MECH 338 - Robotics II
Final Project

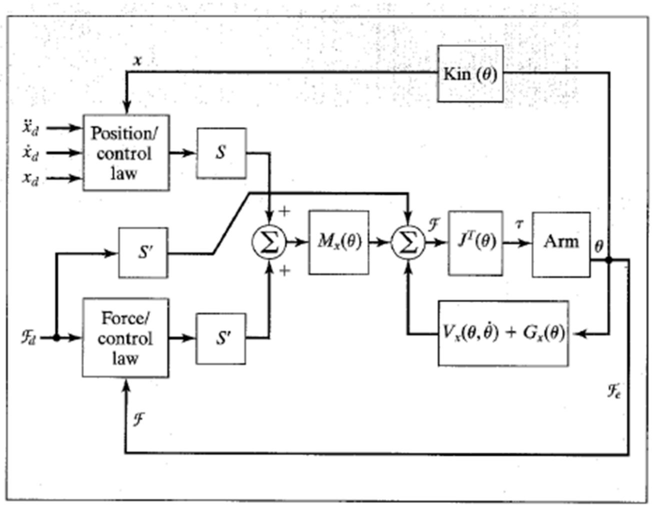
THIS PROJECT IS TO BE 100% ON AN INDIVIDUAL BASIS. DO NOT COLLABORATE WITH OTHER STUDENTS. DO NOT DISCUSS THE PROJECT WITH OTHER STUDENTS. DO NOT UTTER ANOTHER STUDENT'S NAME. DO NOT ACKNOWLEDGE THE EXISTENCE OF OTHER STUDENTS IN THE CLASS. DO NOT LEAVE YOUR FILES ON COMMON COMPUTERS. DO NOT DO NOT DO NOT.....

NOTE – As I am asked questions with answers worthy of sharing, I will post those Q&A nuggets on a Camino page, so check there often to see if there is any late-breaking answers/advice that can help you. I will not be announcing when there are updates to that page.

ANOTHER NOTE: This is a truly comprehensive project given it uses knowledge from nearly every part of the Mech/Ecen 337/338 course sequence. That said, we've incrementally built our simulations up to the point where hybrid control is the next logical step.

Objective: The objective of this assignment is to demonstrate a comprehensive understanding of the concepts presented in this course sequence. You will demonstrate the ability to implement manipulator kinematics/dynamics, to generate trajectories, and to implement a nonlinear hybrid position/force control system. The parts of this project lead you, step by step, to the development of a functional simulation of a 2-DOF nonlinear hybrid manipulator controller as shown in the text figure below. I urge you to be as methodical as possible in the development of your simulation. See the instructor exclusively for questions/comments.

For this project, you'll be using our beloved 2-link RR arm operating in a VERTICAL plane, which means compared to your prior RR arm simulations, you will now need to reorient the arm and include the effect of gravity. There is a horizontal planar surface at the level of the base of the robot (Zg=0). Ultimately, you will develop a hybrid controller that applies a force perpendicular to this surface while implementing sine wave position control of the arm's endpoint in the +/- Xg direction. This will be developed in a sequential manner.



You may develop your simulation in either Matlab or Simulink.

- If you use the Matlab approach, this presumably means that you will have 3 files working together as we've done earlier in the class. Your controller will be in your TAU file; you MUST have a clear, commented structure of this file so that it is very clear what the different terms of your controller are, with terms matching the graphical elements in the diagram shown above. This should include trajectory generation switching matrices, error and servo torque/force control computation for both sides of the controller, computation of alpha and beta, the Jacobian transpose computations, etc.
- If you use the Simulink approach, the graphical elements of your controller should be spatially arranged in your simulation panel in a manner similar to that of "hybrid position/force controller" diagram shown above, with signals and functions appropriately labeled, etc. It should be easily interpreted. You may use Matlab blocks for computation of key blocks, such as the mass matrix, etc.

Note that I am not specifying certain things - use your judgement in order to select appropriate specifications and quantities. Given what we've done in the class, it would make sense to shoot for things like critical damping, large scale relocations of the arm over 3-5 sec, motion that dies out over 1-2 sec due to friction, and force control time response on the order of a second or so…. But these are just wags – you may alter as you see fit as long as what you're achieving is realistic. You must take friction and gravity into account in addition to the full dynamics of the arm.

Hybrid Control for an RR Manipulator:

a. Nonlinear 2-DOF Position Control (15%) – Demonstrate sine wave endpoint position control of your arm. You will need to convert your prior planar RR robot simulation to a version that now operates in the vertical plane (the XZ plane) and which is affected by gravity. Each link should have a length of 1 unit and modeled with an equivalent endpoint mass of 3 units. Select damping values in a reasonable manner.

Although this portion of the assignment considers only position control, include the S switching matrix as an explicit element of your position controller; presumably, for this portion of the problem, S=I.

Have your system control the endpoint of the arm so that it moves back and forth in the Zg=0.25 units plane with a sine wave oscillation in the +/- Xg direction. Have the limits of motion be x=0.5 and x=1.5. The period of oscillation should be on the order of 5 sec. For now, assume there is no horizontal surface that the endpoint can contact… we'll add that in the next section.

NOTE: successful implementation of this part requires you to adapt your model from one of the assignments such that the arm is in the vertical plane.

DELIVERABLE: Provide your model/code for this section. Provide the endpoint time response plot showing the trajectory and actual endpoint position over time.

b. Nonlinear 2-DOF Force Control (30%) – Now assume that there is a horizontal surface in the X-Y plane at Zg=0. Develop a force control system for the arm such that it maintains a desired force with the surface of 10 units given a Kenv=1000. You may place the manipulator right at the surface of the wall, but NOT at any steady state location into the wall. Use an endpoint position roughly at x=1.

Although for this part of the problem you are only implementing force control, you should "integrate" your controller with elements of the controller from part a. Specifically, you should use the same alpha and beta functions. In addition, you should introduce an S' matrix value and now set the S and S' values so that only force control is on. Also – it should be very clear how you are computing the position of the arm into the wall and what the environmental force of the wall is on the arm's endpoint.

NOTE: The text diagrams assume that the "Arm" dynamic model includes the force of the wall. However, for our ROBOT simulation block, it does NOT assume any environmental force. Therefore, you must explicitly include the wall force; it must be very clear in your simulation how this is being done. In general, this should look like an additional contribution to the F signal; it should be Kenv * (perpendicular distance into the surface – be sure it makes not contribution with the arm is NOT touching the surface).

DELIVERABLE: Provide your model/code for this section. Provide the endpoint force time response plot showing the setpoint and actual endpoint force over time. Also show the time response of position over time as well as a view of motion of the endpoint in the XZ plane (a side view rather than an overhead view given the reorientation of the arm).

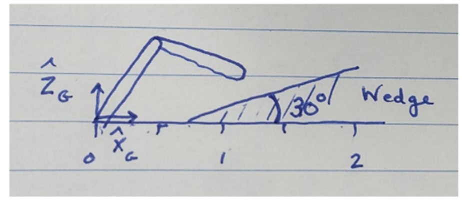
HINT: I would expect to see an oscillatory force response as the force moves from a non-ss initial condition to its ss value. Since position is not controlled, it is perfectly OK for the endpoint of the arm to move a little along the wall - this is due to coupling, and since we currently have no position control this is OK.

CAUTION: You should be sure that your wall model (a spring) only pushes on the manipulator when it is pressing into the wall; it should not be pulling the endpoint toward the wall when the endpoint is not in contact.

c. Nonlinear Hybrid Control (45%) - Now, as you maintain force control perpendicular to the wall, add a trajectory-based position controller to have your arm move back and forth along the wall in a sine-wave-like motion with a range of motion similar to that of part a. Initial conditions should be at approximately the initial point of the position trajectory along the wall and at the surface of the wall.

DELIVERABLE: Provide your model/code for this section. Provide the endpoint force time response plot showing the setpoint and actual endpoint force over time. Also show the time response of position over time as well as a view of motion of the endpoint in the XZ plane (a side view rather than an overhead view given the reorientation of the arm).

d. Surface Switching (10%) – For this final part of the problem, assume that wedge is affixed to the horizontal workspace surface. It has a 30 degree angle and its tip is located at x=0.75, as shown in the sketch. Keeping your x-dimension sine wave trajectory as is, your controller should continue to maintain the same amount of force control as the endpoint moves across the composite surface.



To do this, you must manage your switching matrices such that the force controller maintains the force set point in a direction perpendicular to the surface.

<u>DELIVERABLE</u>: Provide your model/code for this section. Provide the endpoint force time response plot showing the setpoint and actual endpoint force over time. Also show the time response of position over time as well as a view of motion of the endpoint in the XZ plane (a side view rather than an overhead view given the reorientation of the arm).