PROBLEMS

3-1 Verify the statement after equation [3.2.6] that the rotation matrix \( R \) has the form [3.2.4] provided assumptions DH1 and DH2 are satisfied.

3-2 Consider the three-link planar manipulator shown in Figure 3-12. Derive the forward kinematic equations using the DH-convention.

3-3 Consider the two-link cartesian manipulator of Figure 3-13. Derive the forward kinematic equations using the DH-convention.

3-4 Consider the two-link manipulator of Figure 3-14, which has joint 1 revolute and joint 2 prismatic. Derive the forward kinematic equations using the DH-convention.

3-5 Consider the three-link planar manipulator of Figure 3-15. Derive the forward kinematic equations using the DH-convention.

3-6 Consider the three-link articulated robot of Figure 3-16. Derive the forward kinematic equations using the DH-convention.

3-7 Consider the three-link cartesian manipulator of Figure 3-17. Derive the forward kinematic equations using the DH-convention.

3-8 Attach a spherical wrist to the three-link articulated manipulator of Problem 3-6 as shown in Figure 3-18. Derive the forward kinematic equations for this manipulator.
FIGURE 3-15
Three-link planar arm with prismatic joint of Problem 3-5.

FIGURE 3-16
Three-link articulated robot.

FIGURE 3-17
Three-link cartesian robot.

3-9 Attach a spherical wrist to the three-link cartesian manipulator of Problem 3-7 as shown in Figure 3-19. Derive the forward kinematic equations for this manipulator.

FIGURE 3-18
Elbow manipulator with spherical wrist.

FIGURE 3-19
Cartesian manipulator with spherical wrist.
3-10 Consider the PUMA 260 manipulator shown in Figure 3-20. Derive the complete set of forward kinematic equations, by establishing appropriate D-H coordinate frames, constructing a table of link parameters, forming the $A$-matrices, etc.

3-11 Repeat Problem 3-9 for the five degree-of-freedom Rhino XR-3 robot shown in Figure 3-21.

3-12 Suppose that a Rhino XR-3 is bolted to a table upon which a coordinate frame $O_x y z$ is established as shown in Figure 3-22. (The frame $O_x y z$ is often referred to as the station frame.) Given the base frame that you established in Problem 3-11, find the homogeneous transformation $T_0^B$ relating the base frame to the station frame. Find the homogeneous transformation $T_B^E$ relating the end-effector frame to the station frame. What is the position and orientation of the end-effector in the station frame when $\theta_1 = \theta_2 = \cdots = \theta_5 = 0$?

![Figure 3-20](image1)

**Figure 3-20**

PUMA 260 manipulator.

![Figure 3-21](image2)

**Figure 3-21**

Rhino XR-3 robot.