16.32 Principles of Optimal Control

Term Project

Your assignment is to pick a challenging problem appropriate for the class, and solve. By "appropriate," I mean pick a project that is either an interesting optimal control or estimation problem, and that uses techniques taught in this class. By "challenging," I mean a problem that is, in total, significantly more than a few problem set problems. There should be some interesting dynamics, or interesting issues associated with solving the problem. In any event, please talk to me as early as possible to ensure that you are doing an appropriate project. About mid-term, I will schedule consultations to discuss your ideas for a project.

Because optimal control is covered in the first half of the semester, and estimation covered in the second half, as a practical matter most term projects will be on optimal control rather than estimation.

You should work alone on the project. The project may be thesis-related, but may not be part of your thesis. If your project is thesis-related, you should talk to me first.

You should turn in a zip file that contains a folder of all your results. You should have a script `main.m` in the folder that can be run to produce all your results. You should include a writeup (typed, please) that discusses the final results, and shows that all the constraints are met. Remember, your job is to impress me! I'm not looking for length, I'm looking for the wow factor.

The project will be due in class, May 8, along with slides for your presentation for your briefing of the project. I will ask students to give a quick brief of their projects in the following lectures.

Some ideas for projects:

1. The "impossible turn" is the procedure where a pilot tries to land on the runway he departed from after an engine failure by executing a 180 deg turn, and ending up over the runway at the right altitude to make a landing. It's called the impossible turn because so many pilots crash trying to execute the maneuver. You should probably use a three d.o.f. model for the aircraft (i.e., the state is the position and velocity), not a six d.o.f. model (which adds attitudes and attitude rates). If you do this problem, you have to be careful — some of the resulting maneuvers are exciting enough that you will probably want to add state constraints. But if you do, be careful not to add so many constraints the constraints become the answer! I'm looking for practical advice to pilots, so you will have to use some judgement.

2. Control of an "acrobot." An acrobot is an underactuated double pendulum, with a torque motor at the elbow joint, but no motor at the shoulder, or base of the arm. So

it's tricky to balance — it's a little like a gymnast on a high bar, who bends at his waist to control his position. A variational solution to this problem would be interesting, but even better would be a dynamic programming solution that allows feedback control of the acrobot, rather than a single trajectory solution. One problem with the acrobot is that the state of the system isn't really $\mathbb{R}^4$ (two positions and two velocities), it's $U(1)^2 \times \mathbb{R}^2$ (two angles and two angular velocities). As a result, the state-space isn't simply connected, and it's hard to get to the optimal solution by perturbing a local solution. In English, you have to know how many times an angle goes through 2π before you can converge locally to a solution. That problem is avoided in dynamic programming by simply wrapping the grid around.

If you do this problem, you'll want to change some of the parameters, since the linearized system is barely controllable. Talk to me about that!

Also, see the paper at:

http://www.ece.clemson.edu/crb/ece496/spring2002/group1a/acrobot_swingup.pdf

3. Research the properties of the Apollo Lunar Lander, and do three optimal control problems:

   (a) The descent from lunar orbit to a soft landing;

   (b) The ascent to lunar orbit to rendezvous with the Lunar Orbiter; and

   (c) The ascent and rendezvous from an aborted landing.

   The difference between (b) and (c) is the terminal conditions. In case (b), you can wait until the orbiter is in the right position to launch. In case (c), you must reach the desired orbit, *and* end up where the orbiter is.

   Certainly, do a little research first to determine the overall strategy, then design the optimal trajectories. Also, it turns out that the actual descent in the Apollo program used a suboptimal trajectory for a very good reason. What was the reason?

4. Another project! I'm open to any interesting idea.