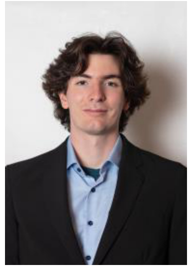
RBE501 Final Presentation, Planar Robot Manipulator

Liam Jennings

Benjamin Laman

Samuel Rooney

Meet the Team

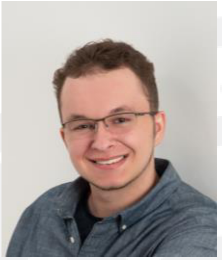


Liam Jennings

CS Undergrad (2025)

Ben Laman

ME Grad (2024)



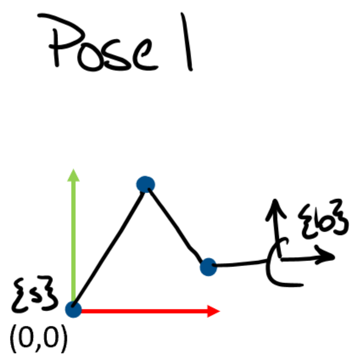
Sam Rooney

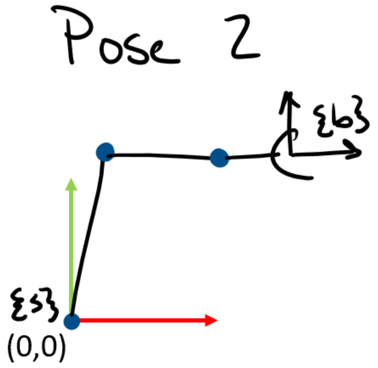
RBE Undergrad (2025)

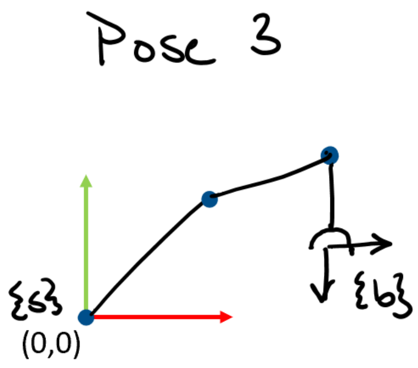
Background

- Design a robot arm that can move a 0.5kg payload between three different know positions in its planar workspace.
- Analysis includes torques, inertia, and trajectories (velocity and acceleration) to reach the positions in a defined amount of time.

Background





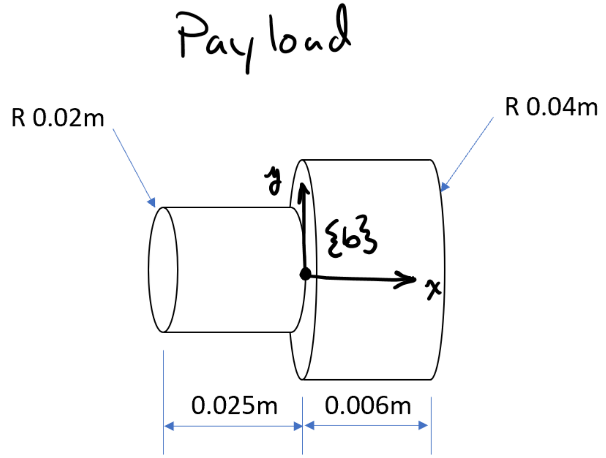


$$T_{sb} = \begin{bmatrix} 1 & 0 & 0 & 0.1 \\ 0 & 1 & 0 & 0.05 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{sb} = \begin{bmatrix} 1 & 0 & 0 & 0.1 \\ 0 & 1 & 0 & 0.1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{sb} = \begin{bmatrix} 0 & 1 & 0 & 0.15 \\ -1 & 0 & 0 & 0.075 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

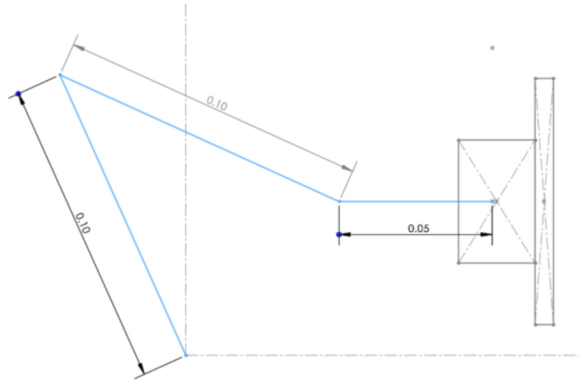
Units are in meters



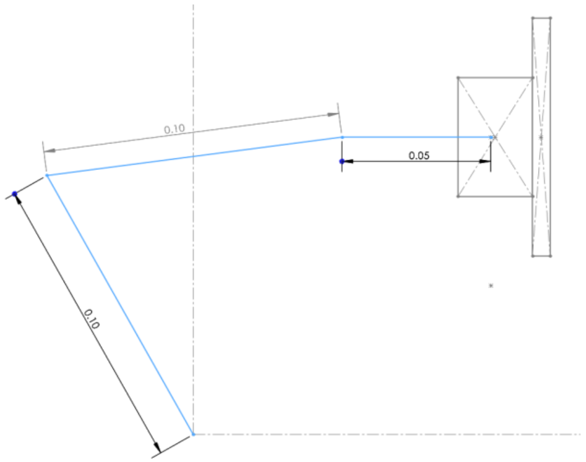
Total mass = 0.5kg
{b} is located at the Center of mass

Kinematic Design & Analysis

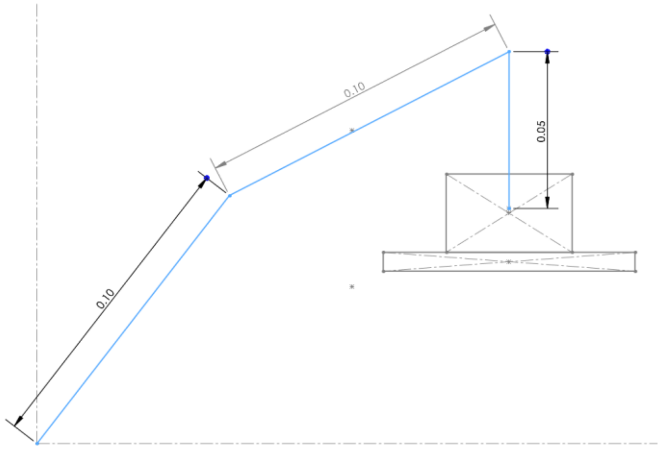
- Planar task space to achieve target poses
- Determine required link lengths using SolidWorks



Pose 1



Pose 2

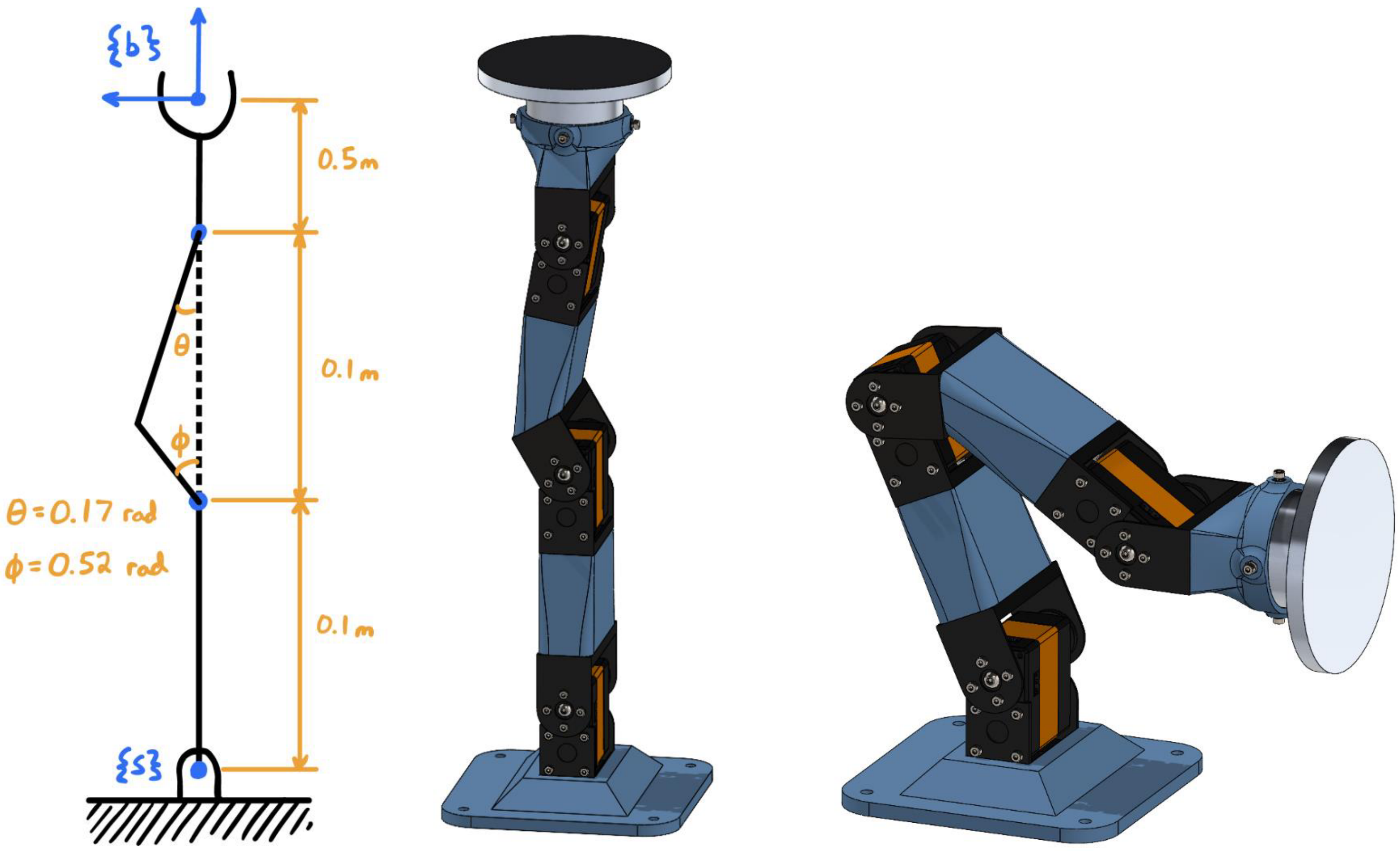


Pose 3

Motor Selection

- Based on the worst-case static model, we initially selected the Hiwonder HTD-45H servo motor
- This gave us a significant safety factor on the torque requirement

Robot Arm CAD Model



A CAD model was created based on our joint parameters and motor selection. Due to some small angles required to certain positions, the second link includes an offset to prevent the arm from colliding with itself. A four-point clamp design was included in the third link to secure the payload.

Kinematic Design & Analysis

- Solve forward kinematics using Product of Exponentials (PoE) formulation
  - Find zero configuration M & screw axes
- Solve inverse kinematics to find necessary joint angles for each pose
  - Calculated geometrically using Law of Cosines and Law of Sines.
  - Two valid solutions
    - "elbow up" and "elbow down configurations
    - "elbow up" positions were chosen for our purposes

Smooth Trajectory Generation

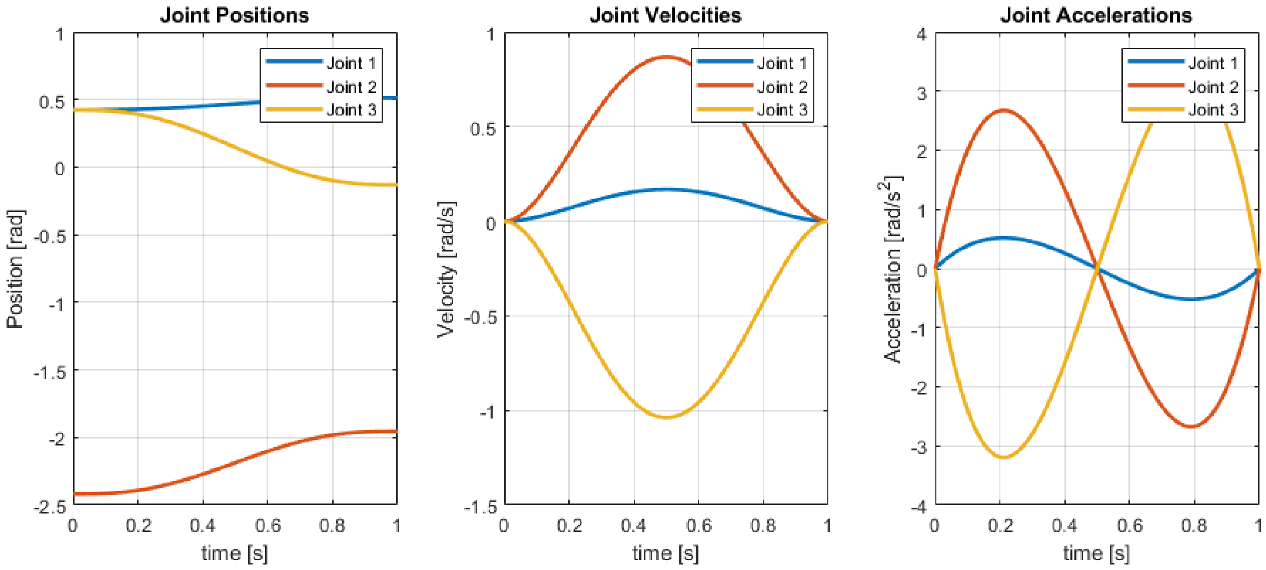
- Trajectories generated using quintic polynomials
- Trajectories generated in joint space

$$\begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 & t_0^4 & t_0^5 \\ 0 & 1 & 2t_0 & 3t_0^2 & 4t_0^3 & 5t_0^4 \\ 0 & 0 & 2 & 6t_0 & 12t_0^2 & 20t_0^3 \\ 1 & t_f & t_f^2 & t_f^3 & t_f^4 & t_f^5 \\ 0 & 1 & 2t_f & 3t_f^2 & 4t_f^3 & 5t_f^4 \\ 0 & 0 & 2 & 6t_f & 12t_f^2 & 20t_f^3 \end{bmatrix} \begin{bmatrix} f \\ e \\ d \\ c \\ b \\ a \end{bmatrix} = \begin{bmatrix} y_0 \\ y_0' \\ y_0'' \\ y_f \\ y_f' \\ y_f'' \end{bmatrix}$$

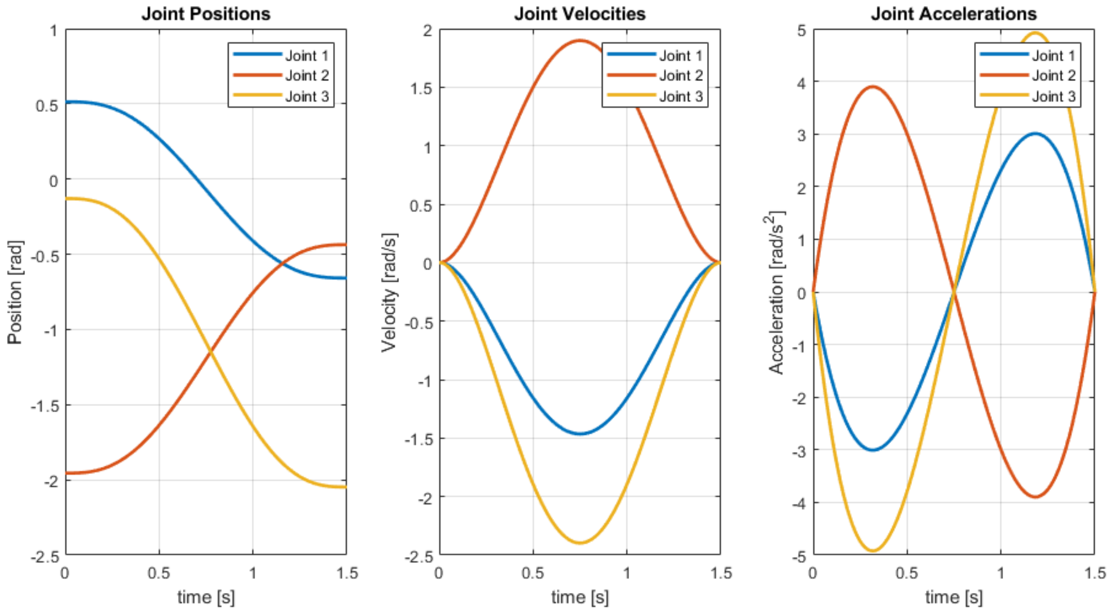
$$TA = Y$$

Smooth Trajectory Generation

Movement 1



Movement 2



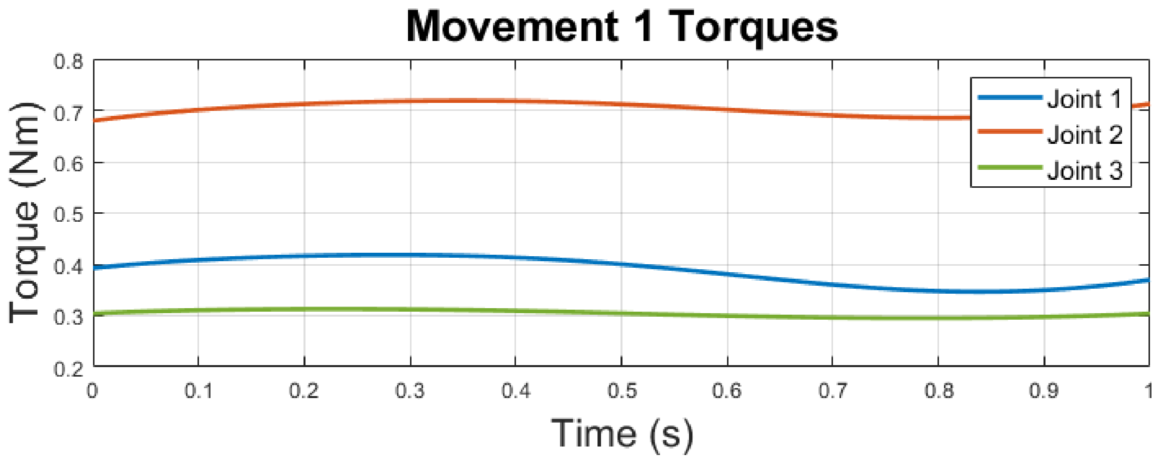
Dynamic Analysis / Smooth Trajectories

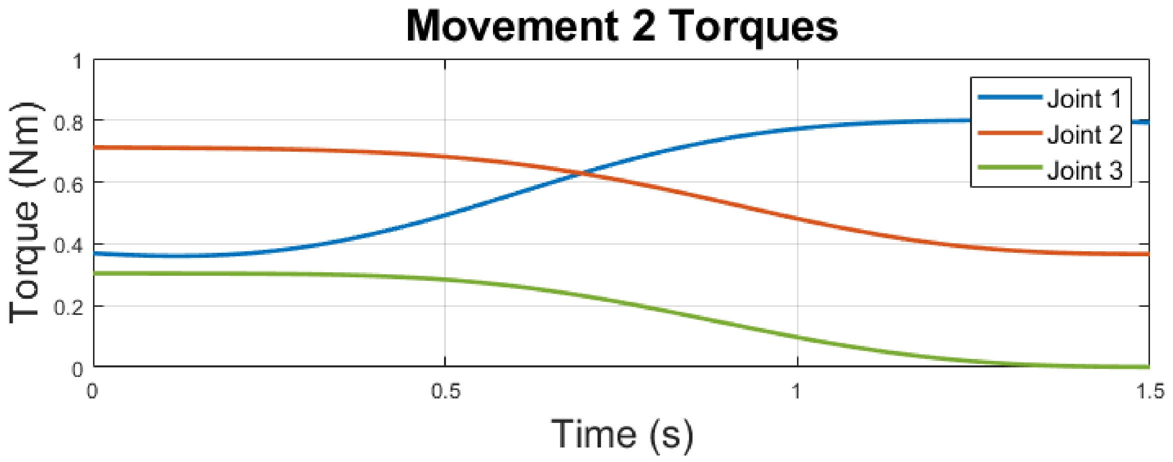
Max. Torque: 0.8 N*m

Max. Velocity: 2.4 rad/s

Max. Accel.: 4.9 rad/s/s

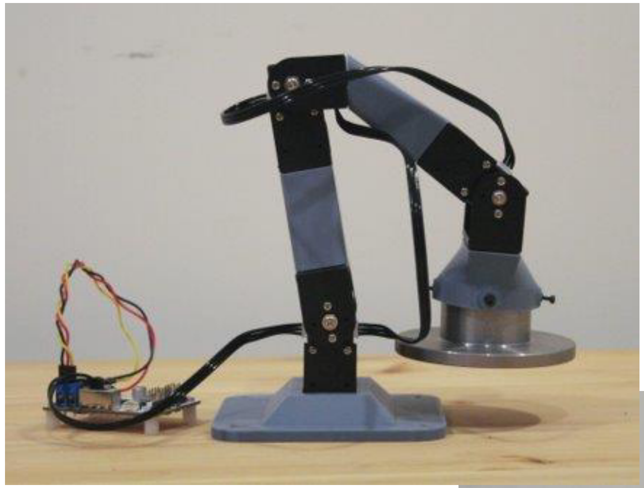
Essentially all medium-torque hobby-grade servos meet these requirements; our Hiwonder HTD-45H motors are cost effective while meeting the specification.





Physical System

- 3D printed PLA base, links, and end effector.
- Mild steel machined payload weighing 0.48kg
- Hiwonder HTD-45H motors



Conclusions

Our robot arm design meets or exceeds all assignment specifications.

https://thesamrooney.com/post/rbe501/