Sfwr Eng/TRON 3DX4, Lab 4 Introduction to Computer Based Control

First lab Week of: Mar. 10, 2014 Demo Due Week of: End of Lab Period, Mar. 17, 2014 Assignment #4 posted: Tue Mar. 20, 2014

Announcements:

This lab has only a demonstration portion. To get your demonstration marks, every time the lab asks you to "show your work/output to your TA", show your TA that portion of the lab, fully working.

Goals:

- Introduction to computer based control of a simple voltage-controllable electomechanical system - the DC motor
- Learn how to create virtual input channels
- Estimate the steady state Gain A of a motor
- Experiment with different set points and constants of a PID contoller while controlling the DC motor
- Estimate the time constant τ

Note: This lab consists of five (5) activities. Demo each part to get the lab marks.

Before you go for your lab session, please read the following NI documents at your own convenient time, in addition to the class notes:

- Fundamentals of Motion Control http://zone.ni.com/devzone/cda/tut/p/id/3367
- Universal Power Module (UPM) user manual (Available in labs/manuals folder on the course web page)
- SRV02 rotary servo plant user manual (Available in labs/manuals folder on the course web page)
- SRV02 rotary experiments series (Available in labs/manuals folder on the course web page)

Equipment Arrangement

Quanser SRV02 rotary servo plant consists of a DC motor, a gear box, a potentiometer, a quadrature encoder and a tachometer. The potentiometer output is used to implement the proportional (P) part of the PID controller. This is an analog signal and must be converted into a digital signal before it is passed on to the computer. The potentiometer is connected through a 6-pin DIN connector to S_1 terminal on the Universal Power Module (UPM). UPM supplies voltage to the potentiometer and picks up the analog signal from its wiper proportional to the position of the motor shaft. The S_1 output from UPM is connected to one of the analog input channels on BNC 2120 board.

The tachometer produces a voltage signal proportional to the angular velocity of the shaft $\frac{d\theta}{dt}$ and is used to implement the derivative (D) part of the PID controller. The 6-pin DIN connector of the tachometer is connected to S_3 terminal of UPM.

The encoder is connected to the terminal board such that it gets a 5v input by connecting two of the wires in its cable to +5v and ground. The wires that have pulses corresponding to channels A and B (shown in encoder literature) are connected to the "Source" and "up-down" terminals of a counter in the DAQ6035E data acquisition card (ensure that this card is installed in the PC being used by you) by using PFI8 and DIO6 terminals respectively for counter 0 or PFI3 and DIO7 terminals for counter 1. Some of the PCs in the lab have DAQ6221M card. If you are using one of these PCs, then connect the source to PFI8 as above but the wire that carries the counter UP/DN direction information has to be connected to PFI9 terminal. It is also necessary in this case, to select UP/DN terminal used (PFI9) on the VI in a field designated for this purpose.

The output of quadrature encoder is used to implement the Integral (I) part of the PID controller (you will also use it for estimation of angular velocity).

Analog output of DAC on 2120-board (AO0) provides the signal to the amplifier to adjust its output according to the difference between the set point and the actual position of the motor shaft.

Output of the amplifier (LOAD terminal of UPM) is connected to power the motor.

A Labview VI implements the PID controller. On its front pannel the user can set the desired position of the motor shaft. Proportional, derivative and integral signals are received from the potentiometer, the tachometer and the encoder as described above. These signals are fed to the Labview VI implementing the controller. The difference between the set point and the actual position results in an output signal from the controller that is fed to the amplifier in UPM for adjusting its output and suitably controlling the motor shaft position.

Activities in the lab:

IMPORTANT NOTE: IN ORDER TO AVOID EXPENSIVE DAMAGE, DO NOT TURN ON YOUR MOTOR WITHOUT APPROVAL FROM A TA. IF YOU DO NOT GET APPROVAL FROM THE TA AT THE APPROPRIATE POINTS, YOU MAY BE ASSIGNED A ZERO FOR THE LAB.

1. Create NI-DAQmax Virtual Channels^[5]

- Run the MAX tool (click on the National Instrument Measurement & Automation icon on the desktop) right click NI-DAQmax and select *create* new NI-DAQmax channel:
 - Create a virtual input channel called position with units degrees with a range of [-180, +180] degrees, sensor type: voltage with range [-5, +5] Volts. Be sure to specify that it is **range mapped** and it is a single-ended referenced signal. (Use *custom scalling* \rightarrow *create new scale* and select 'range mapped')
 - A virtual output channel called control with units degrees with a range of [-360, +360] degrees, with output voltage range [-10, +10] Volts. Be sure to specify that it is range mapped.
 - Create another virtual input channel called velocity with units 'Deg/sec and a range of [-2000, +2000], sensor type: voltage with range [-5, +5] Volts. Be sure to specify that it is **linear**. (Use *custom scalling* \rightarrow *create new scale* and select 'linear'). Enter the slope value as: 285.7143 and the y-intercept as: 0. (The tachometer produces 1.5mv/rpm which translates to 4000 (deg/sec)per volt. The encoder is connected to the motor via a gear with a ratio of 14:1 which results in a linear slope of 4000/14 = 285.7143)
 - Note: Make sure the signal input/output range for the channels is correct - scaled values with scaled units manually corrected as done in lab 1.
 - Test the connections from within MAX:
 - * Connect the potentiometer sensor from the motor to Analog Input Channel 0. Make sure that the BNC/temp switch is set to BNC and the FS/GS switch is set to GS.
 - * Connect Analog Output Channel 0 to the input of the operational amplifier. (Ask your TA if necessary).
 - $\ast~$ Click the control channel under NI-DAQ max Global Virtual Channels
 - * Enter 60 as the output value
 - * Click the button Apply Value to Channel
 - * Click the button Run, abserve the motor is actually running
 - * To stop the motor, enter 0 as the *output value* and click *Apply* Value to Channel button.
 - Show the working channels to your TA before proceeding further.

2. Estimate the steady state gain A[25]

In this exercise estimate the angular velocity $(\theta' = \frac{d\theta}{dt})$ of the motor shaft and use it to calculate the steady state gain $A = \frac{\theta'}{input \ voltage}$

Background:

The open loop transfer function of a motor can be written as:

$$M_{\theta}(s) = \frac{\theta(s)}{V(s)} = \frac{A}{s(\tau s + 1)}$$

Where A is the steady state gain and τ is the time constant (both are positive real valued constants).

The transfer function in terms of angular velocity can be written as:

$$M_{\theta'} = \frac{\theta'(s)}{V(s)} = sM_{\theta}(s) = \frac{A}{\tau s + 1}$$
$$\theta'(s) = \frac{A}{\tau s + 1}V(s)$$

Note that transfer function has a pole at $-\frac{1}{\tau}$ and $\tau > 0$. Therefore system is stable.

Use Final Value Theorem:

$$\lim_{t \to \infty} \theta'(t) = \lim_{s \to 0} \frac{sA}{\tau s + 1} \times \frac{V_0}{s} = V_0 A$$

Where V_0 is the amplitude of the applied voltage.

In the lab, if we can estimate the angular velocity $\theta'(t)$ for a given input voltage V_0 , we can find out A.

Recall that the Quanser rotary servo plant has an encoder that measures the relative position of the motor. We want to use the output of this encoder to experimentally estimate the angular velocity. This can be done if we can record the change in the position of the motor shaft $\delta\theta$ and the corresponding elapsed time δt . Then the angular velocity $\omega = \frac{\delta\theta}{\delta t}$.

In this exercise we shall use a VI named "openloop.vi" (available at the labs/Data folder on the course web page) for open-loop control of the motor. From the 'position' channel of this VI for each iteration of a while loop, the time and position are passed on to shift registers. These values are used in the next iteration for calculating δt and $\delta \theta$. The VI also displays a mean angular velocity both graphically as well as numerically. The signal from the tachometer is directly converted into velocity and displayed both graphically as well as numerically.

- Ensure that the motor's position encoder and the tachometer are connected as explained under equipment arrangement (the TA will do this for you).
- The motor's encoder has 1024 pulses/revolution. Load the BNC-2120 encoder example from the previous lab (QuadratureEncoder.vi). Save the file as MotorEncoder.vi and edit the example so that it reads the correct angle for the motor's position.

- Download "openloop.vi" from the course web page. Use the VI to read the encoder for the position of the motor and the tachometer for the velocity of the motor. The VI uses the position to estimate the value of $\theta' \simeq \frac{d\theta}{dt}$. The VI should plot the estimate of the derivative and have a numeric display of the sliding average of the derivative over a user-setable number of samples. Corresponding velocity values are also read from the tachometer for comparison.
- In order to select both input channels from the control pannel of the VI, choose 'Browse' from a drop down list and then use control key to select both the position and the velocity channels. Also select 'control channel' from another drop-down list.
- Set the control channel for different set points -120,-90,-45, 0, 45, +90, +120 and for each setpoint record the value of your estimate of θ' and the angular velocity read from the tachometer. Make a chart recording values: setpoint | estimated velocity from encoder | velocity value from tachometer. (Make sure that you stop the running VI, change the preset point and then run it again. Changing the preset point without first stopping the VI may result in unpredictable behaviour of the system.)
- Calculate the steady state gain for each set point and the mean value of the steady state gain and show them to your TA.

3. The importance of $K_i[25]$

The purpose of this exercise is to observe how an integral compensator (K_i) improves the steady state error. Note that when you asked below to load file PIDdemo.vi, you must have first also downloaded file "simple PID.vi" (downloadable from the labs/Data folder on the course web page) as PIDdemo.vi requires it.

- In Labview, load the PIDdemo.vi (downloadable from the labs/Data folder on the course web page) and save it as mypid.vi. Edit this file to make the controller suitable for use with the motor. Note that the lower and upper limits on the output should be changed to -360 and +360 respectively. Save the mypid.vi file and ask the TA to inspect it before running it. Once the TA has approved your design, have the TA help you connect your design to the motor.
- Set proportional gain K_p to a value of 1.2 and set the integral K_i and derivative K_d gains to 0. Test the different set points -120,-90,-45, 45, +90, +120 and record any steady state offset in the output for each setpoint.
- Now set K_i to be greater than zero, between say 1 and 5. Observe the change in the steady state errors at the previous set points. Record the steady state error values. Show the TA your recorded values for the last two steps (i.e. with and without K_i).

4. Estimating the time constant $\tau[25]$

This exercise examines two methods for estimating the time constant τ .

Background:

Consider the feedback control configuration with $D(s) = K_p$ (i.e. proportional control), $K_p > 0$. The closed loop transfer function is:

$$G_{\theta d} = \frac{\theta(s)}{R(s)} = \frac{K_p A}{\tau s^2 + s + K_p A}$$

When a system is critically damped, it has two equal values for poles. We can use this observation to calculate τ . Note the value of $K_p = K_*$ that results in critical damping of the system and use steady state gain A calculated in part 2 of this lab.

Another approach to calculate τ is to consider that the Root Mean Square (RMS) value of a signal f(t) that is periodic with period T is given by the equation:

$$\sqrt{\frac{1}{T}\int_0^T (f(t))^2 dt}$$

RMS values are often easier to measure and more accurate than trying to determine peak amplitudes. It can be shown that the RMS value of $u(t) = B \sin \omega t$ is $\frac{B}{\sqrt{2}}$.

Suppose $u(t) = B \sin \omega t$ is the input to a strictly stable transfer function $G(s) = \frac{Y(s)}{U(s)}$. In steady state, the RMS value of y(t) is $|G(j\omega)| \frac{B}{\sqrt{2}}$. Thus

$$\frac{RMS \ value \ of \ y(t)}{RMS \ value \ of \ u(t)} = |G(j\omega)|$$

This method of estimating τ is to experimentally determine the bandwidth of the closed loop system $G_{\theta cl}(s)$ corresponding to the -3dB frequency ω_{bw} for a critically damped system. Then we have:

$$|G(j\omega_{bw})| = \frac{1}{\sqrt{2}}$$

For a critically damped system $K_p = K_*$, at ω_{bw} :

$$\left|\frac{K_*A}{(j\omega_{bw})^2\tau + j\omega_{bw} + K_*A}\right| = \frac{1}{\sqrt{2}}\tag{1}$$

If we know values of K_* and A, the above equation can be used to calculate τ . If we have a + jb, its magnitude is $\sqrt{a^2 + b^2}$. To convert $\frac{1}{c+dj}$ into the form of a + jb, multiply top and bottom by the complex conjugate of c + dj.

- Open your mypid.vi file and save it as a file called pidbode.vi. Edit this file to replace the setpoint control with a basic function generator. Add in controls to allow you to change the amplitude and frequency of a reference signal into the motor control loop. Add plots of the RMS value of the reference signal and the motor position as well as a numeric display of these values.
- Once the TA has approved your design, have the TA help you connect your design to the motor. Using this set up, make $K_i = K_d = 0$ and then tune the value of K_p until the system is critically damped (i.e. just before overshoot occurs). Record the value. Use a square wave reference signal of a reasonably low frequency to help you tune the system. Note this value of $K_p = K_*$
- Leave $K_i = K_d = 0$ and $K_p = K_*$. Change the input to your system to a low frequency sinusoid of amplitude 90. Increase the frequency of the sinusoid until the RMS value of the output is $\frac{1}{\sqrt{2}}$ of the RMS value of the input. Record this frequency as ω_{bw} .
- Use equation 1 to calulate τ . Show the TA your value for K_* , ω_{bw} and τ .