System Identification and Control of DC Motor with PID Controller

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Abstract

This paper presents an estimation of a mathematical model of a direct current motor (DC motor) system through an application of system identification with transfer function model. This method is performed by means of testing and collecting input current signals, fed into the system, and position output signals – the system response. The findings suggest that the system identification can provide the estimation results similar to those of the real system, this model gives the best fit of 96.87%. A concrete proof of this is that a PID controller designed for the system using the model is capable of controlling the motion position of motor rotation, in accordance with good position tracking; and produces the system response as required.

Keywords : DC Motor, Estimation Model, System Identification, Position Control, PID control.

1. Introduction

At present, electric motors are widely applied to a range of engineering work and industries, especially to the production with an automation system (Kama, Mahanijah, Nasirah & Norhayati. (2009), Shanmuga, Mythile, Pavithra & Nivetha. (2020), Surajudeen (2016)) i.e. regulation of the throttling orifice position of a valve, to control the flow of sugar manufacturing; electricity generation process; and petroleum production. Apart from this, these products have been constantly improved to meet requirements for daily uses, to further convenience; for example: hard disk drives and power engines of electric vehicles, to replace the use of fuel oil in internal combustion engines which has impacted the environment in terms of both noise and air pollutions. As for the control of speed or of motion position of motors in engineering work which requires high precision, however, there are still various factors to be taken into consideration. Also, the proper knowledge of parameters from mathematical modeling of a system is necessitated, in order to enable a design of a device to control operation of a motor according to requirements (Byamakesh & Sangeeta. (2019), Kama, Mahanijah, Nasirah & Norhayati. (2009)). Determination of such model parameters is considerably complex for computational approaches, such as equations of motion of a system based on Newton's laws or energy method based on Lagrangian machanics (Saab & Kaed-Bey. (2001), Surajudeen (2016)), or based on Kirchoff's law (Byamakesh & Sangeeta. (2019), Shanmuga, Mythile, Pavithra & Nivetha. (2020), Wai. (2007)). Moreover, other factors which also affect a system, e.g. friction, inertia of an axel set, mechanical torque occurring to a motor, delay of the control signals and nonlinearity, are variables with unknown value (Kama, Mahanijah, Nasirah & Norhayati. (2009)). Accordingly, these variables may result in improperness of a controller, which, in turn, leads to unstable control of a system.

In light of this, this research is conducted in order to propose an estimation of parameters of a mathematical model with system identification (Mei, Chen & Wenlin. (2009)), a practice-oriented method which is centered around testing and collecting input current signals, fed into the system, and position output signals – the actual system response. This method enables the estimation of a mathematical model of the system through transfer function modeling (Sofia, Hicham & Bahloul. (2014), Wei. (2012)), and helps eliminate problems caused by errors from computational methodology previously mentioned. Furthermore, the model derived from the estimation is employed to design a PID controller for the system; and the stability and the system response, according to requirements, result.

2. Research Objectives

2.1 To estimation of a mathematical model of a direct current motor (DC motor) system through an application of system Identification with transfer function model.

2.2 To design PID controller for the system using the model is capable of controlling the motion position of motor rotation, in accordance with good position tracking; and produces the system response as required.

3. Methods

3.1 DC Motor and System for testing

The research develops a testing set for estimating parameters of a mathematical model utilizing system identification with testing and collecting input current signals, fed into the system, and position output signals – the actual system response. All signals obtained are then used for estimating the mathematical model, as shown in Figure 1.
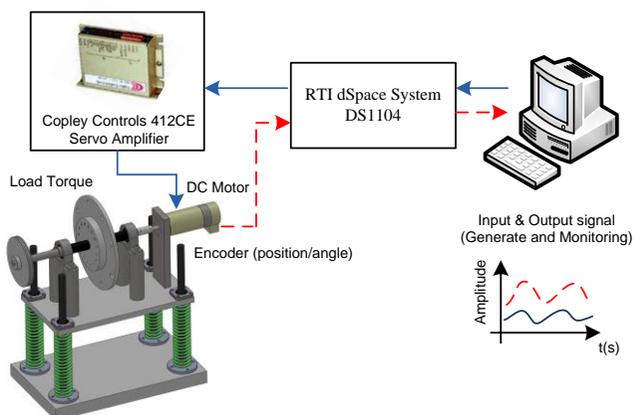

Figure 1 DC motor system test

3.2 System Identification

The method used for the research is system identification with transfer function model approach of a dynamical system, as shown in Figure 2. This method is regarded as art and science of creating mathematical models from measured input-output data; a model generates the response, to the input signals fed to the system (measured), with output signals closest to those of the real system.
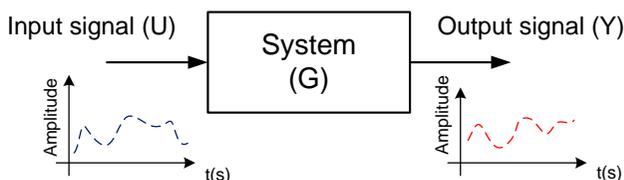

Figure 2 System identification with transfer function model

The system transfer function is a well-known relationship between input $U(s)$ and output $Y(s)$ of a system for linear time invariant system, and can be expressed as below.

$$G(s) = \frac{Y(s)}{U(s)} \tag{1}$$

As for discrete time, the mathematical model presents a generalized relationship between input and output (with an exclusion of noise) which can be expressed in time-series model (Kama, Mahanijah, Nasirah & Norhayati. (2009)) with the following mathematical Equation (2)

$$y(t) + a_1 y(t-1) + \ldots + an_a y(t - n_a) = b_1 u(t-1) + \ldots + bn_b u(t - n_k - n_b + 1) \tag{2}$$

Where $y(t)$ is the output at time (t).

$a_1 \ldots a_n$ and $b_1 \ldots b_n$ are the parameter to be estimated.

n_a is the number of pole of system.

$n_b - 1$ is the number of zero of system.

n_k is the number of input samples. That occur before the input that affect the current output.

$y(t-1) \ldots y(t - n_a)$ are the previous output on which the current output depends.

$u(t - n_k) \ldots u(t - n_k - n_b + 1)$ are the previous input on which the current output depends.

The mathematical model can also be written in a compact way using the following notation

$$A(q)y(t) = B(q)u(t - n_k) \tag{3}$$

Where $A(q) = 1 + a_1 q^{-1} + \ldots + a_{n_a} q^{-n_a}$, $B(q) = b_1 + b_2 q^{-1} + \ldots + b_{n_b} q^{-n_b + 1}$ and q^{-1} is backward shift operator, define by

$$q^{-1} u(t) = u(t-1) \tag{4}$$

From there, the measured transfer function is as below

$$G(q) = \frac{B(q)}{A(q)} \tag{5}$$

By employing Laplace transform of this system (based on an assumption that all initial conditions are zero), the transfer function obtained is as follows

$$G(s) = \frac{b_m s^{(m)} + b_{m-1} s^{(m-1)} + \ldots + b_0}{a_n s^{(n)} + a_{n-1} s^{(n-1)} + \ldots + a_0}$$

(6)

Where n is the number of pole.

   m is the number of zero.

   $a_0 \ldots a_n$ and $b_0 \ldots b_m$ are the parameters to be estimated.

3.3 Real time interface system

The research employs RTI dSpace System DS1104 (Real Time Interface System) together with Matlab for testing and collecting input and output signals at sampling processing time of 0.001 s. The result is a creation of a block diagram, to feed current input signals to the system, in a form of sin value with maximum current of ± 0.18 A and noise of ± 0.005 A, as shown in Figure 3 (a); and to convey the signals to a digital to analog converter (DAC) for converting into current signals which are then send to a servo amplifier for activating the motion of the motor. Next, the signals of the motion position are read by an encoder, as shown in Figure 3 (b), and the feedback is then transferred to the RTI dSpace System DS1104 and a computer for a collection of output signals, for calculation and estimation of system parameters.
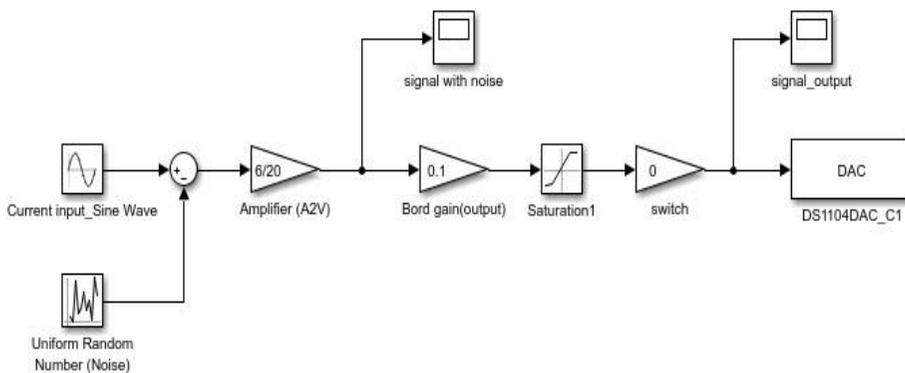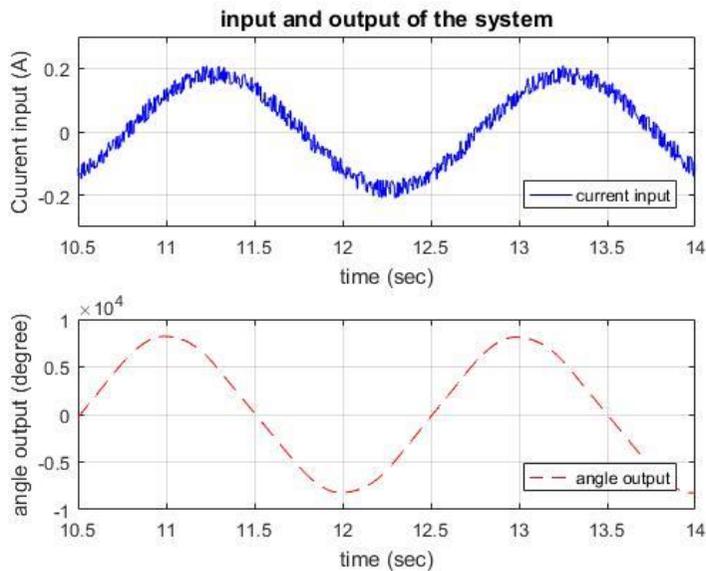

(a)
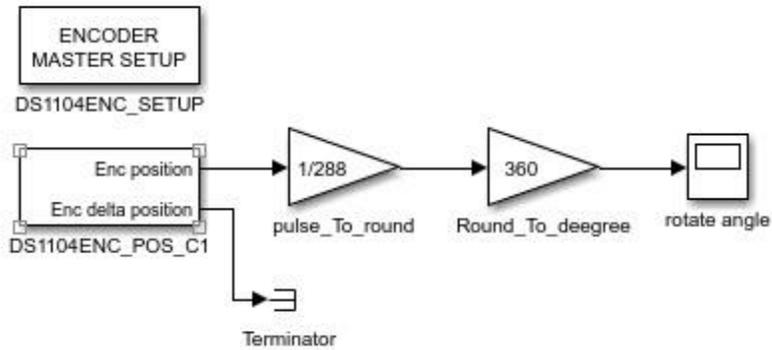
(b)

Figure 3 Block diagram to measure signals of input (a) and output (b) with RTI dSpace System
DS1104

From the testing, current input (A) and angle output (degree) are obtained as shown below.

Figure 4 Input and Output Signal (Real System)
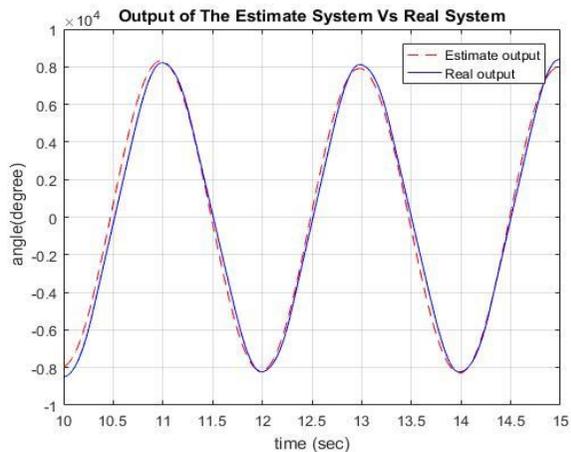
4. Results

From there, the measured signals, current input and angle output, are analyzed and
estimated for parameters of the mathematical model of the system utilizing system identification
with transfer function model, based on the transfer function of the system having the number of

poles = 2 and the number of zeros = 0. The result provides the system estimate as a transfer function of the dynamic system as given below.

$$G(System\_Estimate) = \frac{-4.689 \times 10^{5}}{s^{2} + 2.468s + 2.937} \tag{7}$$

4.1 Real output Vs Estimate output

The results from testing current input with the system estimate, in comparison to the real system, indicate that the output signals from the system estimate represents the response similar to that of the real system, as shown in Figure 5. Also, this model gives the best fit of 96.87%, when comparing the output signals to those of the real system.

Figure 5 Real output Vs Estimate output

4.2 Block diagram and Step response for system estimate with PID controller

As a result of the above, the model of the system from the system estimate can be employed to design a controller. Since the study is on the single input-single output system, however, the design focuses a PID controller. The block diagram of control system with PID controller is illustrated below.
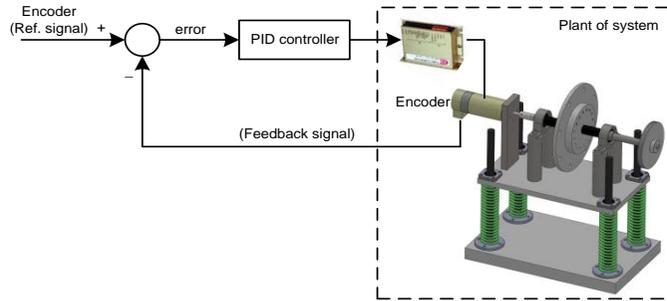
Figure 6 Block diagram of control system with PID controller

Below is the design of a PID controller ($C_{(PID)}$), as expressed in Equation (8), which enables the stability of the system and good response, with the rise time of 0.02 s. and no overshoot, as shown in Figure 7.

$$C_{(PID)} = -14 \times 10^{-4} \frac{(1+0.55s)(1+0.68s)}{s(1+0.00088s)} \tag{8}$$
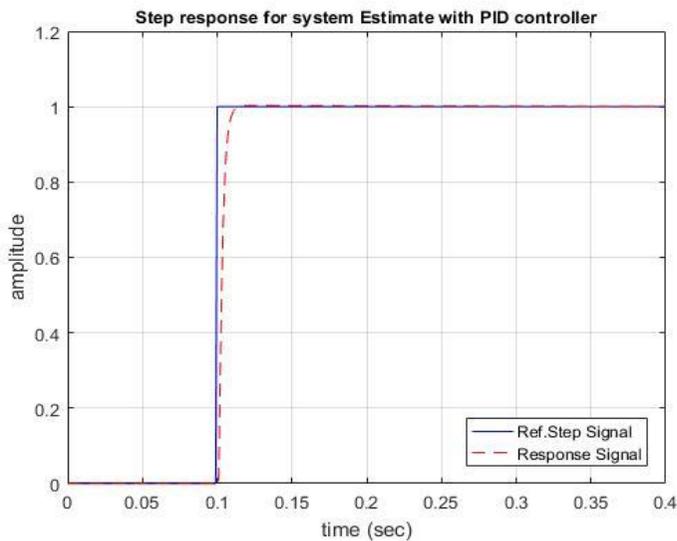
Figure 7 Step response for system estimate with PID controller

4.3 Testing controller with real system

After the completion of the PID controller design and also the simulation of the system response, a test on the controller with the real system is performed in order to determine whether or not the controller is workable. The test results reveal that the system response indicates good position tracking between reference signal and feedback signal, as exhibited in Figure 8. Nonetheless, the controller causes an on the system, that is, a delay of a control signals at

approximately 0.45 s.; thus, resulting in position error and non-real time system control, as shown in Figure 9.
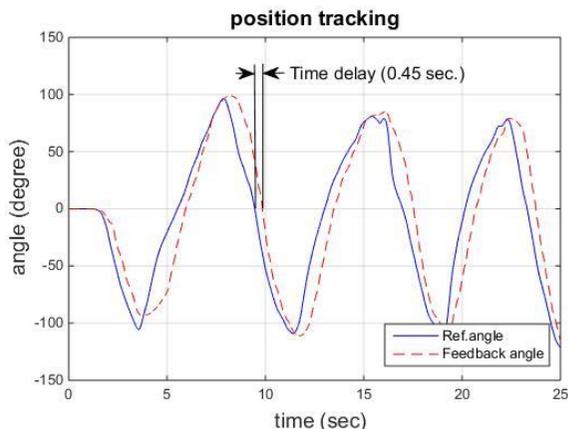

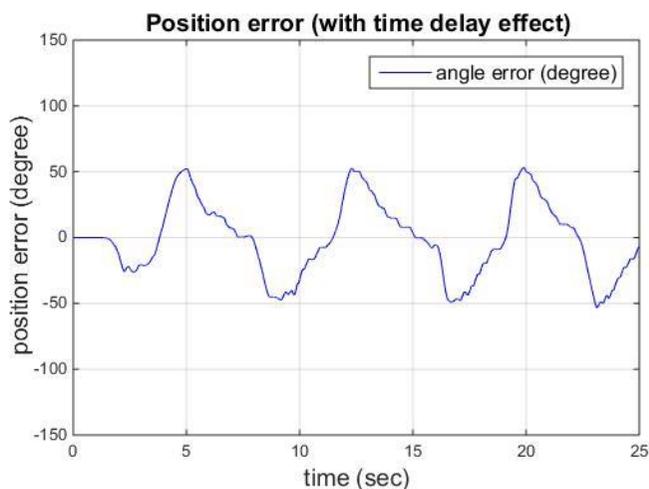**Figure 8** Position tracking (Real system testing)

Figure 9 Position error (with time delay effect)

5. Discussion and Conclusion

The research is conducted with the emphasis on an estimation of a mathematical model of a direct current motor (DC motor) system mounted with an encoder – a motion position sensor which is a single input-single output system. The method of system identification with transfer function model is used for an estimation of parameters of a mathematical model of the real system, and for proving that such a mathematical model can be utilized to design a PID controller for system controlling. From the simulation, the controller designed generates the system response with the rise time of approximately 0.02 s. and no overshoot. In addition, the test with the real

system demonstrates that controller is, to some extent, capable of activating the motor rotation in various positions, in accordance with good position tracking.

6. Suggestion

The findings suggest that the system identification can provide the estimation results similar to those of the real system, although this is owing to the fact that the model excludes a delay of control signals and nonlinearity of the system. However, an improvement for better system response can be made through a design of a more proper PID controller in order that, depending on a certain type of system operation, the system can have either faster or slower response.

7. Acknowledgment

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Academic Value

This research is conducted in order to propose an estimation of parameters of a mathematical model with system identification technique, a practice-oriented method which is centered around testing and collecting input signals, fed into the system, and output signals – the actual system response. This method enables the estimation of a mathematical model of the system through transfer function modeling, and helps eliminate problems caused by errors from computational methodology such as equations of motion of a system based on Newton's laws or energy method based on Lagrangian machanics, or based on Kirchoff's law. Furthermore, the model derived from the estimation can be employed to design a PID controller for the system; and development of the system stability and system response as required.