AME 454/554 Project 1 (due 3/25 6:00pm) Spring 2025

General Instructions

This is a group project (for 454 and 554 students) in which you will work in groups of 2-3 for AME 454 and in groups of 1-2 for AME 554. Each group of 454 students will work Task 1 and Task 2. (Completing all three tasks will earn extra credit.) Each group of 554 students must complete all three tasks. One project report for each group will be submitted in pdf format by the due date/time above in the Assignments folder on D2L. Your Matlab code must be submitted as a separate file (or a zip file) as well. The required format for the report is described in the last section below.

Task 1 (required for all groups)

Write **Matlab codes** to perform attitude regulation control (i.e. drive the attitude to the identity attitude) using **principal rotation vector, quaternions, and MRPs**. Discuss where any singularities exist and if they are avoided by the controller. Compare the performances of the **linear and nonlinear control laws** for MRPs as shown in Lec. 10 for at least a couple initial conditions that show both small-angle and large-angle reorientation maneuvers, where the initial condition for the large-angle maneuver is 3 rad about the axis (1, -2, 3). (You can include an option in your code to switch between the linear and nonlinear control laws.) For quaternion-based control, show results for initial conditions that illustrate how the unwinding phenomenon occurs with linear feedback but not with the discontinuous control law or the nonlinear control law. Choose control gains for the control laws that results in convergence in 45 sec from the initial attitude while allowing you to make valid comparisons between the controllers. For each control law discuss why the controller behaves the way it does. Discuss and compare the results in terms of control effort (i.e. angular velocity magnitude) and the response speed. You should choose the best way to show your results visually in your plots.

<u>AME 554 students should also do the following</u>: For each attitude set develop the proof of asymptotic stability of the identity attitude based on Lyapunov's direct method, starting with a Lyapunov candidate function and the kinematic differential equation.

Task 2 (required for all groups)

A) Work Prob. 3.38 and 3.39c) in the text. (The DCM $[\overline{B}I]$ means the estimated attitude of the B frame relative to the inertial frame, which in the Lec. 14 slides is $[\hat{B}N]$. The three estimated DCMs you are computing can be called $[\hat{B}N_{12}]$ using measurements 1 and 2, $[\hat{B}N_{13}]$ using measurements 1 and 3, and $[\hat{B}N_{14}]$ using measurements 1 and 4. To answer the question which of measurements 2, 3, and 4 is least accurate, you can find the principal angles associated with the <u>attitude differences</u> between these three estimated DCMs. If these principal angles are higher when a specific measurement 2, 3, or 4 is used than when that measurement is not used, then it is likely the least accurate measurement.)

B) Using the attitude estimated in part A) as the initial attitude, and assuming the spacecraft is initially at rest, implement an *optimal rest-to-rest maneuver* to drive the attitude to the identity attitude in under two minutes. Assume the spacecraft has inertias 1500 kg m^2 for rotations about the 1-axis, 1000 kg m^2 for rotations about the 2-axis, and 800 kg m^2 for rotations about the 3-axis. Your strategy should involve three sequential rotations about these axes in any desired order, but it is not required to come to rest until the identity attitude is achieved. Plot the response in terms of Euler angles, principal angle, and the control effort versus time, and also report the total cost given by

$$J = \frac{1}{2}\int_{t_0}^{t_f} u^2(t)dt$$

Note that, unlike Task 1 which uses kinematics only, this control strategy uses the full inertia properties of the spacecraft.

<u>AME 554 students should also do the following</u>: Add a critically damped tracking controller to the nominal rest-to-rest controller and show that the identity attitude is achieved in the required time even with initial conditions that vary from those used to design the nominal control.

Task 3 (required for 554 students)

Design a controller that performs regulation control for the DCM-based Morse-Lyapunov controller on *SO*(3) (see extra 554 slides in Lec. 10), and modify the Matlab code for the variational integrator to implement it. Choose appropriate initial conditions and control gains that result in convergence in under one minute. Show the proof of asymptotic stability of the identity attitude using Lyapunov's direct method.

<u>Helpful background material</u>:

Lec. 10-11 slides, textbook Chp. 3.10.1, 3.10.2, 3.10.5, and Module 2 Additional Reading files on D2L (especially Hall Attitude Determination Chapter).

Note each student in every group must complete and sign a Percentage Contribution statement with estimates of the percentage of the total work (i.e. in coding, plotting, and writing the report) completed by all team members. These statements will be available on D2L in the Projects folder and should be uploaded into the separate folder for Project 1 Percentage Contribution in the Assignments folder on D2L.

Project Report Document

A project report document, not exceeding 20 pages with figures and hard copies of computer code (if any), has to be submitted by the due date. The document should be neatly hand-written or (preferably) typed out on a computer using a word-processing software. This report (like any technical report) should be neatly arranged into the following sections: (1) abstract, (2) introduction, (3) methods used, (4) results and discussion, (5) summary (conclusions and recommendations), (6) references (if any), and (7) appendices (optional). These sections should contain (at the least) the information itemized below.

Abstract The abstract should summarize the work done in half a page. It must include the important results and significance of these results to the reader (your "boss"). It is usually the last part of the project document you write.

Introduction Introduces the reader to the project, which in this case is the given mission design problem. Be specific with the description of the problem, and be general with your description of methods used. Also mention here what each team member's contributions were. End this section by summarizing what will follow in the report. It is typically one to two pages in length and is usually the first section written.

Methods What theoretical knowledge did you employ to get your results? This is the section where you describe the "science" behind your mission design. This section also contains any equations you might use, as well as your rationale for using them. You could put a discussion of the software (if any) used (but not the code itself; that could go into an appendix), as well as drawings/sketches, relevant numbered equations, and any other technique you used that would enable someone to reproduce your results. It can include a justification for what your goal was in terms of accuracy of results.

Results and Discussion By far the most important section–especially the discussion. Here is where the "meat" of the report resides. It includes all the important results, of course, but not the derivations for it (which go into the methods section). A good approach to this section is to assemble all the results with facts and figures (for example, of the full trajectory of the spacecraft over the mission), and then "explain" to the reader what these results mean.

Conclusion Here you repeat some information from the Abstract, Introduction, and Discussion within a page; but tie together the problem and the solution. You can include what you would recommend to future students to obtain a good mission design.

References What written or oral references did you rely on to write your report? The references should be numbered here and the numbers used throughout your report in the text, such as: "These results are in agreement with West [1]." You can use numbered superscripts (e.g., ^{1} instead of [1]), if you wish. In order to reference a statement made in class, for example, you should use the following format:

E. Butcher, personal communication (2022).

For other references, include the website(s), OR the name(s) of the author(s), the title of the publication, the name of the journal or the publisher, the page numbers, and the date it was published.

Appendices Here is where you may want to put figures and additional materials you dont think are needed in the text. If your figures, computer codes, etc are too big or too difficult to see in the text, put them in an Appendix and refer the reader to the Appendix.