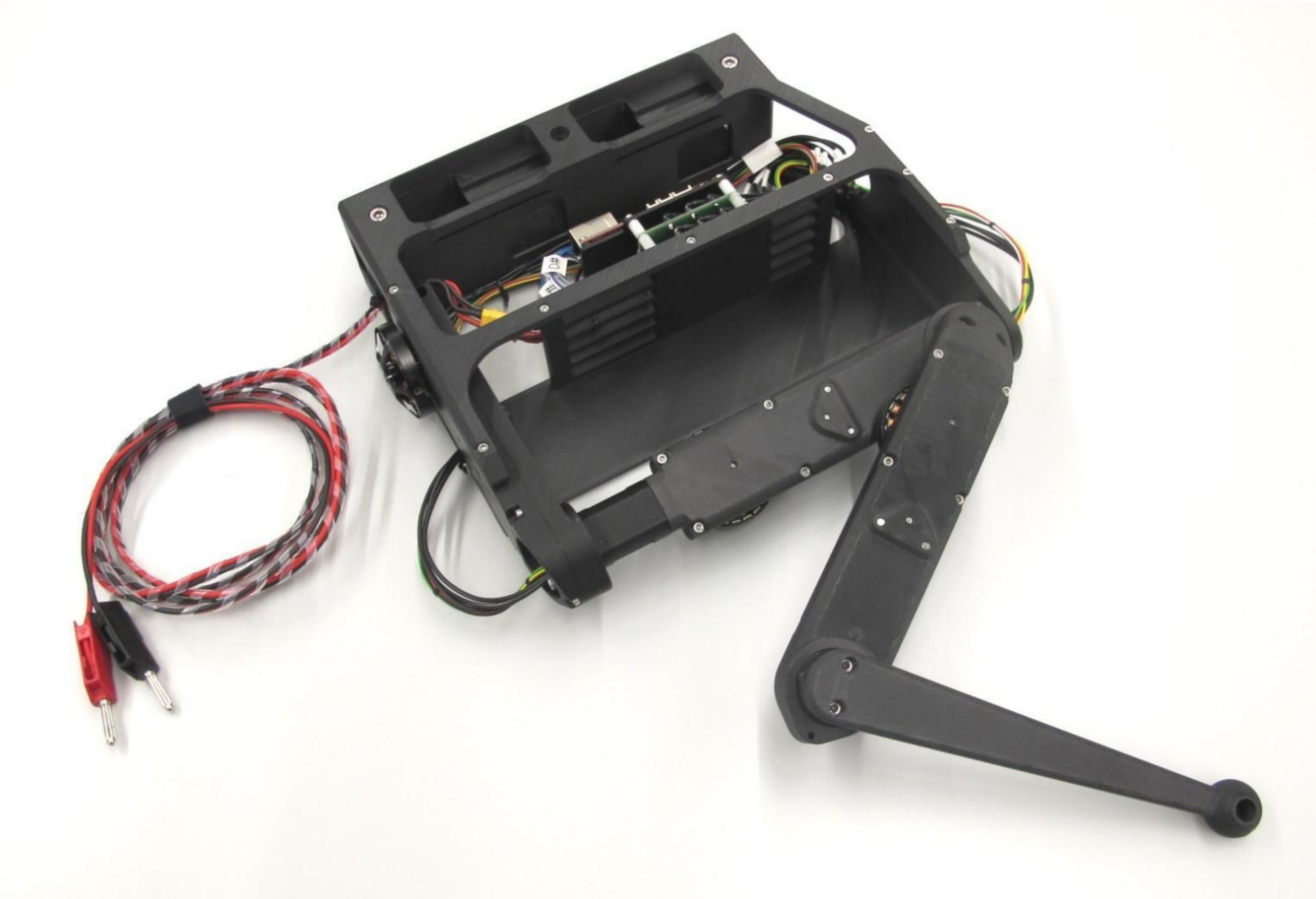

Laboratory 1

Andy Qin, Gaurang Ruparelia, Kyle Wang| ROB-UY 2004 | 02/12/23

Section 1: Sensors and Actuators

Q1: What is the control rate that we used in this example in Hz?

$$\frac{Number\ of\ steps}{running\ time} = \frac{5000\ steps}{5\ seconds} = 1000Hz$$

Q2: Describe the behavior of the robot when 0.1 Nm is applied to the 1st joint and 0 Nm applied to the others. What is the physical explanation for this behavior (in words)?

When 0.1 Nm is applied to the 1st joint and 0 Nm to the others, the robot oscillates back and forth like a pendulum, only the upper motor is rotating while the middle and lower motor are stationary. The physical explanation is that the torque, a measure of force applied to a body that causes rotational motion, will make the 1st rigid body move and will gradually stop.

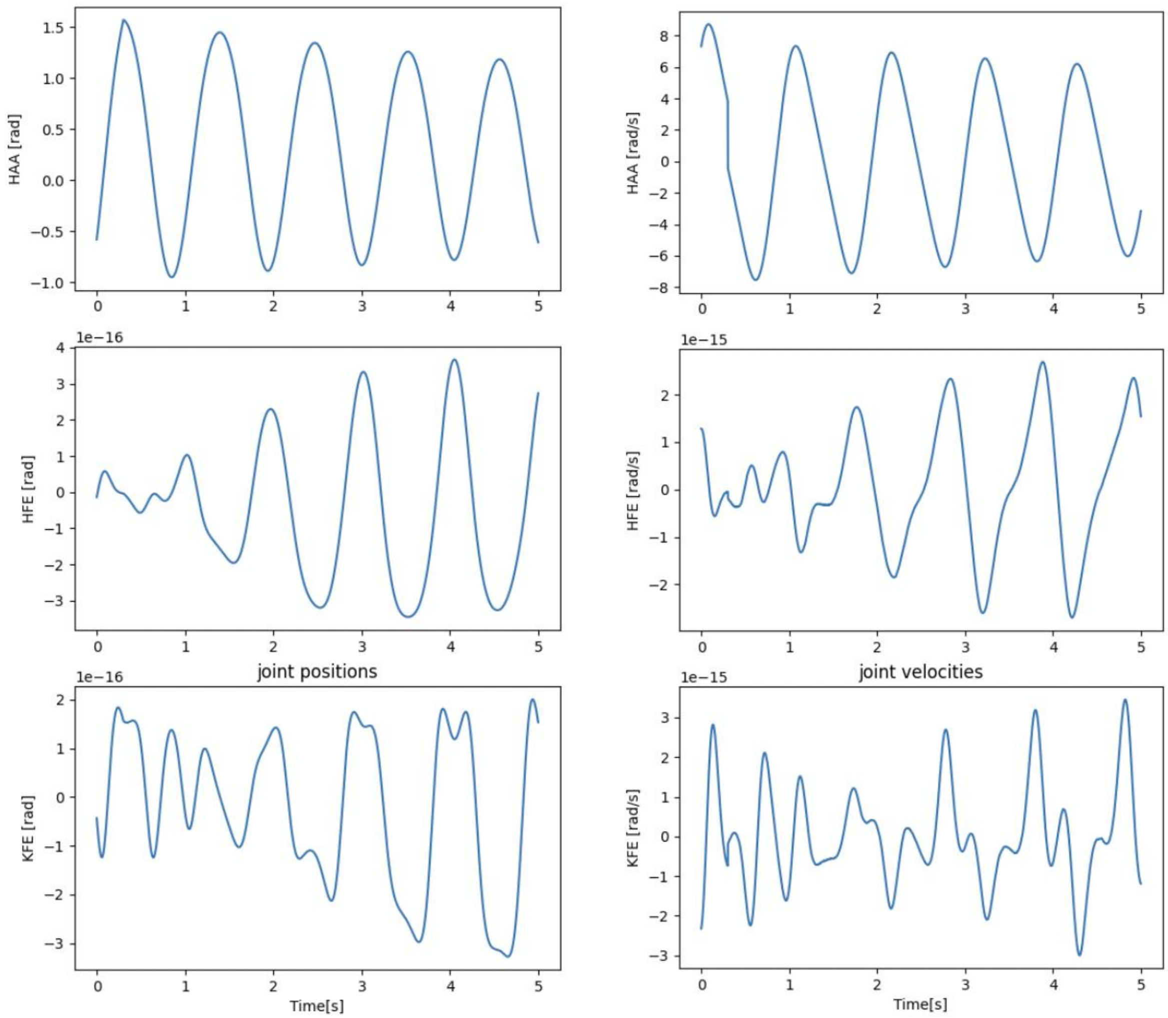

Figure 1: Joint positions and velocities for Sec.1 Q2 from simulation

Q3: Apply a periodic torque of $0.05sin(2\pi t)$ Nm on the first joint. What do you observe? Join a plot of the position and velocity for each joint. (Start from the same initial pose for the robot)

We observe that 1st joint of the robot rotates in a periodic motion. The maximum torque experienced by the robot is 0.05 Nm (amplitude) with a frequency of 1 Hz. The robot keeps oscillating on a constant pattern like in the previous question, the robot swings back and forth in an increasing scale. The robot started at a relatively small angle, and the angle of the swing gradually increases over time. The velocity of the joint during the motion is also sinusoidal. The position and velocity of the other joints will depend on the interactions between the joints and may exhibit some motion in response to the motion of the first joint, although it will likely be smaller in magnitude.

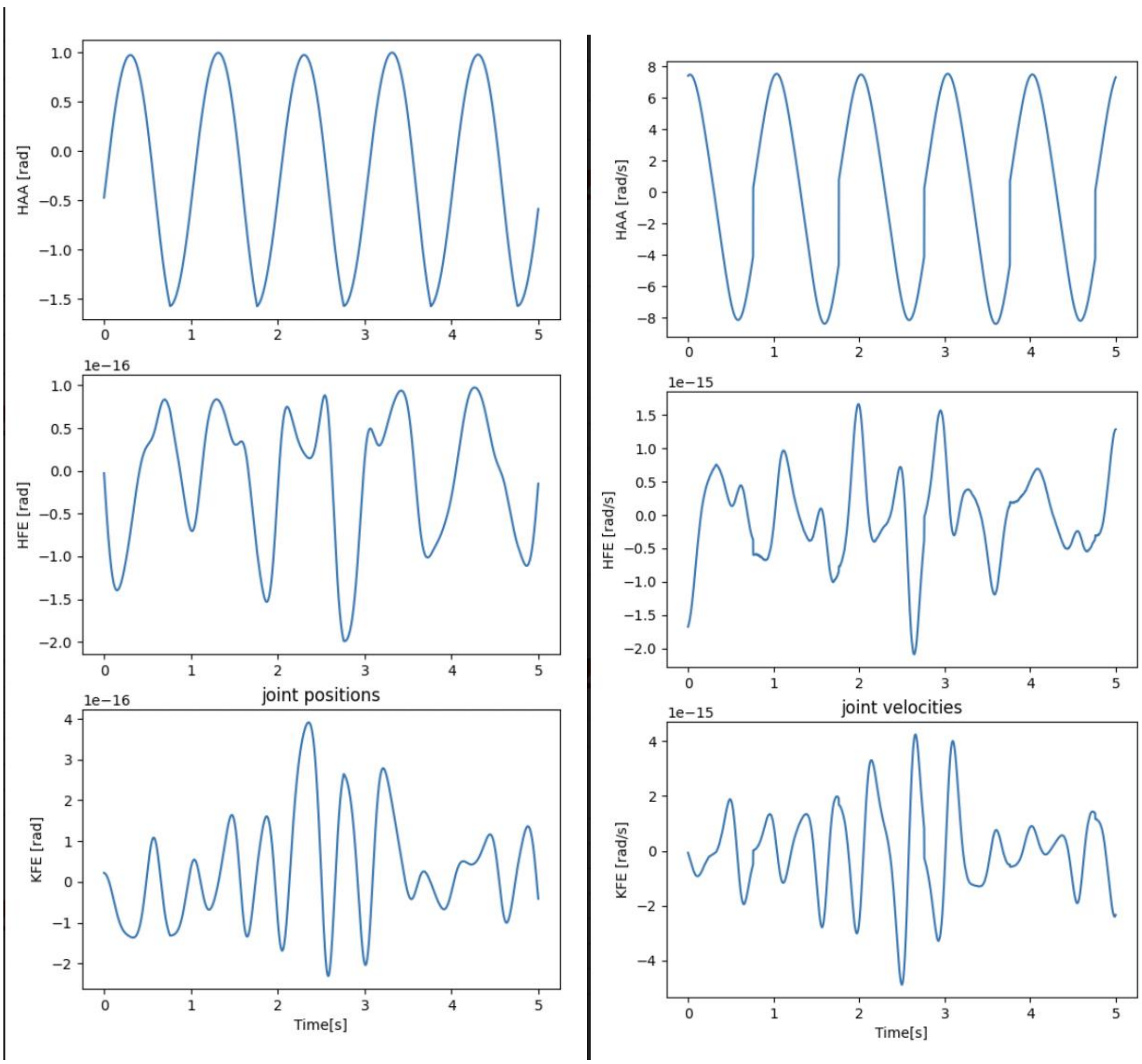

Figure 2: Joint positions and velocities for Sec.1 Q3 from simulation

Q4: Answer 2 and 3 using the real robot - compare with the results in simulation.

ii) When 0.1 Nm torque is applied to the 1st joint along with 0 Nm on others, we observe a small rotational motion in joint 1 that is barely noticeable. The physical explanation is that the torque, a measure of force applied to a body that causes rotational motion, will make the 1st rigid body move and will gradually stop due to frictional forces (air resistance, and joint friction) acting against the robot arm. Comparison: here the torque is very minimal and air resistance and friction between joints is high which is why you see lesser motion than you would with the simulation.

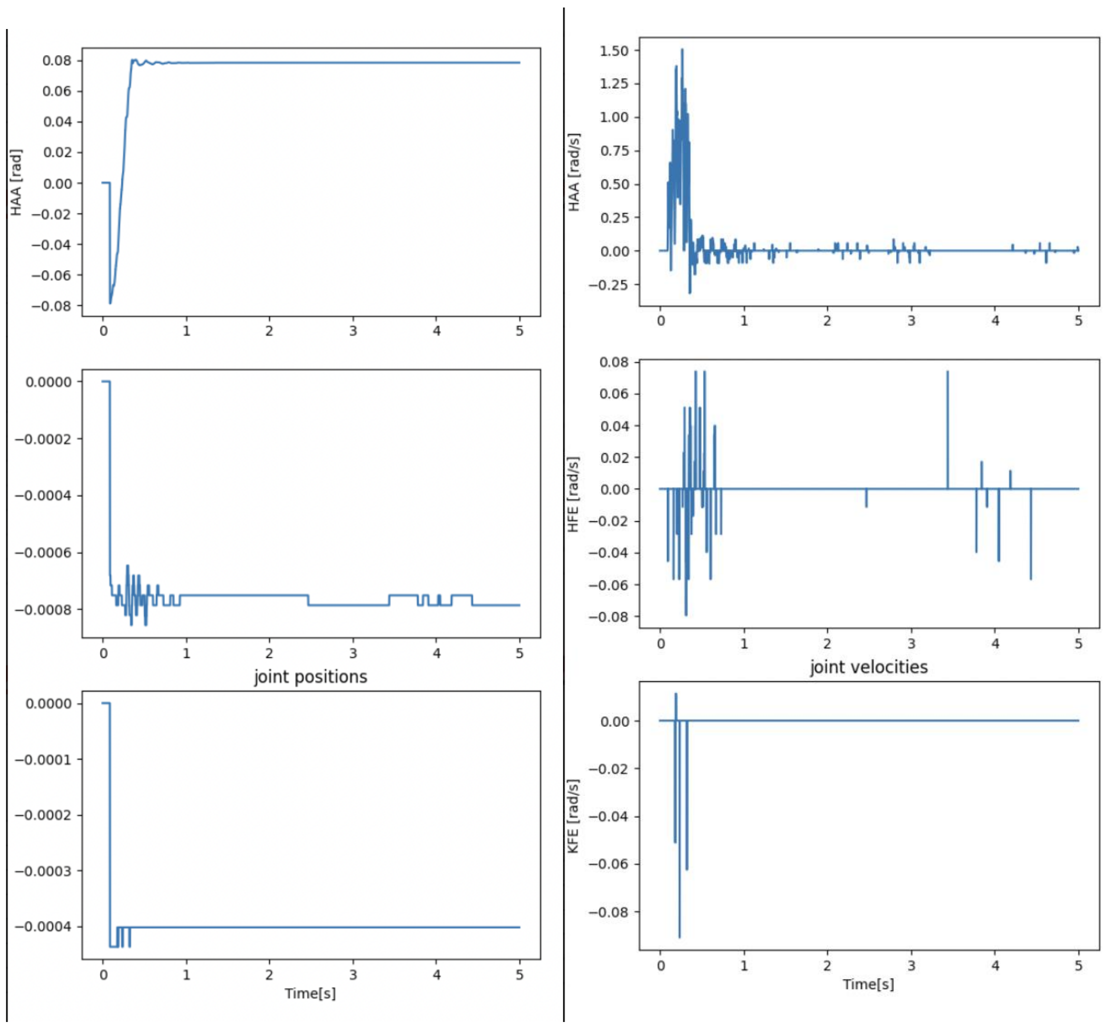

Figure 3: Joint positions and velocities for Sec.1 Q2 from real robot

iii) We observe that 1st joint of the robot rotates in a periodic motion. The maximum torque experienced by the robot is 0.05 Nm (amplitude) with a frequency of 1 second. The robot started at a relatively small angle, and the angle of the swing gradually increases over time. The position and velocity of the other joints will depend on the interactions between the joints and may exhibit some motion in response to the motion of the first joint, although it will likely be smaller in magnitude. But here again, the real counteracting forces of friction (air resistance and friction between joints) are very strong and reduce the effect of the torque on the joint by making the motion barely observable.

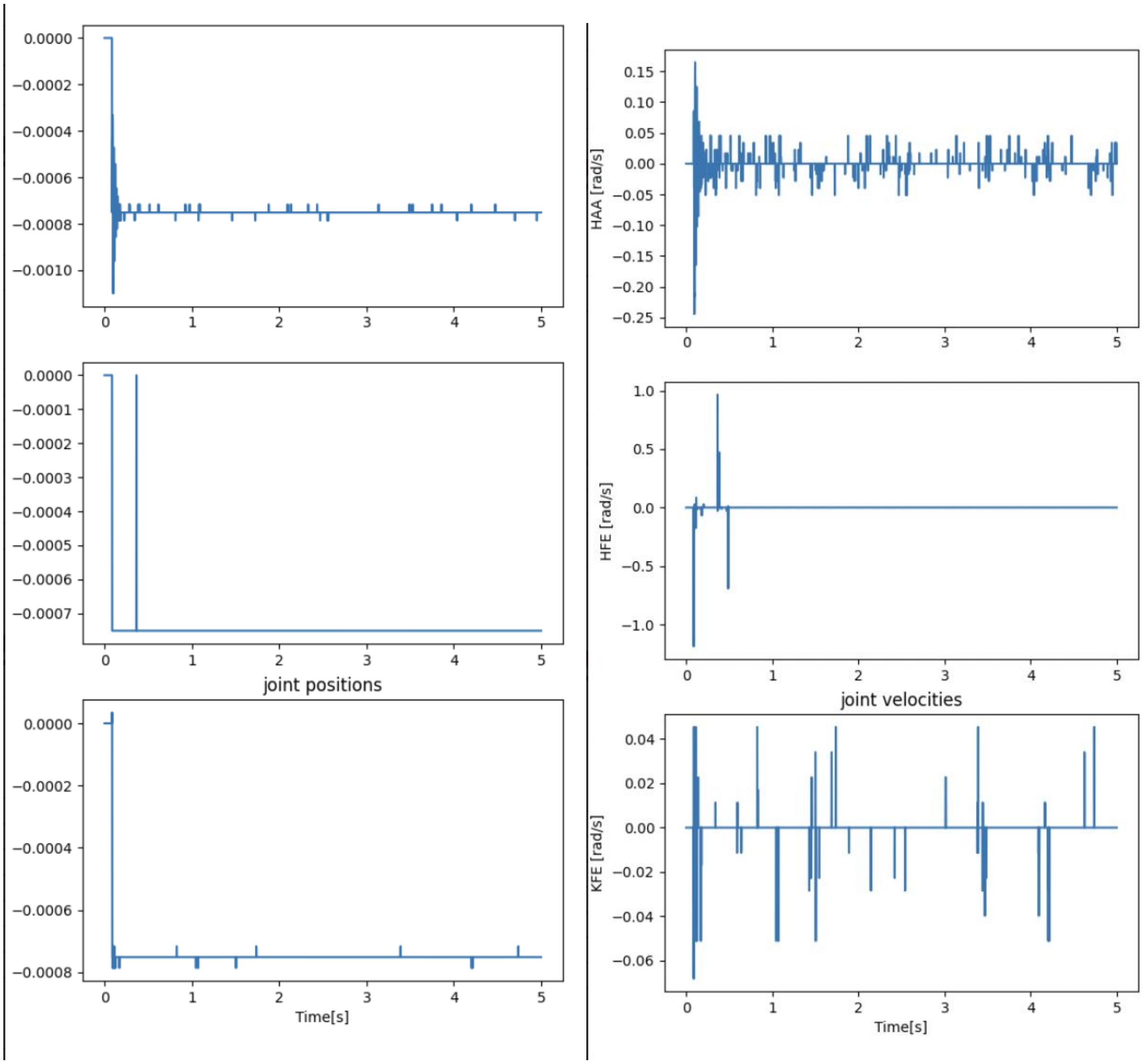

Figure 4: Joint positions and velocities for Sec.1 Q3 from real robot

Section 2: PD Controller

Q1: Describe qualitatively what you observe when you increase/decrease P and D.

When P is increased, the output value of the proportional path increases, and so the output torque increases as well. After increasing P-gain from 1.5 to 4.5, the joint achieves its desired position at a faster rate compared to P-gain at 1.5. Conversely, when P is decreased, the joint takes a longer time to reach the final position. As for D-gain, when it is decreased, the joint accomplishes the desired position at a slower rate and additional oscillations are created. When increased, a lot less oscillations are created, and the joint stabilizes at the final position faster.

Q2: Tune the P and D gains to have a good tracking of the positions $[\mathbf{0}, \mathbf{0}, \frac{\pi}{2}]$ without any oscillations. The P and D gains need not be the same for different joints. What gains did you find? Plot the position and velocities of each joint as a function of time with these gains.

$$P = [1.5, 1.5, 1.5];\ D = [0.1, 0.1, 0.1]$$

The graphs do not have much oscillation which indicates that our P and D values are correct and do not go overboard.

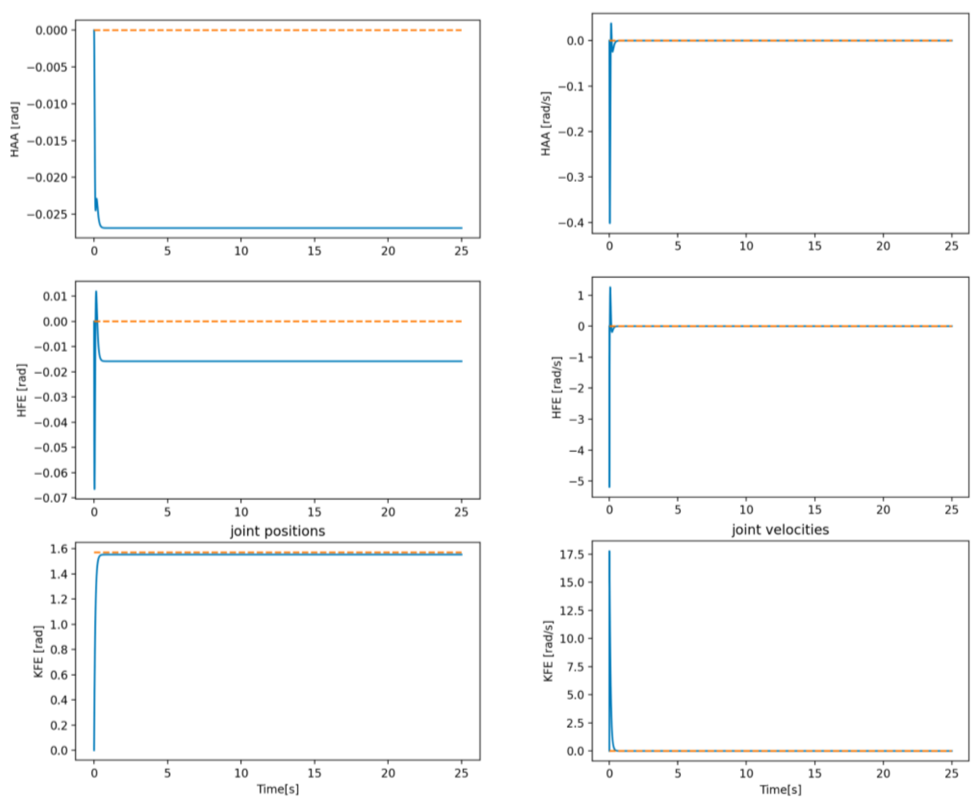

Figure 5: Joint positions and velocities for Sec.2 Q2 from simulation

Q3: Use the PD controller to do the following task: keep the position of the first two joints fixed and follows the following position trajectory for the last joint $\mathbf{0.8}\boldsymbol{sin}(\boldsymbol{\pi t})$. Plot the results (positions and velocities as a function of time for all joints). Simulate for at least 10 seconds.

$$q_{des} = [0, 0, 0.8\sin(\pi t)]$$

$$dq_{des} = [0, 0, 0.8\pi\cos(\pi t)\ ]$$

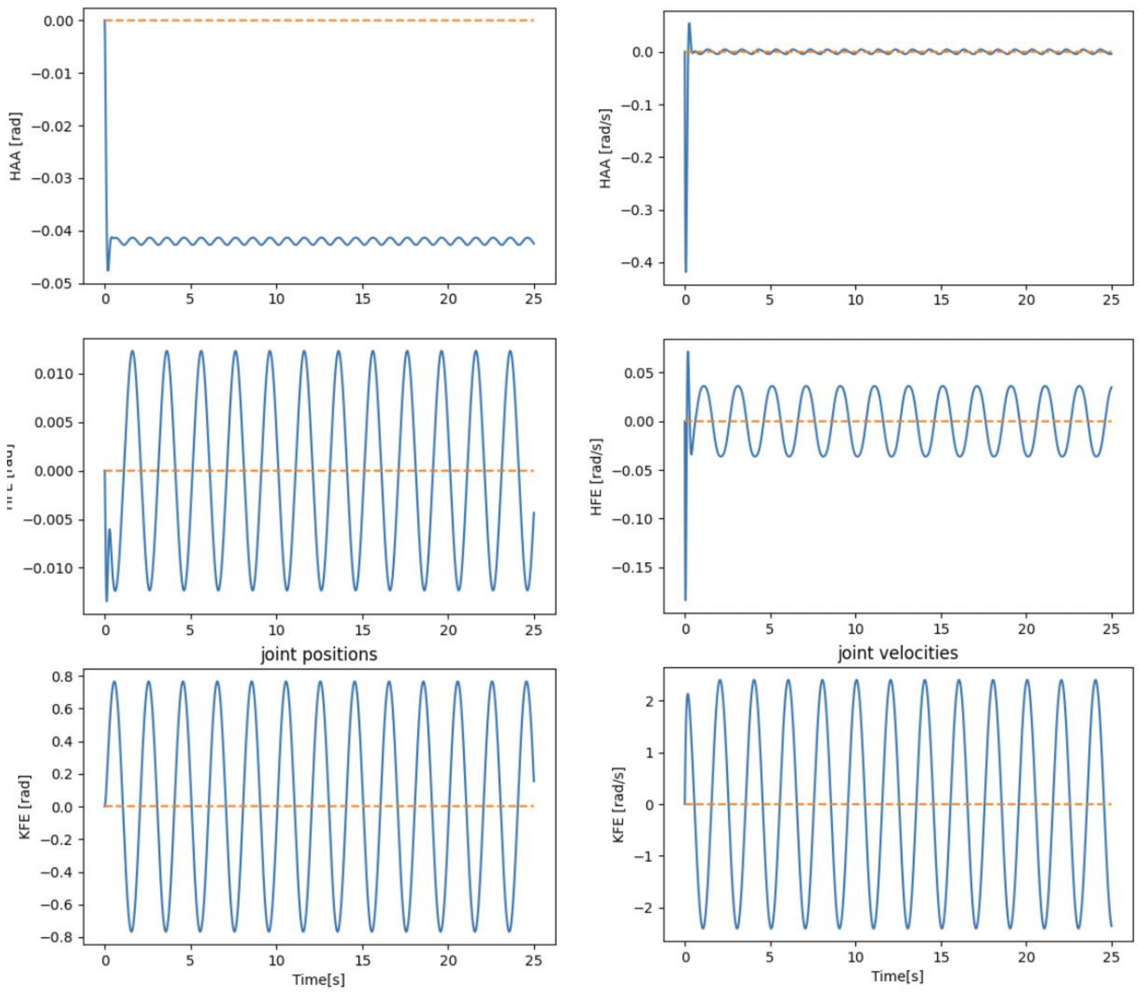

Figure 6: Joint positions and velocities for Sec.2 Q3 from simulation

Q4: Do question 3. on the real robot.

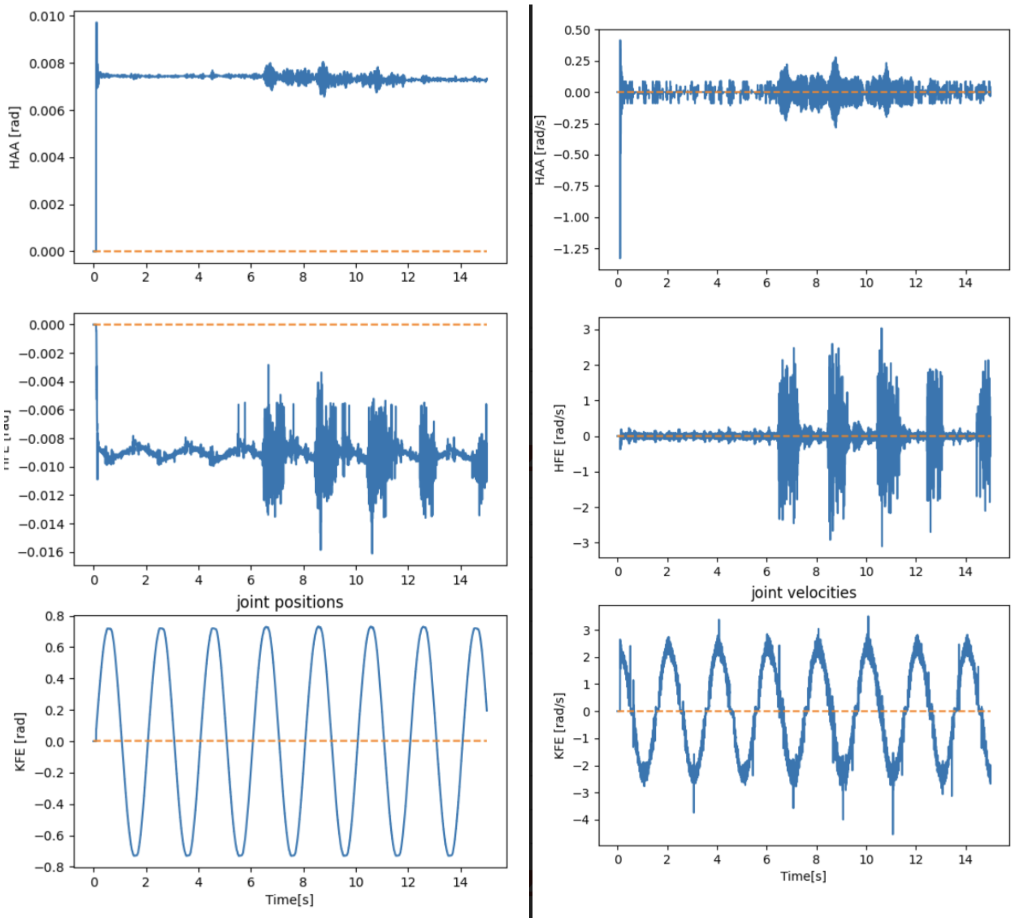

Figure 7: Joint positions and velocities for Sec.2 Q4 from real robot

Q5: Change the joint trajectories to get the robot to draw a circle in the air with its fingertip.

$$q_{des} = [0.15\pi\cos(4t)\,, 0.15\pi\sin(4t), 0\,]$$

$$dq_{des} = [-0.6\pi\sin(4t)\,, 0.6\pi\cos(4t), 0\,]$$

Using a cosine function for the 1st joint's position trajectory and a sine function for the 2nd joint's position trajectory, we were able to make the robot draw a circle horizontal to the ground in the air with its fingertip (using right hand rule axes, a circle in the XY plane). We use the same PD gains, and the line of code are the position trajectories used for each joint in this question. The trajectory was tested in simulation.