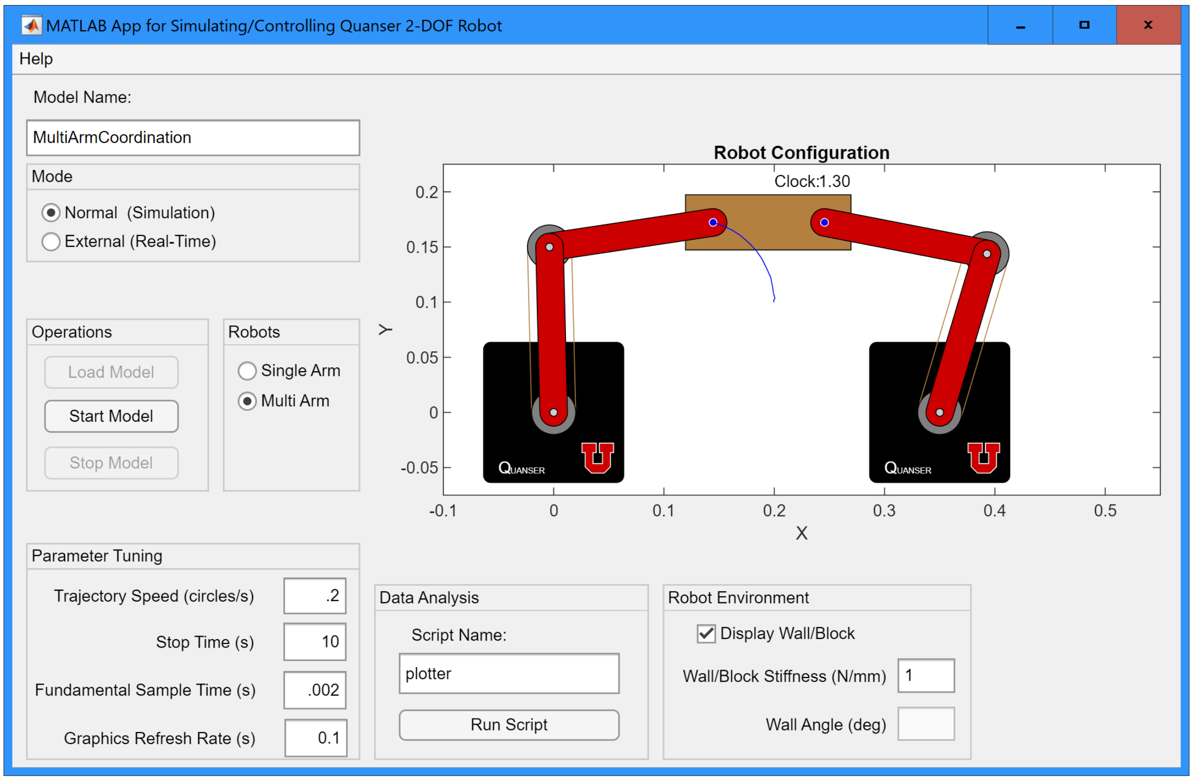
ME EN 5230/6230, CS 6330, ECE 6651

Intro to Robot Control – Spring 2023

Problem Set #10: Multi-Arm Coordination

Required for 6000 Level Students Only

1. In this problem you will design and simulate a multi-arm control scheme for two planar 2-DOF robots to cooperatively manipulate an object. You are provided with a template <PS10_template2023>, which models the dynamics of the two robots pin-jointed to a massless rectangular block of stiffness k_w, and provides a desired circling trajectory for Robot 1. You are also provided with a new graphical user interface *RobotApp2* to visualize the robots and block, as shown in the figure below. Your goal is to control the robots to cooperatively move the block in the circular trajectory, while maintaining a constant internal force in the block.



As in lecture, you should set up a *Relative Task Frame* consisting of the absolute op-space velocity of Robot 1 (the left robot) and the relative op-space velocity between Robot 1 and Robot 2. You can then create a table of constraints and formulate a Hybrid Position/Force controller to perform the task as specified. Note that since the robot end-effectors are pin-jointed to the block, there is only a natural kinematic constraint on one degree of freedom (e.g. the x-component of the relative velocity).

I recommend you start with a desired relative y-position of 0, which means the block will be oriented horizontally, a desired internal force of 1 N in the x-direction, which means the block will be in tension, and a relatively low wall stiffness of 1 N/mm. Since we have not modeled the inertia of the block in our plant, we should stick with a slow speed (0.2 circles/sec). Once you get your controlling working, you should experiment with the stiffness of the block, the magnitude of the internal force, and the block orientation.

1.1 Block Stiffness

Try both a soft block (k=1 N/mm) and a stiff block (k=10 N/mm), and comment on any differences in stability/performance.

1.2 Magnitude of Internal Force

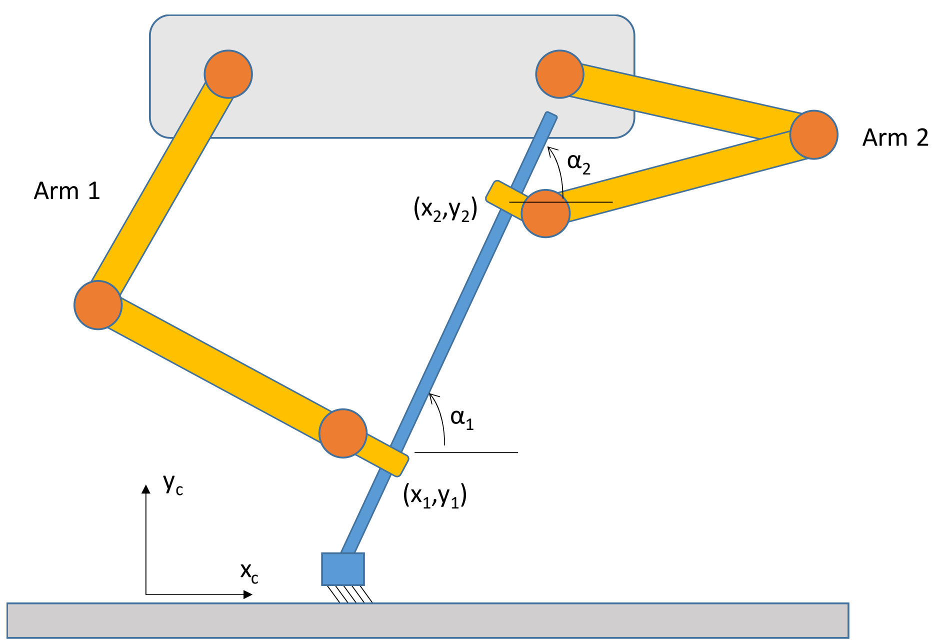
Set the block stiffness back to 1 N/mm, but now try varying the magnitude of the internal force. Try at three cases including (tension, compression, and zero internal force).

1.3 Block Orientation

Keep the block stiffness at 1 N/mm, and the internal force at 1 N, but now trying varying the orientation of the block by specifying a non-zero relative y-position of the two robots. Provide plots for at least three different block orientations. Note that for non-zero orientations, we would like to control the internal force using a coordinate frame that rotates with the block. Can you figure out how to do this?

Provide an image of your Simulink model and code from any new embedded MATLAB functions, and provide a sufficient number of plots as requested above. In each case, plot the position/orientation of the block and the internal force, and the respective position/force tracking errors. Be sure to properly title your plots and label your axes. Compare the stability and performance of each control scheme.

2. A pair of 3-DOF planar robot arms are attached to an overhead gantry and given the task of sweeping the floor with a broom. Each robot has a firm grip on the broomstick and can independently control the planar position (x, y) and orientation (α) of its end-effector, imparting both force (F_x, F_y) and torque (T_z) to the broomstick. So the robots have a combined total of 6-DOF in operational space ($\dot{x}_1, \dot{y}_1, \dot{\alpha}_1, \dot{x}_2, \dot{y}_2, \dot{\alpha}_2$).



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2.1 Formulate an appropriate task space using a combination of absolute and relative velocities, and show how to map between this task space and joint space. (i.e. derive an expression for J_{rel} in terms of J_1 and J_2).

2.2 Setup a table of natural and artificial constraints with respect to your task space (consider the interactions of the robot with the broomstick as well as the interaction of the broomstick with the floor). Derive the corresponding selection matrix.

2.3 Show how you would implement a hybrid position/force controller for this task. Draw a block diagram. Show what you would use as the desired positions and forces.