Exercise 1

Consider the three degree-of-freedom PPR robot with two prismatic joints q_1 and q_2, and a revolute joint q_3, shown in Fig. 1.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 1.1 b).

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 1.1 as black and white circles. [1p]

2. Using the previously defined coordinate frames and the lengths shown in the Fig. 1.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]

3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^3$, respectively. [1p]

4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, and the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$ relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 1.1. [1p]

5. Finally, compute the Jacobian matrices for the end-effector $\mathbf{J}_{\mathrm{ef}}^0(\mathbf{q})$ and for each c.m. $\mathbf{J}_{\mathrm{cm_i}}^0(\mathbf{q})$ relative to the robot base (link 0). The end-effector pose (6D) is shown in the Fig. 1.1 with the coordinate frame $\mathbf{O}_{\mathrm{ef}}$. [1p]

The blue arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.a.

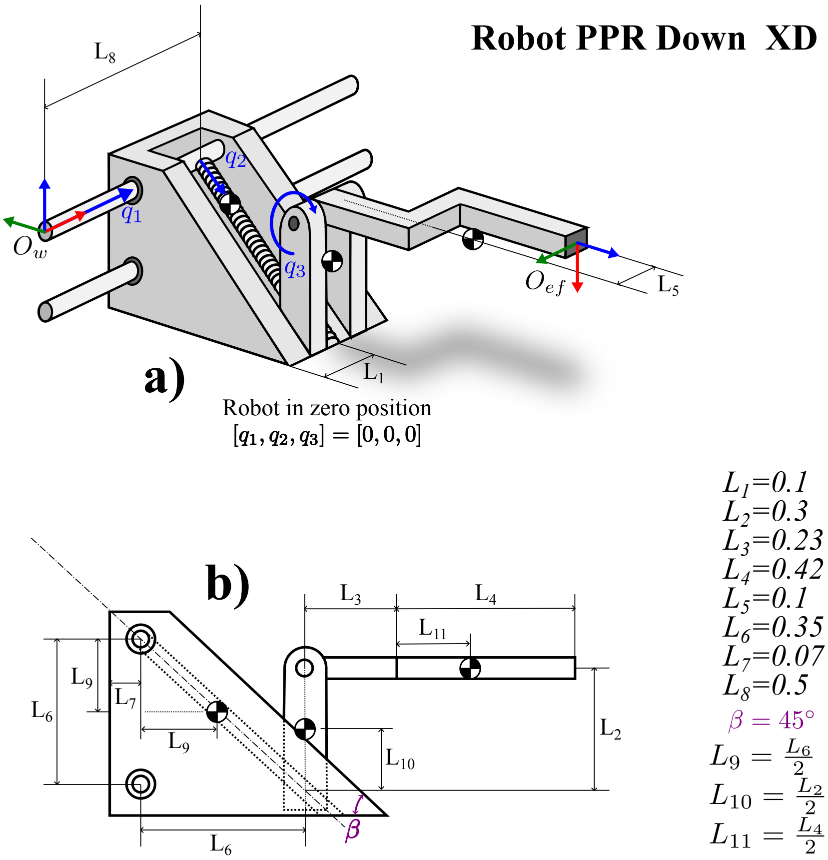


Figure 1.1

Exercise 2

Consider the four degrees-of-freedom RPPR robot composed of an initial revolute joint q_1, followed by two prismatic joints q_2 and q_3, an ending with a revolute joint q_4, shown in Fig. 2.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 2.1 i). For this exercise, you will assume that one of the joints is broken and no longer moves. In this case, the movable joints are q_1, q_2, and q_3. Note that q_4 must be considered fixed in the zero position $q_4 = 0 \forall t$. This condition makes the robot a 3DOF robot (RPP). Consider the origin of the end-effector frame O_{ef} to be located at cm_4 but disregard cm_4.

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 2.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 2.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i}-1}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i}-1}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$, and each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 2.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\left(\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})\right)$ and for each c.m. $\left(\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})\right)$ relative to the robot base (link 0). [1p]

The purple arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.b.

$[mm]$
$L_1 = 300$
$L_2 = 340$
$L_3 = 583$
$L_4 = 80$
$L_5 = 80$
$L_6 = 115$
$L_7 = 82$
$L_8 = 108$
$L_9 = 123$
$L_{10} = 167$
$L_{11} = 28$
$L_{12} = 50$
$c = d = 320$
$\theta_1 = 45°$
$\theta_2 = 30°$

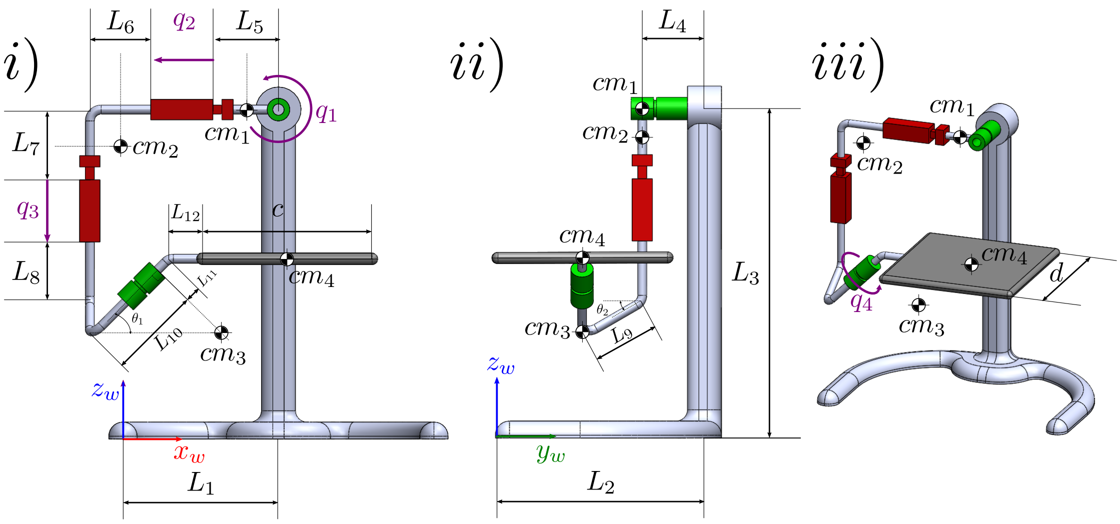


Figure 2.1: 3DOF robot (RPP). The movable joints are q_1, q_2, and q_3.

Exercise 3 Consider the three degree-of-freedom PRP robot with one initial prismatic joint q_1, followed by a revolute joint q_2, and a prismatic joint q_3 at the end, shown in Fig. 3.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 3.1.

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 3.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 3.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, and the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$ relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 3.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})$ and for each c.m. $\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})$ relative to the robot base (link 0). The end-effector pose (6D) is shown in the Fig. 3.1 with the coordinate frame $\mathbf{O}_{\mathrm{ef}}$. [1p]

The blue arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.c.

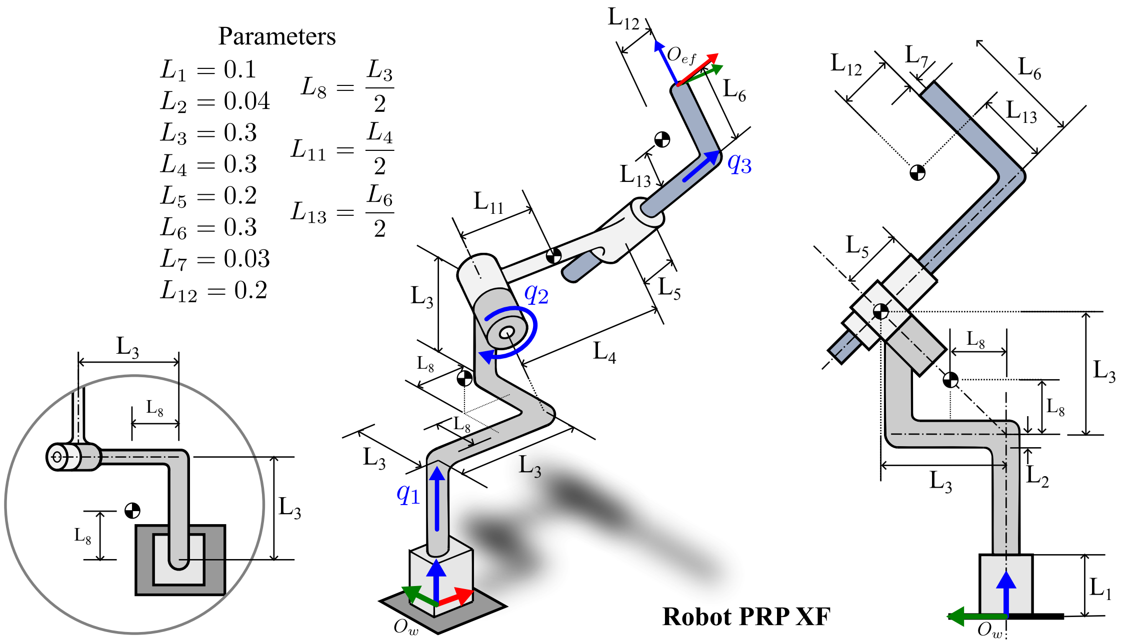


Figure 3.1

Exercise 4

Consider the four degrees-of-freedom RPPR robot composed of an initial revolute joint q_1, followed by two prismatic joints q_2 and q_3, an ending with a revolute joint q_4, shown in Fig. 4.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 4.1 i). For this exercise, you will assume that one of the joints is broken and no longer moves. In this case, the movable joints are q_1, q_2, and q_4. Note that q_3 must be considered fixed in the zero position $q_3 = 0 \forall t$. This condition makes the robot a 3DOF robot (RPR). Consider the origin of the end-effector frame O_{ef} to be located at cm_4 and disregard cm_3.

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 4.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 4.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$, and each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 4.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\left(\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})\right)$ and for each c.m. $\left(\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})\right)$ relative to the robot base (link 0). [1p]

The purple arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.b.

$[mm]$
$L_1 = 300$
$L_2 = 340$
$L_3 = 583$
$L_4 = 80$
$L_5 = 80$
$L_6 = 115$
$L_7 = 82$
$L_8 = 108$
$L_9 = 123$
$L_{10} = 167$
$L_{11} = 28$
$L_{12} = 50$
$c = d = 320$
$\theta_1 = 45°$
$\theta_2 = 30°$

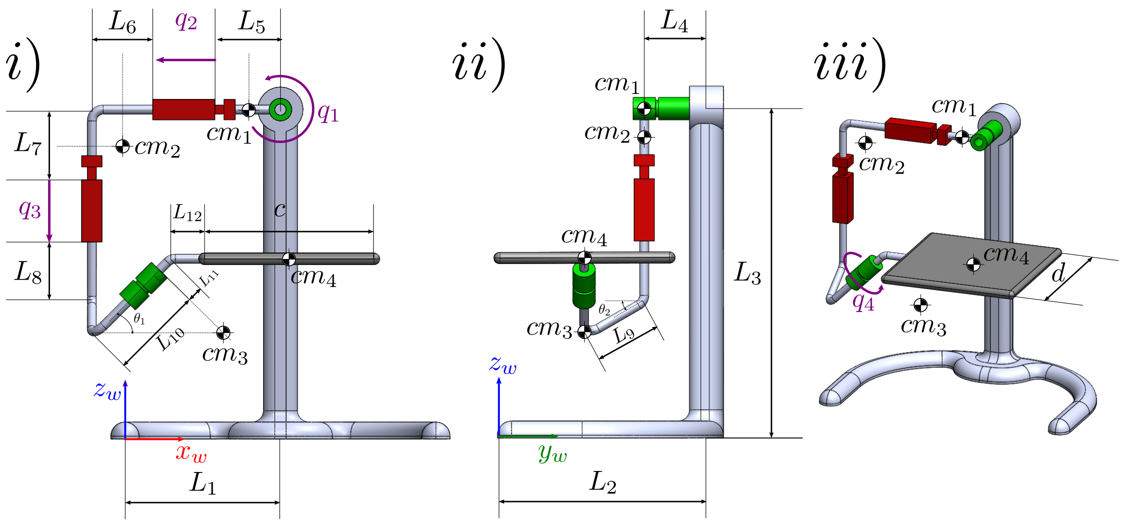


Figure 4.1: 3DOF robot (RPR). The movable joints are q_1, q_2, and q_4.

Exercise 5

Consider the three degree-of-freedom PPR robot with two prismatic joints q_1 and q_2, and a revolute joint q_3, shown in Fig. 5.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 5.1 b).

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 5.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 5.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_{0}^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, and the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$ relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 5.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})$ and for each c.m. $\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})$ relative to the robot base (link 0). The end-effector pose (6D) is shown in the Fig. 5.1 with the coordinate frame $\mathbf{O}_{\mathrm{ef}}$. [1p]

The blue arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.d.

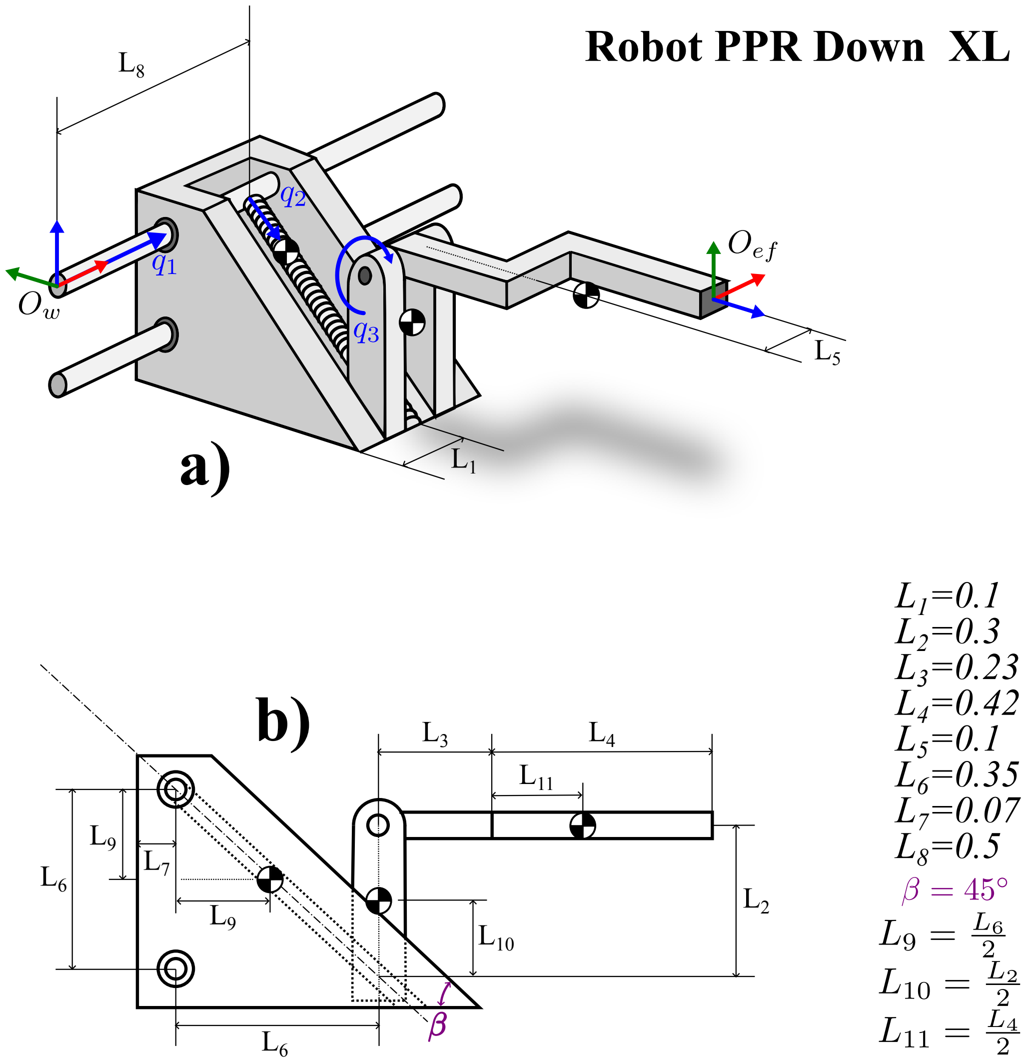


Figure 5.1

Exercise 6

Consider the four degrees-of-freedom RPPR robot composed of an initial revolute joint q_1, followed by two prismatic joints q_2 and q_3, an ending with a revolute joint q_4, shown in Fig. 6.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 6.1 i). For this exercise, you will assume that one of the joints is broken and no longer moves. In this case, the movable joints are q_1, q_3, and q_4. Note that q_2 must be considered fixed in the zero position $q_2 = 0 \forall t$. This condition makes the robot a 3DOF robot (RPR). Consider the origin of the end-effector frame O_{ef} to be located at cm_4 and disregard cm_2.

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 6.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 6.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$, and each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 6.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\left(\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})\right)$ and for each c.m. $\left(\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})\right)$ relative to the robot base (link 0). [1p]

The purple arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.b.

$[mm]$
$L_1 = 300$
$L_2 = 340$
$L_3 = 583$
$L_4 = 80$
$L_5 = 80$
$L_6 = 115$
$L_7 = 82$
$L_8 = 108$
$L_9 = 123$
$L_{10} = 167$
$L_{11} = 28$
$L_{12} = 50$
$c = d = 320$
$\theta_1 = 45°$
$\theta_2 = 30°$

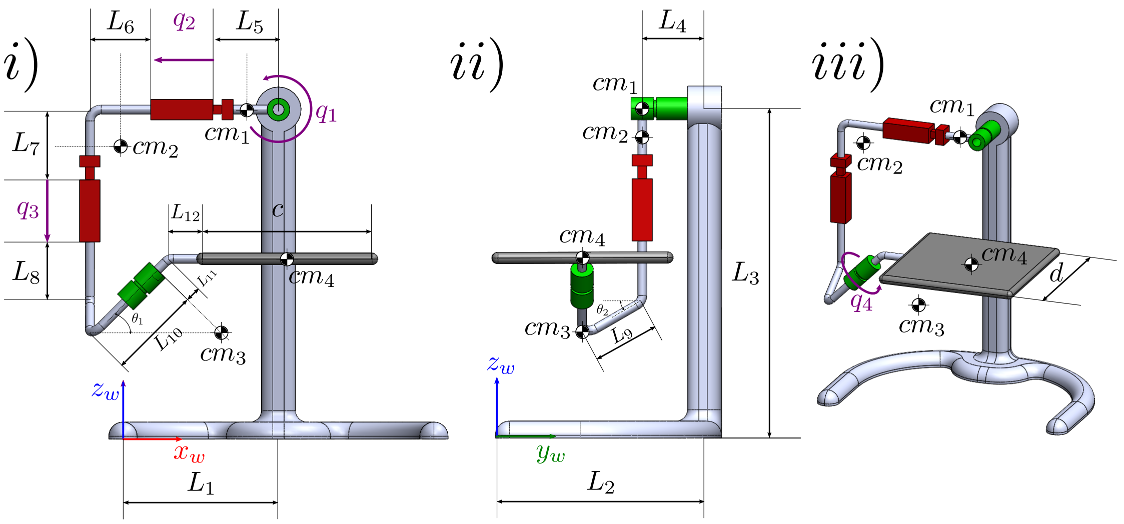


Figure 6.1: 3DOF robot (RPR). The movable joints are q_1, q_3, and q_4.

Exercise 7

Consider the three degree-of-freedom PPR robot with two prismatic joints q_1 and q_2, and a revolute joint q_3, shown in Fig. 7.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 7.1 b)-c).

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 7.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 7.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i}-1}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i}-1}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_{0}^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, and the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$ relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 7.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})$ and for each c.m. $\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})$ relative to the robot base (link 0). The end-effector pose (6D) is shown in the Fig. 7.1 with the coordinate frame $\mathbf{O}_{\mathrm{ef}}$. [1p]

The blue arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.e.

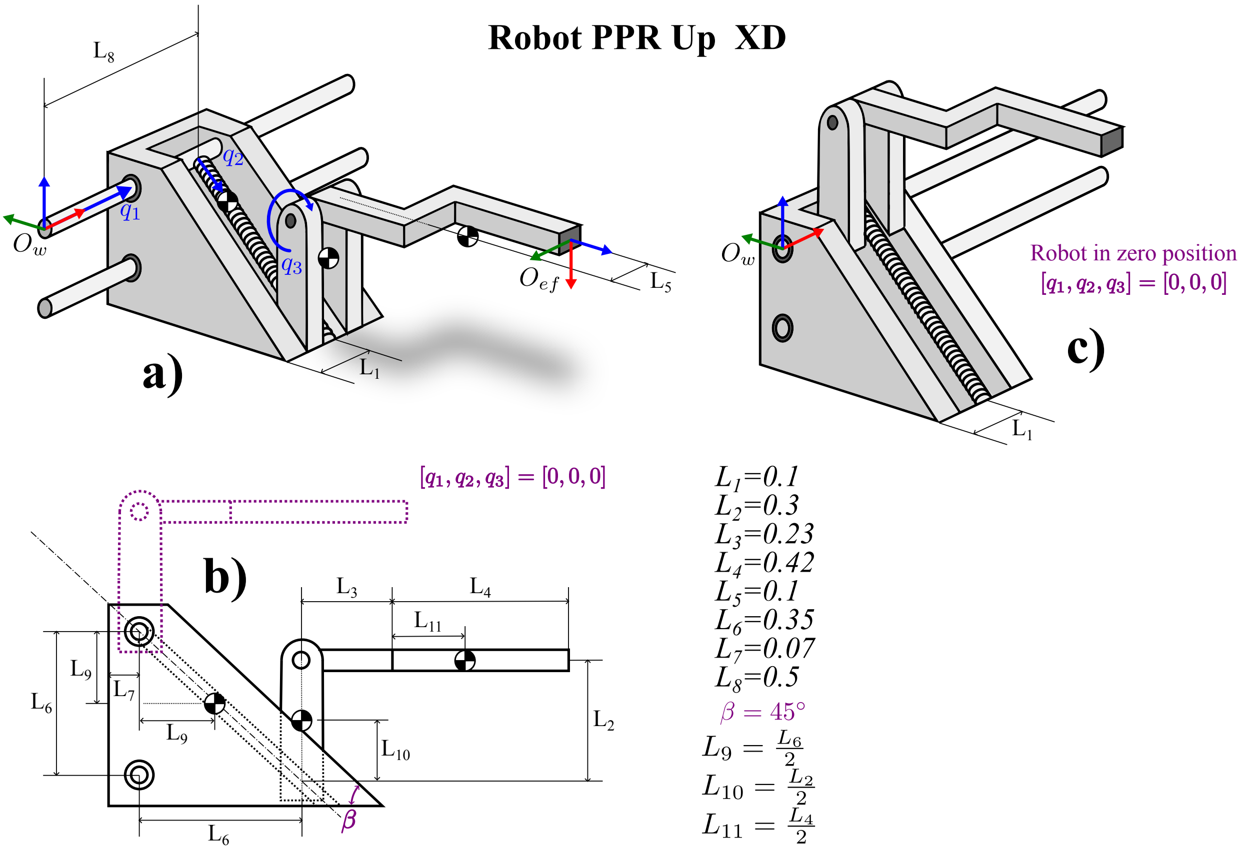


Figure 7.1

Exercise 8 Consider the four degrees-of-freedom RPPR robot composed of an initial revolute joint q_1, followed by two prismatic joints q_2 and q_3, an ending with a revolute joint q_4, shown in Fig. 8.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 8.1 i). For this exercise, you will assume that one of the joints is broken and no longer moves. In this case, the movable joints are q_2, q_3, and q_4. Note that q_1 must be considered fixed in the zero position $q_1 = 0 \forall t$. This condition makes the robot a 3DOF robot (PPR). Consider the origin of the end-effector frame O_{ef} to be located at cm_4 and disregard cm_1.

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 8.1 as black and white circles. [1p]

2. Using the previously defined coordinate frames and the lengths shown in the Fig. 8.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]

3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i}-1}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i}-1}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]

4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$, and each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 8.1. [1p]

5. Finally, compute the Jacobian matrices for the end-effector $\left(\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})\right)$ and for each c.m. $\left(\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})\right)$ relative to the robot base (link 0). [1p]

The purple arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.b.

$[mm]$
$L_1 = 300$
$L_2 = 340$
$L_3 = 583$
$L_4 = 80$
$L_5 = 80$
$L_6 = 115$
$L_7 = 82$
$L_8 = 108$
$L_9 = 123$
$L_{10} = 167$
$L_{11} = 28$
$L_{12} = 50$
$c = d = 320$
$\theta_1 = 45°$
$\theta_2 = 30°$

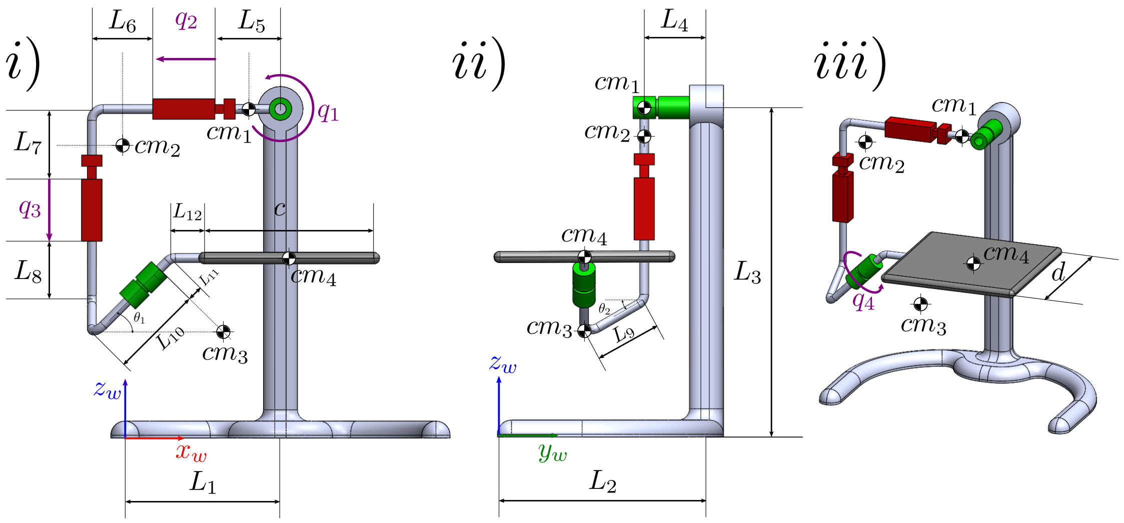


Figure 8.1: 3DOF robot (PPR). The movable joints are q_2, q_3, and q_4.

Exercise 9 Consider the three degree-of-freedom PPR robot with two prismatic joints q_1 and q_2, and a revolute joint q_3, shown in Fig. 9.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 9.1 b)-c).

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 9.1 as black and white circles. [1p]
2. Using the previously defined coordinate frames and the lengths shown in the Fig. 9.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]
3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_{0}^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]
4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, and the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$ relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 9.1. [1p]
5. Finally, compute the Jacobian matrices for the end-effector $\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})$ and for each c.m. $\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})$ relative to the robot base (link 0). The end-effector pose (6D) is shown in the Fig. 9.1 with the coordinate frame $\mathbf{O}_{\mathrm{ef}}$. [1p]

The blue arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.f.

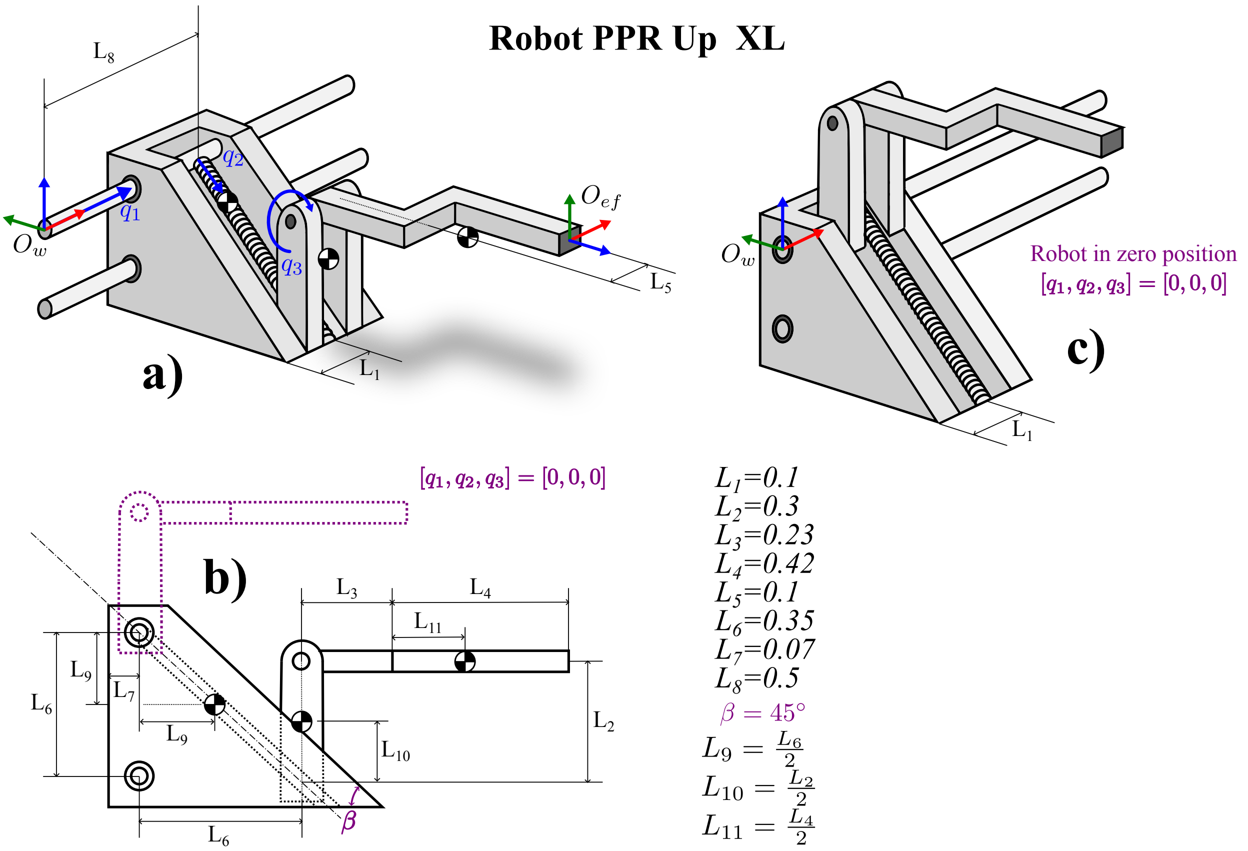


Figure 9.1

Exercise 10 Consider the three degree-of-freedom PRP robot with one initial prismatic joint q_1, followed by a revolute joint q_2, and a prismatic joint q_3 at the end, shown in Fig. 10.1. The zero position, i.e., the position of the robot when the joint positions are $\mathbf{q} = [q_1, q_2, q_3] = [0, 0, 0]$ is depicted in Fig. 10.1.

1. Define the coordinate frames for the three links and centers of mass (c.m.) according to the Distal Denavit-Hartenberg (D-H) convention. The c.m. are depicted in Fig 10.1 as black and white circles. [1p]

2. Using the previously defined coordinate frames and the lengths shown in the Fig. 10.1, obtain the D-H tables and parameters for the joints and the centers of mass. [1p]

3. Compute the relative Homogeneous Transformations for each link and each c.m. $\mathbf{H}_{\mathrm{i}}^{\mathrm{i-1}}$ and $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{i-1}}$, respectively. Determine the transformations for the base and end-effector $\mathbf{H}_0^{\mathrm{w}}$ and $\mathbf{H}_{\mathrm{ef}}^{3}$, respectively. [1p]

4. Compute the absolute Homogeneous Transformations for each link $\mathbf{H}_{\mathrm{i}}^{\mathrm{w}}$, each c.m. $\mathbf{H}_{\mathrm{cm_i}}^{\mathrm{w}}$, and the end-effector $\mathbf{H}_{\mathrm{ef}}^{\mathrm{w}}$ relative to the world coordinate frame (wcf) $\mathbf{O}_{\mathrm{w}}$, depicted in the Fig. 10.1. [1p]

5. Finally, compute the Jacobian matrices for the end-effector $\mathbf{J}_{\mathrm{ef}}^{0}(\mathbf{q})$ and for each c.m. $\mathbf{J}_{\mathrm{cm_i}}^{0}(\mathbf{q})$ relative to the robot base (link 0). The end-effector pose (6D) is shown in the Fig. 10.1 with the coordinate frame $\mathbf{O}_{\mathrm{ef}}$. [1p]

The blue arrows in the figure define the positive direction of the actuators and must be taken into account when setting the coordinate frames. Furthermore, the needed kinematic parameters for the tasks are also depicted in the figure. For convenience, a larger image of the robot is presented in the Appendix 2, Fig. 2.g.

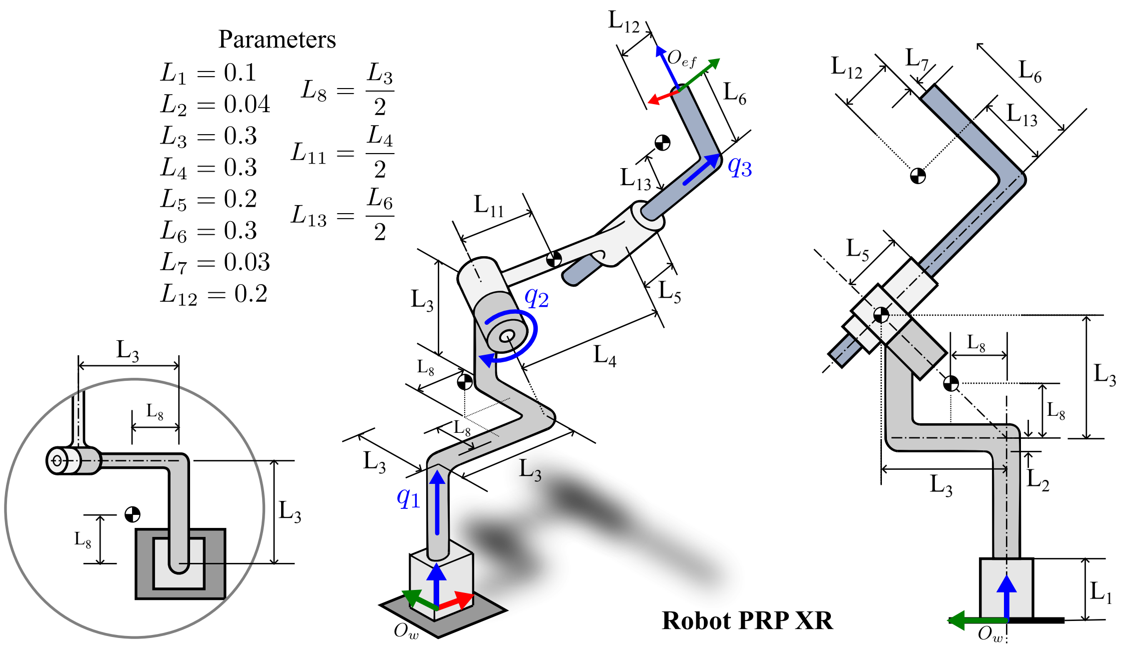
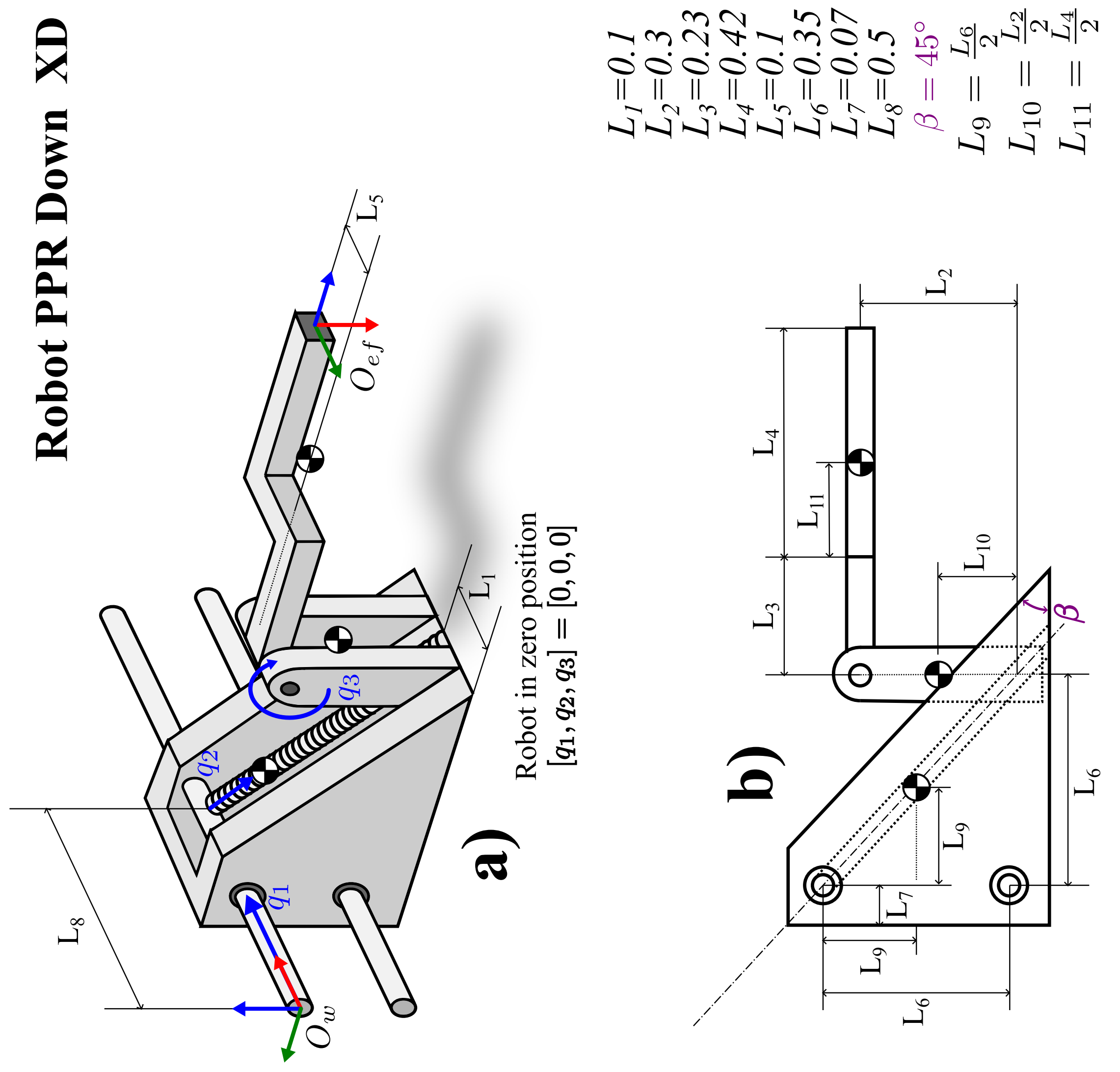


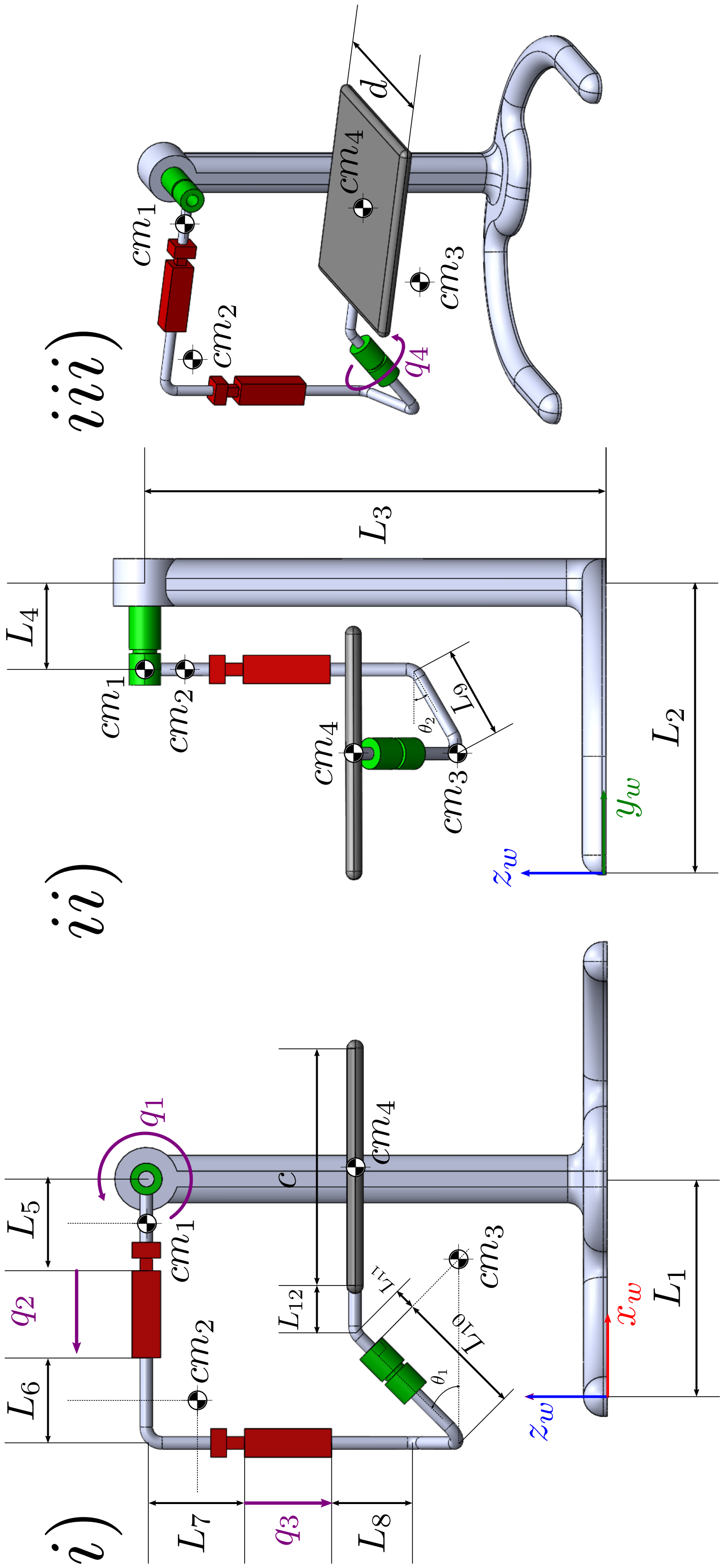
Figure 10.1

1 Appendix A: Figures

1.a Robot Exercise 1



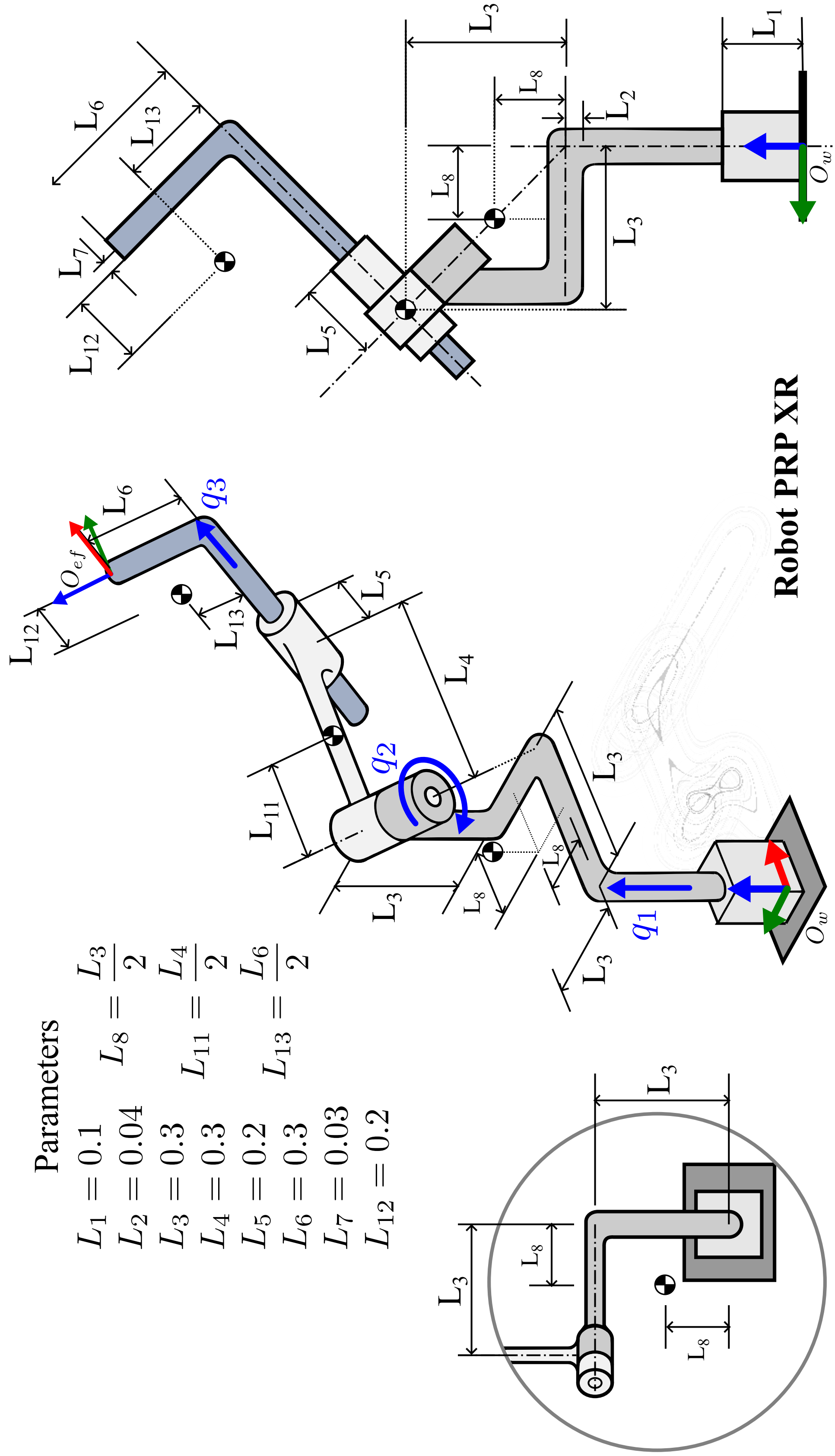
1.b Robot Exercise 2, 4, 6, and 8



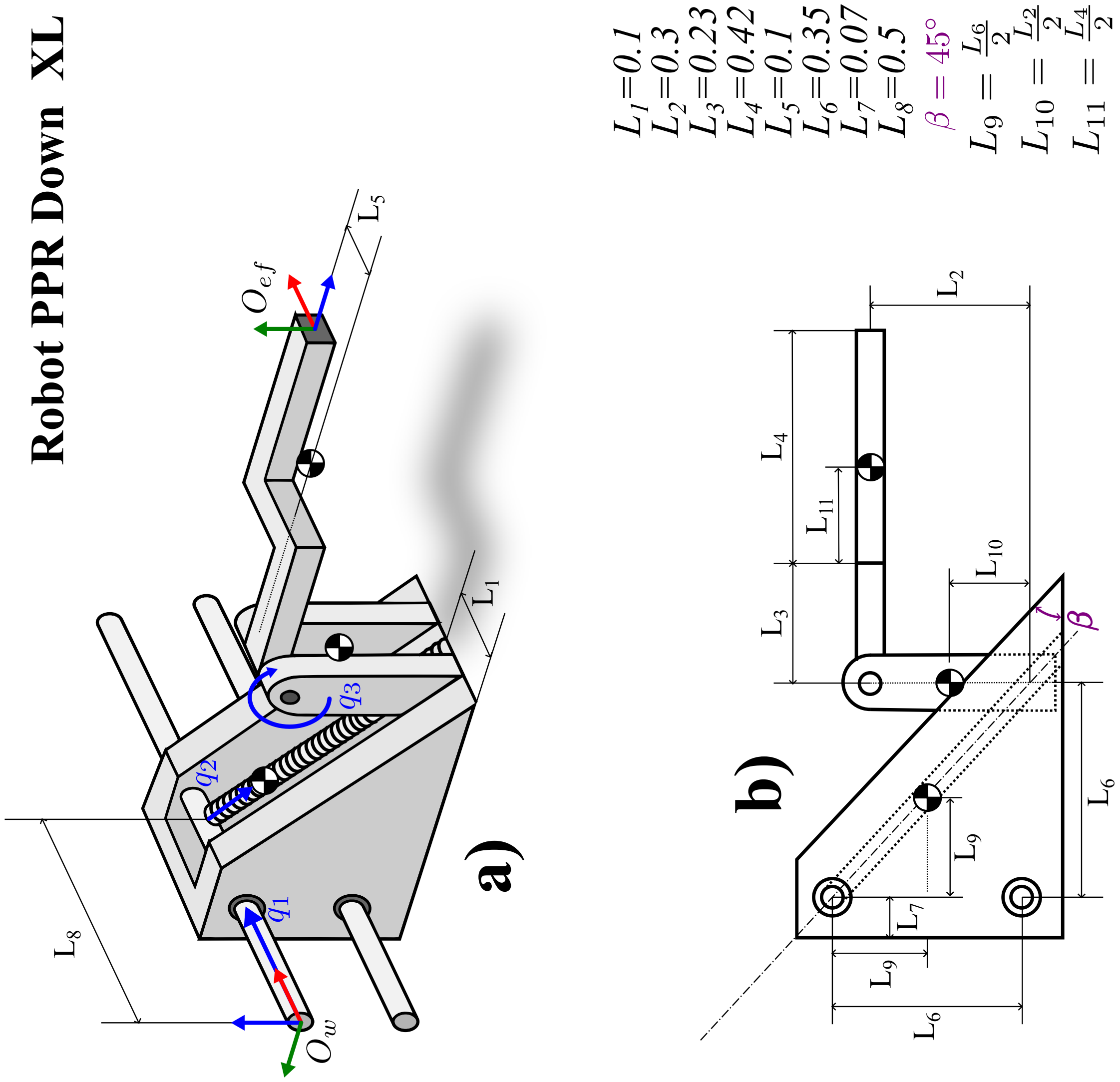
$[mm]$

$L_1 = 300$
$L_2 = 340$
$L_3 = 583$
$L_4 = 80$
$L_5 = 80$
$L_6 = 115$
$L_7 = 82$
$L_8 = 108$
$L_9 = 123$
$L_{10} = 167$
$L_{11} = 28$
$L_{12} = 50$
$c = d = 320$
$\theta_1 = 45°$
$\theta_2 = 30°$

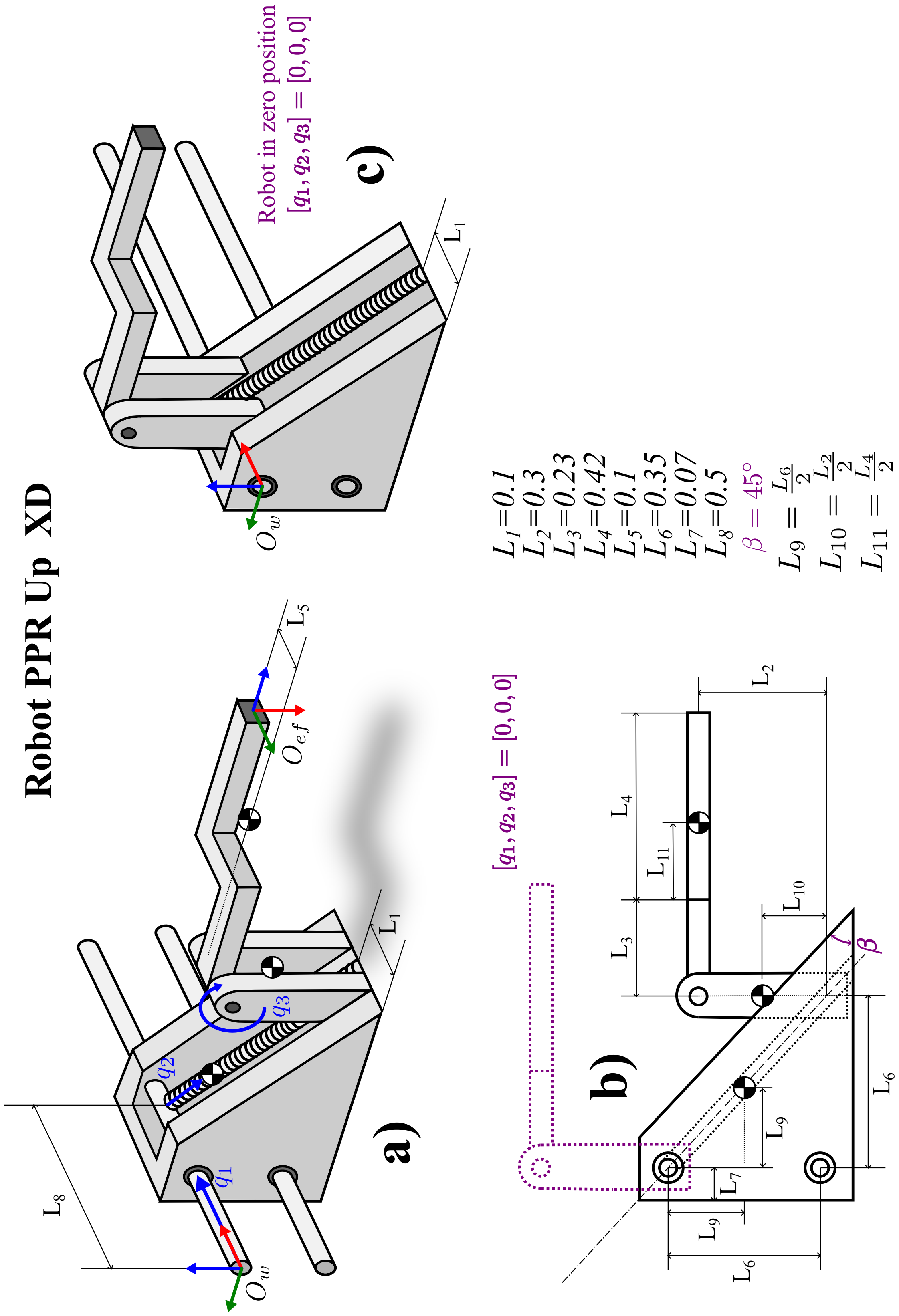
1.c Robot Exercise 3



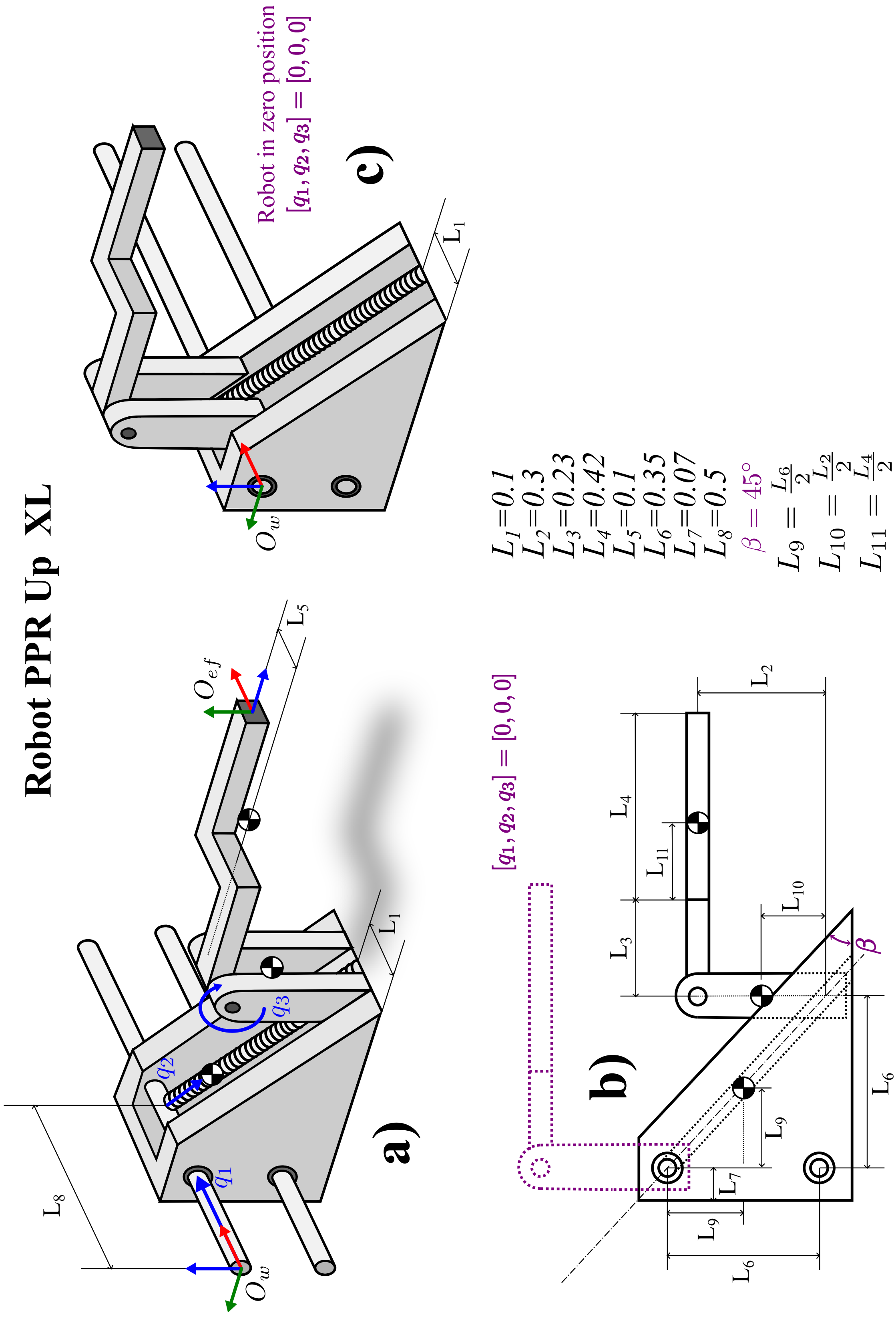
1.d Robot Exercise 5



1.e Robot Exercise 7



1.f Robot Exercise 9



1.g Robot Exercise 10