, and b is the motor friction constant.

After using the mathematical processing with (1) and (2), we obtained

$$L \frac{di}{dt} = -Ri - K_e \omega + v \quad (3)$$

$$J\dot{\omega} = -b\omega + K_t i \quad (4)$$

Define the state space variables and the control signal variable as

$$x_1 = \omega \quad (5)$$

$$x_2 = i \quad (6)$$

$$u = v \quad (7)$$

Then, we obtained the derivation of the state space variable as

$$\dot{x}_1 = \dot{\omega} = \frac{d\theta}{dt} = -\frac{b}{J}\omega + \frac{K_t}{J}i \quad (8)$$

$$\dot{x}_2 = \dot{i} = \frac{di}{dt} = -\frac{K_e}{L}\omega - \frac{R}{L}i + \frac{1}{L}u \quad (9)$$

Then, we used the substitution to obtain

$$\dot{x}_1 = -\frac{b}{J}x_1 + \frac{K_t}{J}x_2 \quad (10)$$

$$\dot{x}_2 = -\frac{K_e}{L}x_1 - \frac{R}{L}x_2 + \frac{1}{L}u \quad (11)$$

The state-space model is

$$\dot{x} = Ax + Bu \quad (12)$$

$$y = Cx \quad (13)$$

Where

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad A = \begin{bmatrix} -\frac{b}{J} & \frac{K_t}{J} \\ -\frac{K_e}{L} & -\frac{R}{L} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} \quad C = [1 \quad 0]$$

The parameter value of DC Motor is shown in Table I. The parameter was used in the simulation and controller design.

The state-space model in (12) and (13) using the parameter from Table 1 was

$$\dot{x} = \begin{bmatrix} -5.5 & 37.5 \\ -0.01852 & -0.1481 \end{bmatrix} x + \begin{bmatrix} 0 \\ 0.3704 \end{bmatrix} u \quad (14)$$

$$y = [1 \quad 0]x \quad (15)$$

Based on the state-space model, the transfer function model can be obtained as (it can use Matlab function ss2tf)

$$\omega(s) = \frac{13.89}{s^2 + 5.648s + 1.509} v(s) \quad (16)$$

TABLE I. DC MOTOR PARAMETER VALUE [52]

Parameter	Value
R	0.4
L	2.7
J	0.0004
K_b	0.0022
K_t	0.015
K_e	0.05

III. SLIDING MODE CONTROLLER DESIGN

The sliding mode controller needs the model in the state space controllable form. Thus, the transfer function model in (16) can be written time domain as

$$\ddot{\omega} + 5.648\dot{\omega} + 1.509\omega = 13.89v \quad (17)$$

Then, we define the state space variable as

$$x_1 = \omega \quad (18)$$

$$x_2 = \dot{\omega} \quad (19)$$

$$u = v \quad (20)$$

We obtain the state-space model in the controllable canonical form as

$$\dot{x}_1 = x_2 \quad (21)$$

$$\dot{x}_2 = -5.648x_2 - 1.509x_1 + 13.89u \quad (22)$$

The first step to designing the sliding mode controller was designing the sliding mode function as

$$s = ce + \dot{e} \quad (23)$$

Where variable e is the tracking error and variable c must satisfy the Hurwitz condition ($c > 0$).

The tracking error and the derivation are

$$e = \omega_d - \omega \quad (24)$$

$$\dot{e} = \dot{\omega}_d - \dot{\omega} \quad (25)$$

$$\ddot{e} = \ddot{\omega}_d - \ddot{\omega} \quad (26)$$

where variable ω_d is the reference signal, and ω is the actual angular speed.

Define the Lyapunov function as

$$V = \frac{1}{2}s^2 \quad (27)$$

To guarantee the stability condition, the derivation of the Lyapunov function in (27) must be $\dot{V} < 0$ as

$$s\dot{s} < 0 \quad (28)$$

The derivation of the sliding mode function is

$$\dot{s} = c\dot{e} + \ddot{e} \quad (29)$$

$$= c\dot{e} + \ddot{\omega}_d - \ddot{\omega} \quad (30)$$

$$= c\dot{e} + \ddot{\omega}_d + 5.648\dot{\omega} + 1.509\omega - 13.89u \quad (31)$$

Thus the derivation of the Lyapunov function \dot{V} is

$$s\dot{s} = s(c\dot{e} + \ddot{\omega}_d + 5.648\dot{\omega} + 1.509\omega - 13.89u) \quad (32)$$

To satisfy the condition $s\dot{s} < 0$, the sliding mode controller is designed as

$$u = \frac{1}{13.89} (1.509\omega + 5.648\dot{\omega} + \ddot{\omega}_d + c\dot{e} + K \operatorname{sgn}(s)) \quad (33)$$

Where

$$\operatorname{sgn}(s) = \begin{cases} 1, & s > 0 \\ 0, & s = 0 \\ -1, & s < 0 \end{cases} \quad (34)$$

Substitute (33) to (28), then we get

$$s\dot{s} = -K \operatorname{sgn}(s) < 0 \quad (35)$$

IV. RESULTS AND DISCUSSION

The section will be divided into two. The first part is the numerical simulation using Matlab Software. Then, the second part is the hardware implementation using the Arduino microcontroller.

A. Numerical Simulation

In the section, the simulation used the Simulink Matlab Software. The Simulink setup is shown in Figure 2. The SMC control signal is in (33).

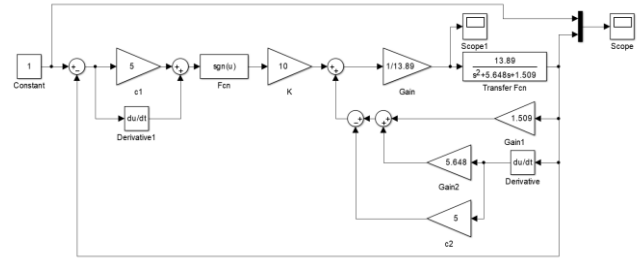


Fig. 2. Simulation Setup in Simulink Matlab

Comparing system response with PID, the result for the step reference signal is shown in Figure 3. The detailed system response is shown in Table II. It can be seen that the SMC response did not have an overshoot. Meanwhile, the PID response had a 22.48% overshoot. Thus, the SMC response was better than the PID Controller.

TABLE II. SYSTEM RESPONSE PERFORMANCE

Controller	System Response Performance		
	Rise Time	Settling Time	Overshoot
SMC	0.6070	1.0899	0
PID	0.1830	1.0014	22.4793

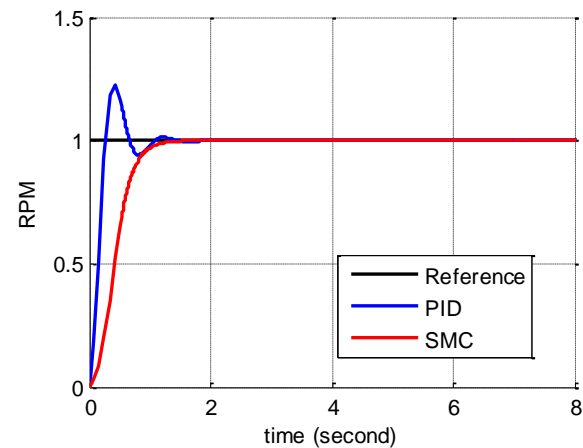


Fig. 3. Response system

B. Arduino Hardware Implementation

In this section, the hardware implementation would be conducted using Arduino, DC Motor JGA25, Driver Motor L298, Encoder, and Current Sensor INA219. The device setup is shown in Figure 4.

The result is shown in Figure 5. The SMC control signal is shown in Figure 6. It can be seen that the system could reach the reference but had an oscillation. The SMC control signal had a chattering effect.

The sliding mode controller was modified to reduce the chattering effect, as

$$u = \frac{1}{13.89} \left(1.509\omega + 5.648\dot{\omega} + \ddot{\omega}_d + c\dot{e} + K \frac{s}{|s| + \delta} \right) \quad (36)$$

Where the parameter δ is the scalar tuning parameter to reduce the chattering effect.

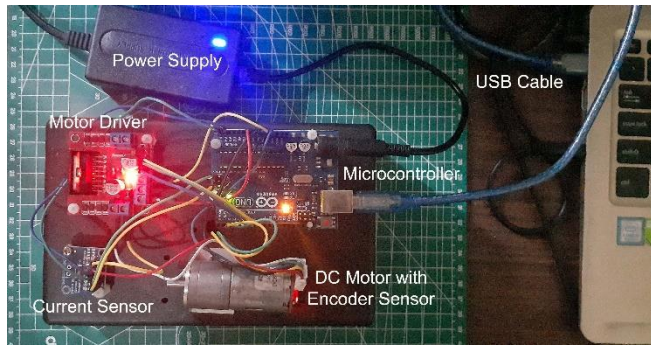


Fig. 4. DC Motor Hardware Setup

The system's responses and control signal using modified switching function in (36) is shown in Figure 7 and Figure 8. It can be shown that the chattering effect was reduced, and the system response was better than before.

The subsequent examination was a comparison between the SMC and PID controller. The result is shown in Figure 9. It can be seen that SMC 1 and SMC 2 did not have any overshoot. Meanwhile, the PID control had an overshoot. The PID had a small oscillation than the SMC.

V. CONCLUSIONS AND FUTURE WORK

The paper proposed DC Motor control using the sliding mode controller in simulation and hardware implementation. Based on the simulation, the SMC had a better response than PID Controller. Meanwhile, in hardware implementation, SMC had oscillation to follow the reference. Thus, the SMC could be implemented in the hardware system but still need improvement to reduce the oscillation.

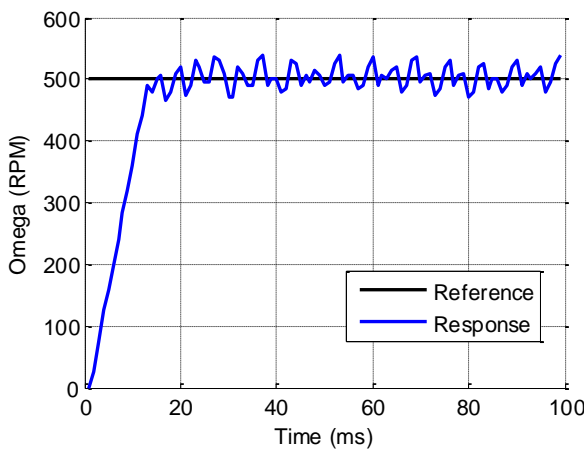


Fig. 5. SMC System Response

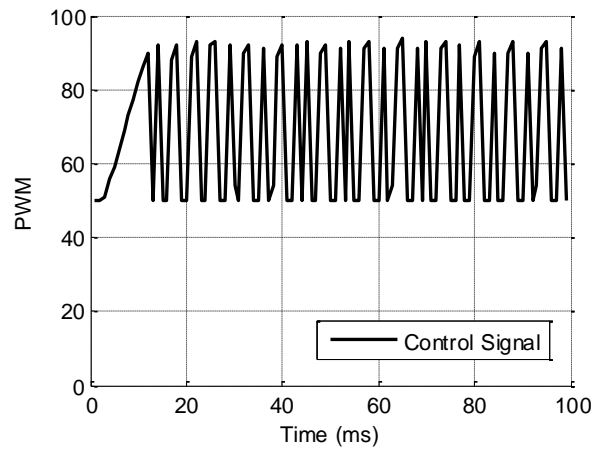


Fig. 6. SMC Control Signal

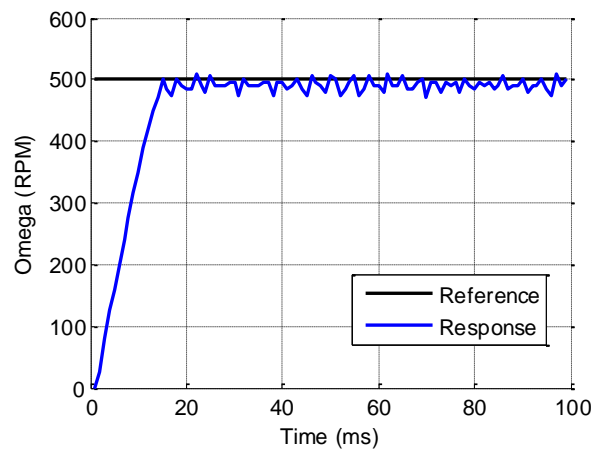


Fig. 7. SMC System Response

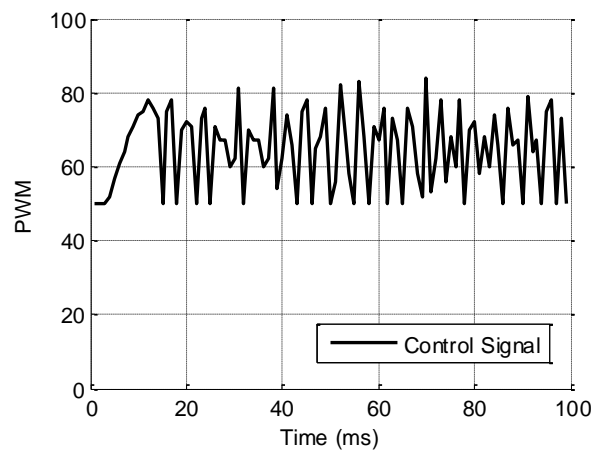


Fig. 8. SMC Control Signal

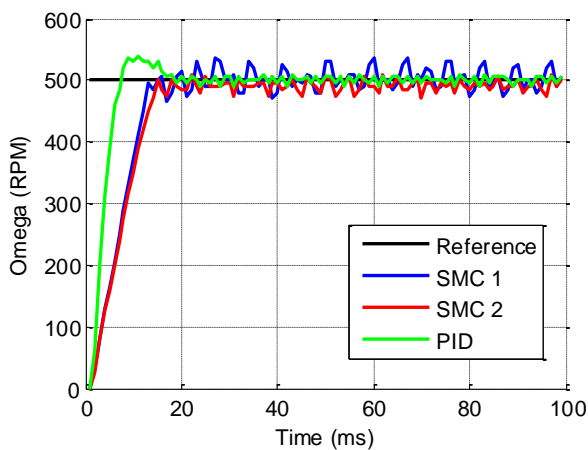


Fig. 9. Comparing SMC with PID

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