National University of Singapore
Faculty of Engineering

ME5402/EE5016R Advanced Robotics

Exercise 2

1. Figure 1 shows the schematic diagram of the Intelledex Robot Model 605T. This robot is a six-axis manipulator consisting of all rotational joints with axes 1, 2 and 3 always co-intersecting at a common joint. (Axis 6 intersects at the same co-intersection point only at the configuration shown in Fig. 1.)

a. Assign coordinate frames to each link according to the Denavit-Hartenberg convention and the following rules:
   - The base frame (frame 0) should be as indicated in the figure. Its origin should coincide with the co-intersection point of axes 1, 2 and 3.
   - The end-effector frame and the z-axes of the rest of the frames should be as indicated in the figure.
   - To the maximum extent possible, make a_i and d_i be equal to zero.
   - The values of the six joint coordinates ($[\theta_1\ \theta_2\ \theta_3\ \theta_4\ \theta_5\ \theta_6]$) for the robot at the configuration shown in Fig. 1 are $[0\ -90^o\ 90^o\ 0\ -90^o\ 0]$.

b. Identify the kinematic parameters of the robot by filling in the table in Table 1.

c. If at the configuration shown in Figure 1, axis 2 has a joint motion range of $\pm 115^o$, determine the joint motion range in terms of θ_2 (joint variable for 2nd joint, assigned according to the Denavit-Hartenberg convention, item a above.).

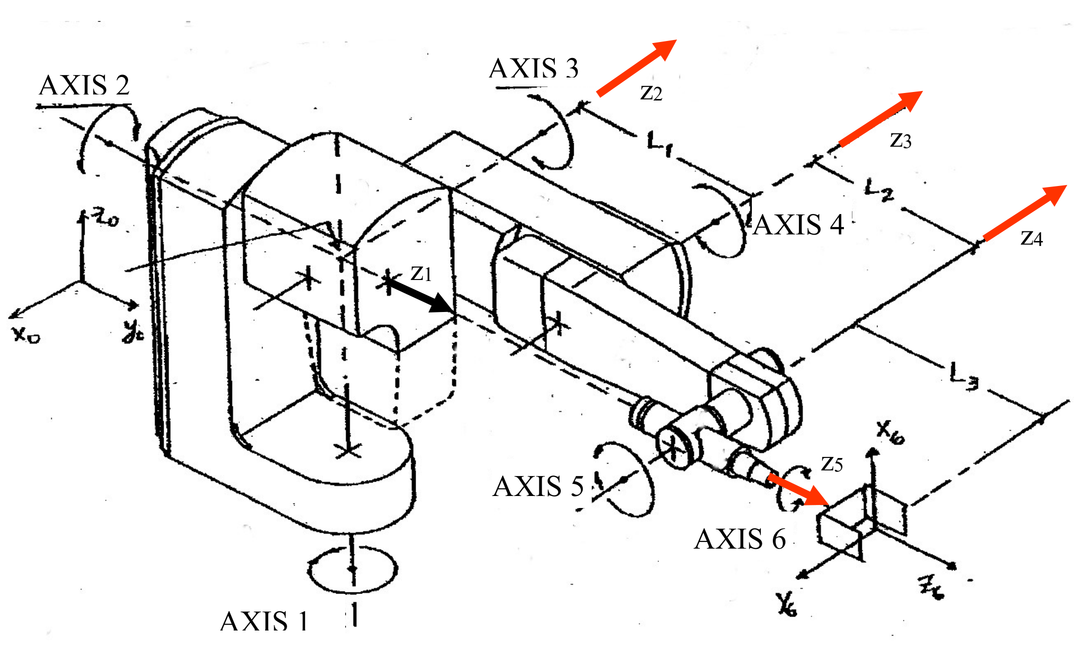

Figure 1

Table 1:

Link number	θ_i	d_i	α_i	a_i

1				
2				
3				
4				
5				
6				

2. Figure 2 shows a 3-joint robot with one translational joint. It is a cylindrical robot whose first two joints are analogous to polar coordinates when viewed from above. The last joint provides "roll" for the hand.

a. Assign a coordinate frame to each link according to the Denavit-Hartenberg convention.
b. Identify and tabulate the Denavit-Hartenberg parameters.
c. Compute ${}^{0}_{3}T$.
d. Describe the three degrees-of-freedom of the robot in Cartesian space. Sketch the reachable workspace of the robot.
e. Derive the complete inverse kinematic equations for the robot.

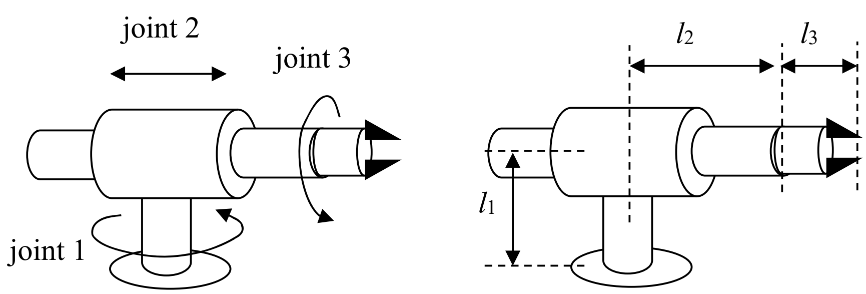

Figure 2

3. Coordinate frame N is attached to an end-effector as shown in Figure 3. It is desired to design an N-joint robot that can provide the following position and orientation of the end-effector:

$$ {}^{0}_{N}T = \begin{bmatrix} n_x & o_x & 0 & p_x \\ n_y & o_y & 0 & p_y \\ 0 & 0 & -1 & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

where n_x, n_y, o_x, o_y, p_x, p_y, and p_z are functions of the robot joint coordinates.

a. What is the minimum number of degrees-of-freedom required of the robot? (That is, what is the minimum number of joints?)
b. Suggest a robot structure/configuration that can satisfy the task ${}^{0}_{N}T$. That is, identify the number and type of joints, draw the base frame 0 and provide a schematic diagram of the robot including the end-effector and its frame N.

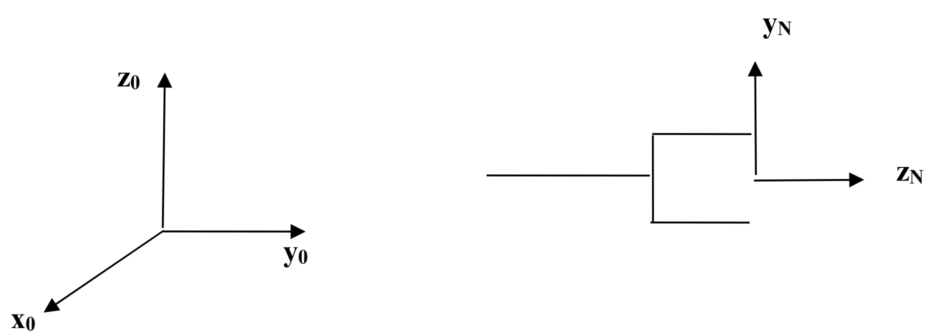

Figure 3

4. A three-degree-of-freedom RPR robot is as shown in Figure 4. The joint variables are (θ_1, d_2, θ_3) and $l_3 = 1\ m$.

   a. Assign the remaining coordinate frames based on Denavit-Hartenberg notation and fill out the link parameters table.
   b. Obtain the ${}^{0}_{3}T$ matrix that describes the position and orientation of Frame {3} relative to Frame {0}.
   c. Given the desired position vector of the tip of the arm, ${}^{0}p = [p_x, p_y, 0]^T$ and the desired x_3 axis direction expressed in terms of angle ϕ, which is measured anti-clockwise from x_0, find the expressions of the joint variables in terms of p_x, p_y and ϕ. Assume $d_2 > 0$.

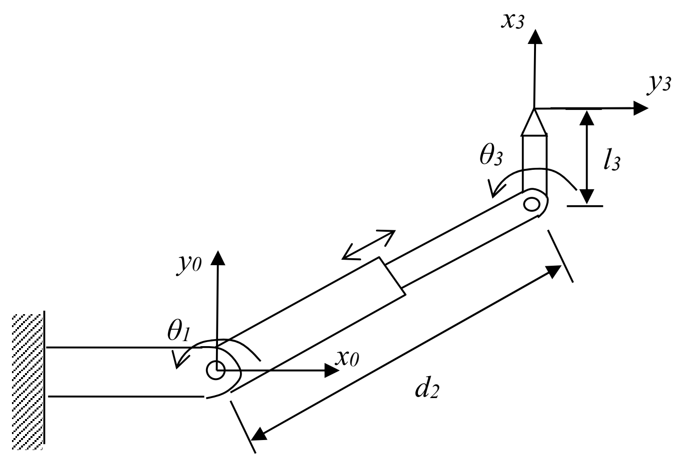

Figure 4