EE366L/CE366L: Introduction to Robotics Lab

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Lab 4: Forward Kinematics

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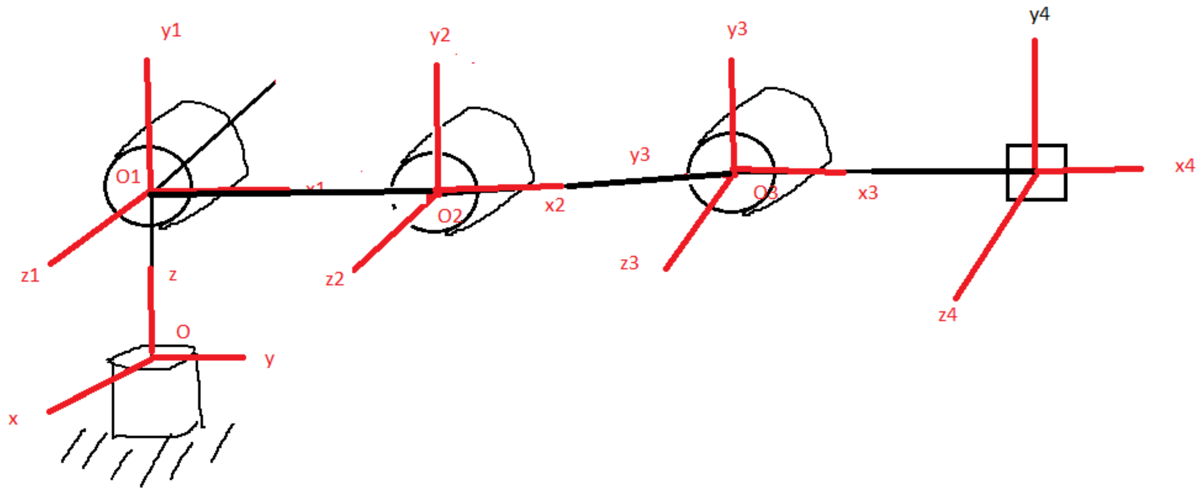
Task 4.1

DH Frame Assignment



Task 4.2

Link	α_i (degrees)	a_i (cm)	θ_i(degrees)	d_i(cm)
1	90	0	θ_1	L1=14.1 cm
2	0	L2=10.3 cm	θ_2	0
3	0	L3=10.3cm	θ_3	0
4	0	L4=9.2 cm	θ_4	0

We saw that the difference between the actual and the model was 3 mm. Here, by model we mean the manufacturer provided 3D model.

Task 4.3

a, b)

Matlab Script

```
syms('theta_1');
syms('theta_2');
syms('theta_3');
syms('theta_4');
T01 = [cos(theta_1) 0 sin(theta_1) 0; sin(theta_1) 0 -cos(theta_1) 0;0 1 0 141; 0 0 0
1];
T12 = [cos(theta_2) -sin(theta_2) 0 103*cos(theta_2); sin(theta_2) cos(theta_2) 0
103*sin(theta_2);0 0 1 0; 0 0 0 1];
```

```
T23 = [cos(theta_3) -sin(theta_3) 0 103*cos(theta_3); sin(theta_3) cos(theta_3) 0
103*sin(theta_3);0 0 1 0; 0 0 0 1];
T34 = [cos(theta_4) -sin(theta_4) 0 103*cos(theta_4); sin(theta_4) cos(theta_4) 0
92*sin(theta_4);0 0 1 0; 0 0 0 1];
T04 = T01 * T12 * T23 * T34;
T = simplify(T04)
```

c)

$$\begin{pmatrix} \sigma_3 \cos(\theta_1) & -\sigma_1 \cos(\theta_1) & \sin(\theta_1) & \cos(\theta_1)\, \sigma_2 \\ \sigma_3 \sin(\theta_1) & -\sigma_1 \sin(\theta_1) & -\cos(\theta_1) & \sin(\theta_1)\, \sigma_2 \\ \sigma_1 & \sigma_3 & 0 & 92\, \sigma_1 + 103 \sin(\theta_2 + \theta_3) + 103 \sin(\theta_2) + 141 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Where,

$$\sigma_1 = \sin(\theta_2 + \theta_3 + \theta_4)$$

$$\sigma_1 = \sin(\theta_2 + \theta_3 + \theta_4)$$

$$\sigma_3 = \cos(\theta_2 + \theta_3 + \theta_4)$$

Here, the first three elements in the 4^{th} column define the position of the end-effector. The first three columns and rows correspond to the rotation matrix with respect to the base frame which defines the orientation of the end-effector.

Task 4.4

Code

```
function [x,y,z, R] = findPincher(jointAngles)


theta_1 = jointAngles(1);
theta_2 = jointAngles(2);
theta_3 = jointAngles(3);
theta_4 = jointAngles(4);


T =[cos(theta_2 + theta_3 + theta_4)*cos(theta_1), -sin(theta_2 + theta_3 +
theta_4)*cos(theta_1), sin(theta_1), cos(theta_1)*(92*cos(theta_2 + theta_3 +
theta_4) + 103*cos(theta_2 + theta_3) + 103*cos(theta_2)); cos(theta_2 + theta_3
+ theta_4)*sin(theta_1), -sin(theta_2 + theta_3 + theta_4)*sin(theta_1), -
cos(theta_1), sin(theta_1)*(92*cos(theta_2 + theta_3 + theta_4) + 103*cos(theta_2
+ theta_3) + 103*cos(theta_2)); sin(theta_2 + theta_3 + theta_4), cos(theta_2 +
theta_3 + theta_4), sym(0), 92*sin(theta_2 + theta_3 + theta_4) + 103*sin(theta_2
+ theta_3) + 103*sin(theta_2) + 141; sym(0), sym(0), sym(0), sym(1)];
format short
```

```
x = round(T(1,4),3);
y = round(T(2,4),3);
z = round(T(3,4),3);
R = [T(1,1:3); T(2,1:3); T(3,1:3)];


end
```

Task 4.5

The 4-5 random configurations for the manipulator are the following where all the results match.

(pi,pi/3,pi/6,pi/8)

(0,pi/3,0,pi/3)

(pi/3,pi/3,pi/3,pi/3)

(pi/4,pi.4,pi/4,pi/4)

Task 4.6

Zero Configuration of the Robot

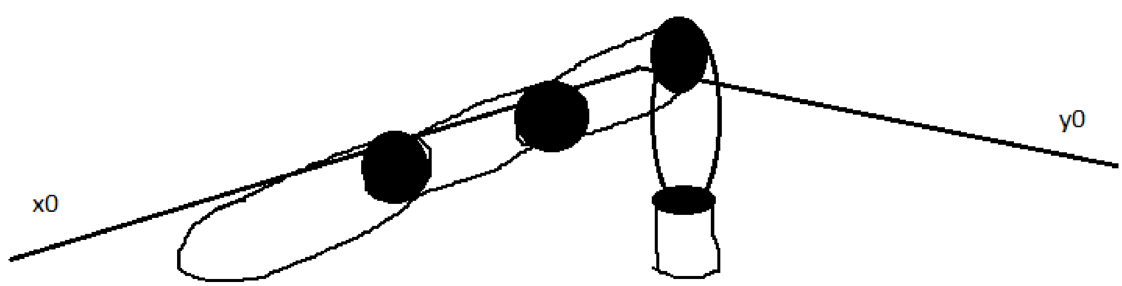


Table 4.1

Motor ID	DH Joint Angle	Servo Angle
1	0	0
2	0	90
3	0	0
4	0	0

Matlab Code for errorCode

```
function f= setPosition(arb, jointAngles) % order from base to wrist in radians
    jointAngles(2) = - jointAngles(2) + pi/2; % the offset in motor 1 is
determined to be 90 degrees
```

```
    jointAngles(3) = - jointAngles(3);
    jointAngles(4) = - jointAngles(4);
    f = 1;
    for i = 1:4
        if jointAngles(i) >=5*pi/6 || jointAngles(i) <= -5*pi/6
            f = 0;
        end
    end

    if f
        arb.setpos([jointAngles 0],[50,50,50,50,50]);
    end
end
```

Task 4.7

Configuration (θ_1, θ_2, θ_3, θ_4) (rad)	**Actual Robot Location(x,y,z) (mm)**	**findPincherModel Location (x,y,z)**	**Euclidean Distance (mm)**
-0.4309,2.5802,-1.9990, -1.4841	56,-22.9,180	50.7682,-23.3387,180.1519	5.252
-0.9365,1.0832,-0.6170,-1.6643	120,-142,189	102.9743,-139.9648,192.6104	17.523
2.2271,2.2866,1.3203,0.5008	130,-169,90	129.3261,-167.9126,96.818	6.937
1.6342,1.3668,1.9861,0.6339	9,-130,160	8.9271,-140.6087,151.4352	13.63
1.5198, 1.8296,1.5303,1.7947	2,-90,130	-4.4625,-87.4314,135.112	8.631

There is error observed between the coordinates produced by the findPincher model and the measured distance. This can be due to human error in determining the projection of the end-effector position on the x-y plane. There could be a parallax error when measuring the height of the end-effector. This error would become larger for instances where the end-effector was at a larger height above the base frame's x-y plane.

Task 4.8

<u>Code</u>

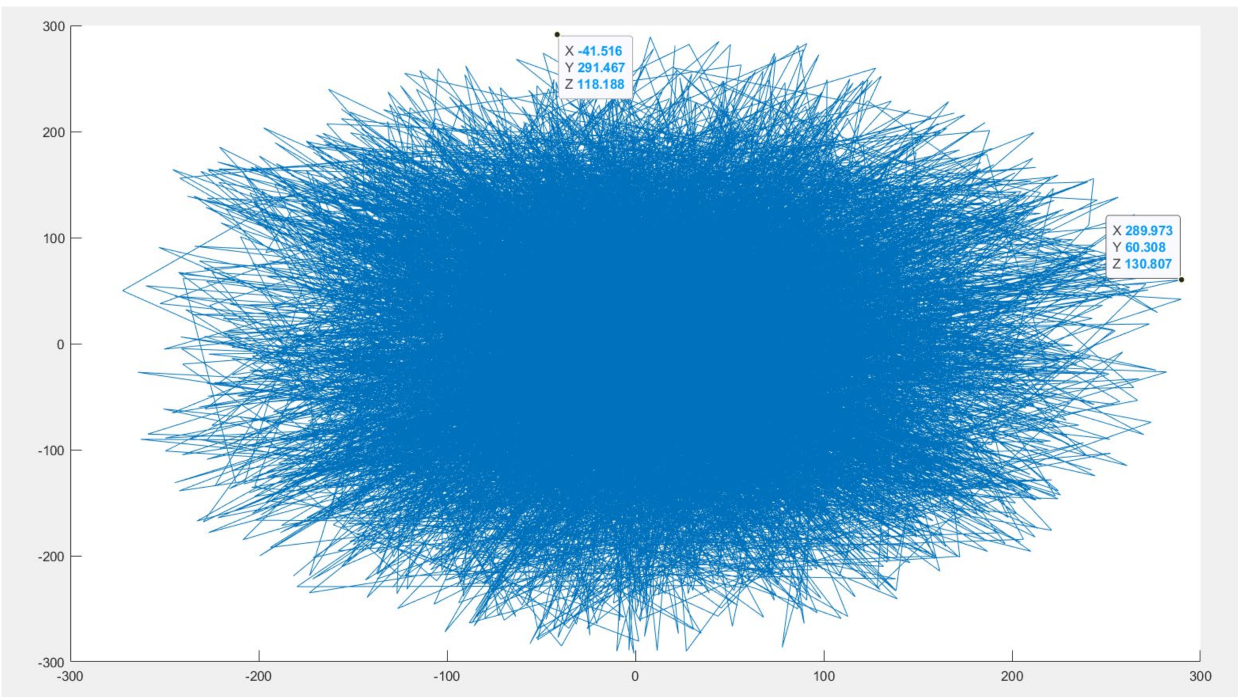
```
N = 5000;
theta_min = -5*pi/6;
theta_max = 5 * pi/6;

theta1 = theta_min +(theta_max-theta_min)*rand(N,1);
theta2 = theta_min +(theta_max-theta_min)*rand(N,1);
theta3 = theta_min +(theta_max-theta_min)*rand(N,1);
theta4 = theta_min +(theta_max-theta_min)*rand(N,1);
```

```
X =[];
Y=[];
Z=[];
for i = 1:N
    [x, y, z, R] = findPincher([theta1(i), theta2(i), theta3(i), theta4(i)]);
    X(i)=x;
    Y(i) = y;
    Z(i) = z;

end
plot3(X,Y,Z)
```

Projection in the x-y Plane



The maximum horizontal reach is around 291.467 in the y direction and 289.973 in the x direction.