

## **RBE 500 Homework #2**

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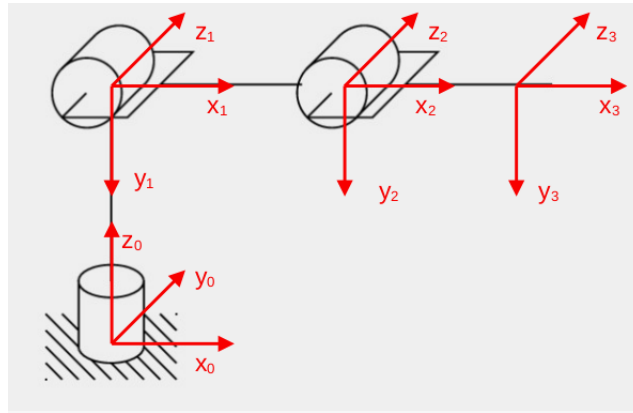
## Problem 3.5

Consider the three-link articulated robot of Figure 3.16. Derive the forward kinematic equations using the DH convention.



### Solution

First we assign coordinate frames 0 through 3 (links 0 through 3). This is done as per the following figure.



Now, we create a table for quantities  $\alpha_i, a_i, \theta_i, d_i$  for links 1 through 3.

Link	$\alpha_i$	$a_i$	$\theta_i$	$d_i$
1	$-90^\circ$	0	$\theta_1$	$d_1$
2	0	$a_2$	$\theta_2$	0
3	0	$a_3$	$\theta_3$	0

Next, we use the matrix obtained from equation 3.10 of the textbook to calculate  $A_1, A_2, A_3$ .

$$A_1 = \begin{bmatrix} \cos \theta_1 & -\sin \theta_1 \cos(-90^\circ) & \sin \theta_1 \sin(-90^\circ) & 0 \cdot \cos \theta_1 \\ \sin \theta_1 & \cos \theta_1 \cos(-90^\circ) & -\cos \theta_1 \sin(-90^\circ) & 0 \cdot \sin \theta_1 \\ 0 & \sin(-90^\circ) & \cos(-90^\circ) & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_1 & 0 & -s_1 & 0 \\ s_1 & 0 & c_1 & 0 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where  $s_1 = \sin \theta_1$  and  $c_1 = \cos \theta_1$ . Similarly,

$$A_2 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2 c_2 \\ s_2 & c_2 & 0 & a_2 s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, A_3 = \begin{bmatrix} c_3 & -s_3 & 0 & a_3 c_3 \\ s_3 & c_3 & 0 & a_3 s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Now we can find  $T_3^0 = A_1 A_2 A_3$ . We use the following MATLAB code to compute this.

```

1 % Calculation code for problem 3.5 of the RBE500 textbook (HW 2)
2
3 clear; close all; clc;
4
5 syms c1 s1 d1 c2 s2 a2 c3 s3 a3;
6 A1 = [c1 0 -s1 d1; s1 0 c1 0; 0 -1 0 d1; 0 -1 0 d1; 0 0 0 1];
7 A2 = [c2 -s2 0 a2*c2; s2 c2 0 a2*s2; 0 0 1 0; 0 0 0 1];
8 A3 = [c3 -s3 0 a3*c3; s3 c3 0 a3*s3; 0 0 1 0; 0 0 0 1];
9
10 T = A1*A2*A3;
11
12 % Generate LaTeX code
13 latex(T)

```

Therefore,

$$T_3^0 = \begin{bmatrix} c_1 c_2 c_3 - c_1 s_2 s_3 & -c_1 c_2 s_3 - c_1 c_3 s_2 & -s_1 & d_1 + a_2 c_1 c_2 - a_3 c_1 s_2 s_3 + a_3 c_1 c_2 c_3 \\ c_2 c_3 s_1 - s_1 s_2 s_3 & -c_2 s_1 s_3 - c_3 s_1 s_2 & c_1 & a_2 c_2 s_1 - a_3 s_1 s_2 s_3 + a_3 c_2 c_3 s_1 \\ -c_2 s_3 - c_3 s_2 & s_2 s_3 - c_2 c_3 & 0 & d_1 - a_2 s_2 - a_3 c_2 s_3 - a_3 c_3 s_2 \\ -c_2 s_3 - c_3 s_2 & s_2 s_3 - c_2 c_3 & 0 & d_1 - a_2 s_2 - a_3 c_2 s_3 - a_3 c_3 s_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

This gives the configuration of frame 3 with respect to the base frame (frame 0).

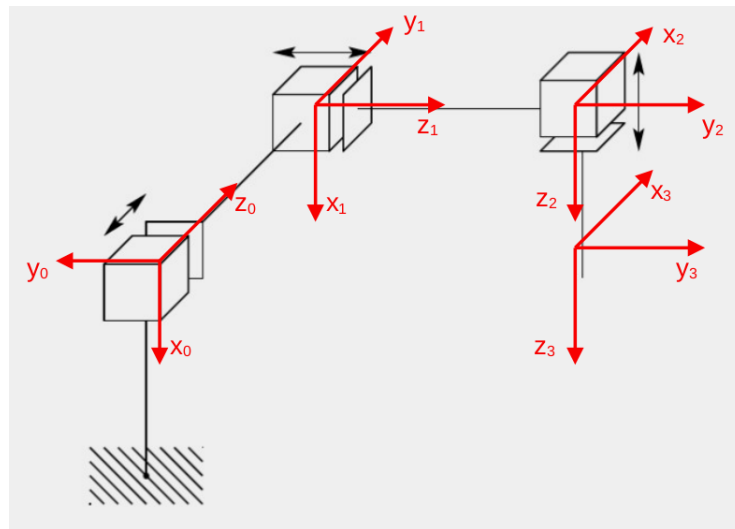
## Problem 3.6

Consider the three-link Cartesian manipulator of Figure 3.17. Derive the forward kinematic equations using the DH convention.



### Solution

First we assign coordinate frames 0 through 3 (links 0 through 3). This is done as per the following figure.



Now, we create a table for quantities  $\alpha_i, a_i, \theta_i, d_i$  for links 1 through 3.

Link	$\alpha_i$	$a_i$	$\theta_i$	$d_i$
1	$90^\circ$	0	0	$d_1$
2	$90^\circ$	0	$90^\circ$	$d_2$
3	0	0	0	$d_3$

Next, we use the matrix obtained from equation 3.10 of the textbook to calculate  $A_1, A_2, A_3$ .

$$A_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}, A_2 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}, A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Now we can find  $T_3^0 = A_1 A_2 A_3$ . We use the following MATLAB code to compute this.

```

1  % Calculation code for problem 3.6 of the RBE500 textbook (HW 2)
2
3  clear; close all; clc;
4
5  syms d1 d2 d3;
6  A1 = [1 0 0 0; 0 0 -1 0; 0 1 0 d1; 0 0 0 1];
7  A2 = [0 0 1 0; 1 0 0 0; 0 1 0 d2; 0 0 0 1];
8  A3 = [1 0 0 0; 0 1 0 0; 0 0 1 d3; 0 0 0 1];
9
10 T = A1*A2*A3;
11
12 % Generate LaTeX code
13 latex(T)
```

Therefore,

$$T_3^0 = \begin{bmatrix} 0 & 0 & 1 & d_3 \\ 0 & -1 & 0 & -d_2 \\ 1 & 0 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

This gives the configuration of frame 3 with respect to the base frame (frame 0).

## Problem 5.3

Prompt

**Problem 5.6**

Suppose we would like to fit a straight line through the origin.

## Report for ROS2 Portion