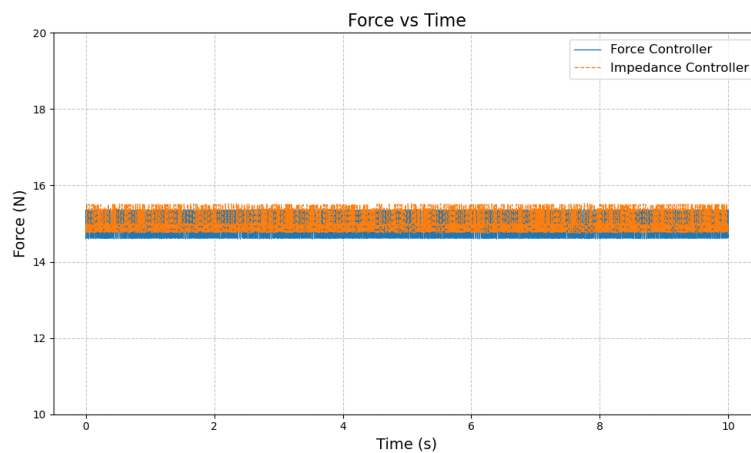16-662

Robot Autonomy

Boxiang Fu

boxiangf
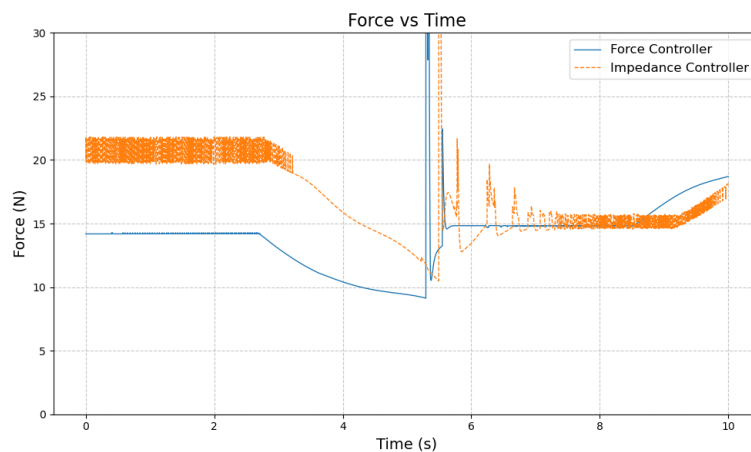
01/26/2025
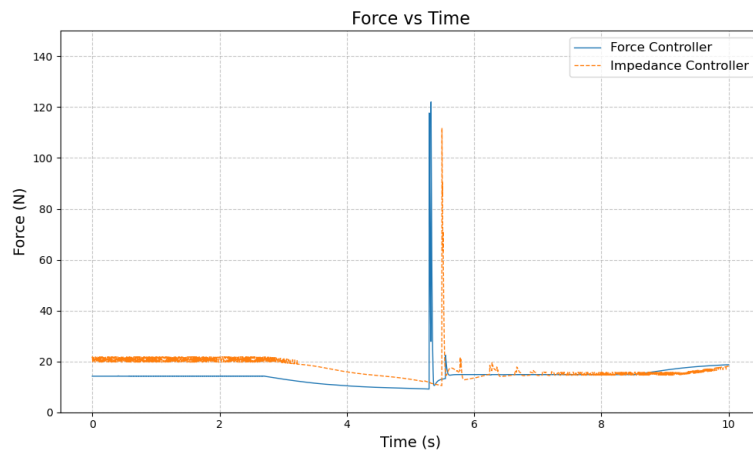
Q3.

The force plots for the force and impedance controller when the whiteboard is static is
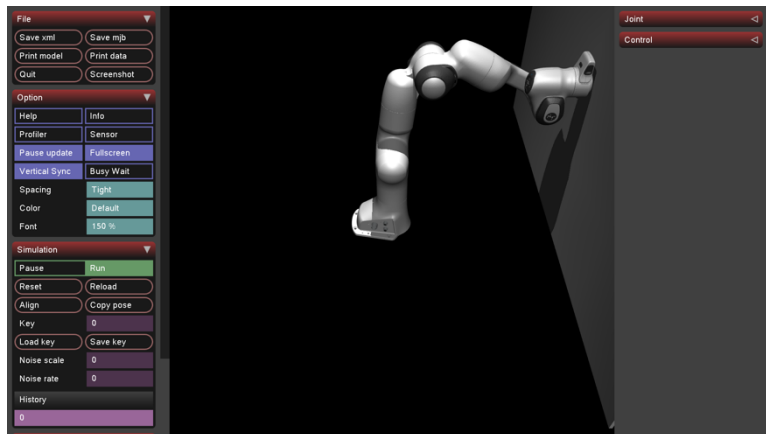
plotted below:

The force plots for the force and impedance controller when the whiteboard is oscillating is plotted

below. The period corresponds to the board being closest to the robot, then receding to its static

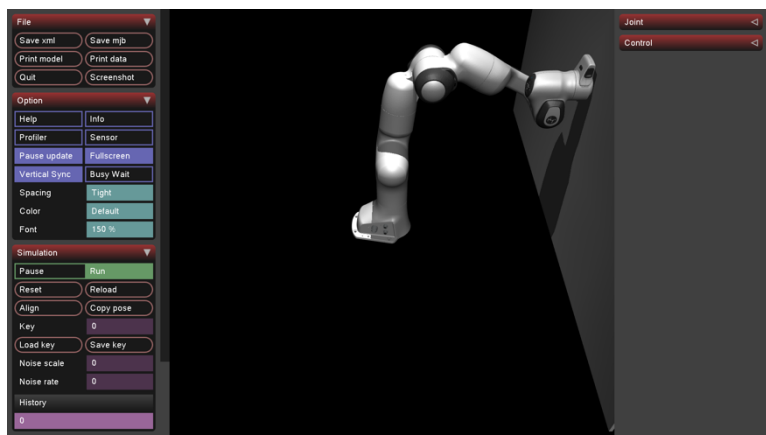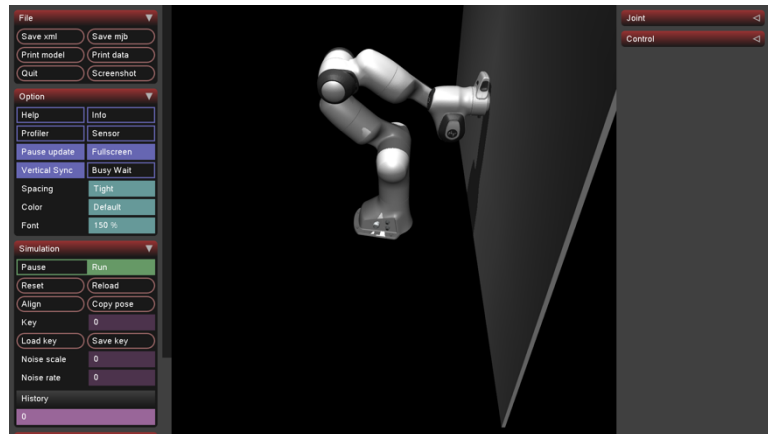position, and then pushing towards the robot.

Force vs Time

A screenshot of the robot when the board is near its maximum amplitude (closest to the robot) for the force controller on a static whiteboard is shown below:


A screenshot of the robot when the board is near its maximum amplitude (closest to the robot) for the impedance controller on a static whiteboard is shown below:

A screenshot of the robot when the board is near its maximum amplitude (closest to the robot) for the force controller on an oscillating whiteboard is shown below:

A screenshot of the robot when the board is near its maximum amplitude (closest to the robot) for the impedance controller on an oscillating whiteboard is shown below:
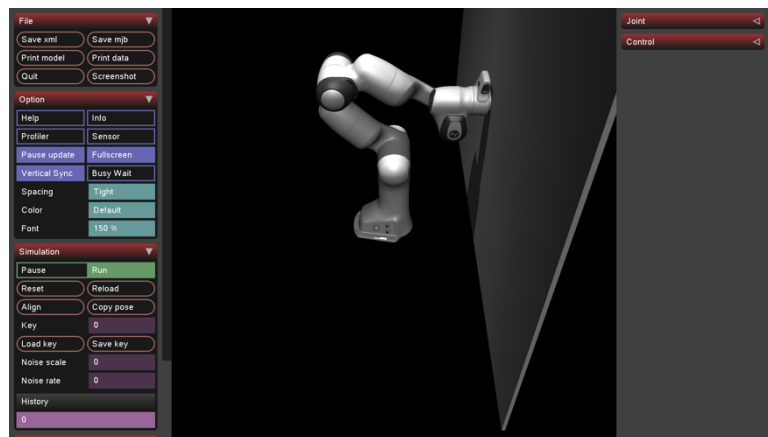
Referring to the force vs time plots above, we note that the force and impedance controllers exhibit similar behaviors for the static case. This is to be expected since we have designed the controller to generate 15 Newtons of force in equilibrium. Without external disturbances, both controllers eventually reach this equilibrium.

However, this is different for the oscillating case. From the force vs time plots, we note that for the force controller, the force is relatively well tracked with minimal oscillation and deviation (when the board is not moving). However, for the impedance controller, the controller deviates from the

required 15 Newton force and oscillates wildly. This is to be expected since the force controller is more aggressive in its policy of maintaining desired force. It does not consider the motion constraints of the environment and if imposing such a force would cause damage. On the other hand, the impedance controller is "compliant" to changes in the environment and will yield when external force disturbances are imposed. This shows up as deviations from the desired 15 Newton force on the force graph, where the end-effector compliantly "gives-way" when interacting with the moving board.

Q4.

The three end effector poses are:

Pose for q1:

```
Joints:
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
computed FK ee position
[ 8.80000000e-02 -8.93992163e-18  9.26000000e-01]
computed FK ee rotation
[[ 1.0000000e+00  0.0000000e+00  0.0000000e+00]
 [ 0.0000000e+00 -1.0000000e+00 -1.2246468e-16]
 [ 0.0000000e+00  1.2246468e-16 -1.0000000e+00]]
```

Pose for q2:

```
Joints:
[0, 0, -0.7853981633974483, -0.2617993877991494, 0.3490658503988659, 0.2617993877991494, -1.3089969389957472]
computed FK ee position
[ 0.15710277 -0.10259332  0.93602711]
computed FK ee rotation
[[ 0.64935398  0.75871099  0.05193309]
 [ 0.7552124  -0.65137389  0.07325497]
 [ 0.08940721 -0.00834789 -0.99596017]]
```

Pose for q3:

```
Joints:
[0, 0, 0.5235987755982988, -1.0471975511965976, -1.1344640137963142, 0.7853981633974483, 0.0]
computed FK ee position
[0.40136375 0.08742801 0.85526363]
computed FK ee rotation
[[ 0.98015816 -0.18113365 -0.08050201]
 [-0.17410263 -0.5925751  -0.78647507]
 [ 0.09475362  0.78488557 -0.61235316]]
```

The final joint angles for moving to the end effector goal pose is:

$$q_{final} = \begin{pmatrix} 0.683186996507673 \\ 0.3452335158930178 \\ -0.8195164368276641 \\ -2.0759188895342455 \\ -0.1469670600567182 \\ 3.9192133821936697 \\ -2.7850389771292003 \end{pmatrix}$$

```
Found IK solution in 263 epochs
Error 6.704424776121306e-07 0.000338330398253691
Computed IK angles [np.float64(0.683186996507673), np.float64(0.3452335158930178), np.float64(-0.8195164368276641), np.float64(-2.0759188895342455), np.float64(-0.14696706005
67182), np.float64(3.9192133821936697), np.float64(-2.7850389771292003)]
```

The robot moved to this position using a position controller is shown below:
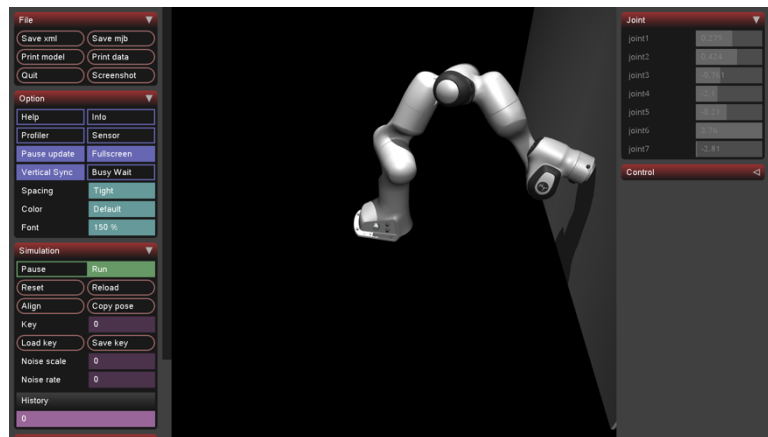
Note: The actual pose deviates from the desired pose as the pose may not be achievable.