ME EN 5230/6230, CS 6330, ECE 6651

Intro to Robot Control – Spring 2023

LAB ASSIGNMENT #5: INDIRECT FORCE CONTROL

Introduction

The purpose of this assignment is to implement **indirect force control** in **operational space** using the Quanser 2-DOF serial robots. The robot should be oriented on the desk in the same configuration as in Lab 4, and the same lab protocols (including homing) will be used. However the desired circling trajectory has been altered to intersect with the benchtop, as in Problem Set #8, and you will need to position the robot towards the back of the benchtop so that the benchtop is in the workspace of the robot. A two-axis force sensor has also been added to the robot end-effector to measure the contact forces between the robot and the benchtop.

Force Sensor Safety

Please take care to avoid damaging the force sensors and straining/entangling the wires. The load cells are mechanically robust, but the electrical connections (where the wires are soldered to the load cells) are fragile and cannot be repaired. Do not attempt to operate the robot at high speed with the force sensor. Use only a slow speed of 0.2 circles/sec. Be ready to immediately activate the E-stop if the robot goes out of control. It's probably a good idea to first test the trajectory tracking in free space (position the robot towards the front of the benchtop so that the end effector reaches out over the edge of the benchtop and cannot make contact with the benchtop). Then use the E-stop to disable the motors and try manually pushing on the force sensor in the x and y directions to make sure the force signals are responding properly. If everything works fine, then re-enable the motors and move the robot back towards the rear of the benchtop to allow for contact to occur. When you home the robot, be sure that you are not touching the force sensor. Otherwise you will interfere with the bias removal, which assumes that the force sensor is not in contact for the first 0.5 second after starting the model.

Lab Exercises

On Canvas, you are provided with a Simulink Template <Lab5_template2023.slx>, which has Jacobian Transpose Control already implemented in operational space with a reasonably stiff set of PD gains. Note that a gravity compensator is included in the template and the mass parameters have been updated to compensate for the added mass of the force sensor. The forward kinematics have also been adjusted to increase the length of link 2. Since we will only be using slow trajectories in this lab exercise, PD control with gravity compensation is sufficient to get good position tracking (full inverse dynamics control should not be necessary). The template also contains blocks for measuring the forces from the force sensor. Note that the force sensors have been calibrated for you and the template has been designed to filter the noise and automatically remove any bias in the force readings, as well as rotate the forces from the end-effector frame to the base frame. Your task is to design and simulate a series of indirect force controllers in operational space, such that the force on the wall is limited to 1 N or less when using a relatively slow speed of 0.2 circles/sec.

1. First use the provided template without changing anything. Record the position and force data and note the maximum force in the y-direction. When the force in the y-direction becomes large, this may result in significant friction in the x-direction, resulting in stick-

slip behavior as the end-effector slides along the benchtop. This is fine as long as the robot does not go unstable.

2. Next implement **Stiffness/Damping Control** by lowering the PD gains in the y-direction. See if you can find a set of gains that limit the y-force to less than 1 N. Again record both position and force data. Note that as the y-force is reduced, the friction is also reduced and the robot will slide more smoothly along the benchtop.

3. Finally, implement **Compliance Control** by restoring the PD gains to their original values and using force feedback to alter the desired trajectory. Try to find a compliance (or admittance transfer function) in the y-direction that limits the y-force to less than 1 N. You can first try a compliance only. However if the robot exhibits instability, you may need to try an admittance transfer function in order to add some damping in addition to the compliance.

In each of the above cases, comment on both the position tracking and the force magnitudes. Use only a slow speed (0.2 circles/sec). Note that in PS#8 we tried using different wall stiffnesses. However in this lab, the force sensor itself has some physical compliance. So even though the benchtop is very stiff, the physical compliance of the force sensor makes it appear as if the benchtop has some compliance (the controller can't tell the difference).

Note: Make plots of the x-y trajectory, the operational space errors vs. time, and the contact forces vs. time. For each controller, provide an image of your Simulink model and printouts of any new Embedded MATLAB Functions. Be sure to properly title your plots and label your axes. If you wish you can use the *RobotApp* that is posted on Canvas to control the experiments. However the App does not account for the increase in length of link 2, and the trajectory drawn on the App will not be representative of the actual end-effector trajectory.