ASEN 3200 LAB A-3 Spacecraft Pitch Axis Control

Assigned: Tuesday, September 29, 2020

Report Due: Monday, October 19, 2020 (due in Canvas at 10 PM)

OVERVIEW & OBJECTIVES

In this experimental lab students will design and implement an active reaction wheel control system to cause a spacecraft model to follow a reference trajectory in one degree of angular freedom. It includes using the spacecraft rigid body mass properties and calculation of feedback controller gains to cause desired closed loop tracking behavior.

PRELIMINARY QUESTIONS

1. Describe how you would measure the spacecraft moment of inertia about the spin axis, where the spacecraft is mounted on a spin table, so it can freely move about the vertical axis. The spin table allows a specific torque to be applied about the spin axis, and the resulting angular rate is to be measured.

2. Draw a block diagram of the single degree of freedom system comprising a spacecraft, a reaction wheel actuator, a rate gyro sensor, a rate integrator, and a PD (proportional + derivative) control law implemented in LabVIEW. Use “K1” for the proportional gain and “K2” for the derivative gain. Label all boxes and the units for all signals.

3. The closed loop pointing system is required to have a 5% settling time of less than 1.5 s with an overshoot less than 10%. Compute the locations of the system poles in the s-plane, the values for the natural frequency (ω_n), and (ζ). Compute the required values for K1 (Nm/rad) and K2 (Nm/rad/s) in terms of the moment of inertia about the spin axis.

LAB TASKS

1. Measure the moment of inertia of your spacecraft unit about the spin axis as mounted on base. Refer to the procedure below, which is the same method you employed in lab A-1 to determine the MOI of the reaction wheel. **Use the Base Encoder for the Angular Velocity Sensor.**

2. Explore the response of the closed-loop feedback system using gains within the range of 0 < K1 <= 0.2 and K2 <= 0.003. Take notes on how the pointing response varies with the gains. To complete this operation set the Reference Height to 0.5 rad, and Reference Frequency to 0.2 Hz. During this stage, damped oscillations should be observed with a commanded step every 5s. Remember to turn the Control Off and hand stop the reaction wheel if needed between runs (i.e. if the Reaction Wheel Speed rises above 4000 rpm) as well as to “Reset the Position from Gyro” between runs.

3. Design appropriate state feedback gains using the measured inertia and the parameters list in the Prelim question 3 above. Express them in the units of Nm/rad (K1) and Nm/rad/s (K2).

4. Run the Control tab in LabVIEW VI with a step reference command of plus and minus 0.5 rad, at 0.2 Hz and use your K1 and K2 values. Take data from the rate integrator (angular position), reference angle, and applied reaction wheel torque. (Note that the data saved has actuator current, not torque. The torque constants are listed in the datasheets for the RW and base motors in Nm/A). Use these data to evaluate the behavior of the closed loop system relative to your design objectives.

5. Now run the control system VI with a Reference Height [rad] = 0 to provide a **zero** reference command. Choose a gain between 0 < K1 <=0.2. When this is run, the S/C should sit still and the reaction wheel should not move

much. Give the S/C a small disturbance of about 1 radian. Here it should be observed that the S/C responds by oscillating back and forth. The reaction wheel should spin up and down to try to bring the satellite back to zero. Notice the response. Remember to turn the Control Off and hand stop the reaction wheel if needed between runs (i.e. if the Reaction Wheel Speed rises above 4000 rpm) as well as to "Reset the Position from Gyro" between runs. For each operation with various gains, determine if the pointing angle returns to the initial angle after the disturbance torque are applied.

6. How would you implement feedback gains that cause the spacecraft to stop moving (i.e. ignoring the actual angular position.)? Implement this feedback and record your results.

7. (OPTIONAL) Consider that the reaction wheel interface with the spacecraft and the spacecraft interface with the base unit all have friction, which is unmodeled in our equations. Use an integral control gain (in addition to the proportional and derivative gains) to meet the requirements specified in preliminary question 3 given a step input reference command. Note, the proportional and derivative gains may or may not need to be different from those computed in Lab Task 3. Record your results.

ANALYSIS

1. Discuss how closed loop poles were determined from the step response performance objectives. Use MATLAB to plot the expected step response for the closed loop system.

2. Plot the experimental results you recorded from your spacecraft control design. Make sure plots show data in mechanical units, not voltages. Plot the reference angle and the integrated gyro output on the same graph. Discuss how the measured motion about the vertical axis corresponds with the step reference. Refer to specific plots in the discussion. Compare your results to the design requirements.

3. Describe the behavior of the reaction wheel during the step response. Does this make sense compared to the recorded data for torque versus time?

4. Discuss the response of the control system to the disturbance input by your hand.

5. Discuss the response of the modified control system in part 5 above (Experimental Procedure).

6. (OPTIONAL) Discuss the differences of your controller performance to a step input reference command without integral control gain (Lab Task 4) and with the integral control gain (Lab Task 7).

Acknowledgments

The original spacecraft modules were developed by Prof. Dale Lawrence and Walter Lund, Matt Rhode (manufacturing), Brad Dunkin (LabVIEW) with lab updates by Trudy Schwartz, Gabe LoDolce, Prof. Penina Axelrad, Prof. Hanspeter Schaub and others.

The new spacecraft modules were developed by grad students Lewis Gillis, Devon Campbell, Joshua White and others along with instructors Bobby Hodgkinson and Trudy Schwartz. New simulations were developed by Prof. Dan Scheeres and graduate student Nicola Baresi.

We are especially grateful to the instructors and learning assistants who have created all the videos, sample data sets, and opportunities for new experimental recordings to support our lab activities under the COVID-19 lab closures.

UPDATED LAB PROCEDURES FOR COVID-19

For any lab tasks that students cannot or prefer not to complete in the lab, due to campus restrictions on in-person classes, or other COVID-19 related concerns, Bobby Hodgkinson and the lab assistants have provided pre-recorded data sets and videos for each portion of the assignment. They also have set up experimental systems that they will use to collect data for you based on parameters you submit via an online form.

For the first lab task, given the current 2 week remote-only class restriction, all students will have to use the prerecorded data sets for determining the satellite moment of inertia about the spin axis. In order to accomplish this task we've provided data using the same Torque .vi that you used for the reaction wheel experiment in Lab A-1 but instead of spinning the reaction wheel we applied torque to the base motor (also measured the current through the base motor), and used the base motor encoder to measure the spin rate of the base motor and hence the satellite. A zip file with this data set is on Canvas in the Lab A-3 folder.

In an attempt to provide unique data for your designed control gains they have set up three spin module units at their homes. Please use the google form (https://forms.gle/XAVLkqXRGEs45kW88) to request data from one of these units. (For the first round the unit choice is not important but please request the same unit for subsequent tests.) Please complete the form by Monday at 8:30am so that the tests can be completed and the data provided to you before your lab period on Tuesday or Thursday. This way you can analyze the data before/during lab, ask questions during normal lab hours, and request additional data with modified control gains if necessary. Due to unmodeled dynamics (friction, motor dead band, etc.) the designed gains need to be large enough to yield a reasonable response from the system. Additional data has been posted which should help you determine the appropriate size of your gains.

In past experiments we've noticed that the satellite seems to perform better moving one way than the other. The exact cause(s) of this is difficult to determine but our best guess is that it has to do with imperfections in the perpendicularity of the support shaft which would cause the satellite to spin on a slight 'hill' instead of on a plane perpendicular to the gravity vector. This is to say, please use the upward or downward transition in the data that looks the best.

REPORT OUTLINE & GRADING

Title Page (1 pts) – Lab, Course Number, Group Members, Date

Abstract (5pts) – Briefly summarize the rest of the report including (1) the objectives of the lab, (2) what was actually done, (3) the most important qualitative and quantitative results, and (4) your conclusions. The abstract should be less than 200 words – generally 4-5 sentences. Good rule of thumb is one sentence for each numbered item, plus one extra sentence to use wherever you need it.

Table of Contents

Preliminary Questions (15 pts) – Answer the preliminary questions associated with the lab.

Experiment and Analysis (55 pts + up to 5 pts EC)

- Inertia (5 pts)
- Control design (10 pts)
- Control results (10 pts)
- Control analysis/comparison (10 pts)
- Reaction wheel behavior (10 pts)
- Disturbance response (10 pts)
- (OPTIONAL) PID vs. PD empirical comparison (up to 5 pts EC)

Conclusions and Recommendations (5 pts)

- What did you learn from this experiment?
- What would you recommend to improve the experiment or to extend it beyond the given objectives?

Team Member Participation Table (2 pts)

Acknowledgements (1 pt) List any outside assistance you received

References (1 pt.)

[Style & Clarity 15 pts]
Organization (3) – clear flow, follows required outline, numbered pages
Figures (4) – clear figures, appropriate axes, informative titles, clearly labeled units
Tables (4) – clear tables, significant figures, headings, informative titles, clearly labeled units
Spelling & Grammar (4)

Spin Module Setup Procedure (All Spin Module Labs VI)

NOTE: The order of operations for power up is ***IMPORTANT!*** Follow these steps carefully and correct order listed:

1. Use the clamp provided to secure the spin module base to the labstation top. Place the clamp on the base plate at the spot labeled “clamp here”.
2. Check that you have completed step 1. Seriously, if you do not clamp the spin module down and you run the motor it will fly off the table and be damaged!
3. Connect the USB cable Type B end to the National Instruments myRIO port labeled “DEVICE” and seen as the middle port in Figure 1. The other Type A end connects to the lab station computer. (Do not connect to the Type A top port on the myRIO.)
4. Connect the power adapter to the barrel connector also shown in Figure 1. The power light on the myRIO should now be illuminated blue.
5. Wait 1-2 minutes until the Status light on the myRIO turns from orange to off.
6. Verify the lab assistant has setup the U8002A power supply on the labstation to a limit of 12.00 V and 0.300 A by pressing the “Display Limit” button on the power supply. Do not plug in any power connections until power supply settings have been verified.
7. Confirm that the 9V battery pack has been plugged in.

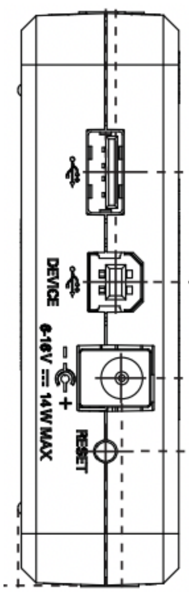


Figure 1. myRIO

8.Then plug in the power connector with red and black banana cables. The polarized black Samtec connector plugs into the base printed circuit board (PCB), while the red banana connects to the Output (+) and the black banana connects to the Output (-) . Once verified, turn the Output ON.

9.Wait for the lower board motor controller to flash its green LED.

10. Once the above steps have been completed. Now turn on the satellite board power located on top, inside the spin module chassis using the red toggle switch.

11. Verify the board goes through a series of status LEDs shown near the toggle switch. The remaining LED under the switch should be Yellow and the Alive LED will be green.

12. Open the All Spin Module Labs.VI located in your current semester’s class folder but do not run the VI yet.

13. Take note of the status indicators in the bottom right corner of the VI. Here the “battery voltage” meter is displayed. If this battery voltage of the satellite’s onboard battery pack drops below 14V turn off the top satellite board with the red toggle switch and request staff assistance for new batteries. This is VERY IMPORTANT as the battery pack does not have a built-in safety cutoff implemented yet.

14. The “Reset Gyro Offset” button is used if you notice the gyro voltage drift over time from zero voltage at zero motion. With this you can reset this offset bias.
15. The green indicators show if the myRIO (on the base) and the Arduino DUE (inside the satellite) are properly connected and communicating.
16. The “Link Speed” dial is used to show the quality of the Xbee wireless communication link. A good typical speed is 1.5 or higher. If you see frequent dropouts to zero the Xbee channel may be experiencing too much interference from other wireless sources OR the battery voltage is too low.

Operating the Spin Module for TORQUE measurements (MOI Calculations)

1) Triple check that you have clamped the spin module to the table. Especially important for this step as we will use the highest torque values.
2) First select the appropriate TAB labeled "Torque" on the VI front panel to enable the torque to be commanded to the motors.
3) Start running the VI by clicking on the "play" button in the upper left corner of the VI. Again, you will probably need to select the "ignore" button twice.
4) Determine Spacecraft Moment of Inertia:
   a) Select the "Base" switch, to apply a constant torque to the base motor. This will

      display "Torque Applied to BASE" on the top Commanded Torque plot.

   b) Under "Angular Velocity Sensor" select the "Base (Encoder)". The base motor has

      an additional encoder installed to use to measure angular speed instead of the built-in hall-effect sensors in the brushless motor. The base encoder data will be displayed on the second plot, Angular Speed.

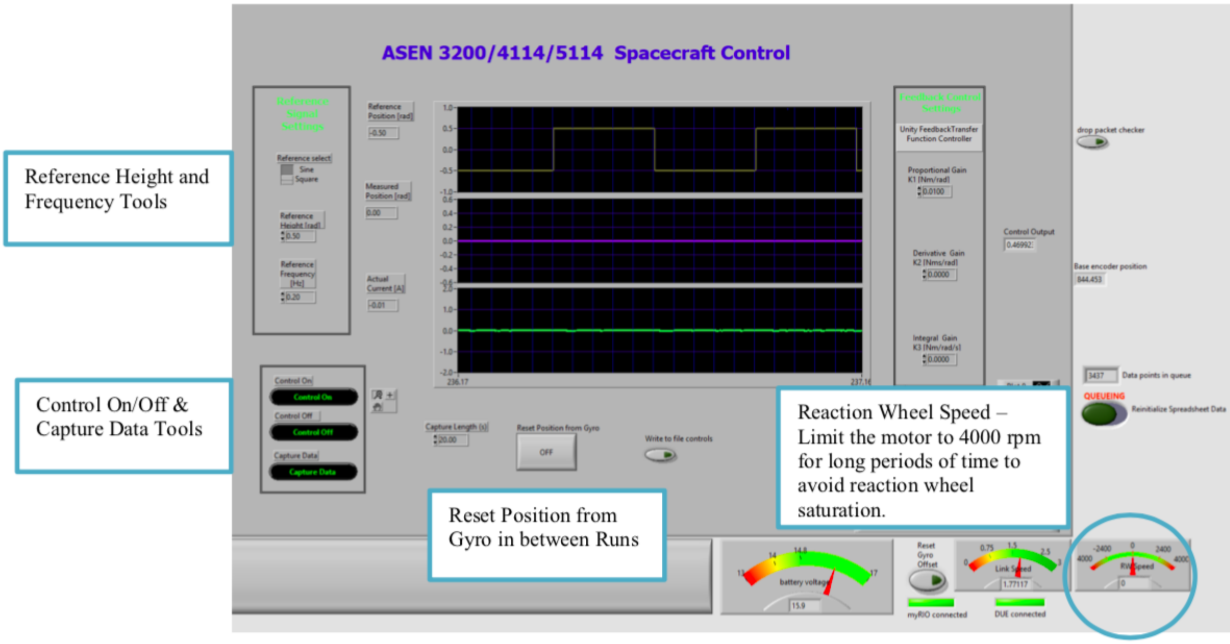
   c) Select the "Base" for the Current Sensor to display the actual current drawn by the BASE motor during testing on the third plot.
5) Enter the desired Torque in mNm to apply.
6) Use the Write to File button if the data collected is as desired.
7) Repeat as necessary.
8) Use the "STOP" button when done.

NOTES:

- For safety, you cannot change the operating mode of the Spin Module while the VI is running.
- The Angular Velocity Sensor option of using the satellite gyro is available for future use in other labs in the curriculum.
- The Torque Applied, Angular Velocity Sensor and Current Sensor selections CAN be changed while the VI is running.

Operating the Spin Module for CONTROL measurements

1) Once again, check that you have clamped the spin module to the table.
2) First select the appropriate TAB labeled "Control" on the VI front panel to run the satellite in closed loop feedback control.
3) Start running the VI by clicking on the "play" button in the upper left corner of the VI. Again, you will probably need to select the "ignore" button twice.
4) To control the type of command sent to the satellite, enter the desired **Reference Signal Settings**:
    a) Sine or Square wave
    b) Reference Height in radians
    c) Reference Frequency in Hz
5) Setup the feedback control gains that you wish to implement in the Feedback Control Settings section:
    a) K1 is the Proportional Gain in Nm/rad
    b) K2 is the Derivative Gain in Nm/rad/s
    c) K3 is the Integral Gain (NOT USED in this lab.)
6) WARNING! If the gain(s) you type in are **unstable** the satellite will spin out of control. If this occurs, use the Control Off button to stop the satellite spinning if needed and enter new gains.
7) Enter the Capture Length in seconds. This is the time that data will be logged in the following steps. A value between 10 and 40 seconds is reasonable depending on the gain values.
8) Make sure the satellite is still and **level**, then press the "Reset Position from Gyro" button to null out the Measured Position in radians – middle plot – it should now read constant zero value. Note, if this is not a constant zero this will cause unstable spinning.
9) Press the Capture Data button when you are ready to begin testing then immediately press the Control On button to start feedback control. The satellite will track your desired reference signal on the top plot.
    NOTE: If you leave the controller running too long the integration of gyro data to get position will wind-up and cause the satellite to go unstable. To remedy this:
    a) You can toggle the Control On button OR press the Control Off button to stop the motors.
    b) Before running another test. First Reset Position from Gyro to re-zero the numerical integration value for position.
    c) Resume testing from step 9.
10) If the data captured in the Queue looked good, be sure select the "Write to File Controls" button to write the queued data to a data file. When pressed, a dialog box will appear.
11) Repeat as necessary. Change gains and settings as needed while the VI stays running, just be sure the Control is Off when changing settings.
12) Use the "STOP" button on the bottom right when are done testing.


ASEN 3200/4114/5114 Spacecraft Control
Reference Height and Frequency Tools
Control On/Off & Capture Data Tools
Reset Position from Gyro in between Runs
Reaction Wheel Speed – Limit the motor to 4000 rpm for long periods of time to avoid reaction wheel saturation.