ASEN 3128 LAB 4: Quadrotor Control

- Assigned: Friday 5 March
- Due: Friday 19 March, 1:30 pm

For all assignments students will work in groups of two to four students. Groups are determined by the instructors. A single assignment should be submitted for the group.

OBJECTIVE

⇒ Design and implement feedback control for a quadrotor aircraft

BACKGROUND

Modal response

For this assignment students will use *modal response theory* to design and analyze closed loop control laws for the Parrot Mambo minidrone. Modal analysis was covered in detail in Lectures 10-11. In summary, students will derive state-space models that result from their control laws, and analyze the model response by looking at the eigenvalues of the resulting matrices.

Feedforward speed command

This assignment asks students to determine the "open loop" or "feedforward" speed command to change the position of the quadrotor. This is different from the feedback control process described in lecture that uses the gain K_4. Here, the reference speed command is explicitly given as a function of time based on the desired behavior of the quadrotor.

Consider the reference forward speed command $\Delta u_r^E(t)$ specified from time t_1 to time t_2. If we assume that the inner loop control works well and $\Delta u^E(t) = \Delta u_r^E(t)$, then if we know the position at t_1, the position at t_2 is

$$\Delta x_E(t_2) = \Delta x_E(t_1) + \int_{t_1}^{t_2} \Delta u_r^E(t)dt.$$

The challenge is then to determine the speed command as a function of time to achieve a desired final result. In the lab you are asked to consider a reference command that is constant over a given short time interval and zero afterward.

UPDATED Quadrotor parameters

These are the parameters for the Parrot Mambo Minidrone. **They are updated** from the values provided for previous labs, so be sure to use these values.

Quadrotor mass, m:	0.068 kg
Radial distance from CG to propeller, R:	0.060 m
Control moment coefficient, k_m:	0.0024 N*m/(N)
Body x-axis Moment of Inertia, I_x:	**5.8E-5 kg*m^2**
Body y-axis Moment of Inertia, I_y:	**7.2E-5 kg*m^2**
Body z-axis Moment of Inertia, I_z:	**1.0E-4 kg*m^2**
Aerodynamic force coefficient ν:	1E-3 N/(m/s)^2
Aerodynamic moment coefficient μ:	2E-6 N*m/(rad/s)^2

PROBLEMS

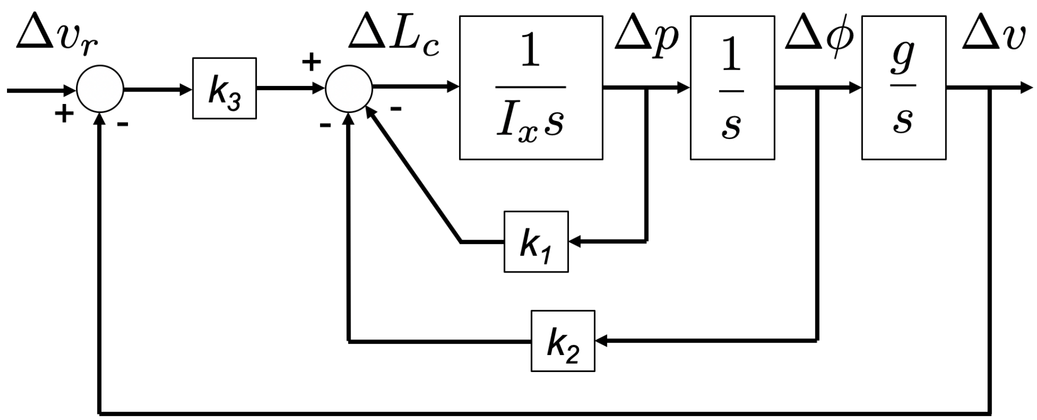
1. Design a feedback control system for the linearized lateral and longitudinal dynamics of the quadrotor to stabilize roll and pitch attitude. Use feedback gains on roll rate and pitch rate, along with feedback gains on roll and pitch angles. **Design these feedback gains to produce modal behavior for the "top two" states (e.g. roll and roll rate) in the lateral and longitudinal sets such that the modes have real eigenvalues, and one eigenvalue dominates the time constants in each set with a value of 0.5 sec.** Keep the angular rate feedback control from Lab Assignment 3 for the spin portion of the system.

2. Simulate the response of the **closed-loop linearized** system to initial condition deviations from the steady hover trim state as follows:
   a. Deviation by +5 deg in roll
   b. Deviation by +5 deg in pitch
   c. Deviation by +0.1 rad/sec in roll rate
   d. Deviation by +0.1 rad/sec in pitch rate

   Discuss the resulting behavior. Does it correspond to the expected behavior from the linearized modal response theory? Is steady hover now a stable flight condition?

3. Repeat Problem 2 using the **non-linearized** dynamics model together with the feedback control design for the linearized system, and compare the closed loop linearized and non-linearized behaviors.

4. Using the feedback control gains K_1 and K_2 designed in Problem 1 for the linearized lateral and longitudinal rotation dynamics of the quadrotor as an "inner loop" control law, arranged so that the roll and pitch angles track their corresponding reference angles, design an "outer loop" tracking control law with gain K_3 to cause the translational inertial velocity components to track corresponding reference commands, as shown in the block diagram (Figure 1) for the linearized lateral set. Design K_3 so that the closed loop three-state systems (lateral and longitudinal) have real eigenvalues, with corresponding modal time constants no larger than 1.25 sec. Use Matlab's `eig` function to find the eigenvalues of the system for a range of gains K_3 and plot the locus of these eigenvalues in the complex plane. Use this locus to determine gain values that satisfy the design objectives. Pay careful attention to the sign of K_3 in the longitudinal set.



$$\Delta L_c = -k_1 \Delta p - k_2 \Delta\phi + k_3 \left(\Delta v_r - \Delta v\right)$$

Figure 1. The block diagram for the lateral speed guidance of a quadrotor aircraft.

5. Design "open loop" or "feedforward" commands Δv_r^E and Δu_r^E to cause the corresponding inertial displacements Δy_E and Δx_E (assuming $\psi_o = 0$) to change by 1.0 m in 2.0 sec. Assume that the quadrotor will maintain altitude (an existing altitude controller will be active---you do not need to design this). Also assume that the velocity commands can be set to non-zero constants over a specified time, after which they will return to zero. Simulate this system in Matlab, for both longitudinal and lateral translation, one at a time, and verify that the simulation behaves as desired.

6. Submit your control design for implementation using this form:

   https://forms.gle/ed3SiL9HMJQiLJzn6

   Students will choose to implement the longitudinal OR lateral control they designed. Using the results of your control gains, or the default results provided to the class, compare the performance of the predicted (simulated) and actual responses. Provide engineering reasoning for the differences where you can, but no wild guesses please!

ASSIGNMENT

This assignment does not require a full lab report. Instead, submit **a single PDF file** that includes answers to all questions with plots generated for the problems and the text of any code specifically requested for a problem. All code used for the assignment should be included as an appendix. Only a single example of the code is expected even if students made multiple versions (e.g. each student wrote their own).

Be sure to add titles to all figures that include both the problem number and a description of the plot, e.g. 2.c Output x versus Time. The assignment will be evaluated based on i.) correct answers; ii.) proper commenting and documenting of code; and iii.) the quality of the figures submitted (e.g. labeling, axis, etc).

All lab assignments should include the Team Participation table and should be completed and acknowledged by all team members. Description of the Team Participation table is provided in a separate document.