CSCE 990-001: Cyber-Physical Systems HW #2

Assigned: 2016-08-25
Due: 2016-09-22 in class

Homework Overview

There are multiple objectives of this homework:

- Inform me about your strengths and weaknesses in designing a CPS from beginning to end
- Discover for yourself your strengths and weaknesses in designing a CPS from beginning to end
- Practice the parts of design you are good at, and learn some about the parts of design you're not good at

Note that I **do not** expect you to be able to complete this entire assignment. I want you to get as far as you can and **at least attempt** each part of the homework. If you cannot complete a question tell me what process you would use to find out how to answer the question appropriately. Indicate what tools you would use and your general process. **The goal of this homework is to move away from the mathematical narrow focus of any individual area and think on a more "systems" level. Use your creativity!!!** Also, on this particular assignment you may collaborate with others if it will help. Also feel free to use Google, and any other resources at your disposal.

Grading

I ONLY expect you to make a reasonable effort for full credit. So convince me.

HW #2

The CPS we will be designing in this homework is control of a small satellite. A small sketch of the system can be seen in Figure 1. (I know it's not a small satellite, but it doesn't really matter).

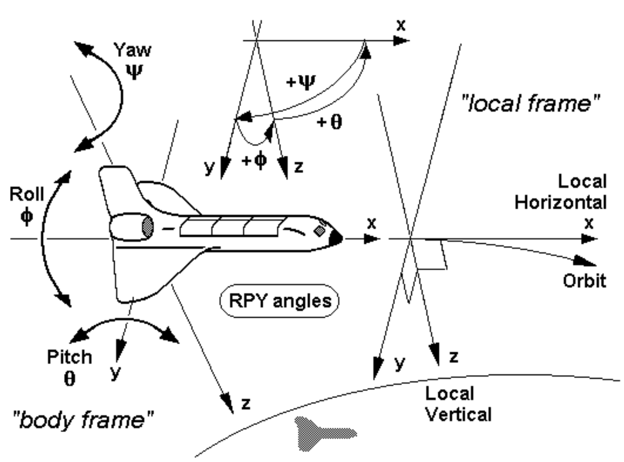

Figure 1: Use this model of a "small satellite"

You can make the following assumptions:

1. full-state feedback
2. reliable A/D and D/A conversion whose conversion times are 0 s
3. you can control the velocity of the rear wheels of a set of reaction wheels
    (a) the reaction wheels are located such that they impact each axis of rotation only.
4. the vehicle is always in the Local Vertical Local Horizontal (LVLH) orientation
5. inertia matrix $\mathbf{J} = \text{diag}\left(0.005, 0.025, 0.025\right)\ \text{Kg}\cdot\text{m}^2$
6. an altitude of 500 km and an orbital angular velocity of $\omega_o = 0.0011\ ^{rad}\!/\!_{\text{s}}$
7. mass of 3 kg with dimensions 30 cm × 10 cm × 10 cm

Any other assumptions your make are fine as long as you tell me what they are and why you made them.

Now complete the following:

1. Design the controller:
    (a) Derive equations of motion
    (b) If you were unable to derive the equations of motion here they are. In the pitch direction (rotation about y)

$$\dot{\theta}_2 = \omega_2$$
$$\dot{\omega}_2 = \frac{3\omega_o^2\left(J_3 - J_1\right)}{J_2}\theta_2 + \frac{M_2}{J_2}$$

and in the roll and yaw directions (rotation about x and z respectively)

$$\begin{aligned}\dot{\theta}_1 &= \omega_1 - \omega_o\theta_3 \\ \dot{\theta}_3 &= \omega_3 - \omega_o\theta_1 \\ \dot{\omega}_1 &= \frac{\omega_o\left(J_2 - J_3\right)}{J_1}\omega_3 + \frac{3\omega_o^2\left(J_3 - J_2\right)}{J_1}\theta_1 + \frac{M_1}{J_1} \\ \dot{\omega}_3 &= \frac{\omega_o\left(J_1 - J_2\right)}{J_3}\omega_1 + \frac{M_3}{J_3}\end{aligned}$$

Note that θ represents the angles of rotation, and ω are the angular velocity. J refers to the moment of inertia, ω_o the orbital angular velocity constant, and M are the torques (or moments) applied to the spacecraft by the reaction wheels. M are the things you control. In the traditional control vernacular, they would be u (the control input and the thing you design). These equations are already linearized so you should be able to easily form the traditional state-space control equations in the form

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$

where $\dot{x}$ is the derivative of all the states, $\mathbf{A}$ is the system matrix, and $\mathbf{B}$ is the control input matrix. Now you should be able to design a controller of some kind.

    (c) Prove stability of the controller

2. Think about, and write a paragraph about how you might control the vehicle to perform a slewing maneuver. In this case, because the equations have been linearized, they are only "valid" for small angles of rotation. If the slewing maneuver requires a large angular maneuver you will need a way of issuing small commands to your designed controller such that the controller can accomplish the designed maneuver. This is the essence of a "guidance" layer in your architecture.

3. Design the real-time system:

(a) Write pseudocode for the following tasks and include the task period you've chosen in the design. In each case justify the task period and demonstrate how it connects to the corresponding layer you've designed. For example, if you chose period P_τ for the control task, tell me how P_τ relates to the design of your control law.

   i. Control task

   ii. Guidance task

(b) Tell me what OS or RTOS you would use and why.

(c) What scheduling algorithm will you select, and why (RMS, EDF, Cyclic executive, etc.)?

(d) Estimate the worst case execution time (WCET) of each task or describe how you might determine it.

(e) Assuming the WCET you've estimated, consider a 3 task system (your two tasks above, and one additional task, a planner). Assume that the planner has execution time $e_p = 3\,\text{ms}$, and a task period of $P_p = 10\,\text{ms}$. Assuming the task periods you determined above and your chosen scheduler show that your tasks are schedulable.

4. Simulate the system and show plots.

5. Write a couple paragraphs on which parts were easy, which parts were hard and what you need to learn going forward to design this system well.