MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Aeronautics and Astronautics
16.30: Estimation and Control of Aerospace Systems
Spring 2004

Lab 1: Elevation Dynamics and Control
Due: 03/15/2004

Objective

The objectives of this lab are:

1. To use a collective motor voltage to experimentally determine the plant transfer function for the elevation axis of the Quanser from both step response and frequency response characteristics.
2. To design a controller for the elevation axis which achieves bandwidth of about 3 rad/sec and phase margin of at least 45° with no steady state error.
3. To implement the controller and compare its performance to that of the open loop system in terms of step response characteristics and disturbance rejection.

Administrative

The machines are located in the lab. The lab is open 9am-5pm weekdays. There will be a TA available for you on Monday 3-5pm downstairs in the lab to answer any questions. You can do this lab individually or with one partner.

Introduction

Quanser helicopter is a mechanical device that essentially emulates the flight of a reduced degree of freedom (DOF) helicopter. Instead of the usual six DOF of a free-flying helicopter, the Quanser only exhibits three: the roll/pitch motion ϕ, the elevation motion θ, and the travel motion ψ. The Quanser system is actuated by two rotors and the inputs to the system are V_{cyc}, which is an electric voltage that results in differential change in the two rotor speeds, and V_{col}, which is an electric voltage that controls the speed of the two propellers collectively. The outputs of the system are the three angles: the pitch ϕ, the elevation θ, and the travel ψ. For this lab, you are going to be working with the elevation mode. Please keep the limits of the system in mind, in particular, the voltage is limited to $[-5, 5]$ Volts, pitch motion should be limited to $[-40°, 40°]$, the physical limits on elevation are $[-25°, 30°]$.

Getting Started on Computer

1. On the computer, make yourself a directory in C:/MATLAB6p1/work/16.30/. Copy the files lab1_ident.mdl and lab1_ctrl.mdl to your directory. IMPORTANT NOTE: at the end of the lab session, you should save all of your work to a floppy disk and clean out the directory on the hard drive.
   You only need to save your .mdl files and your data. Simulink creates a lot of runtime files that you don't need to save. IF YOU LEAVE YOUR FILES ON THE HARD DRIVE THEY MAY BE DELETED.
2. Make sure you are working in your own directory. Double click on lab1_ident.mdl to start Matlab. You should see the beginnings of a Simulink model appear. The "Quanser Subsystem" block is the computer's interface to the Quanser. It applies the given voltages to the two engines and reads the elevation angle in radians. Be aware that the Quanser takes all measurements to be zero when you click Run. The elevation angle has been adjusted so that it reads zero at hover if you start on the table.
3. You will need to use step and sine inputs to obtain the model. Work with the file lab1_ident.mdl. Obtain the corresponding input blocks in the Simulink Library Browser → Sources → Step and adjust parameters accordingly. Click OK. Connect the blocks to the Collective voltage inputs. The hover voltage has been set for you to keep the Quanser horizontal. You are also given an option to turn on a *Pitch Controller* in order to keep the Quanser from swinging. To do that double-click on the "Quanser Subsytem" block and check off the box for the "Turn on the Pitch Controller".

4. Build the Simulink model by choosing Tools/Real Time Workshop/Build (or Ctrl-B).

5. Before you start your system, set up your scope to capture the data. In the WinCon Server window choose Plot/New/Scope. Open the 'Elevation' folder. The measurements are done in radians. In the Axis menu of the scope plot choose Auto Scaled. In the Update menu, choose Real time and choose Buffer, set it to the time you want to run the experiment.

6. Press Run and record the response. After the Quanser reaches a steady state, go to Update- Freeze Plot. You can now save the data to the Matlab workspace by choosing 'File/Save/Save to Workspace'. Or you can press Stop and save the data as before.

7. The plot data is now stored in Matlab. To see its name, type *who* at the Matlab prompt. Two arrays have been created: PLOT_TIME stores the x-axis (time) and lab1_elev_rad_ stores the y-axis (elev angle). We need to save the data to a different Matlab variable. We also need to truncate the vector (so that all of our responses are the same length). We will keep the first 25,000 elements of the response. To rename lab1_elev_rad_ to STEP1 and truncate, type 'STEP1 = lab1_elev_rad_(1:25000,1);' at the Matlab prompt. Note that your plot data may have a slightly different name. Plot the response in Matlab: 'plot(PLOT_TIME, STEP1)'.

8. To implement your controller, you might want to use lab1_ctrl.mdl file and modify it accordingly. Again, you have an option to turn on the Pitch Controller by double clicking on the "Quanser Subsystem".

Lab Procedure

1. Record the number of the machine and the position of the counterweight. Should anything go wrong, apply the *kill switch*, i.e. flip the lighted button on the table.

2. Turn on the machine so that it is at hover, always start on the table to ensure that the angle is zero when the arm is horizontal.

3. Obtain and record the open-loop step response of the transfer function from the motor collective voltage to the elevation. From this data, identify the transfer function as well as you can.

4. Obtain experimental steady-state frequency response data to produce a Bode magnitude and phase plots for the transfer function from the motor collective voltage to the elevation angle. Since you don't get perfect sinusoids and you can't make perfect measurements, at each frequency, you should have a range of possible magnitudes and a range of possible phases. In getting the frequency response, let the system come to steady state at each frequency you try. You may want to run your signals through gains and/or summers with offset constants so that you can get the input and the output at the same magnitude and offset on the same plot in order to make a good phase measurement. Pick your frequencies wisely; start at dc, then 0.3 rad/sec and up. Please remember that the amplification of the plant is different at different frequencies. Pick the size of your inputs large enough to see the output easily (10-15 degrees is good).

5. Design a controller for the elevation axis that achieves a bandwidth of about 3 rad/sec and phase margin of at least $45°$ with no steady state error. Test your controller by making a Simulink simulation of your plant and the controller. Finally, implement your controller on the plant. Obtain and record the response of the elevation of your controlled system to a step command input of a change in elevation. Obtain and record the step response of the elevation of your controlled system to a step disturbance at the controller output or plant input.

Post Processing, Requirements and Write-up

- The write-up should be clear and concise. Include graphs or tables of your data as appropriate.
- Include the final model obtained using the open loop step response and the model obtained using frequency identification. Compare the performance of controlled system to the response of the open loop system. Compare the response of the controlled system to the one simulated.