16-662 Autonomy Homework 1

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1 Control

For this section, I wrote a force and impedance controller for the Franka arm and tested them via simulation in MuJoCo.

1.1 Stationary Board

Below are two images that show the force plots for the force controller and impedance controller. The first is over the entire 10-second window. The second is zoomed in to a 3-second section showing the transient response. One major differences that can be observed is that the force controller has large noise when at steady state. This can be attributed to it relying on the force sensor for feedback, which introduces the sensor noise into the controller. The second difference in the controllers is in the transient response. They behave similarly on a large scale, but the force controller has small oscillations, suggesting that the PI controller used for force control is under-damped.

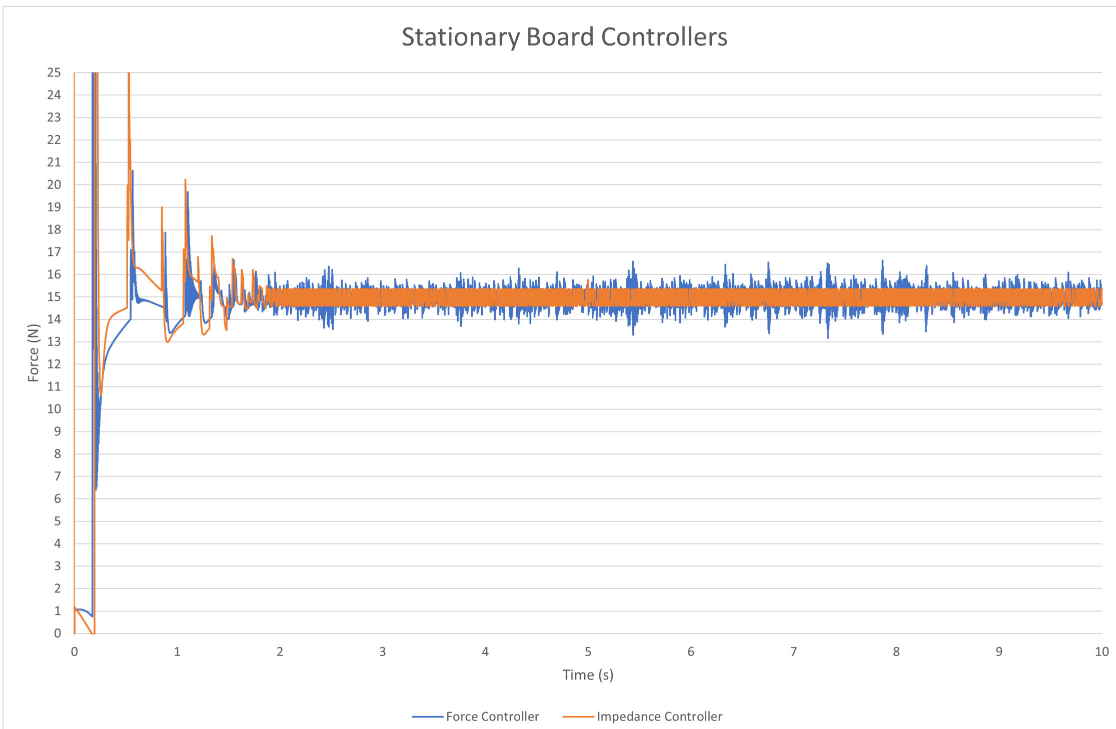

Figure 1: Force applied by robot to a stationary board under two controlling schemes; desired force is 15N.

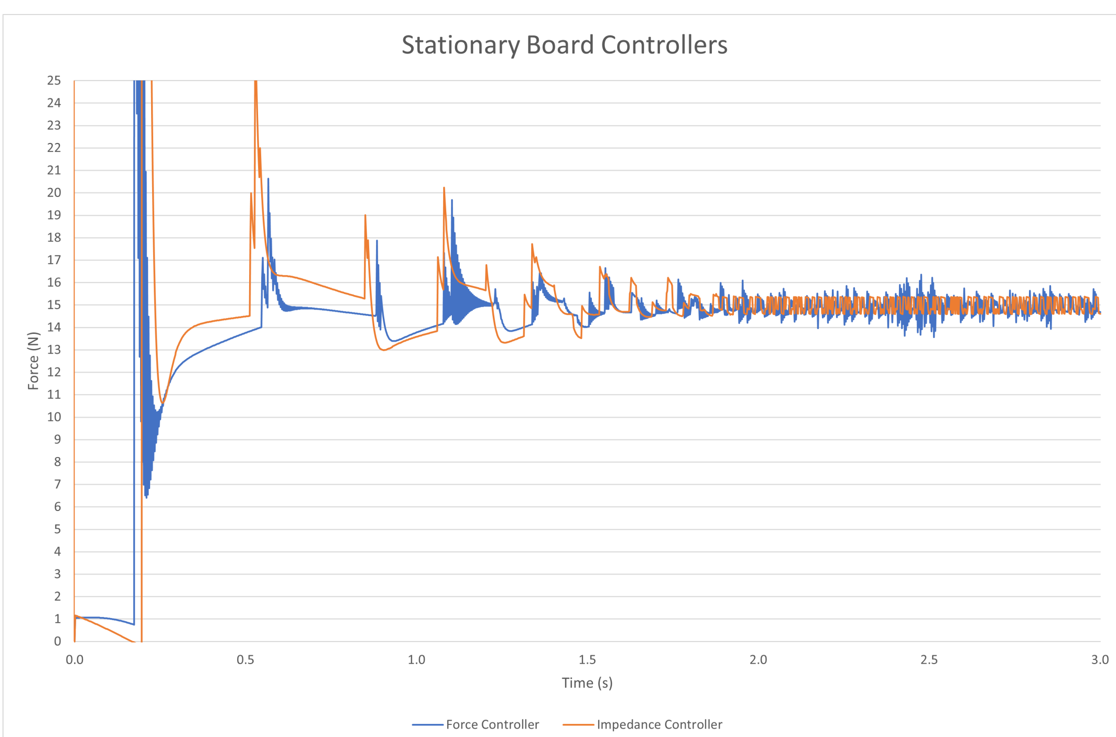

Figure 2: Zoomed in, force applied by robot to a stationary board under two controlling schemes; desired force is 15N.

1.2 Oscillating Board

In this second test, the board is oscillating instead of being fixed. There is one additional difference between the two controllers that was not evidenced in the first test. The impedance controller has a larger force error when the board is in motion. This can be seen in two sections of the graph. From t=0.2s to t=1.2s, the board is moving towards the arm. In response, the force controller produces a force of about 17N while the impedance controller produces a force of about 24N. Conversely, from t=9 to t=10, the board is moving away from the robot. In response, the force controller produces a force of about 14N while the impedance controller produces a force of about 11N. Thus, when a target is moving, impedance control will struggle to maintain the desired force.

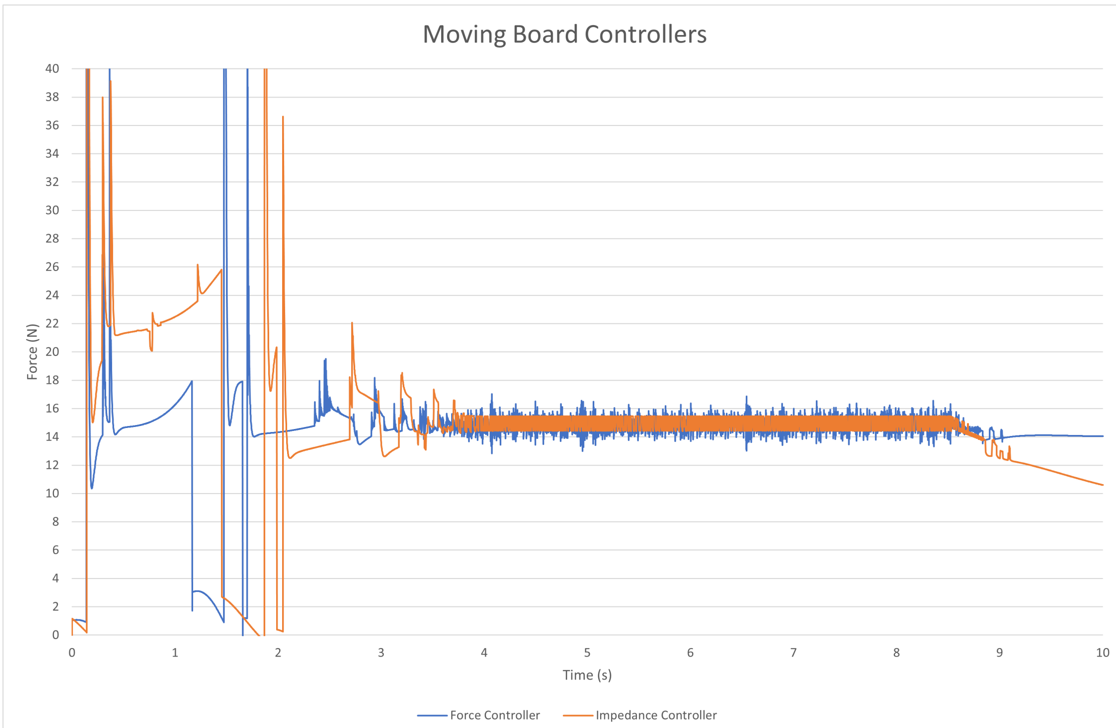

Figure 3: Force applied by robot to an oscillating board under two controlling schemes; desired force is 15N.

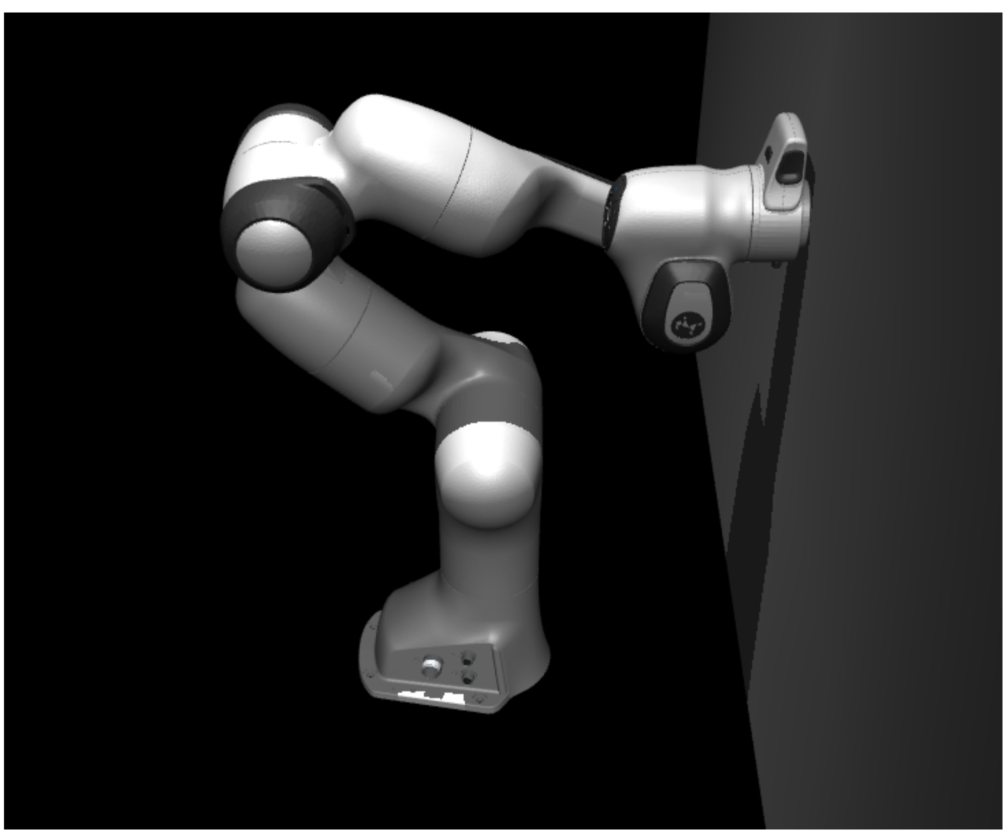

Figure 4: Franka robot in MuJoCo when board is at maximum amplitude.

2 Kinematics

For this section, I wrote a function to compute the forward and inverse kinematics of a Franka robot arm. The inverse kinematics function used the damped least squares method.

2.1 Forward Kinematics

Below are the results of the forward kinematics tests:

$$q_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$t_1 = \begin{bmatrix} 0.088 \\ 0 \\ 0.926 \end{bmatrix} \quad R_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

$$q_2 = \begin{bmatrix} 0 & 0 & -45 & -15 & 20 & 15 & -75 \end{bmatrix}$$

$$t_2 = \begin{bmatrix} 0.15710277 \\ -0.10259332 \\ 0.93602711 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0.64935398 & 0.75871099 & 0.05193309 \\ 0.7552124 & -0.65137389 & 0.07325497 \\ 0.08940721 & -0.00834789 & -0.99596017 \end{bmatrix}$$

$$q_3 = \begin{bmatrix} 0 & 0 & 30 & -60 & -65 & 45 & 0 \end{bmatrix}$$

$$t_3 = \begin{bmatrix} 0.40136375 \\ 0.08742801 \\ 0.85526363 \end{bmatrix} \quad R_3 = \begin{bmatrix} 0.98015816 & -0.18113365 & -0.08050201 \\ -0.17410263 & -0.5925751 & -0.78647507 \\ 0.09475362 & 0.78488557 & -0.61235316 \end{bmatrix}$$

2.2 Inverse Kinematics

Below are the final joint angles for moving to the supplied end effector goal pose, along with an image of the robot in this configuration in MuJoCo.

$$q = \begin{bmatrix} -0.51293991 \\ 0.07921995 \\ 0.52316144 \\ -1.85316041 \\ -3.11343046 \\ 2.79019664 \\ -0.06636301 \end{bmatrix}$$

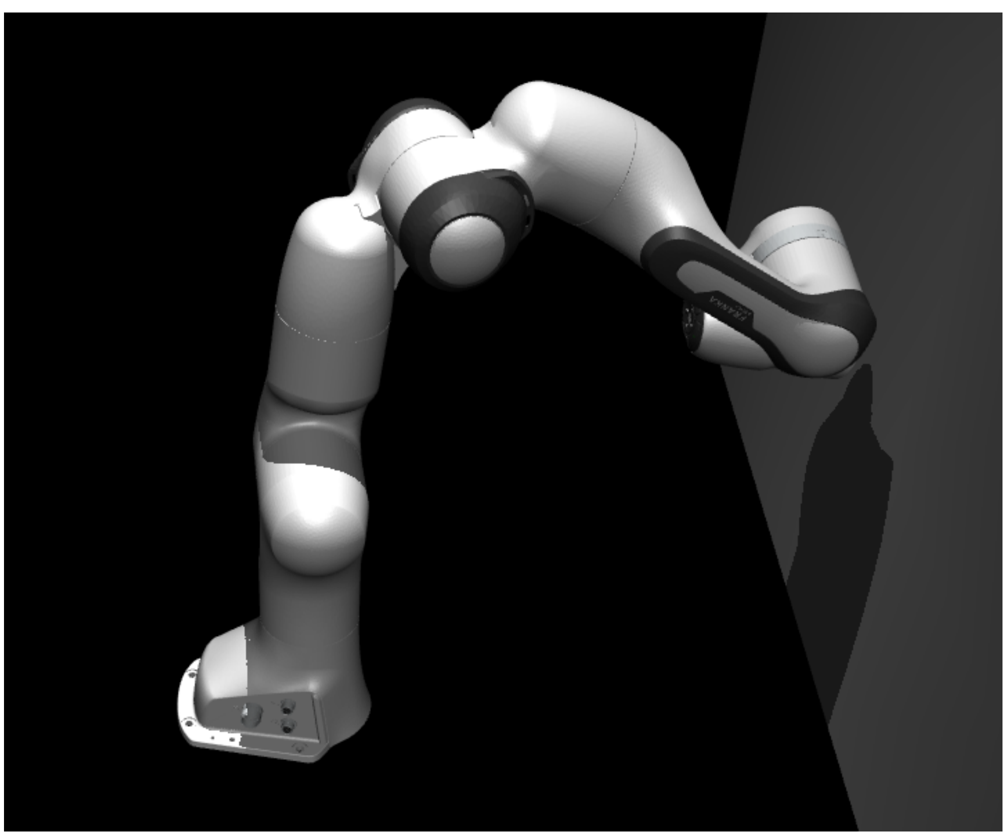

Figure 5: Joint values produced by inverse kinematics on the Franka arm in MuJoCo.