Computer Exercise 2

Submitted by:

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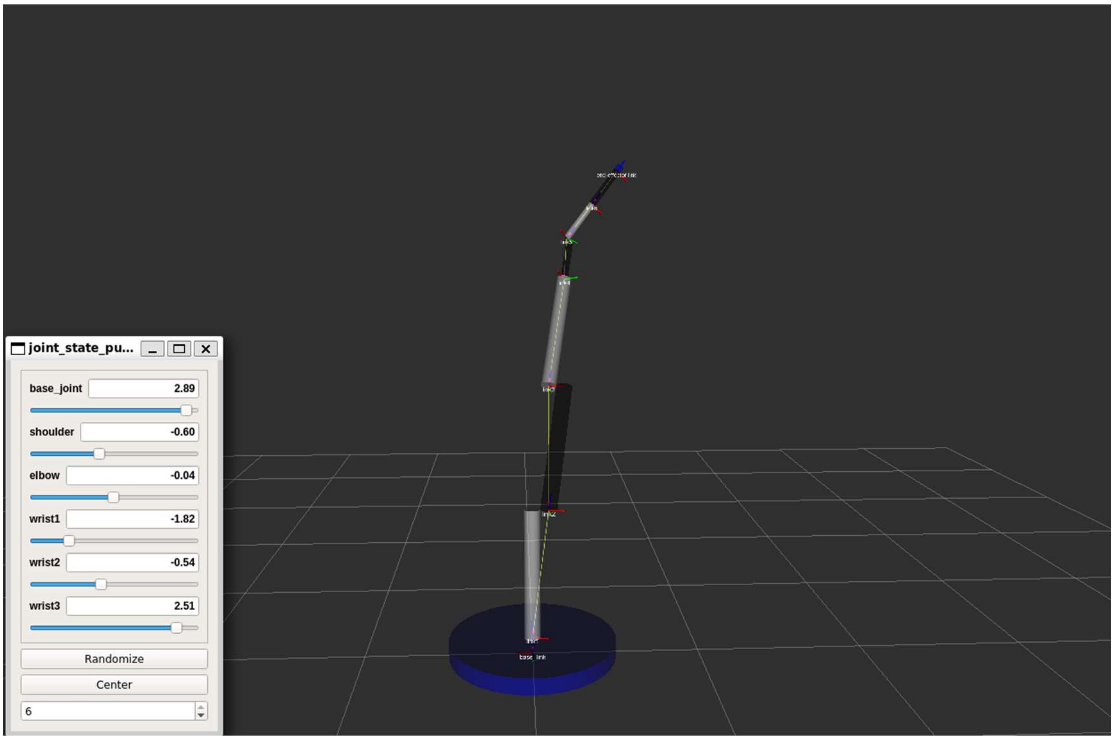
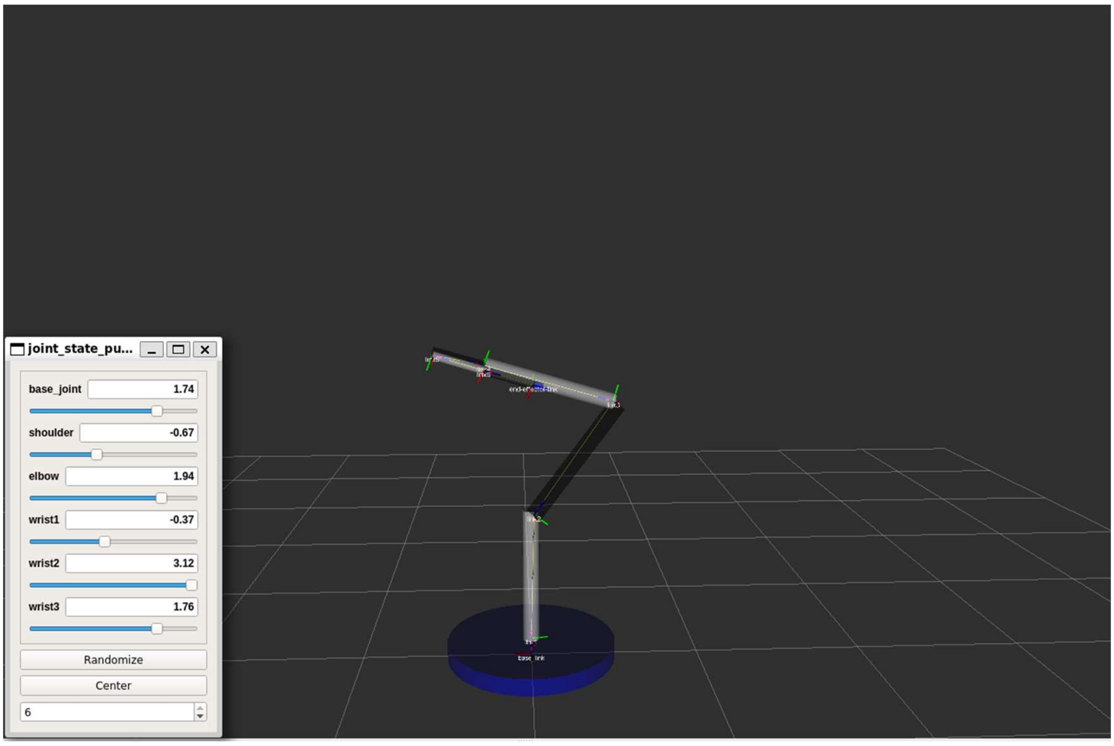
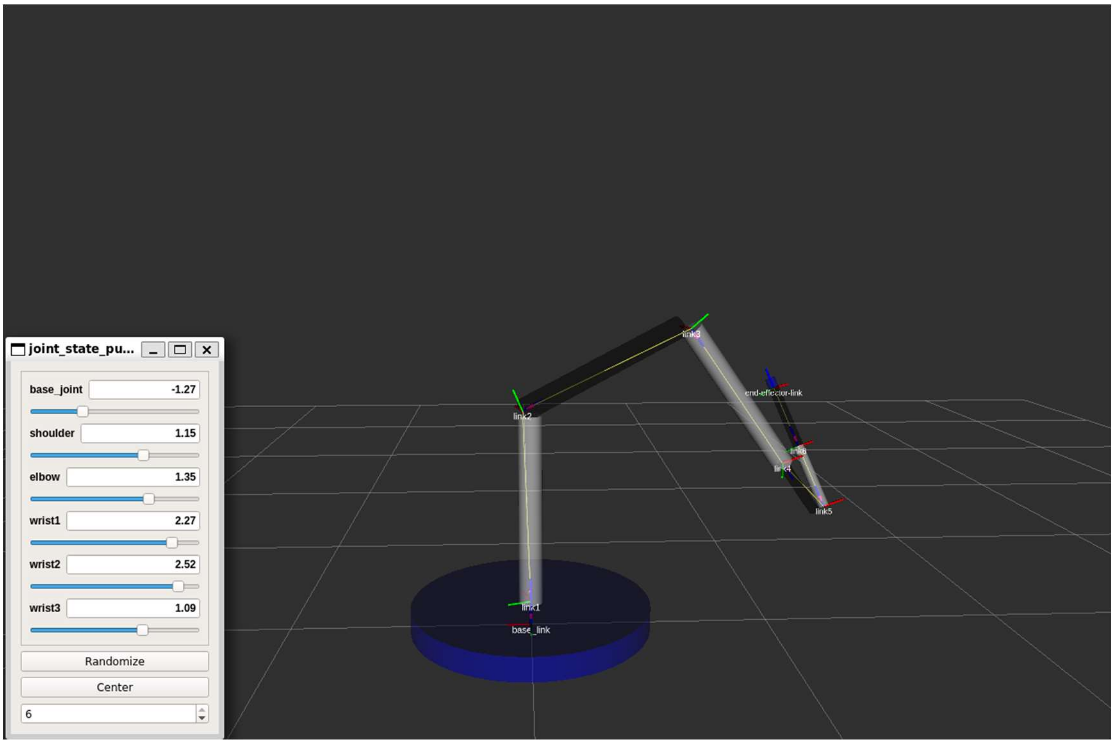
Part II: Visualizing and Moving the Robot:

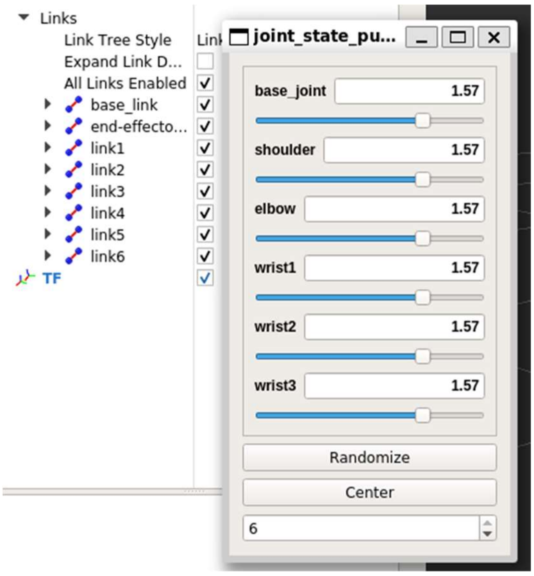
1.



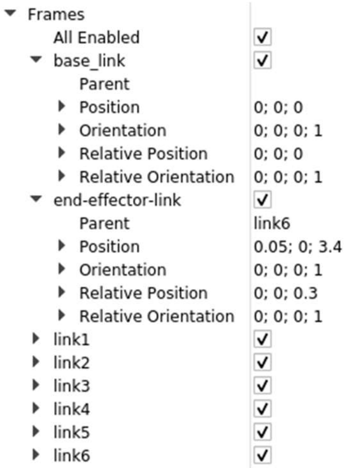

joint_state_pu...
base_joint 1.74
shoulder -0.67
elbow 1.94
wrist1 -0.37
wrist2 3.12
wrist3 1.76
Randomize
Center
6


joint_state_pu...
base_joint -1.27
shoulder 1.15
elbow 1.35
wrist1 2.27
wrist2 2.52
wrist3 1.09
Randomize
Center
6
link3
end-effector-link
link2
link5
link1
base_link

2. The robot consist 6 Revolute joints, 6 links, a base link, and an end_effector.



3.



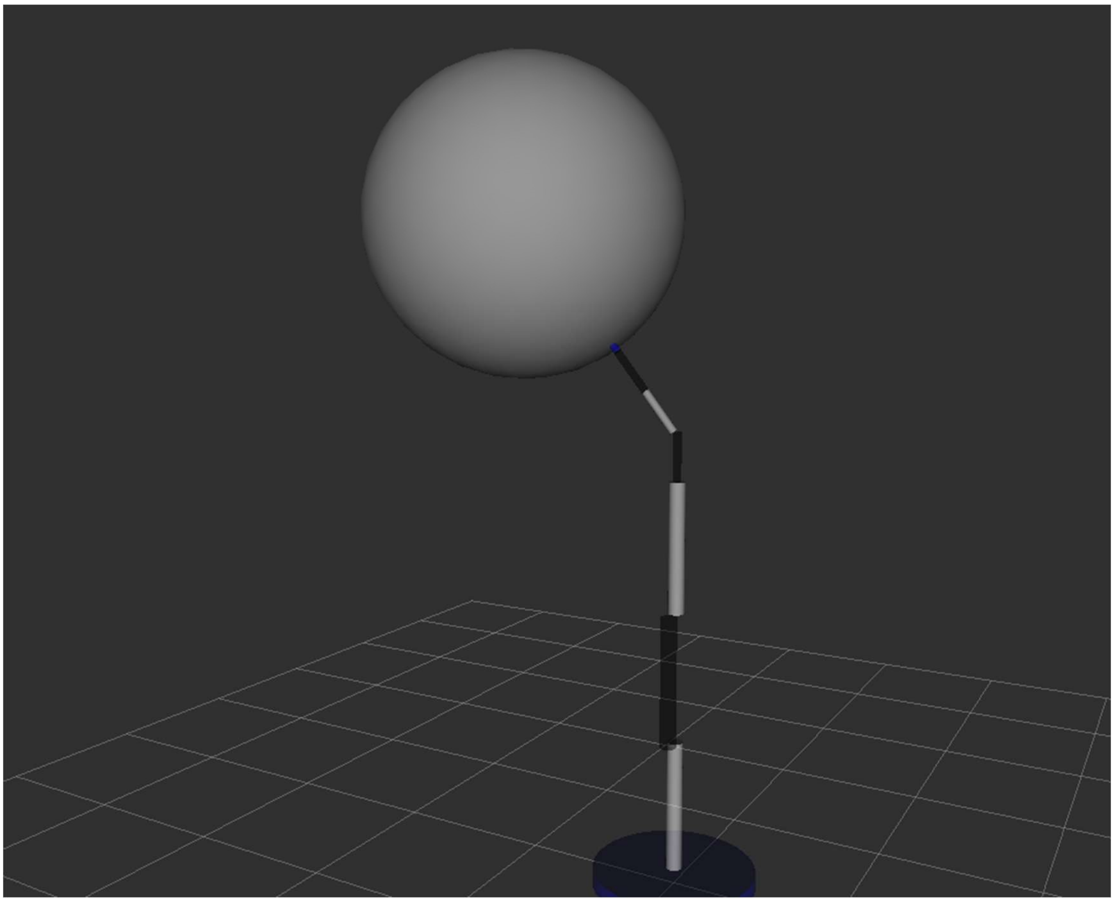
The relative rotation between the base_link and the end_effector is 0 in its center position. Both of them rotate around the z axis with their x axis pointing towards the left.

4. We used a fixed type of joint so it moves with the end effector's movement.

here is the modified section of the URDF file, the rest of the file remains the same:

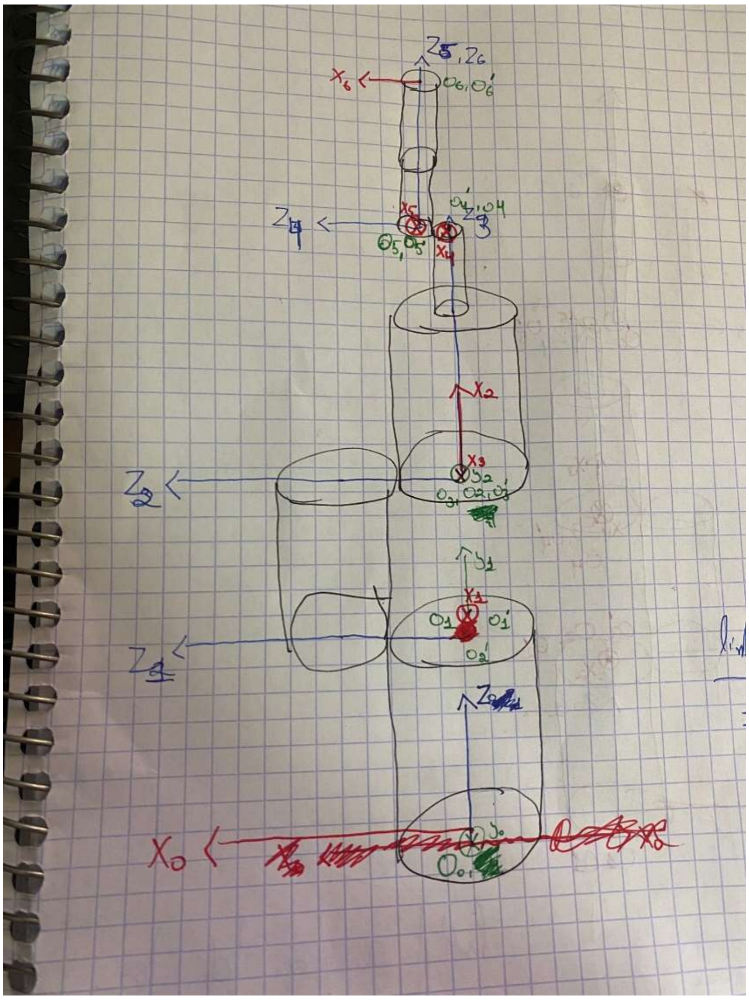
```
  <link name="sphere-end-effector">
  <visual>
   <origin xyz="0 0 0" rpy="0 0 0" />
   <geometry>
    <sphere radius="1"/>
```

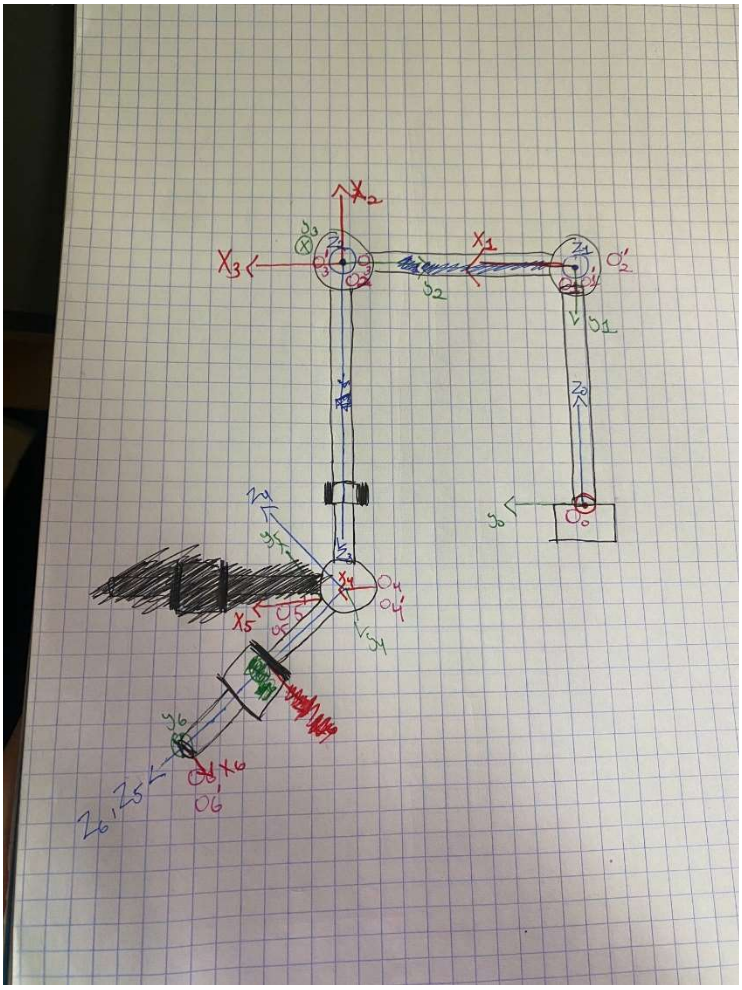
```
    </geometry>
    <material name="white"/>
  </visual>
 </link>

 <joint name="sphere_joint" type="fixed">
  <origin xyz="0 0 1.05" rpy="0 0 0"/>
  <parent link="end-effector-link"/>
  <child link="sphere-end-effector"/>
 </joint>
</robot>
```



Part III: Denavit-Hartenberg

1.



2. 

3.

Link	a_i	α_i	d_i	θ_i
1	0	$-\frac{\pi}{2}$	0.8	$\theta_1 - \frac{\pi}{2}$
2	0.8	0	0	$\theta_2 - \frac{\pi}{2}$
3	0	$\frac{\pi}{2}$	0	$\theta_3 + \frac{\pi}{2}$
4	0	$-\frac{\pi}{2}$	1.1	θ_4
5	0	$\frac{\pi}{2}$	0.05	θ_5
6	0	0	0.6	$\theta_6 + \frac{\pi}{2}$

4. The first frame is aligned to the base_link frame, but the first link is located in a 0.1 offset along the z axis. There is no rotation between those 2 links.

The last link is aligned to the last frame and there is no offset between them, Therefor:

$$T_0^B = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$T_{EE}^{n} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

5. a)

```
muhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$ rosrun tf tf_echo base_link end-effector-link
At time 1712875302.852
- Translation: [0.050, 0.000, 3.400]
- Rotation: in Quaternion [0.000, 0.000, 0.000, 1.000]
            in RPY (radian) [0.000, -0.000, 0.000]
            in RPY (degree) [0.000, -0.000, 0.000]
At time 1712875303.451
- Translation: [0.050, 0.000, 3.400]
- Rotation: in Quaternion [0.000, 0.000, 0.000, 1.000]
            in RPY (radian) [0.000, -0.000, 0.000]
            in RPY (degree) [0.000, -0.000, 0.000]
^Cmuhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$
```

b)

```
muhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$ rosrun tf tf_echo base_link end-effector-link
At time 1712875383.251
- Translation: [0.852, 0.599, -0.200]
- Rotation: in Quaternion [-0.501, 0.500, 0.499, 0.500]
            in RPY (radian) [-1.893, 1.568, -0.322]
            in RPY (degree) [-108.462, 89.856, -18.462]
At time 1712875383.951
- Translation: [0.852, 0.599, -0.200]
- Rotation: in Quaternion [-0.501, 0.500, 0.499, 0.500]
            in RPY (radian) [-1.893, 1.568, -0.322]
            in RPY (degree) [-108.462, 89.856, -18.462]
At time 1712875384.951
- Translation: [0.852, 0.599, -0.200]
- Rotation: in Quaternion [-0.501, 0.500, 0.499, 0.500]
            in RPY (radian) [-1.893, 1.568, -0.322]
            in RPY (degree) [-108.462, 89.856, -18.462]
```

Part IV: Forward Kinematics

4. The result for joints configuration j1 matches the results of tf as we can see in the next picture.

```
muhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$ rosservice call get_tf_ee
success: True
message: "translation [0.8517521084990601, 0.5993613529372814, -0.19976046729458904], rotation\
  \ [0.5007961679241607, -0.4996018366446332, -0.49920288087164444, -0.5003975287141568]"
muhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$ rosservice call get_ee_pose
success: True
message: "translation [ 0.85175211  0.59936135 -0.19976047] rotation [-0.50079617  0.49960184\
  \  0.49920288  0.50039753]"
muhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$ |
```

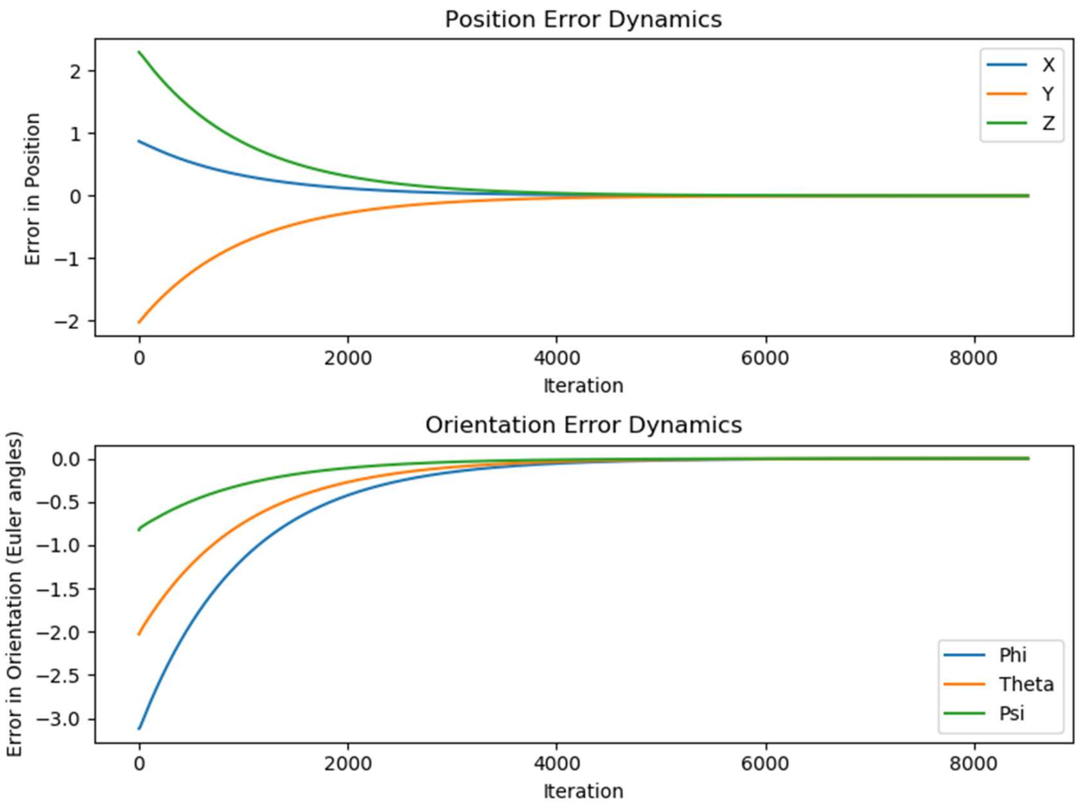
** in quaternion, q and -q resemble the same rotation.

Part V: Inverse Kinematics

1.

```
muhammadgha@DESKTOP-RN6FR8J:~/hw2_ws/src/scripts$ python hw2_services.py
[1.680388874611447, 2.327935788857583, 2.562857292534119]
```

4.




```
^CFinal Position Error:[ 0.00017568 -0.00040761  0.00046185], Final Orientation Error: [-0.00063093 -0.0004069
1 -0.00016114]
```

Part VII: Trajectory Planning

First of all, we notice that both joints have the same trajectory planning in terms of how both joints start from $\theta = 0$ $at\ t = 0, then\ \theta = \frac{\pi}{2}\ at\ t = 2\ and\ finally\ \theta = -\frac{\pi}{2}\ at\ t = 4.$

$therefor\ both\ joints\ should\ have\ the\ same\ defined\ \theta(t).$

$we\ define\ the\ following\ constraints:$

$\theta(0) = 0\ , \theta(2) = \frac{\pi}{2}, \theta(4) = -\frac{\pi}{2}, \dot{\theta}(0) = 0\ and\ \dot{\theta}(4) = 0.$

$and\ as\ a\ result\ we\ define\ a\ polynom\ of\ 4_{th}\ degree.$

$\theta(t) = a_4 t^4 + a_3 t^3 + a_2 t^2 + a_1 t + a_0.$

$from\ the\ defined\ constraints, we\ get\ the\ following:$

1. $a_0 = 0$

$2.\ a_1 = 0$

$3.\ 16a_4 + 8a_3 + 4a_2 + 2a_1 + a_0 = \frac{\pi}{2}$

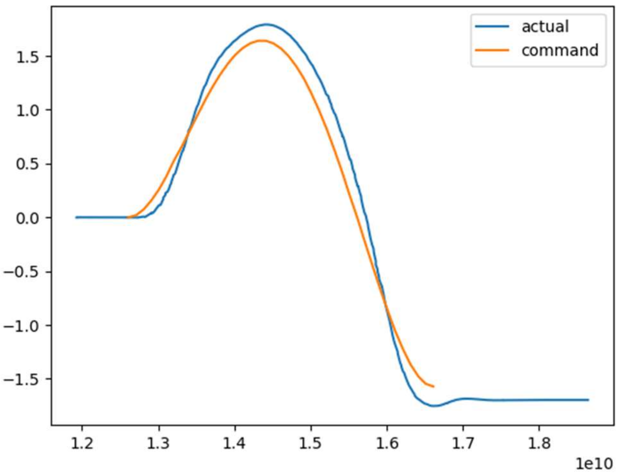
$4.\ 256a_4 + 64a_3 + 16a_2 + 4a_1 + a_0 = -\frac{\pi}{2}$

$5.\ 256a_\$ + 48a_3 + 8a_2 + a_1 = 0$

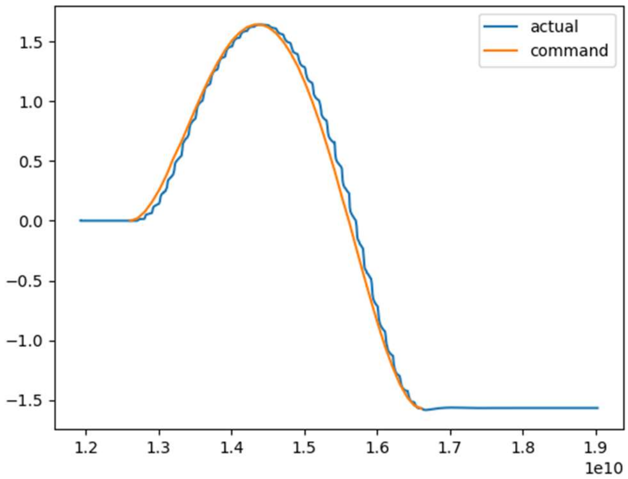
$after\ solving\ the\ set\ of\ equations, we\ get\ the\ following:$

$a_4 = 0.19726\quad a_3 = -1.129\ \ and\ a_2 = 2.0616.$

$\rightarrow \theta(t) = 0.19726t^4 - a.129t^3 + 2.0616t^2.$



Joint1



Joint2