

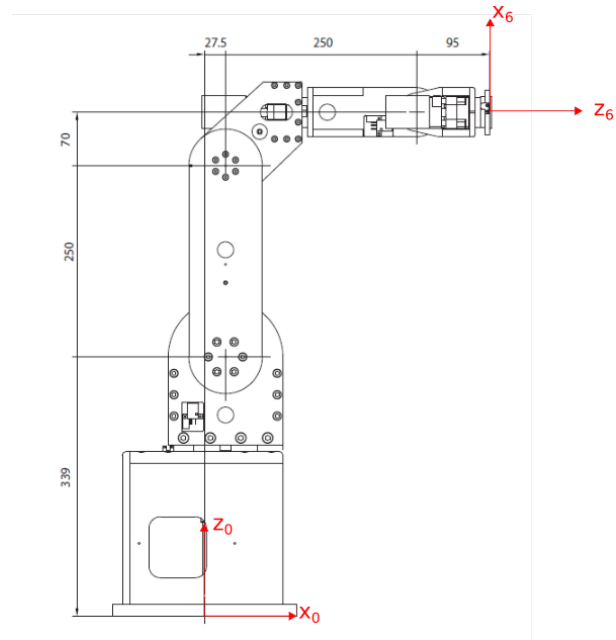
ME 4/567 – ECE 564: Robotics and Automated Systems Spring 2025 — Project III: Robot-Arm Kinematics

In this project, we will solve the position and velocity level forward kinematics of the NeX-CoM 6-DoF miniBoT and optionally verify that our solution matches with the output of its implementation in MuJoCo.

Question 1 60 (main) + 0 (bonus) points

The figure on the right is a depiction of miniBOT6-R robot. Use the Denavit-Hartenberg (DH) convention to assign frames on each link. Furthermore, fill in the table on the left with DH parameters. A skeleton diagram of the robot is provided in Figure 1.

	α	a	d	θ
1				
2				
3				
4				
5				
6				



- (a) [30 points] Solve the position-level forward kinematics problem. Use this solution to find the end-effector pose ξ given that the joint angles are

$$\theta = \begin{bmatrix} 0^\circ & 90^\circ & 0^\circ & 0^\circ & -90^\circ & 0^\circ \end{bmatrix}.$$

Your end-effector ξ should be given by a 6-vector, the first three components of which are the components of the translation vector from the base to the origin of the end-effector expressed in the base frame, and the last three of which are the EulerZYX angles of the end-effector frame with respect to the base frame.

- (b) [30 points] Solve the position-level inverse kinematics of the problem in closed-form. Use this solution to find the joint angles whenever the end-effector pose is given by $\xi = (\mathbf{R}, \mathbf{t})$, where

$$\mathbf{R} = \begin{bmatrix} 0.7551 & 0.4013 & 0.5184 \\ 0.6084 & -0.7235 & -0.3262 \\ 0.2441 & 0.5617 & -0.7905 \end{bmatrix}, \quad \mathbf{t} = \begin{bmatrix} 399.1255 \\ 171.01529 \\ 416.0308 \end{bmatrix}$$

Question 2 40 (main) + 0 (bonus) points

Compute the kinematic Jacobian for this manipulator that relates the joint angle rates to the end-effector spatial twist in closed-form. This expression can be performed without choosing a frame, as discussed in class.

Implement your Jacobian matrix in Python and solve for the joint angle rates needed to produce an end-effector spatial twist of

$$\boldsymbol{\nu} = \begin{pmatrix} \boldsymbol{\omega} & \mathbf{v} \end{pmatrix}^\top = \begin{pmatrix} 2 & -1 & 0.5 & 10 & -20 & -30 \end{pmatrix}^\top$$

whenever the manipulator is at a configuration given in question 1b.

Question 3 20 (bonus) points

Implement the miniBoT6-R in MuJoCo by imitating this example: [\[link\]](#), that performs a similar construction for a different robot arm, the Franka arm. You will have to replace the `xml` corresponding to the Franka arm with the one you will produce of the miniBoT6-R. You may have to convert rotation matrices to quaternions as needed as you proceed through the example.

Verify your solutions from questions 1 and 2 using functionality provided by MuJoCo, as done in the tutorial provided above.

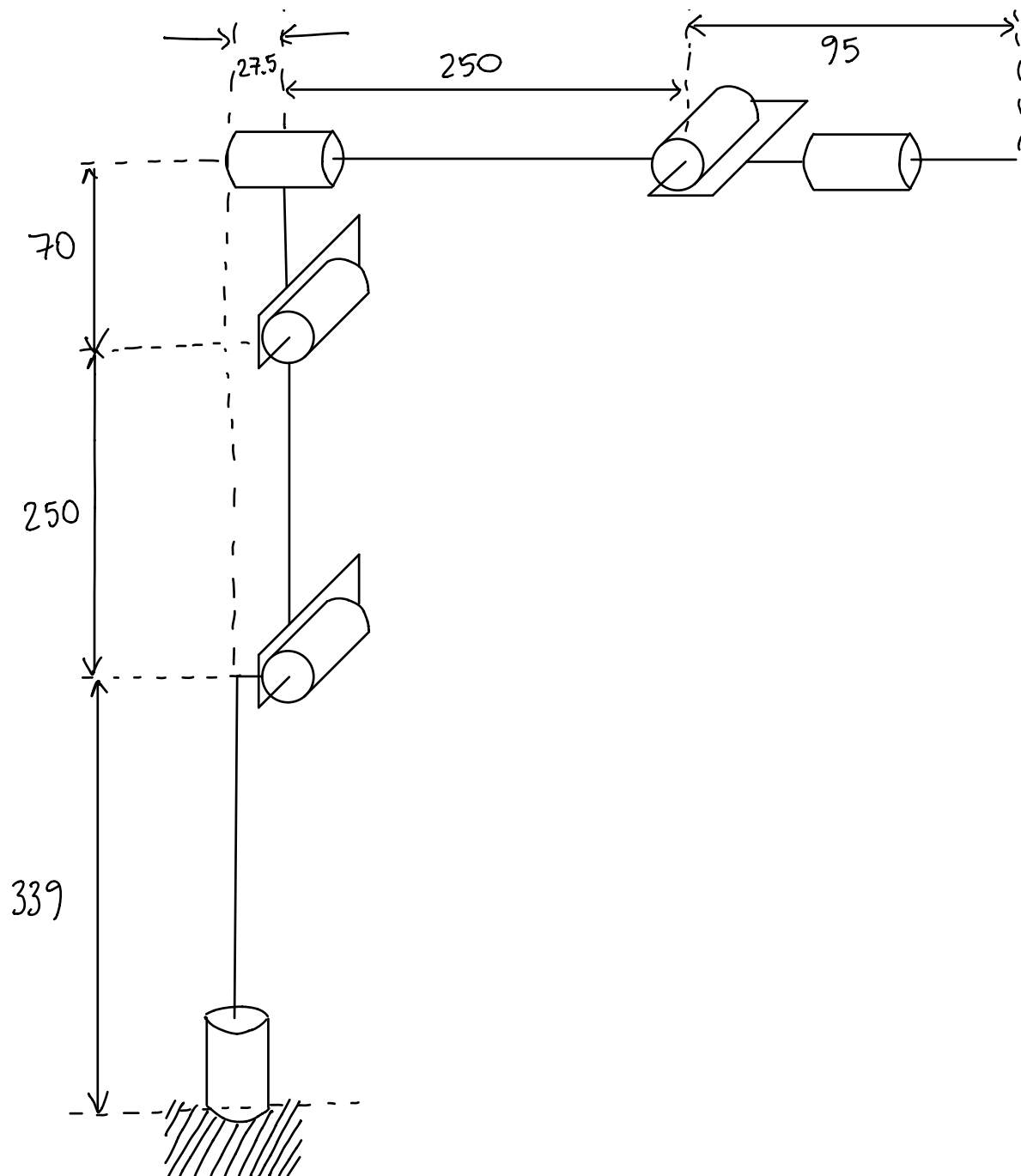


Figure 1: Skeleton diagram of the NeXCoM miniBOT-6