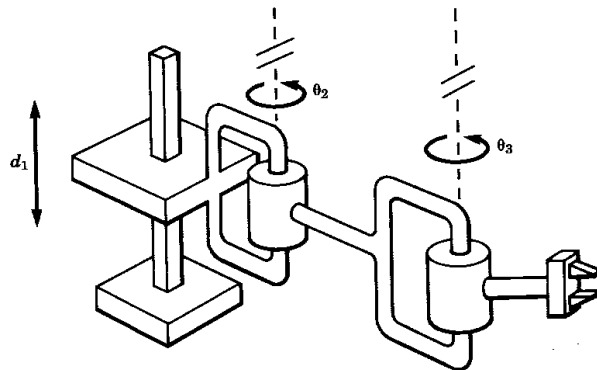


Some tips for doing CS223A problem sets:

- Use abbreviations for trigonometric functions (e.g., $c\theta$ for $\cos(\theta)$, s_1 or $s\theta_1$ for $\sin(\theta_1)$) in situations where it would be tedious to repeatedly write sin, cos, etc.
- Unless instructed otherwise, leave square roots in symbolic form rather than writing out their decimal values.
- Use common sense for decimals — if the question states $a = 1.34$, then don't give answers like $2*a = 2.680001245735$.
- If you give a vector as an answer, make sure that you specify what frame it is given in (if it is not clear from context). The same rule applies to rotation and transformation matrices.

1. [25 marks]

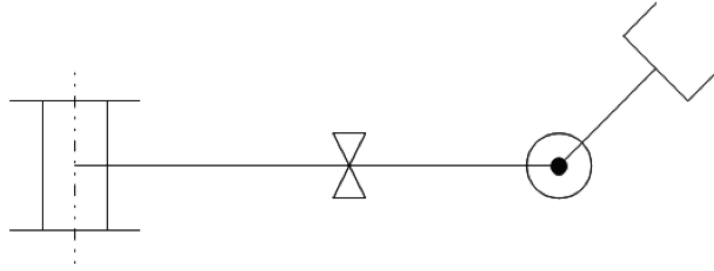
Consider the following PRR manipulator.



- Draw a schematic of this manipulator, with the axes of frames $\{0\}$ through $\{3\}$ labeled. Also, include the parameters d_1 , a_1 , θ_2 , a_2 and θ_3 on your schematic. Assume that this diagram shows a configuration where $\theta_2 = \theta_3 = 0$. For the case when \hat{Z}_i and \hat{Z}_{i+1} axes are intersecting, take the perpendicular to both in the point of intersection and assign \hat{X}_i along it in such a direction that the angle α_i from axis i to axis $i + 1$ is measured in a positive sense.
- Find the Denavit-Hartenberg parameters for this manipulator — that is, fill in the entries for the following table:

i	a_{i-1}	α_{i-1}	d_i	θ_i
1				
2				
3				

- Derive the forward kinematics for this manipulator — that is, find the matrix 0_3T .



2. [25 marks]

Consider the following RPR manipulator.

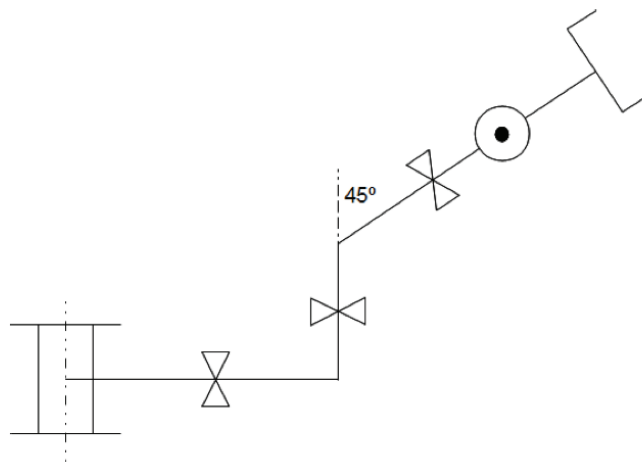
- Assign and label the axes of frames $\{0\}$ through $\{3\}$. Also, include the parameters θ_1 , d_2 , and θ_3 on your schematic. Assume that this diagram shows a configuration where $\theta_1 = 0$. For the case when \hat{Z}_i and \hat{Z}_{i+1} axes are intersecting, take the perpendicular to both in the point of intersection and assign \hat{X}_i along it in such a direction that the angle α_i from axis i to axis $i + 1$ is measured in a positive sense.
- Find the Denavit-Hartenberg parameters for this manipulator — that is, fill in the entries for the following table:

i	a_{i-1}	α_{i-1}	d_i	θ_i
1				
2				
3				

- Derive the forward kinematics for this manipulator — that is, find the matrix 0_3T .

3. [30 marks]

Consider the 5-DOF manipulator.



- Assign link frames $\{0\}$ through $\{5\}$. For the case when \hat{Z}_i and \hat{Z}_{i+1} axes are intersecting, take the perpendicular to both in the point of intersection and assign \hat{X}_i along it in such a direction that the angle α_i from axis i to axis $i + 1$ is measured in a positive sense. Also, remember to follow the conventions for the first and last link, as described in the course reader.

(b) Find the Denavit-Hartenberg parameters for this manipulator.

i	a_{i-1}	α_{i-1}	d_i	θ_i
1				
2				
3				
4				
5				

(c) Find the link transformation matrices ${}^0T_1, {}^1T_2, {}^2T_3, {}^3T_4, {}^4T_5$.

4. [15 marks] You may have noticed that the D-H parameters $\{a, \alpha, d, \theta\}$ and (Eqn 2.7) cannot be used to define an arbitrary rigid body transformation.

- Explain why, referring to degrees of freedom or other physical arguments.
- Label the unit vectors of the two bases below such that D-H parameters cannot describe the transformation. (Hint: Look at the structure of Equation 2.7). Write the transformation matrix that relates your frames.

