**Final Project**

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**Abstract**

Controllers are useful tools engineers use to modify the natural behavior of physical systems to meet desired performance specifications. To do this, the transfer function of a physical system must be found. Time and frequency domain techniques were used to develop the transfer functions that describe the Azimuth of a small satellite imaging payload called NexStar. After analyzing the telescope’s step response, a transfer function is determined from its system parameters. Controllers were then added to this transfer function in a closed-loop system where the performance specifications of the overall system were modified to within a desired range. This process can occur in several different ways, using root locus, Bode, and state-space techniques. The classical controllers also yield insight into compensators that can be implemented to further tweak the specifications of the system to within acceptable ranges. In order to validate these models, the controllers were tested on the NexStar telescope in the laboratory to verify their functionality. Through comparison of the theoretical and analytical models, both the root locus and Bode classical designs were proven to alter the natural behavior of the telescope into the acceptable range of the given performance specifications. Additionally, a state-space model using three states (position, velocity, and acceleration) is used to modify the transfer function using full-state feedback to alter the percent overshoot and rise time of the response into acceptable ranges. This model was validated in a similar fashion to the classical controllers, and was also proven to work. Through comparison of the results of the Bode and root locus controller, the EMMONS controller was determined to be more effective, but the OTHER EMMONS controller was found to be the most inexpensive.

**Nomenclature**

– Steady-state tracking error

- Bode gain

- Bode decibel gain (dB)

– Closed-loop resonant peak

- Percent overshoot

- Peak time (seconds)

- Rise time (seconds)

- Settling time (seconds)

- Peak value

- Settling value

- Steady-state value

- Phase shift (degrees)

– Operating point frequency

– Closed-loop bandwidth

- damping ratio

**Objectives**

For this lab, mode 5 of the telescope’s azimuth axis rate is modeled. Both classical and full-state feedback algorithms are implemented. First, the transfer function relating azimuth rate to the commanded azimuth rate voltage is found. Then, feedback and control principles are implemented to alter the natural behavior of the physical system to meet the following performance specifications using both Root Locus and Bode techniques:

Time to initial target acquisition (10-90% rise time) < 0.40 sec

Maximum target overshoot error (percent overshoot) < 13%

Closed-loop bandwidth > 4 rad/sec

Closed-loop resonant peak < 3 dB

Steady-state tracking error (to a ramp input) < 5%

Both controllers will be used to identify a compensator so that the output angular position of the telescope will meet these specifications. Next, the theoretical designs are analyzed to verify that these performance specifications are satisfied. Both designs are tested on the lab hardware and verified that at least one of the closed-loop systems meets all the performance specifications. The analytical and the actual results for these two compensators are compared to determine their effectiveness. Finally, a state space representation for the system is developed and used to design a full-state feedback controller to meet the rise time and percent overshoot specifications identified above. The design is analyzed to verify that the performance specifications are satisfied. The state-space model is then tested on the lab hardware to demonstrate its effectiveness and compare the results with those obtained from the classical controllers.

**Approach**

In order to find the transfer function relating azimuth rate to the commanded azimuth rate voltage, the response from the motion of the NexStar pointing system is analyzed. Data was collected according to the Lab Procedures in Appendix A.

**Assumptions**

One important assumption for this lab is that the telescope performs relatively small changes of angle in order to keep the system linear. It is also assumed that the motion of the NexStar pointing system can be modeled by a second-order underdamped system. A final important assumption that was taken into consideration is that the internal friction of the telescope is negligible.

**Appendix A**

**Test Procedures**

**PREPARATION:**

1. Before performing this lab, ensure that the Simulink interface for the NexStar system (NexStar Control Lab Software) is downloaded onto the computer that will be used to collect the data. This will allow the user to command the imager’s resulting azimuth and will ultimately return the imager’s resulting azimuth slew rate.
2. Ensure that all the required hardware is present:
3. NexStar Telescope
4. Hand Controller
5. Power Cord
6. USB cable with standard and mini connecter ends
7. Computer with NexStar Control Lab Software

**LAB SET-UP:**

3) Verify the power cord is plugged into the outlet and telescope mount

4) Verify the mini-USB is plugged into the bottom of the hand controller and that the other end is plugged into the computer

5) Turn on the mount using the mount’s power switch

6) The hand controller should display “NexStarSLT”. Press ENTER to begin alignment

7) Use the left and right arrow buttons on the hand controller to point the telescopes azimuth so that the power cord and hand controller connectors are roughly above the hand controller, then use the up and down arrows to level the telescope horizontally

8) Use the mount’s power switch to turn the mount off and then on again (this will reset the telescope’s default position after the adjustments made in step 7)

9) Open Matlab and verify that the working directory is “NexStar Control Lab”

**DATA COLLECTION:**

10) For the Step Response:

a. Open scopeinterface.slx and save it as Engr341\_Lab2\_Step.slx

b. Establish a link between the telescope hardware and Simulink using the following format for the “startscope” function in the Matlab window.

i. Startscope(telescope#, 3)

c. Connect a Step input, a Scope, and two Two Workspace blocks (name one out.input, and the other one out.output, and change the save format to “Array” in both blocks)

d. Run this model multiple times, adjusting the Step block final value until the output peaks between 3.5 and 4 deg/sec

e. Plot the input and output variables vs. time using the command below

i. Plot(out.tout, out.input, out.tout, out.output)

f. Save the data

11) For the Frequency Response:

a. The startscope command does not need to be run again because the same mode (mode 3) will be tested

b. Replace the step input with a sine input

c. Save this model as Engr341\_Lab2\_Frequency.slx

d. Run this model many times with different sine frequencies. Enough data should be collected to create a satisfactory Bode plot from the generated points (around 20 points total). More data points should be collected around the resonant peak so that this second of the plot can be clearly defined.

i. For each case, adjust the Step block final value until the output peaks between 3.5 and 4 deg/sec

ii. Make sure to wait for steady-state by letting the transient response die out

e. Plot the input and output variables vs. time using the command below

i. Plot(out.tout, out.input, out.tout, out.output)

f. Save the data

**LAB SHUTDOWN:**

12) Ensure all data files are saved

13) Delete all files from the lab computer

14) Turn off the telescope

15) Shut down Matlab and then shut down the computer

16) Clear/clean the work area