MCE4101
Robotic Engineering

Assignment 6

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Assignment 6 : Q1

Q1. Given DH table for RPP manipulator.

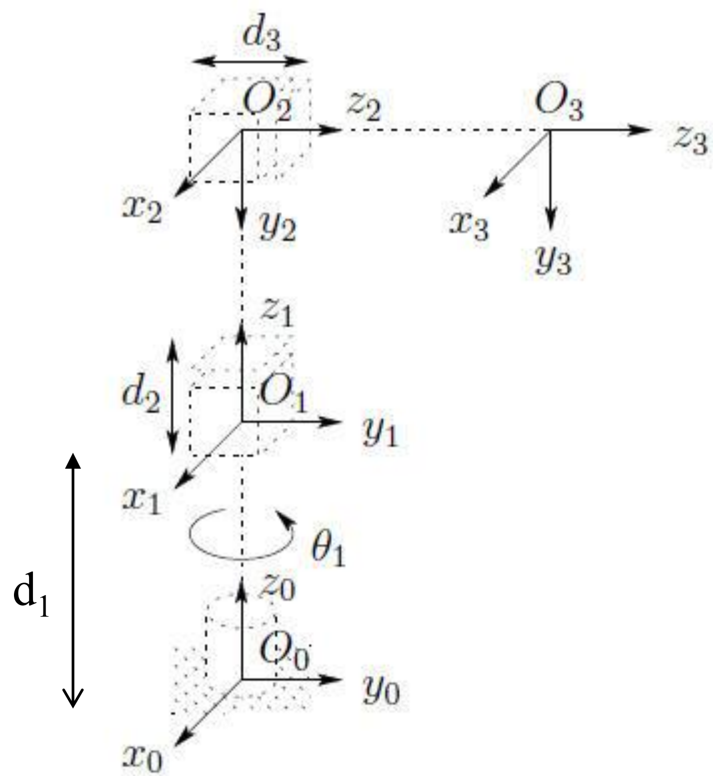
a. Obtain θ_1, d_2 *and* d_3 by inverse kinematic analysis method for positions: P0 (0,0.2,0.5) and P1 (1,1.2,0.5).

b. With the <u>calculated angle and movements</u>, obtain the trajectory, velocities and acceleration <u>equations</u> for P0 and P1 with required time as 2 s. Initial and final velocity is 0 unit/s.

Given

d1 = 0.5

Link	a_i	α_i	d_i	θ_i
1	0	0	d_1 (offset)	θ_1^*
2	0	-90°	d_2^*	0
3	0	0	d_3^*	0



a)

```
%RPP
clear all; clc;
%A) DH and T0end
syms th1_1 th1_2 d2_1 d2_2 d3_1 d3_2
d1 = 0.5;
%A) Analytic Method
%POSITION1
Pend1 = [0; 0.2; 0.5];
Xc_1 = 0; Yc_1 =0.2; Zc_1 = 0.5;
d2_1 = Zc_1-d1
th1_1 = atan2(Yc_1,Xc_1)
th1_1_deg = atan2d(Yc_1,Xc_1)
d3_1 = Yc_1/cosd(th1_1)
%DH Table
%%L = link([alpha A theta D])
L1 = link([0 0 th1_1 d1,0]);
L2 = link([-pi/2 0 0 d2_1,1]);
L3 = link([0 0 0 d3_1,1]);
iVMErobot_1 = robot({L1 L2 L3});
T03_1 = fkine(iVMErobot_1, [th1_1 d2_1 d3_1])
P0end_1 = T03_1*[0;0;0;1]
%POSITION2
Pend2 = [1; 1.2; 0.5];
Xc_2 = 1; Yc_2 =1.2; Zc_2 = 0.5;
d2_2 = Zc_2-d1
th1_2 = atan2(Yc_2,Xc_2)
th1_2_deg = atan2d(Yc_2,Xc_2)
d3_2 = Yc_2/cosd(th1_2)
%DH Table
%%L = link([alpha A theta D])
L1 = link([0 0 th1_2 d1,0]);
L2 = link([-pi/2 0 0 d2_2,1]);
L3 = link([0 0 0 d3_2,1]);
iVMErobot_2 = robot({L1 L2 L3});
T03_2 = fkine(iVMErobot_2, [th1_2 d2_2 d3_2])
P0end_2 = T03_2*[0;0;0;1]

%ikine POSITION1
position1 = transl(Pend1);
IG1 = [0 0 0]; %Data given
M = [1 1 1 0 0 0]; %3DOF
Data1_rad = ikine(iVMErobot_1, position1, IG1, M)
Data1_deg = rad2deg(Data1_rad)
%T0end1 = fkine(iVMErobot_1, Data1_rad)

%ikine POSITION2
position2 = transl(Pend2);
IG2 = [0 0 0]; %Data given
M = [1 1 1 0 0 0]; %3DOF
Data2_rad = ikine(iVMErobot_2, position2, IG2, M)
Data2_deg = rad2deg(Data2_rad)
%T0end2 = fkine(iVMErobot_2, Data2_rad)
```

```
d2_1 =

     0

th1_1 =

    1.5708

th1_1_deg =

    90

d3_1 =

    0.2001
```

```
d2_2 =

     0

th1_2 =

    0.8761

th1_2_deg =

    50.1944

d3_2 =

    1.2001
```

b)

Q2.m | FN_Q1.m | Assignment6Q1.m

```
%B) Polynomial trajectories, velocities amd accelerations equation
%Cubic Polynomial
t0 = 0; tf = 2;
%joint 1
q1_0 = Data1_deg(1,1);
q1_f = Data2_deg(1,1);
v1_0 = 0; v1_f = 0;
Y1 = [q1_0;v1_0;q1_f;v1_f];
B1 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
%A1 = [a1_0; a1_1; a1_2; a1_3];
A1 = inv(B1)*Y1

%joint 2
q2_0 = Data1_deg(1,2);
q2_f = Data2_deg(1,2);
v2_0 = 0; v2_f = 0;
Y2 = [q2_0;v2_0;q2_f;v2_f];
B2 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
%A2 = [a2_0; a2_1; a2_2; a2_3];
A2 = inv(B2)*Y2

%joint 3
q3_0 = Data1_deg(1,3);
q3_f = Data2_deg(1,3);
v3_0 = 0; v3_f = 0;
Y3 = [q3_0;v3_0;q3_f;v3_f];
B2 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
%A3 = [a3_0; a3_1; a3_2; a3_3];
A3 = inv(B2)*Y3
```

```
A1 =

         0
         0
  -29.8542
    9.9514

A2 =

   1.0e-14 *

         0
         0
   -0.2385
    0.0795

A3 =

   11.4592
         0
   58.5298
  -19.5099
```

$$
\begin{aligned}
q_0 &= a_0 + a_1 t_0 + a_2 t_0^2 + a_3 t_0^3 \\
v_0 &= a_1 + 2a_2 t_0 + 3a_3 t_0^2 \\
q_f &= a_0 + a_1 t_f + a_2 t_f^2 + a_3 t_f^3 \\
v_f &= a_1 + 2a_2 t_f + 3a_3 t_f^2
\end{aligned}
$$

$$
\begin{matrix} q_0 = \\ v_0 = \\ q_f = \\ v_f = \end{matrix}
\begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 \\ 0 & 1 & 2t_0 & 3t_0^2 \\ 1 & t_f & t_f^2 & t_f^3 \\ 0 & 1 & 2t_f & 3t_f^2 \end{bmatrix}
\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}
$$

Assignment 6 : Q2

Q2. From Q1) RPP robot,

a. Obtain $\theta_1, d_2\ and\ d_3$ by inverse kinematic (invk) function for positions: P0 (0,0.2,0.5) and P1 (1,1.2,0.5). For P0 use initial guess as (0, 0, 0) and P1 use initial guess as (pi, 0, 0).

b. With the angle and movements obtained, find the trajectory data using jtraj for P0 and P1 with required time as 2s with sampling of 0.1s.

a)

signment6Q2.m*

```
%RPP
clear all; clc;
%A) DH and T0end
syms th_1 th_2 d2_1 d2_2 d3_1 d3_2
d1 = 0.5;
%A) Analytic Method
%POSITION1
Pend1 = [0;0.2;0.5]; %Xc;Yc;Zc
d2_1 = Pend1(3,1)-d1
th1_1 = atan2(Pend1(1,1),-Pend1(2,1))
th1_1_deg = atan2d(Pend1(1,1),-Pend1(2,1))
d3_1 = Pend1(1,1)/sin(th1_1)-d1
%DH Table
%%L = link([alpha A theta D])
L1 = link([0 0 th1_1 d1,0]);
L2 = link([-pi/2 0 0 d2_1,1]);
L3 = link([0 0 0 d3_1,1]);
iVMErobot_1 = robot({L1 L2 L3});
%POSITION2
Pend2 = [1;1.2;0.5]; %Xc;Yc;Zc
d2_2 = Pend2(3,1)-d1
th1_2 = atan2(Pend2(1,1),-Pend2(2,1))
th1_2_deg = atan2d(Pend2(1,1),-Pend2(2,1))
d3_2 = Pend2(1,1)/sin(th1_2)-d1
%DH Table
%%L = link([alpha A theta D])
L1 = link([0 0 th1_2 d1,0]);
L2 = link([-pi/2 0 0 d2_2,1]);
L3 = link([0 0 0 d3_2,1]);
iVMErobot_2 = robot({L1 L2 L3});
```

```
d2_1 =

     0

th1_1 =

    3.1416

th1_1_deg =

   180

d3_1 =

   -0.5000
```

```
d2_2 =

     0

th1_2 =

    2.4469

th1_2_deg =

  140.1944

d3_2 =

    1.0620
```

```
Data1_rad =

         0         0    0.2000

Data1_deg =

         0         0   11.4592

Data2_rad =

    2.4469    0.0000   -1.5620

Data2_deg =

  140.1944    0.0000  -89.4989
```

```
%ikine POSITION1
position1 = transl(Pend1);
IG1 = [0 0 0]; %Data given
M = [1 1 1 0 0 0]; %3DOF
Data1_rad = ikine(iVMErobot_1, position1, IG1, M)
Data1_deg = rad2deg(Data1_rad)
%ikine POSITION2
position2 = transl(Pend2);
IG2 = [pi 0 0]; %Data given
M = [1 1 1 0 0 0]; %3DOF
Data2_rad = ikine(iVMErobot_2, position2, IG2, M)
Data2_deg = rad2deg(Data2_rad)
```

b)

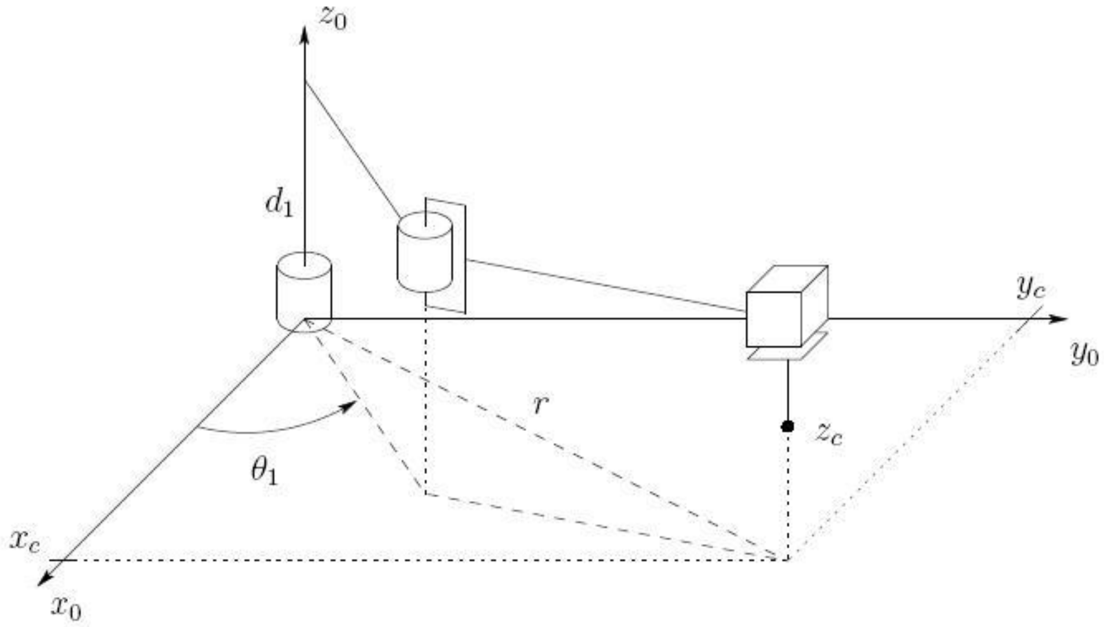
```
%B) Fina trajextory data using jtraj
%POSITION1
%POSITION2
t = [0:0.1:2]
Q = jtraj(Data1_rad,Data2_rad,t)
for i = 1:3
    Q1(i) = Q(i,1);
    Q2(i) = Q(i,2);
    Q3(i) = Q(i,3);
    figure(1)
    plot(iVMErobot_1,[Q1(i),Q2(i),Q3(i)])
    figure(2)
    pause(1)
    plot(iVMErobot_2,[Q1(i),Q2(i),Q3(i)])
    pause(1)
%end
```

```
t =

  Columns 1 through 15

         0    0.1000    0.2000    0.3000    0.4000    0.5000    0.6000    0.7000    0.8000    0.9000    1.0000    1.1000    1.2000    1.3000    1.4000

  Columns 16 through 21

    1.5000    1.6000    1.7000    1.8000    1.9000    2.0000
```

```
Q =

         0         0    0.2000
    0.0028    0.0000    0.1980
    0.0209    0.0000    0.1849
    0.0651    0.0000    0.1531
    0.1417    0.0000    0.0979
    0.2533    0.0000    0.0176
    0.3990    0.0000   -0.0874
    0.5754    0.0000   -0.2144
    0.7767    0.0000   -0.3593
    0.9956    0.0000   -0.5169
    1.2234    0.0000   -0.6810
    1.4513    0.0000   -0.8451
    1.6701    0.0000   -1.0027
    1.8714    0.0000   -1.1477
    2.0478    0.0000   -1.2747
    2.1936    0.0000   -1.3797
    2.3051    0.0000   -1.4600
    2.3817    0.0000   -1.5152
    2.4259    0.0000   -1.5470
    2.4440    0.0000   -1.5600
    2.4469    0.0000   -1.5620
```

Assignment 6 : Q3

Q3. With RRP (SCARA).
Given DH table and Transformation matrix.
a). Find the Jacobian Matrix J equation, J will be 6x3 matrix.
b). Obtain the Jacobian Matrix value when
a1 = 3
a2 = 5
θ1 =20° , θ2 = -10°
d1 = 5 (Link offset from base)
d3 = 1



a) $j = \begin{bmatrix} j_v \\ j_w \end{bmatrix}$

$$j_v = \begin{bmatrix} Z_0(O_3 - O_0) & Z_1(O_3 - O_1) & Z_2 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{\partial}{\partial 1}\begin{pmatrix} a_1C_1 + a_2C_1C_2 - a_2S_1S_2 \\ a_1S_1 + a_2C_1S_2 + a_2C_2S_1 \\ d_1 - d_3 \end{pmatrix} & \frac{\partial}{\partial 2}\begin{pmatrix} \cancel{a_1C_1} + a_2C_1C_2 - a_2S_1S_2 \\ \cancel{a_1S_1} + a_2C_1S_2 + a_2C_2S_1 \\ \cancel{d_1} - d_3 \end{pmatrix} - \begin{pmatrix} \cancel{a_1C_1} \\ \cancel{a_1S_1} \\ \cancel{d_1} \end{pmatrix} & \begin{matrix} 0 \\ 0 \\ -1 \end{matrix} \end{bmatrix}$$

$$= \begin{bmatrix} -a_1S_1 + a_2(-S_1)C_2 - a_2C_1S_2 & a_2C_1(-S_2) - a_2S_1C_2 & 0 \\ a_1C_1 + a_2(-S_1)S_2 + a_2C_2C_1 & a_2C_1C_2 + a_2(-S_2)S_1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

$$= \begin{bmatrix} -a_1S_1 - a_2S_{12} & -a_2S_{12} & 0 \\ a_1C_1 + a_2C_{12} & a_2C_{12} & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

$$j_w = \begin{bmatrix} Z_0, & Z_1, & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix}$$

$$j_{eq} = \begin{bmatrix} -a_1S_1 - a_2S_{12} & -a_2S_{12} & 0 \\ a_1C_1 + a_2C_{12} & a_2C_{12} & 0 \\ 0 & 0 & -1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix}$$

b) $$j_{eq} = \begin{bmatrix} -a_1S_1 - a_2S_{12} & -a_2S_{12} & 0 \\ a_1C_1 + a_2C_{12} & a_2C_{12} & 0 \\ 0 & 0 & -1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ -1 & -1 & 0 \end{bmatrix}$$

$\theta_1 = 20^\circ$
$\theta_2 = -10^\circ$
$a_1 = 3$
$a_2 = 5$

$$= \begin{bmatrix} -1.8943 & -0.866 & 0 \\ 7.7431 & 4.9240 & 0 \\ 0 & 0 & -1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix}$$

Assignment 6 : Q4

Q4. Using MATLAB and obtain Jacobian parameter for Q3b) by using jacob0 from robotic toolbox when

$a1 = 3$

$a2 = 5$

$\theta 1 = 20°$, $\theta 2 = -10°$

$d1 = 5$ (Link offset from base)

$d3 = 1$

Attached your code and result.

```
Jvalue =

   -1.8943   -0.8682    0.0000
    7.7431    4.9240   -0.0000
   -0.0000   -0.0000   -1.0000
    0.0000    0.0000         0
         0         0         0
    1.0000    1.0000         0
```

```
clear all; clc;
syms th1 th2 a1 a2 d1 d3
%th1 = 0; th2 = 0;
%B When a1 = 3; a2 =5; d1 =5;  d3 = 1;
%SCARA(RRP) + 1DOF
L1 = link([0 a1 th1 d1,0]);
L2 = link([pi a2 th2 0,0]);
L3 = link([0 0 0 d3,1]);
RRP_1 = robot({L1});
RRP_2 = robot({L1 L2});
RRP_3 = robot({L1 L2 L3});
T01 = fkine(RRP_1, [th1])
T02 = fkine(RRP_2, [th1 th2])
T03 = fkine(RRP_3, [th1 th2 d3])
O1 = T01(:,4)
O2 = T02(:,4)
O3 = T03(:,4)
Z1 = T01(:,3)
Z2 = T02(:,3)
Z3 = T03(:,3)
Jvalue = jacob0(RRP_3,[degtorad(th1) degtorad(th2) d3])
%B When Jvalue = jacob0(RRP_3,[degtorad(20) degtorad(-10) 1])
```