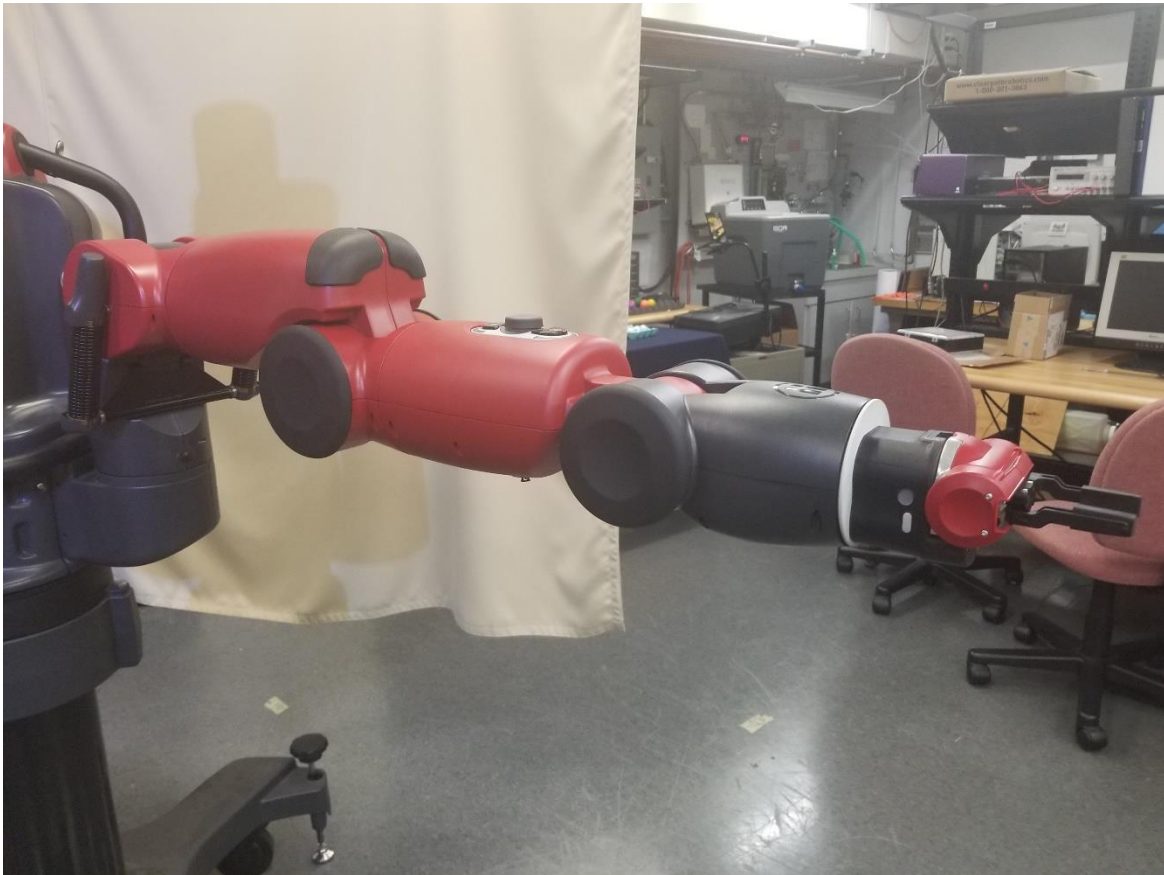


## Test Case 1:

Degrees: 0, 0 ,0 ,0, 0, 0, 0

```
At time 1520276891.414
- Translation: [1.118, -0.002, 0.203]
- Rotation: in Quaternion [-0.000, 0.708, -0.002, 0.707]
           in RPY (radian) [-1.930, 1.568, -1.931]
           in RPY (degree) [-110.556, 89.812, -110.666]
At time 1520276892.414
- Translation: [1.118, -0.002, 0.202]
- Rotation: in Quaternion [-0.000, 0.708, -0.001, 0.706]
           in RPY (radian) [-2.356, 1.568, -2.358]
           in RPY (degree) [-135.000, 89.845, -135.088]
At time 1520276893.434
- Translation: [1.118, -0.002, 0.202]
- Rotation: in Quaternion [0.000, 0.708, -0.001, 0.706]
           in RPY (radian) [-2.737, 1.568, -2.739]
           in RPY (degree) [-156.802, 89.833, -156.912]
At time 1520276894.174
- Translation: [1.118, -0.001, 0.203]
- Rotation: in Quaternion [-0.001, 0.708, -0.001, 0.706]
           in RPY (radian) [-2.279, 1.567, -2.281]
           in RPY (degree) [-130.601, 89.797, -130.668]
^CAAt time 1520276895.384
- Translation: [1.118, -0.002, 0.203]
- Rotation: in Quaternion [0.000, 0.708, -0.001, 0.707]
           in RPY (radian) [-2.356, 1.569, -2.358]
           in RPY (degree) [-135.000, 89.876, -135.088]
[baxter - http://192.168.11.200:11311] CENG6533_G8@D125-43873:~/catkin_ws$
```



Comparing results:

T\_T =

0	0	1.0000	1.0932
0	1.0000	0	0
-1.0000	0	0	0.2023
0	0	0	1.0000

Rotation matrix

```
[ -0.0014174,  0.0028248,  0.9999950;  
  -0.0028248,  0.9999920, -0.0028288;  
  -0.9999950, -0.0028288, -0.0014094 ]
```

## Test Case 2:

Degrees: 0, 0 ,0 ,45, 0, 0, 0

```
>>> larm.move_to_joint_positions({'left_s0':0.0,'left_s1':0.0,'left_e0':0.0,'left_e1':0.78,'left_w0':0.0,'left_w1':0.0,'left_w2':0.0})
```

```
[baxter - http://192.168.11.200:11311] CENG6533_G8@D125-43873:~/catkin_ws$ roslaunch tf tf_echo left_arm_mount left_gripper_base
At time 1520277908.624
- Translation: [0.942, -0.001, -0.223]
- Rotation: in Quaternion [0.001, 0.917, 0.000, 0.398]
             in RPY (radian) [3.140, 0.819, 3.139]
             in RPY (degree) [179.912, 46.934, 179.833]
At time 1520277908.764
- Translation: [0.941, -0.000, -0.224]
- Rotation: in Quaternion [0.001, 0.918, 0.001, 0.397]
             in RPY (radian) [3.138, 0.816, 3.138]
             in RPY (degree) [179.816, 46.780, 179.785]
At time 1520277909.764
- Translation: [0.942, -0.001, -0.224]
- Rotation: in Quaternion [0.001, 0.917, 0.000, 0.398]
             in RPY (radian) [3.140, 0.818, 3.139]
             in RPY (degree) [179.910, 46.890, 179.869]
At time 1520277910.754
- Translation: [0.942, -0.000, -0.224]
- Rotation: in Quaternion [0.001, 0.918, 0.001, 0.398]
             in RPY (radian) [3.138, 0.818, 3.137]
             in RPY (degree) [179.792, 46.867, 179.731]
At time 1520277911.774
- Translation: [0.943, -0.000, -0.222]
- Rotation: in Quaternion [0.001, 0.917, 0.000, 0.399]
             in RPY (radian) [3.140, 0.821, 3.139]
             in RPY (degree) [179.894, 47.043, 179.872]
^At time 1520277911.864
- Translation: [0.943, -0.000, -0.223]
- Rotation: in Quaternion [0.001, 0.917, 0.000, 0.398]
             in RPY (radian) [3.139, 0.820, 3.139]
             in RPY (degree) [179.880, 46.955, 179.831]
```



Comparing results:

$T_I$  =

-0.7033	0	0.7109	0.9116
0	1.0000	0	0
-0.7109	0	-0.7033	-0.2194
0	0	0	1.0000

Rotation matrix

[	-0.6829662,	0.0018353,	0.7304477;
	0.0018353,	0.9999980,	-0.0007966;
	-0.7304477,	0.0007966,	-0.6829682 ]

Test Case 3:

Degrees: 0, 0, 0, 45, 0, 90, 0

```
>>> larm.move_to_joint_positions({'left_s0':0.0,'left_s1':0.0,'left_e0':0.0,'left_e1':0.78,'left_w0':0.0,'left_w1':1.57,'left_w2':0.0})
```

```
[baxter - http://192.168.11.200:11311] CENG6533_G8@D125-43873:~/catkin_ws$ rosrn tf tf_echo left_arm_mount left_gripper_base
At time 1520278078.004
- Translation: [0.573, 0.000, -0.241]
- Rotation: in Quaternion [0.000, 0.928, 0.003, -0.372]
           in RPY (radian) [3.135, -0.762, -3.140]
           in RPY (degree) [179.625, -43.681, -179.908]
At time 1520278078.004
- Translation: [0.573, 0.000, -0.241]
- Rotation: in Quaternion [0.000, 0.928, 0.003, -0.372]
           in RPY (radian) [3.135, -0.762, -3.140]
           in RPY (degree) [179.625, -43.681, -179.908]
At time 1520278078.984
- Translation: [0.573, 0.000, -0.241]
- Rotation: in Quaternion [-0.000, 0.928, 0.003, -0.372]
           in RPY (radian) [3.135, -0.763, -3.139]
           in RPY (degree) [179.622, -43.725, -179.846]
At time 1520278079.994
- Translation: [0.574, 0.001, -0.241]
- Rotation: in Quaternion [-0.000, 0.929, 0.002, -0.371]
           in RPY (radian) [3.136, -0.761, -3.139]
           in RPY (degree) [179.666, -43.593, -179.855]
```



Comparing results:

$T_I =$

-0.7115	0	-0.7027	0.5871
0	1.0000	0	0
0.7027	0	-0.7115	-0.2213
0	0	0	1.0000

Rotation matrix

$\begin{bmatrix} -0.7231148, & 0.0022329, & -0.6907242; \\ -0.0022329, & 0.9999820, & 0.0055704; \\ 0.6907242, & 0.0055704, & -0.7230968 \end{bmatrix}$
---

Test Case 4:

Degrees: 0, 0, 0, 45, 180, 90, 0

```
>>> larm.move_to_joint_positions({'left_s0':0.0,'left_s1':0.0,'left_e0':0.0,'left_e1':0.78,'left_w0':3.14,'left_w1':1.57,'left_w2':0.0})
```

```
^C[baxter - http://192.168.11.200:11311] CENG6533_G8@D125-43873:~/catkin_ws$ roslaunch tf tf_echo left_arm_mount left_gripper_base
At time 1520278193.034
- Translation: [0.942, 0.020, 0.139]
- Rotation: in Quaternion [0.379, 0.038, 0.924, -0.014]
           in RPY (radian) [0.083, -0.778, 3.138]
           in RPY (degree) [4.736, -44.593, 179.794]
At time 1520278193.034
- Translation: [0.942, 0.020, 0.139]
- Rotation: in Quaternion [0.379, 0.038, 0.924, -0.014]
           in RPY (radian) [0.083, -0.778, 3.138]
           in RPY (degree) [4.736, -44.593, 179.794]
At time 1520278193.344
- Translation: [0.942, 0.020, 0.139]
- Rotation: in Quaternion [0.379, 0.037, 0.925, -0.014]
           in RPY (radian) [0.081, -0.778, 3.139]
           in RPY (degree) [4.669, -44.575, 179.836]
At time 1520278194.344
- Translation: [0.942, 0.021, 0.139]
- Rotation: in Quaternion [0.379, 0.038, 0.924, -0.014]
           in RPY (radian) [0.082, -0.778, 3.139]
           in RPY (degree) [4.723, -44.595, 179.825]
```





Comparing results:

$T_T =$

-0.7104	0.0011	0.7038	0.9240
0.0000	-1.0000	0.0016	0.0004
0.7038	0.0011	0.7104	0.1193
0	0	0	1.0000

Rotation matrix

[	-0.7120545,	0.0547276,	0.6999881;
	0.0029348,	-0.9967169,	0.0809123;
	0.7021181,	0.0596683,	0.7095561 ]

Test Case 5:

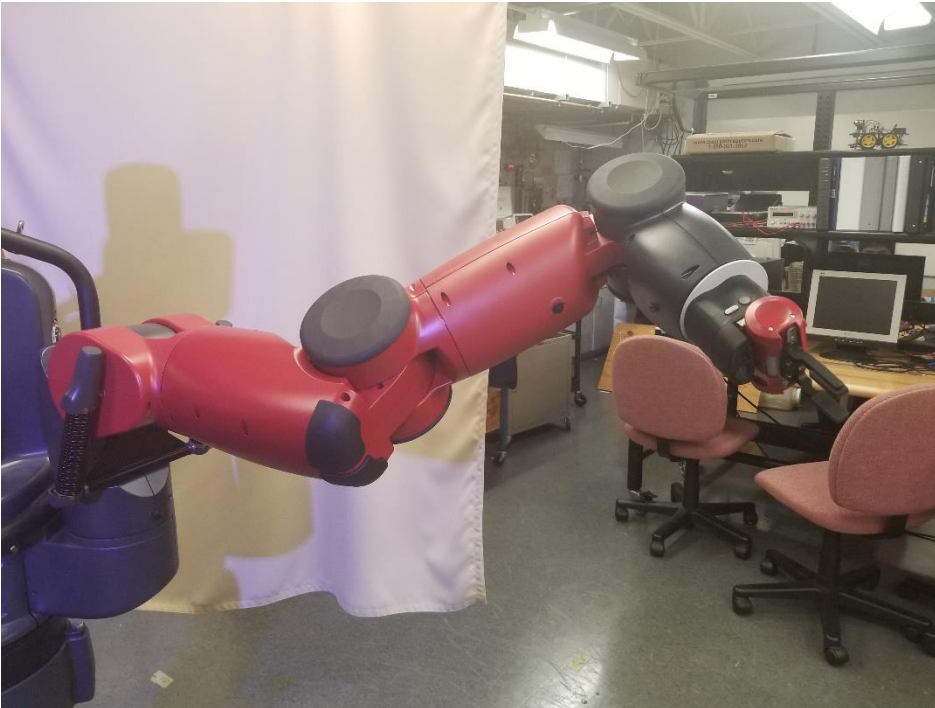
Degrees: 0, 0, 135, 45, 180, 90, 0

```
>>> larm.move_to_joint_positions({'left_s0':0.0,'left_s1':0.0,'left_e0':2.35,'left_e1':0.78,'left_w0':3.14,'left_w1':1.57,'left_w2':0.0})
```

```

AC[baxter - http://192.168.11.200:11311] CENG6533_G8@D125-43873:~/catkin_ws$ roslaunch tf tf_echo left_arm_mount left_gripper_base
At time 1520278318.304
- Translation: [0.941, 0.092, 0.395]
- Rotation: in Quaternion [-0.142, 0.827, -0.414, 0.353]
             in RPY (radian) [-2.050, 0.485, -2.504]
             in RPY (degree) [-117.442, 27.793, -143.475]
At time 1520278318.304
- Translation: [0.941, 0.092, 0.395]
- Rotation: in Quaternion [-0.142, 0.827, -0.414, 0.353]
             in RPY (radian) [-2.050, 0.485, -2.504]
             in RPY (degree) [-117.442, 27.793, -143.475]
At time 1520278319.304
- Translation: [0.941, 0.092, 0.395]
- Rotation: in Quaternion [-0.141, 0.827, -0.415, 0.353]
             in RPY (radian) [-2.048, 0.485, -2.504]
             in RPY (degree) [-117.350, 27.807, -143.454]
At time 1520278320.114
- Translation: [0.941, 0.092, 0.394]
- Rotation: in Quaternion [-0.141, 0.827, -0.415, 0.352]
             in RPY (radian) [-2.049, 0.485, -2.506]
             in RPY (degree) [-117.419, 27.774, -143.567]

```



Comparing results:

$T_I$  =

-0.7104	0.0011	0.7038	0.9240
-0.5470	0.6284	-0.5531	0.1257
-0.4429	-0.7779	-0.4458	0.3836
0	0	0	1.0000

Rotation matrix

[	-0.7104824,	0.0574104,	0.7013693;
	-0.5271003,	0.6169176,	-0.5844467;
	-0.4662403,	-0.7849311,	-0.4080480 ]

## Notes:

For test cases with Baxter I used **radians**, so I think I may have lost some precision in my calculations because of that. Overall, the results look approximately similar to what I got from Baxter.

## MATLAB Code:

```
% Baxter Forward Kinematics
%Link lengths
L0 = 0.28135;
L1 = 0.125;
L2 = 0.36435;
L3 = 0.069;
L4 = 0.37429;
L5 = 0.01;
L6 = 0.229525;
%Theta value
%Here we used different angle values for Theta for every case
t1 = 0;
t2 = 0;
t3 = 0;
t4 = 0;
t5 = 0;
t6 = 0;
t7 = 0;
%Initializing the required transformations
T_01 = [cosd(t1) -sind(t1) 0 0; sind(t1) cosd(t1) 0 0; 0 0 1 L0; 0 0 0 1];
T_12 = [cosd(t2+90) -sind(t2+90) 0 L1; 0 0 1 0; -sind(t2+90) cosd(t2+90) 0 0; 0
0 0 1];
T_23 = [cosd(t3) -sind(t3) 0 0; 0 0 -1 -L2; sind(t3) cosd(t3) 0 0; 0 0 0 1];
T_34 = [cosd(t4) -sind(t4) 0 L3; 0 0 1 0; -sind(t4) -cosd(t4) 0 0; 0 0 0 1];
T_45 = [cosd(t5) -sind(t5) 0 0; 0 0 -1 -L4; sind(t5) cosd(t5) 0 0; 0 0 0 1];
T_56 = [cosd(t6) -sind(t6) 0 L5; 0 0 1 0; -sind(t6) -cosd(t6) 0 0; 0 0 0 1];
T_67 = [cosd(t7) -sind(t7) 0 0; 0 0 -1 -L6; sind(t7) cosd(t7) 0 0; 0 0 0 1];
%Final transformation matrix
T_T = T_01*T_12*T_23*T_34*T_45*T_56*T_67
```