# Algorithmic Robotics

**Question 1:**

We will write 5 configurations in a table [degrees]:

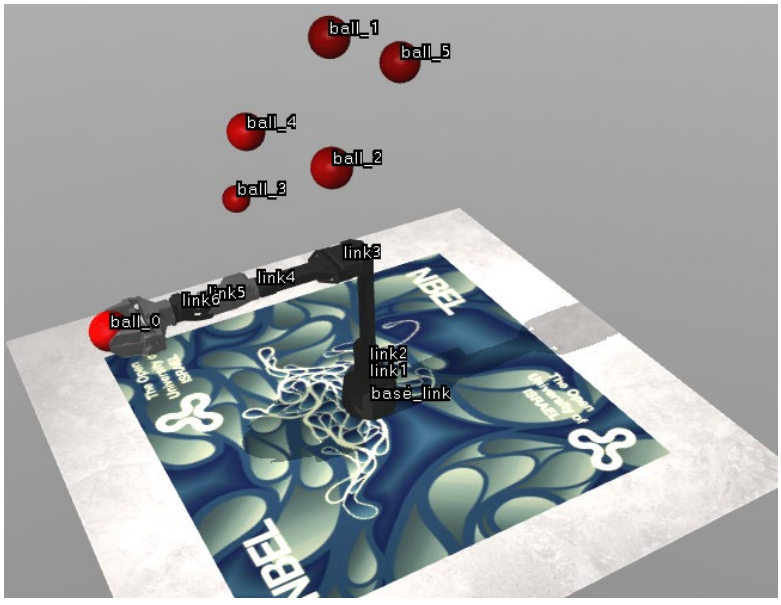
| | q0 | q1 | q2 | q3 | q4 | EE position |
|---|---|---|---|---|---|---|
| Conf' 0 | 0 | 0 | 0 | 0 | 0 | $(0,0.56,0.42)$ |
| Conf' 1 | 0 | 0 | 90 | 0 | 0 | $(0,0.06,0.92)$ |
| Conf' 2 | 45 | 45 | 0 | 0 | 0 | $(-0.13,0.13,0.72)$ |
| Conf' 3 | 90 | 90 | 90 | 90 | 0 | $(0.8,0,0.18)$ |
| Conf' 4 | 135 | 60 | 0 | 0 | 90 | $(0.179, 0.179, 0.682)$ |
| Conf' 5 | 180 | 30 | 30 | 30 | 30 | $(-0.05, -0.0636, 0.863)$ |

Configuration 0:

We reorganized the robot xml file so it will fit configuration 0 as we derived from FK.py.

The new NBEL.xml is in appendix 2.

The EE in NBEL is in $(0,0.56,0.42)$




Configuration 1:

We will write the configurationmatrixes for configurations 1:

$$T_{01} = \begin{bmatrix} \cos(\theta_0) & -\sin(\theta_0) & 0 & 0 \\ \sin(\theta_0) & \cos(\theta_0) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos(0) & -\sin(0) & 0 & 0 \\ \sin(0) & \cos(0) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{12} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\theta_1) & -\sin(\theta_1) & 0 \\ 0 & \sin(\theta_1) & \cos(\theta_1) & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(0) & -\sin(0) & 0 \\ 0 & \sin(0) & \cos(0) & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{23} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\theta_2) & -\sin(\theta_2) & L_3 \\ 0 & \sin(\theta_2) & \cos(\theta_2) & L_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(90) & -\sin(90) & L_3 \\ 0 & \sin(90) & \cos(90) & L_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & L_3 \\ 0 & 0 & 1 & L_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

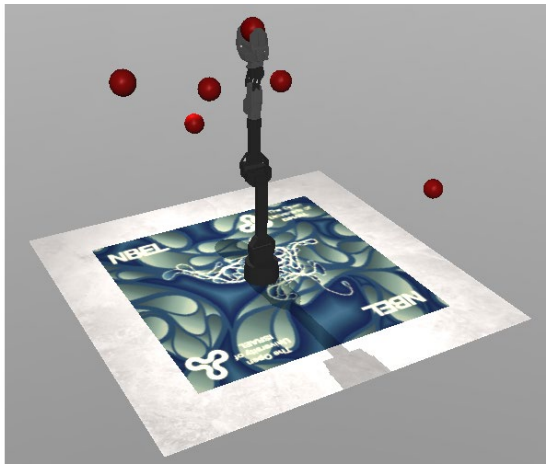
$$T_{34} = \begin{bmatrix} \cos(\theta_3) & 0 & \sin(\theta_3) & 0 \\ 0 & 1 & 0 & L_4 \\ -\sin(\theta_3) & 0 & \cos(\theta_3) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos(0) & 0 & \sin(0) & 0 \\ 0 & 1 & 0 & L_4 \\ -\sin(0) & 0 & \cos(0) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & L_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

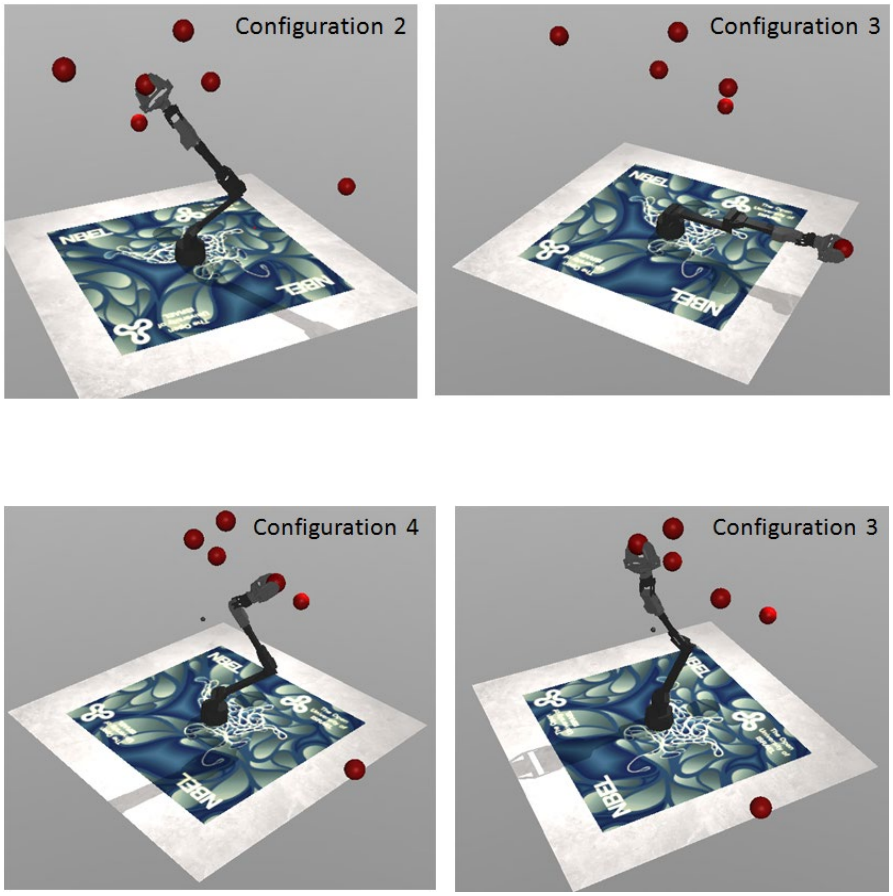
$$T_{45} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\theta_4) & -\sin(\theta_4) & L_5 \\ 0 & \sin(\theta_4) & \cos(\theta_4) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(0) & -\sin(0) & L_5 \\ 0 & \sin(0) & \cos(0) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & L_5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{56} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & L_6 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{06} = T_{01} \cdot T_{12} \cdot T_{23} \cdot T_{34} \cdot T_{45} \cdot T_{56} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & L_3 \\ 0 & 0 & 1 & L_1 + L_2 + L_4 + L_5 + L_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The position of the EE: $[0, 0.06, 0.92]$




Configuration 2
Configuration 3
Configuration 4
Configuration 3

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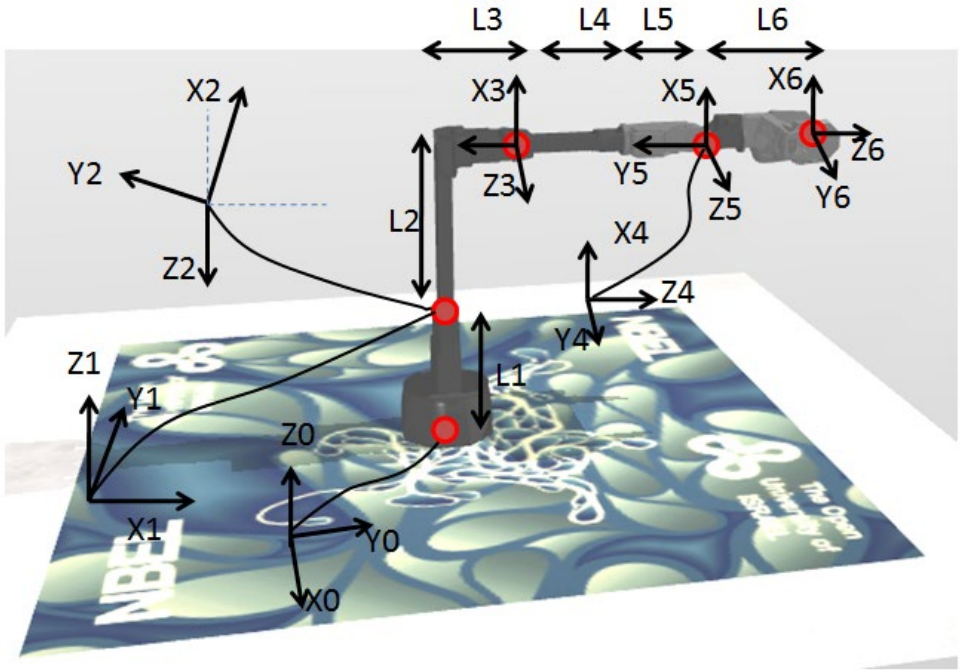
**Question 2:**


L3
L4
L5
L6
X2
X3
X5
X6
Y2
Z3
Y5
Z6
Z5
Y6
L2
X4
Z2
Z4
Y4
Z1
L1
Y1
Z0
X1
Y0
X0

The D-H parameters we defined are below. Pay attention to the special angle $\tan^{-1}\left(\frac{L_2}{L_3}\right)$ And its opposite side angle in the triangle formed by J2, J3 and the corner of the arm. We decided to define the J4 and J5 parameters in the same location, and the it means the L4+L5 could be added in d4.

| $i$ | $\alpha_{i-1}$ | $a_{i-1}$ | $d_i$ | $\phi_i$ |
|---|---|---|---|---|
| 1 | 0 | 0 | $L_1$ | $\theta_1 + 90$ |
| 2 | 90 | 0 | 0 | $\theta_2 + \tan^{-1}\left(\frac{L_2}{L_3}\right)$ |
| 3 | 0 | $\sqrt{L_2^2 + L_3^2}$ | 0 | $\theta_3 + \tan^{-1}\left(\frac{L_3}{L_2}\right)$ |
| 4 | 90 | 0 | $L_4 + L_5$ | $\theta_4$ |
| 5 | $-90$ | 0 | 0 | $\theta_5$ |
| 6 | 90 | 0 | $L_6$ | $\theta_6$ |

Below is the comparison of results between the 2 ways of calculating the End Effectors location, it's very accurate for us.

| | q0 | q1 | q2 | q3 | q4 | Forward Kinematics | DH parameters |
|---|---|---|---|---|---|---|---|
| Conf' 0 | 0 | 0 | 0 | 0 | 0 | $(0,0.56,0.42)$ | $(0,0.56,0.42)$ |
| Conf' 1 | 0 | 0 | 90 | 0 | 0 | $(0,0.06,0.92)$ | $(0,0.06,0.92)$ |
| Conf' 2 | 45 | 45 | 0 | 0 | 0 | $(-0.13,0.13,0.72)$ | $(-0.13,0.13,0.72)$ |
| Conf' 3 | 90 | 90 | 90 | 90 | 0 | $(0.8,0,0.18)$ | $(0.8,0,0.18)$ |
| Conf' 4 | 135 | 60 | 0 | 0 | 90 | $(0.179, 0.179, 0.682)$ | $(0.179, 0.179, 0.682)$ |
| Conf' 5 | 180 | 30 | 30 | 30 | 30 | $(-0.05, -0.0636, 0.863)$ | $(-0.05, -0.0636, 0.863)$ |