ECE 5670/6670 - Lab 2

Modeling and Parameter Estimation for the Brush DC Motor

Objectives

The objective of this lab is to begin experimentation with a brush DC motor. The responses of the DC motor to steps of voltage are measured, and its parameters are estimated.

1. Introduction

A model for the brush DC motor is

$$L\frac{di}{dt} = v - Ri - K\omega$$
$$J\frac{d\omega}{dt} = Ki - C\,\mathrm{sgn}(\omega) - B\omega \qquad (1)$$

where v (V) is the voltage applied to the motor, i (A) is the current, and ω (rad/s) is the angular velocity of the motor. The parameters are:

- R (Ω) the armature resistance,
- L (H) the armature inductance,
- K (N. m/ A or V. s) the torque constant, also called the back-emf constant,
- J (kg. m^2) the rotor inertia,
- C (N. m) the coefficient of Coulomb friction,
- B (N. m. s) the coefficient of viscous friction.

Assuming that the inductance is negligible, so that $v = Ri + K\omega$, the following model is obtained:

$$J\frac{d\omega}{dt} = -\left(\frac{K^2}{R} + B\right)\omega + \frac{K}{R}v - C\,\mathrm{sgn}(\omega) \qquad (2)$$

With constant direction of motion, the Coulomb friction can be viewed as a constant disturbance, and the transfer function from the voltage to the angular velocity is that of a first-order system. Three parameters then define the response of the system:

- $\theta_1 = \frac{1}{J}\,(\frac{K^2}{R} + B)$
- $\theta_2 = \frac{K}{JR}$
- $\theta_3 = \frac{C}{J}$

The parameters can be determined in different ways. A simple procedure consists in applying steps of increasing voltage. The time constant τ of the responses gives $\theta_1 = \tau^{-1}$. The steady-state responses give the remaining parameters. Indeed, the steady-state speed is related to the voltage through

$$\omega_{ss} = \left(\frac{K^2}{R} + B\right)^{-1} \frac{K}{R}\, v_{ss} - \left(\frac{K^2}{R} + B\right)^{-1} C = \frac{\theta_2}{\theta_1}\, v_{ss} - \frac{\theta_3}{\theta_1} \qquad (3)$$

for positive voltage. Measurements for multiple values of the voltage give the information needed to determine the remaining parameters.

2. Experiments

You will need:

- brush DC motor,
- dual power amplifier,
- multimeter,
- encoder cable.

2.1 Preliminary Testing

Be sure to refer to the handout of Lab 1 for basic hardware and software setup of dSPACE.

- Download the files *Lab2.mdl* and *Lab2.lax* and *Lab2.xml* from the lab web page.
- Ensure that Ts = 1e-4; nd = 30; are set up in the model configurations and build the .sdf file. Create a new project & experiment structure in dSPACE (refer to Lab 1 if needed). Import the layout file by going to the **Layout tab > Import Layout.** It should look similar to Figure 1. If the variables aren't mapped when you open the layout, map them by using Figure 1 as a guide. Load the recorder *Lab2.xml* to record your data.

- Connect the encoder input cable from the I/O breakout box port INC1 to the encoder plug on the motor support bracket. Run the program and check the operation of the encoder by manually spinning the motor, noting a change in encoder position in the layout window. Note that this can only be observed when the layout is online and the simulation state is ON.

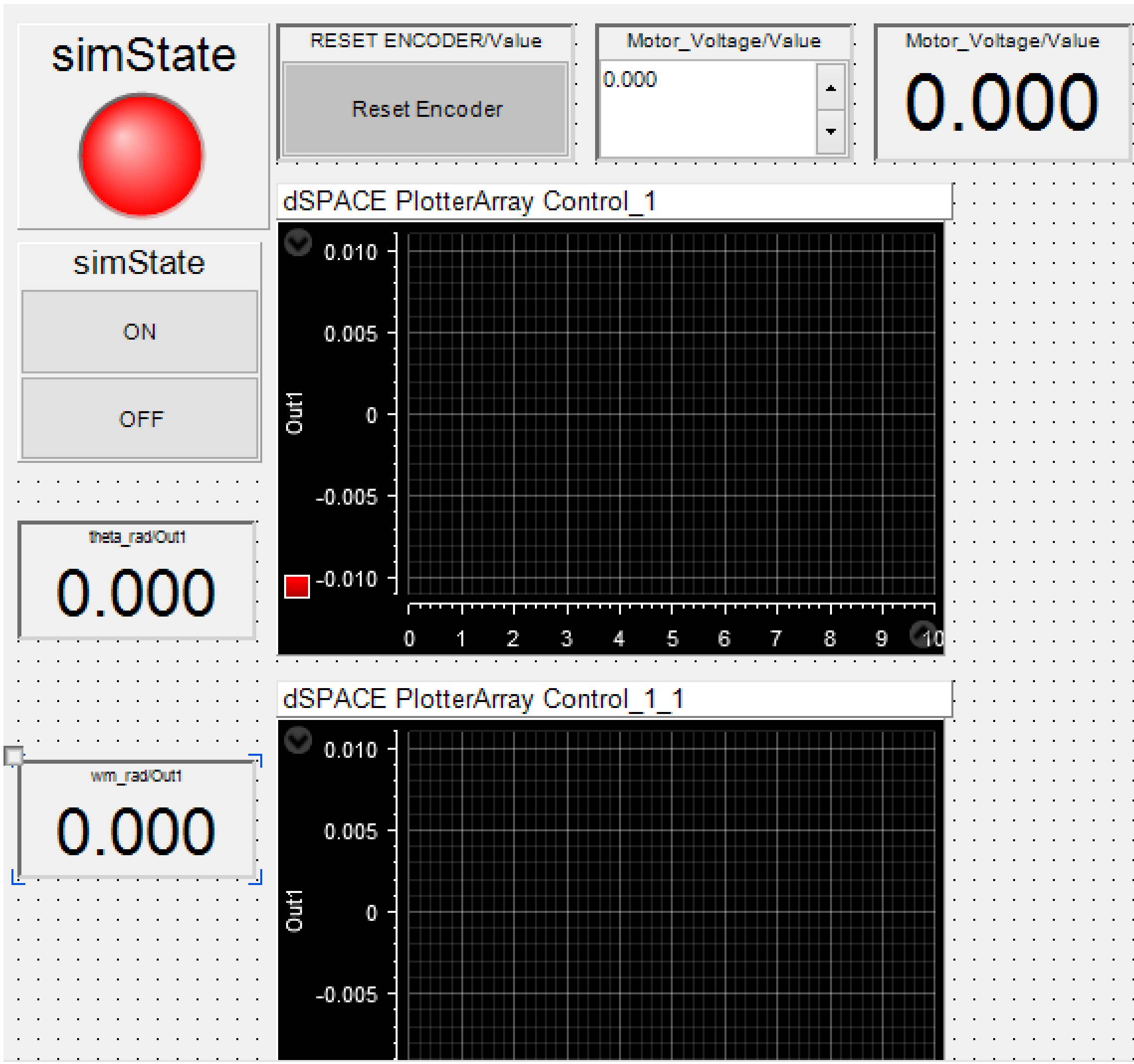

Figure 1: ControlDesk Layout

- Use a BNC-to-BNC cable to connect DACH1 to an input channel on the back of the dual amplifier. Set the voltage in the layout for +10 V and measure the resulting voltage at the output of the amplifier using a multimeter. It should be ~10 V. This also requires the simulation to be active.

- Finish hooking up the system by attaching leads from the motor to the amplifier using banana-banana cables.

2.2 Parameter Estimation

The experiment allows the operator to apply voltages to the DC motor. Note that the layout includes an entry box to specify the voltage to be applied to the channel and accounts for the value of the amplifier gain. The program stores samples at 10 kHz or a sample every 0.1 ms. To capture the data needed for this lab, use the procedure for “Save the data” in Lab 1.

Use “Mat_Unpack” to recover the position, average velocity, voltage, and time which have the units of radians, radians/second, volts, and seconds respectively. If you don’t see the time variable, ask your TA for help. If other data looks corrupted, you can try downsampling the data. This should not be required in this lab, as you are only recording four variables. In general, however, downsampling is obtained by going to **Measurement Configuration>>Acquisition>>Platform>>HostService>>Platform Trigger 1**. Then, in *Downsampling* box, change the value from 1 to 10 (so that data is collected at 1kHz). See Figure 2.

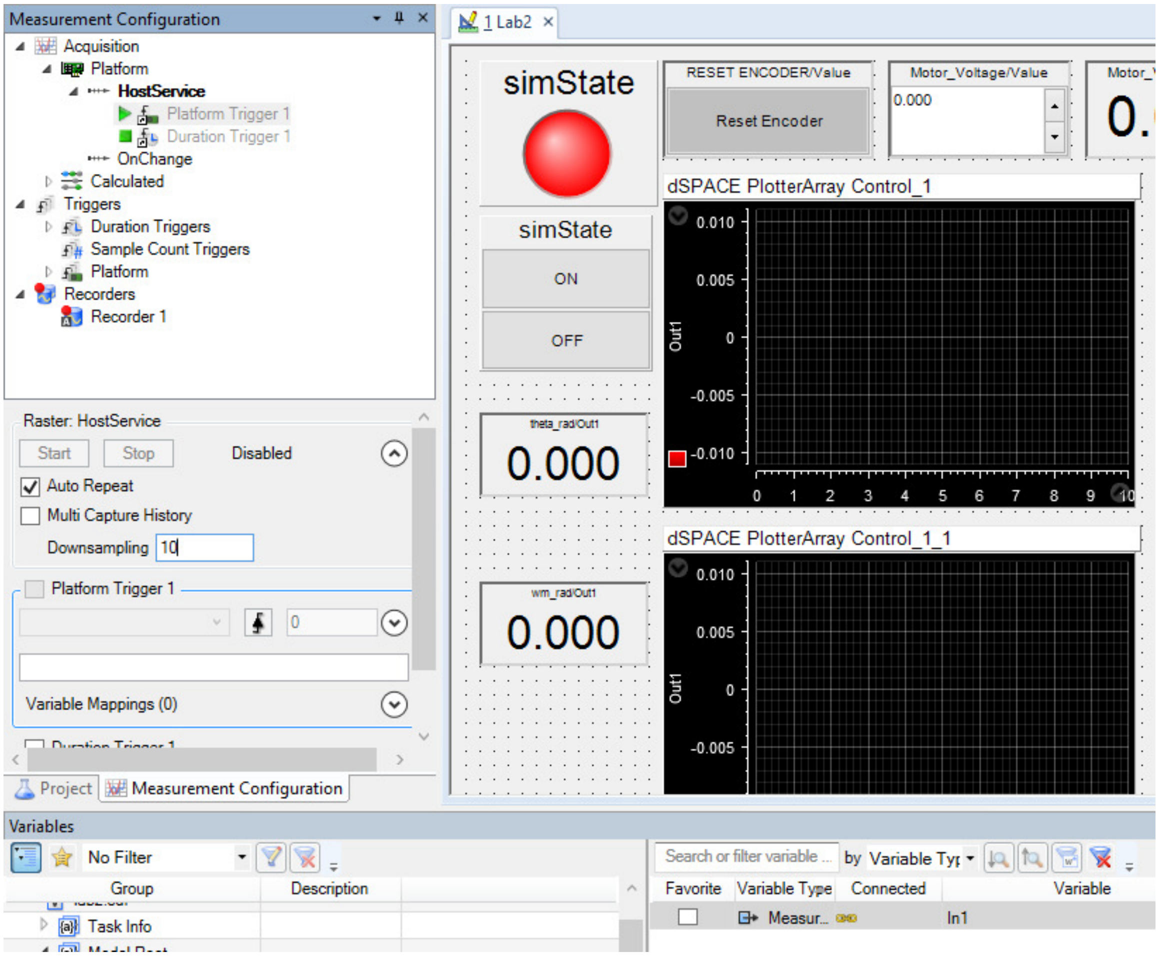

Figure 2: Downsampling recorded data

<u>Helpful hint for Mat_Unpack:</u> when saving data in dSPACE, do not use CAPS or start with a number for naming files with the autosave function. Also, do not change the name of the data structure once it is saved in the Matlab directory.

Proceed with the following experiments:

- From the dSPACE ControlDesk, apply steps of increasing voltage, for example 5, 10, 15, 20, and 25V (the limit on the output of the amplifier is 25V). Complete this test within 8-10 seconds and adjust the length of the data capture to include all of your voltage steps. Remember that the length of time shown on the plotter can be changed from the **Plotter Axes Properties** and the length of time for data capture can be changed from the stop condition properties of the recorder. Alternatively, the recorder can be started and stopped manually. However, avoid storing data for a very long time.

- Save data from the ControlDesk and import it into Matlab. Construct plots of speed vs. time and speed vs. voltage. Determine the steady-state values of velocity at each voltage level, and put the data into a table. Plot the velocity as a function of the voltage.
- From the transient response (from 0 to 5 V input), obtain an estimate of the time constant of the first-order model. The time constant of a first-order system is the time it takes for the output to reach 63% of its steady-state value. Deduce the values of the parameters θ_1, θ_2, and θ_3 from the two steps above.
- The three parameters θ_1, θ_2, and θ_3 are sufficient for control design since they characterize the input/output behavior of the motor. However, it is impossible to deduce the values of the five parameters *R*, *L*, *K*, *B* and *C* without further experiments. Measure the value of *R* using an ohmmeter (use an average or typical value obtained when spinning the motor by hand) and assume that $B = 0$. Deduce values for *K*, *J*, and *C* using the relationships given earlier.
- Compare the results to the numbers given by the manufacturer:

  Torque constant = 14.8 oz.in/A,
  Back-emf constant = 11 V/krpm,
  Rotor inertia = 8.8x10-3 oz.in.sec2,
  Friction torque ≤ 4 oz.in.

- From these results, deduce (calculate) what the maximum torque deliverable by the motor is for a current of 2A.

Requirements for Full Credit: The list below is a reference for your benefit. Be sure you include comments and explanations for all work performed and results observed/produced.

- Introduction with stated objectives
- Description of procedure for setting up and running the experiment
- Table of voltages and steady-state speeds
- Plots of speed vs. time and speed vs. voltage
- Values* for time constant, θ's, and *R*
- Values* for *K*, *J*, and *C* – with correct units
- Comparison to manufacturer specs
- Torque max calculation and result
- Conclusion with reference to stated objectives. Describe what worked well and did not work well in this lab, and make suggestions for possible improvements.

*if unexpected values are obtained, an explanation should be given.

***Be sure to LABEL the axes of all your plots and to include UNITS on all of your values. Comments should also always accompany any plot.**