EE443L Lab 7 Continued: Ball and Beam Control and Simulation

Introduction

Last week through simulation we found unstable results for PID control of the ball and beam system. This control system instability motivates two important points:
1) we should evaluate our control system mathematically with methods such as Routh-Hurwitz or Root-Locus to ensure control system stability and selection of appropriate controller gains, and
2) state-space control approaches, which we'll discuss in the future, remove much of the controller selection difficulties encountered and allow arbitrary pole placement.
This week we'll investigate why last week's PID controller failed and look at one method that can be designed to provide accurate and stable control of the ball and beam system.

Procedure

1) Determine the transfer function $X(s)/X_d(s)$ for the PID controlled ball and beam system of last week.
   a) Are any coefficients of the characteristic equation zero? If so, what does this indicate about the control system's stability?
   b) Use matlab to determine the root-locus of control system assuming ratios of gains similar to those used in previous labs, i.e., $K_P = K_I$ and $K_V = 0.03K_P = 0.03K_I$. Does the root-locus confirm your stability conclusion above? Which open-loop poles appear to the problem as the root-locus varies? Print out the resulting root-locus.
2) The multiple ball/beam/motor system poles at zero imply that we probably shouldn't use a PID controller since it adds another pole at zero and makes our pole placement even more difficult. One solution is to use two PD controllers (beam angle and ball position) that effectively give us two additional zeros to pull unstable poles to the left without adding poles. This approach is shown in Figure 1 where x_d, x are the desired and actual ball position, respectively, and $?_d$, ? are the desired and actual beam angle, respectively.
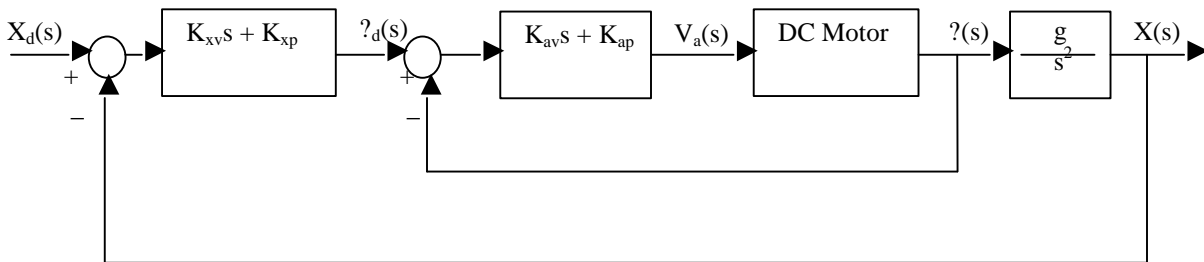

Figure 1: Proposed Ball and Beam Control System

3) Determine the beam angle control system transfer function $?(s)/ ?_d(s)$ and plot its root locus using our typical ratio between the proportional gain K_{ap} and the derivative gain K_{av} noting that this ratio may need to be changed. If possible pick the gains so that an effective damping ratio of approximately $?=0.7$ is achieved. Simulate the step response of the beam angle control system in matlab or simulink for your chosen gains to verify stability and performance. Print out this response.
4) Determine the total ball position control system transfer function $X(s)/X_d(s)$ and plot its root locus starting with approximately the same ratio between the proportional gain K_{xp} and the derivative gain K_{xv}. Pick gains so that an effective damping ratio of approximately $?=0.7$ is achieved and verify a stable and accurate step response of the ball/beam control system through a matlab or simulink simulation remembering the desired ball position must be less that 0.4m. Plot this response and use the ballbeam.m animation to view the system's response. Show me this animation.