16.30/31 Lab #2

1   Introduction

In the second lab, you will be controlling the Quanser on all three axes: roll, pitch, and travel. The primary goal is to develop the controllers for these axes using state space techniques that we developed in class (if not for all 3 axes, then at least for the pitch axis).

This lab requires the use of the classical controllers designed in Lab 1. You may choose to use your previously-developed controllers, design new ones, or use the controllers provided below (which seemed to work well in practice).

$$G_c^{\text{pitch}}(s) = 10\frac{(s+0.9)(s+0.2)}{s(s+40)} \qquad G_c^{\text{roll}}(s) = 10\frac{(s+4.5)(s+3)}{(s+60)(s+30)}$$

2   Designing a Travel Controller

In many aerospace systems, inner control loops are used to control the attitude of the plant, while outer loops are then used to control the location of the plant in space by commanding certain attitudes. Take, for instance, the altitude controller on most aircraft autopilots. The altitude controller itself commands a certain pitch, then an inner controller commands the elevator deflection to attain that pitch.

This is the strategy you will use to control the travel axis of the Quanser. Your travel controller will set the roll angle command, and that command goes through your roll angle controller, then is fed into the actual Quanser. This implies that your roll controller is now part of the system dynamics, and this fact must be accounted for in the system model.

The overall architecture is shown in Figure 1. The model we want to derive is the transfer function from roll angle command to travel angle output, i.e.,

$$G^{\text{travel}}(s) = \frac{\psi(s)}{\phi_c(s)}.$$

The roll and pitch controllers provide the inner control loops:

$$V_{\text{coll}} = G_c^{\text{pitch}}(s)(\theta_c - \theta),$$
$$V_{\text{cyc}} = G_c^{\text{roll}}(s)(\phi_c - \phi).$$
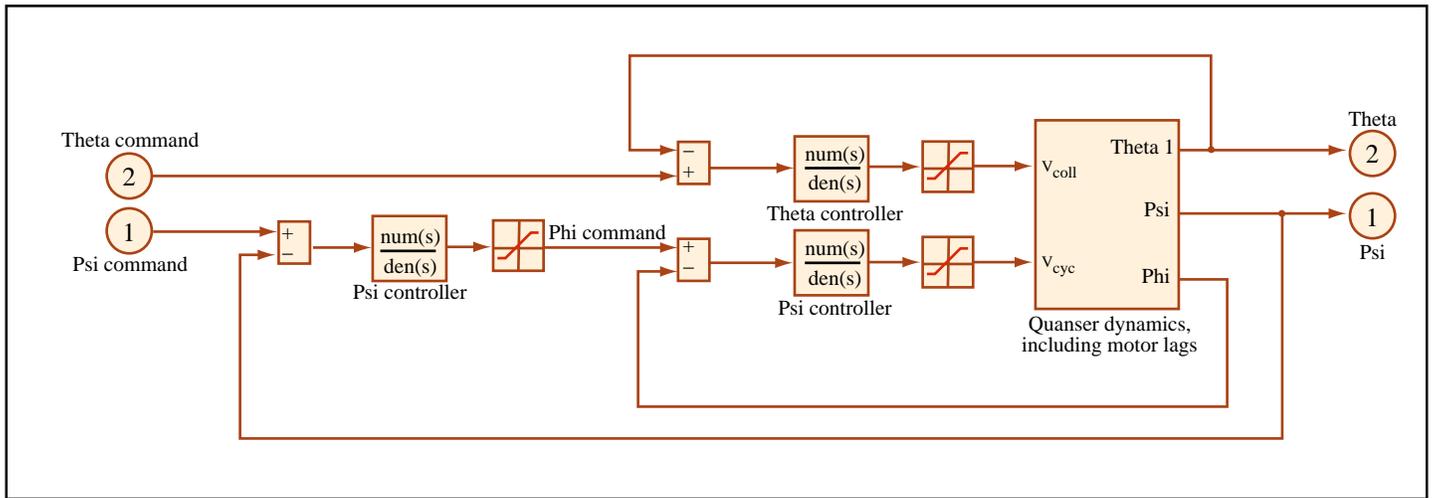
Figure 1: Overall architecture - as noted in Lab 1, all voltages must be saturated at ± 5 V.

The dynamics for the travel control design are established by closing these 2 inner loop controllers, then determining the dynamics from the input ϕ_c to the output ψ. The travel controller is then implemented as

$$\phi_c = G_c^{\text{travel}}(s)(\psi_c - \psi).$$

Table 1: Additional physical parameters (addendum to Lab 1)

Parameter	Value	Units	Description
I_{zz}	0.93	Nm	moment of inertia about z-axis
K_D	0		travel rate drag coefficient
$\bar{\omega}_{\text{coll}}$	$\frac{Mgl_\theta \sin(\theta_{rest})}{K_\tau l_{boom}}$	N	trim collective thrust
K_v	$0.0125\bar{\omega}_{\text{coll}}K_\tau l_{boom}$		travel rate thrust coefficient

3 Schedule

- Mon 11/15: Lab 2 assignment posted
- Wed 11/17: Signup sheets for lab sessions available in lecture
- Fri 11/19: First day of lab sessions
- Mon 11/22: **Lab 2 pre-lab assignment due**
- Thu 12/2: Last day of lab sessions
- Fri 12/3: **Lab 2 writeup due**
- Mon 12/6: Quanser competition parameters released
- Wed 12/8: **Quanser competition (optional)**

4 Pre-Lab Assignment (due 11/22)

The pre-lab assignment may be submitted either in person or online via Stellar. Remember that the pre-lab counts for a substantial portion of the overall lab grade.

1. **Augmented Plant Dynamics.** Select your preferred classical inner-loop controllers (e.g., from your own designs in Lab 1, or otherwise). Augment the linearized plant dynamics from Lab 1 with these controllers, as shown in Figure 1, and develop the linearized model for the travel plant $G^{\text{travel}}(s)$. Show explicitly how you developed this model.

2. **Classical Travel Controller.** Design a candidate, classical travel controller for the system. Please include:

   - A Bode plot of the controller
   - The open loop Bode plot of the controller + plant
   - Simulated step response for a 20° step command in travel angle
   - A paragraph or two describing your design strategy, predicted performance, and pros/cons of your design

3. **DOFB Pitch Controller.** Use state-space techniques to develop a candidate dynamic output feedback (DOFB) controller for pitch, $G_c^{\text{pitch}}(s)$. Your regulator should be designed via LQR, while your estimator should be designed via LQE (see Topic 14 and Recitation 10). Please include:

   - A Bode plot of the controller
   - The open loop Bode plot of the controller + plant
   - Simulated step response for a 15° step command in pitch angle (include the input saturations as discussed in class)
   - Simulate the effects of small sensor noise on your controllers to predict their flight test performance.
   - A paragraph or two describing your design strategy, predicted performance, and pros/cons of your design
   - Compare the DOFB and classical controllers, provide classical interpretations and discussing any key differences that you see.

   Note that you do not need to use the simulation model discussed in Figure 1 for this design - you can simply use the second order model for the pitch transfer function developed in Lab 1 augmented with the motor lags. Since this model is third order, it is likely your DOFB controller design will have a higher order than previously-developed pitch controllers, but as you now know from experience, the result should not differ too much from these designs if you want them to work successfully in the lab. You may want to use the LQ-servo formulation for the pitch axis to robustly achieve zero steady-state error.

4. **Full DOFB Controller Design (optional).** If you're up for the challenge, an alternative design strategy for the travel axis would be to design a DOFB inner-loop roll controller, close the loop using state-space methods, and then design a DOFB outer-loop travel controller. Including the DOFB pitch controller from the previous part, this means all three controllers would incorporate DOFB designs. See the Lab #2 Appendix for information on how to properly augment multiple state-space models.

5 Lab Procedure and Writeup (due 12/3)

1. **Administration:**

   - Lab sessions will take place between November 19 and December 2; you will remain in the same groups as Lab 1. As with the first lab, sign-up sheets for your group will be available in lecture; it is your responsibility to sign up for lab times. Please plan ahead - remember that most groups required 2 two-hour sessions to complete Lab 1.

   - Each member of the group must complete the pre-lab assignment, and you must submit your own lab report.

   - **You must bring a completed pre-lab assignment with you when attending a lab session in order to proceed with the lab.**

   - Specific instructions on how to complete the lab will be posted in the lab, as well as on Stellar.

2. Test your controllers on the Quanser for a variety of input sequences. In particular, you should try similar step responses for pitch as in Lab 1, and try a variety of step and/or ramp responses for travel.

3. Your lab report should provide an analysis of the experimental results for all controllers designed in the pre-lab. Your lab report should match the format used in Lab 1, and may be submitted either in lecture or via Stellar.

6 Optional Competition (12/8)

Once you have designed your full control system and tested it in-lab, you are welcome to enter an optional competition. The competition is min-time/min-error traversal of a course in the travel and pitch axes, requiring you to travel over (and perhaps under) a variety of obstacles placed in the way. There may also be additional "tasks" which your Quanser will be required to perform.

Two days before the competition, we will provide the obstacles, and give you the desired path in terms of $\theta_c(t)$ and $\psi_c(t)$. The team with the best score (see below) will win a small prize.

6.1 Command Generator

The LabVIEW code will provide your team with an interface through which you can pre-program a sequence of time-paramterized travel and pitch commands. Using this interface, you can specify a sequence of "waypoints," to be executed in order at specific times. Each waypoint consists of the time at which the waypoint is to be reached (in sec), the pitch angle (θ) of the waypoint (in degrees), and the travel angle (ψ) of the waypoint (in degrees). The reference pitch and travel at each instant will be generated by interpolating between these waypoints. For example, your waypoint sequence may look as follows:

t	θ	ψ
0	-25	0
5	-5	0
15	-5	90
25	-25	90

Using this input, the Quanser would (starting at rest on the table) increase its pitch at a rate of 4°/sec for 5 seconds, travel at a rate of 9°/sec for 10 seconds, then decrease its pitch at a steady rate such that it hits the table 10 seconds later.

6.2 Scoring

Your team score will consist of your time to complete the course, plus the following penalties:
1. For every second inside an obstacle, 10 seconds will be added to your score.
2. The integral of the absolute error in pitch and travel will be added to your score, scaled by multipliers of 0.025.
3. Other bonuses or penalties may be assessed, depending on the nature of the course.

Thus, a typical scoring function might look like

$$J = T + 10 \int \texttt{inObs}(\psi(t), \theta(t))dt + 0.025 \int |\psi_c(t) - \psi(t)|dt + 0.025 \int |\theta_c(t) - \theta(t)|dt,$$

where T is the completion time in seconds, all quantities are in degrees, and `inObstacle` returns 1 if the given angles are inside an obstacle and 0 otherwise. Doing well will require relatively tight control of both the pitch and travel axes, with good transient and steady-state performance. A robust design may also be advantageous.

6.3 Procedure

On the day of the competition you should expect to have only **one** mission attempt, so make it count! You may compete on any Quanser, but some Quansers are more "well-behaved" than others, so test before the day of the competition. (Each group will have an opportunity for a lab session on the day before the competition.) We will open your file, build it, then press Go; thus, there will be no time for setup or debugging (we only have on hour for everyone to compete). It is suggested that you **not** spend too much time tweaking your Lab 2 controllers. Instead, come up with smart waypoints for your command generator to minimize obstacle collisions. The severity of the penalties suggests that the team that completes the mission with few or no collisions, and with tight tracking, will win. Have fun!

16.30 / 16.31 Feedback Control Systems
Fall 2010