CSE4026 - Introduction to Robotics and Control Theory
Project #1

Scara and Articulated Robot Arm Model

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Scara Robot

```
a1 = 1
a2 = 1
a3 = 1
a4 = 1
a5 = 0.5

T1 = 0
T2 = 0
T3 = 0

T1 = -(T1/180.0)*np.pi
T2 = -(T2/180.0)*np.pi
T3 = -(T3/180.0)*np.pi

R0_1 = [[np.cos(T1), -np.sin(T1), 0], [np.sin(T1), np.cos(T1), 0], [0, 0, 1]]
R1_2 = [[np.cos(T2), -np.sin(T2), 0], [np.sin(T2), np.cos(T2), 0], [0, 0, 1]]
R2_3 = [[np.cos(T3), -np.sin(T3), 0], [np.sin(T3), np.cos(T3), 0], [0, 0, 1]]

R0_2 = np.dot(R0_1, R1_2)

d0_1 = [[a2*np.cos(T1)], [a2*np.sin(T1)], [a1]]
d1_2 = [[a4*np.cos(T2)], [a4*np.sin(T2)], [a3]]
d2_3 = [[0], [0], [a5]]

H0_1 = np.concatenate((R0_1, d0_1), 1)
H0_1 = np.concatenate((H0_1, [[0,0,0,1]]), 0)

H1_2 = np.concatenate((R1_2, d1_2), 1)
H1_2 = np.concatenate((H1_2, [[0,0,0,1]]), 0)

H2_3 = np.concatenate((R2_3, d2_3), 1)
H2_3 = np.concatenate((H2_3, [[0,0,0,1]]), 0)

# Position of end effector
H0_2=np.dot(H0_1, H1_2)
H0_3=np.dot(H0_2, H2_3)
```

Figure 1. Homogeneous Translation Matrices of the Scara Robot Arm Model.

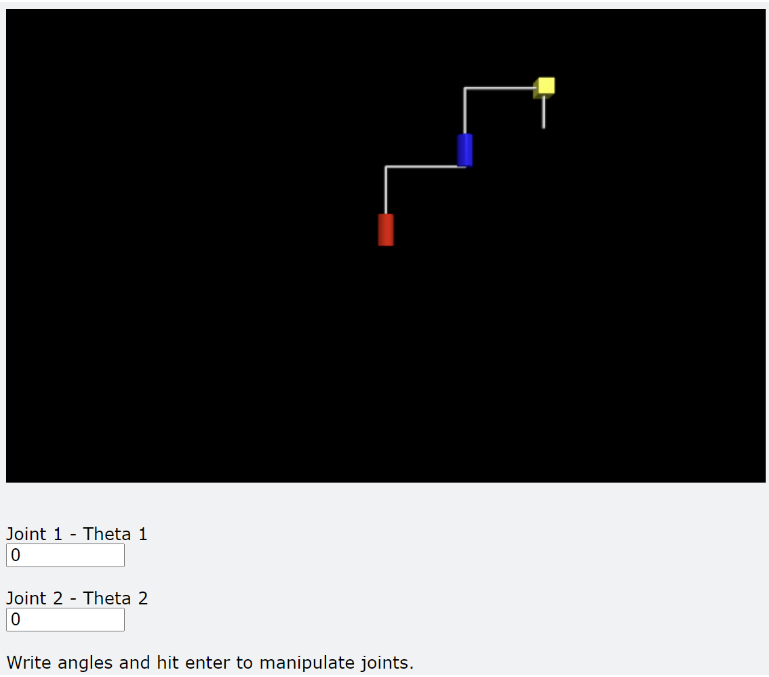
My Scara Robot consists of 3 degree of freedom and 5 links among them.

I draw a kinematic diagram of the robot and I initialized link lengths as a1, a2, a3, a4 and a5. I calculated rotation matrices R0_1, R1_2 and R2_3 of the robot as shown in Figure 1. Then, I calculated d0_1, d1_2 and d2_3. I concatenated these matrices to get homogeneous transformation matrices of the robot.

```python
joint1 = cylinder(pos=vector(0,0,0), axis=vector(0,0.4,0), radius=0.1, color=color.red)
link11 = curve(pos=[joint1.pos, vector(0,a1,0)])
link12 = curve(pos=[vector(0,a1,0), joint2_pos])
joint2 = cylinder(pos=joint2_pos, axis=vector(0,0.4,0), radius=0.1, color=color.blue)
#print(joint2_pos)
link21 = curve(pos=[joint2.pos, vector(joint2.pos.x, joint2.pos.y+a3, joint2.pos.z)])
link22 = curve(pos=[vector(joint2.pos.x, joint2.pos.y+a3, joint2.pos.z), joint3_pos])
joint3 = box(pos=joint3_pos, length=0.2, height=0.2, width=0.2, color=color.yellow)
link31 = curve(pos=[joint3_pos, vector(joint3.pos.x, joint3.pos.y-a5, joint3.pos.z)])
```

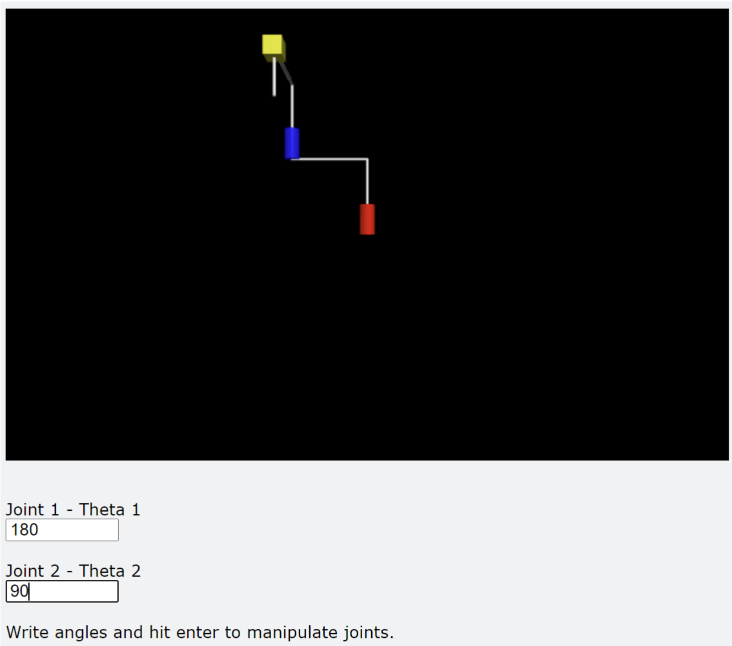
Figure 2. VPython to visualize the Scara Robot.

To visualize the robot I used VPython library of Python language. I used rotation and transformation parts of the homogeneous transformation matrices to visualize the robot.




```
############################################################
Theta1:  0
Theta2:  0
H0_1:
 [[ 1.  0.  0.  1.]
 [-0.  1.  0. -0.]
 [ 0.  0.  1.  1.]
 [ 0.  0.  0.  1.]]
H0_2:
 [[1. 0. 0. 2.]
 [0. 1. 0. 0.]
 [0. 0. 1. 2.]
 [0. 0. 0. 1.]]
H0_3:
 [[1.  0.  0.  2. ]
 [0.  1.  0.  0. ]
 [0.  0.  1.  2.5]
 [0.  0.  0.  1. ]]
Joint 2 Position:  <1, 1, -0>
Joint 3 Position:  <2, 2, 0>
End Effector Position <2, 2.5, 0>
############################################################
```

Figure 3. Model of the scara robot with Theta1 parameter 0 degree and Theta2 parameter 0 degree as shown in left. Homogeneous transformation matrices and positions of joints and end effector as shown in right in this state.




```
###############################################################
Theta1:  180
Theta2:  90
H0_1:
 [[-1.0000000e+00  1.2246468e-16  0.0000000e+00 -1.0000000e+00]
 [-1.2246468e-16 -1.0000000e+00  0.0000000e+00 -1.2246468e-16]
 [ 0.0000000e+00  0.0000000e+00  1.0000000e+00  1.0000000e+00]
 [ 0.0000000e+00  0.0000000e+00  0.0000000e+00  1.0000000e+00]]
H0_2:
 [[-1.8369702e-16 -1.0000000e+00  0.0000000e+00 -1.0000000e+00]
 [ 1.0000000e+00 -1.8369702e-16  0.0000000e+00  1.0000000e+00]
 [ 0.0000000e+00  0.0000000e+00  1.0000000e+00  2.0000000e+00]
 [ 0.0000000e+00  0.0000000e+00  0.0000000e+00  1.0000000e+00]]
H0_3:
 [[-1.8369702e-16 -1.0000000e+00  0.0000000e+00 -1.0000000e+00]
 [ 1.0000000e+00 -1.8369702e-16  0.0000000e+00  1.0000000e+00]
 [ 0.0000000e+00  0.0000000e+00  1.0000000e+00  2.5000000e+00]
 [ 0.0000000e+00  0.0000000e+00  0.0000000e+00  1.0000000e+00]]
Joint 2 Position:  <-1, 1, -1.22465e-16>
Joint 3 Position:  <-1, 2, 1>
End Effector Position <-1, 2.5, 1>
###############################################################
```

Figure 4. Model of the scara robot with Theta1 parameter 180 degree and Theta2 parameter 90 degree as shown in left. Homogeneous transformation matrices and positions of joints and end effector as shown in right in this state.

Articulated Robot

```
a1 = 1
a2 = 1
a3 = 1

T1 = 0
T2 = 0
T3 = 0

T1 = -(T1/180.0)*np.pi
T2 = (T2/180.0)*np.pi
T3 = -(T3/180.0)*np.pi


R0_1 = [[np.cos(T1), 0, np.sin(T1)], [np.sin(T1), 0, -np.cos(T1)], [0, 1, 0]]
R1_2 = [[np.cos(T2), np.sin(T2), 0], [np.sin(T2), -np.cos(T2), 0], [0, 0, -1]]
R2_3 = [[np.cos(T3), -np.sin(T3), 0], [np.sin(T3), np.cos(T3), 0], [0, 0, 1]]

R0_2 = np.dot(R0_1, R1_2)
R0_3 = np.dot(R0_2, R2_3)

d0_1 = [[0], [0], [a1]]
d1_2 = [[a2*np.cos(T2)], [a2*np.sin(T2)], [0]]
d2_3 = [[a3*np.cos(T3)], [a3*np.sin(T3)], [0]]

H0_1 = np.concatenate((R0_1, d0_1), 1)
H0_1 = np.concatenate((H0_1, [[0,0,0,1]]), 0)

H1_2 = np.concatenate((R1_2, d1_2), 1)
H1_2 = np.concatenate((H1_2, [[0,0,0,1]]), 0)

H2_3 = np.concatenate((R2_3, d2_3), 1)
H2_3 = np.concatenate((H2_3, [[0,0,0,1]]), 0)


H0_2 = np.dot(H0_1, H1_2)
H0_3 = np.dot(H0_2, H2_3) # Position of end effector
```

Figure 5. Homogeneous Translation Matrices of the Articulated Robot Arm Model.

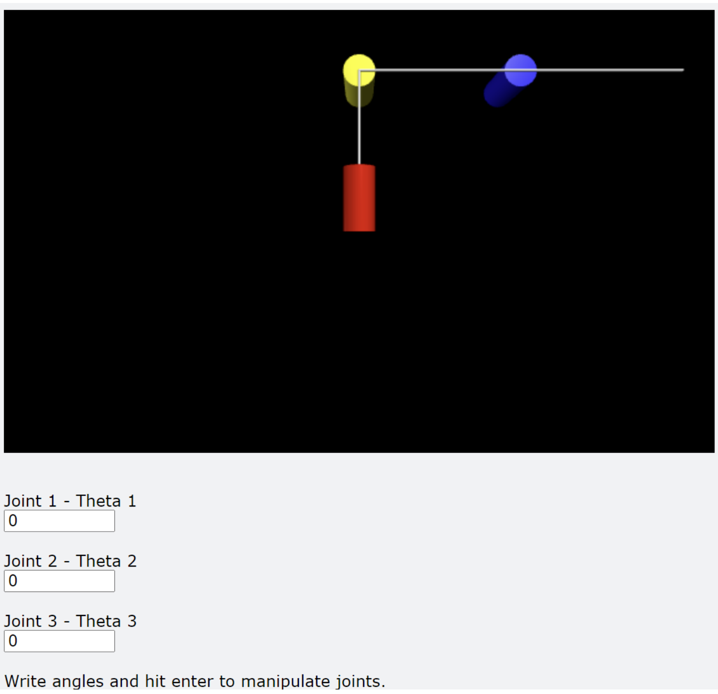
My Articulated Robot consists of 3 degree of freedom and 3 links among them.

I draw a kinematic diagram of the robot and I initialized link lengths as a1, a2, and a3. I calculated rotation matrices R0_1, R1_2 and R2_3 of the robot as shown in Figure 5. Then, I calculated d0_1, d1_2 and d2_3. I concatenated these matrices to get homogeneous transformation matrices of the robot.

```
joint0 = cylinder(pos=vector(0,0,0), axis=vector(0,0.4,0), radius=0.1, color=color.red)
link00 = curve(pos=[joint0.pos, vector(0,a1,0)])
joint1_axis = rotation_y(vector(0,0,-0.4), -T1)
joint1 = cylinder(pos=joint1_pos, axis=joint1_axis, radius=0.1, color=color.yellow)
link10 = curve(pos=[joint1.pos, joint2_pos])
joint2_axis = rotation_y(vector(0,0,-0.4), -T1)
joint2 = cylinder(pos=joint2_pos, axis=joint2_axis, radius=0.1, color=color.blue)
link20 = curve(pos=[joint2.pos, end_effector_pos])
```

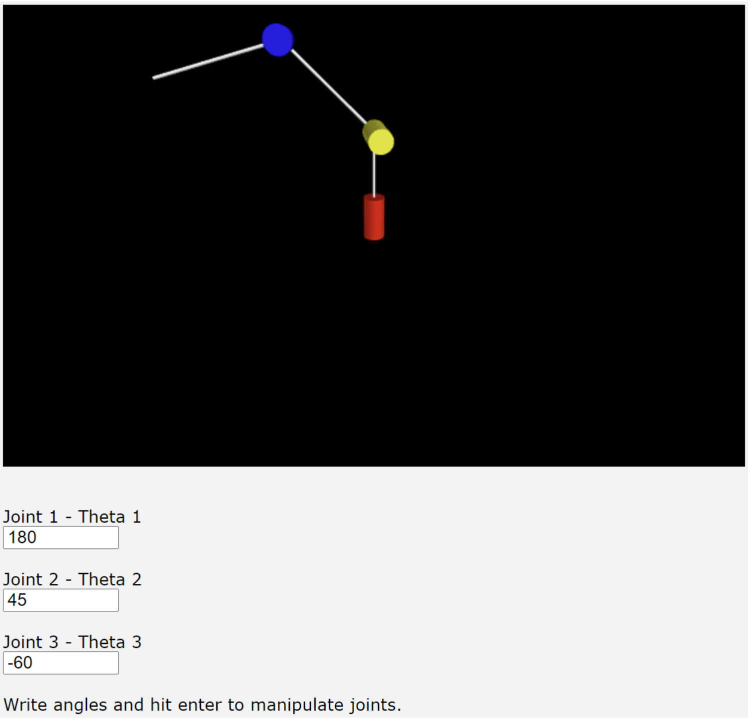
Figure 6. VPython to visualize the Articulated Robot.

To visualize the articulated robot I used VPython library of Python language. I used rotation and transformation parts of the homogeneous transformation matrices to visualize the robot.




```
##############################################################
Theta1:  0
Theta2:  0
Theta3:  0
H0_1:
 [[ 1.  0. -0.  0.]
 [-0.  0. -1.  0.]
 [ 0.  1.  0.  1.]
 [ 0.  0.  0.  1.]]
H0_2:
 [[ 1.  0.  0.  1.]
 [ 0.  0.  1.  0.]
 [ 0. -1.  0.  1.]
 [ 0.  0.  0.  1.]]
H0_3:
 [[ 1.  0.  0.  2.]
 [ 0.  0.  1.  0.]
 [ 0. -1.  0.  1.]
 [ 0.  0.  0.  1.]]
Joint 2 Position:  <0, 1, 0>
Joint 3 Position:  <1, 1, 0>
End Effector Position <2, 1, 0>
##############################################################
```

Figure 7. Model of the articulated robot with Theta1 parameter 0 degree, Theta2 parameter 0 and Theta3 parameter 0 degree as shown in left. Homogeneous transformation matrices and positions of joints and end effector as shown in right in this state.




```
############################################################
Theta1:  180
Theta2:  45
Theta3:  -60
H0_1:
 [[-1.0000000e+00  0.0000000e+00 -1.2246468e-16  0.0000000e+00]
 [-1.2246468e-16  0.0000000e+00  1.0000000e+00  0.0000000e+00]
 [ 0.0000000e+00  1.0000000e+00  0.0000000e+00  1.0000000e+00]
 [ 0.0000000e+00  0.0000000e+00  0.0000000e+00  1.0000000e+00]]
H0_2:
 [[-7.07106781e-01 -7.07106781e-01  1.22464680e-16 -7.07106781e-01]
 [-8.65956056e-17 -8.65956056e-17 -1.00000000e+00 -8.65956056e-17]
 [ 7.07106781e-01 -7.07106781e-01  0.00000000e+00  1.70710678e+00]
 [ 0.00000000e+00  0.00000000e+00  0.00000000e+00  1.00000000e+00]]
H0_3:
 [[-9.65925826e-01  2.58819045e-01  1.22464680e-16 -1.67303261e+00]
 [-1.18291797e-16  3.16961915e-17 -1.00000000e+00 -2.04887403e-16]
 [-2.58819045e-01 -9.65925826e-01  0.00000000e+00  1.44828774e+00]
 [ 0.00000000e+00  0.00000000e+00  0.00000000e+00  1.00000000e+00]]
Joint 2 Position:  <0, 1, 0>
Joint 3 Position:  <-0.707107, 1.70711, -8.65956e-17>
End Effector Position <-1.67303, 1.44829, -2.04887e-16>
############################################################
```

Figure 8. Model of the articulated robot with Theta1 parameter 180 degree, Theta2 parameter 45 and Theta3 parameter -60 degree as shown in left. Homogeneous transformation matrices and positions of joints and end effector as shown in right in this state.