Homework 5: RRR elbow type Robot

Table of Contents

Mostafa Osama Ahmed

Innopolis University - DoNRS course

Github Link:

https://github.com/mostafa-metwaly/DoNRs-HW5

Forward Kinematics

$$H = R_z(\mathrm{q1}) \cdot T_z(\mathrm{L1}) \cdot R_y(\mathrm{q2}) \cdot T_x(\mathrm{L2}) \cdot R_y(\mathrm{q3}) \cdot T_x(\mathrm{L3})$$

```
clear all
close all

% set angles as symbolical
syms q1 q2 q3   real
%Link lengths
L1=1
```

```
L1 = 1
```

```
L2=1
```

```
L2 = 1
```

```
L3=1
```

```
L3 = 1
```

```
L=[L1, L2 L3];
% FK symbolical
FK=simplify(Rz(q1)*Tz(L1)*Ry(q2)*Tx(L2)*Ry(q3)*Tx(L3))
```

```
FK =
```

$$\begin{pmatrix} \cos(q_2+q_3)\cos(q_1) & -\sin(q_1) & \sin(q_2+q_3)\cos(q_1) & \cos(q_1)\,\sigma_1 \\ \cos(q_2+q_3)\sin(q_1) & \cos(q_1) & \sin(q_2+q_3)\sin(q_1) & \sin(q_1)\,\sigma_1 \\ -\sin(q_2+q_3) & 0 & \cos(q_2+q_3) & 1-\sin(q_2)-\sin(q_2+q_3) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where

$$\sigma_1 = \cos(q_2+q_3)+\cos(q_2)$$

```
q=[0.7854 -0.7854 1.3708 ]
```

```
q = 1×3
    0.7854   -0.7854    1.3708
```

```
 FK= (Rz(q(1))*Tz(L1)*Ry(q(2))*Tx(L2)*Ry(q(3))*Tx(L3))
```

```
FK = 4×4
    0.5894   -0.7071    0.3907    1.0894
    0.5894    0.7071    0.3907    1.0894
   -0.5525         0    0.8335    1.1546
         0         0         0    1.0000
```

```
T=FK(1:3,4);
px=T(1)
```

```
px = 1.0894
```

```
py=T(2)
```

```
py = 1.0894
```

```
pz=T(3)
```

```
pz = 1.1546
```

Inverse Kinematics

```
 q=InverseKinematics(FK)
```

```
q = 4×3
   -0.8760   -0.4014    1.9722
    0.8760   -0.4014    1.9722
    3.1416   -0.9854    2.5562
         0    0.5236    2.0944
```

Jacobian

Numerical derivatives

```
syms q1 q2 q3   real
 % forward kinematics
H = Rz(q1)*Tz(L1)*Ry(q2)*Tx(L2)*Ry(q3)*Tx(L3);
H=simplify(H);
% extract rotation matrix
R = simplify(H(1:3,1:3));
% diff by q1
Td=Rzd(q1)*Tz(L1)*Ry(q2)*Tx(L2)*Ry(q3)*Tx(L3)*...
    [R^-1 zeros(3,1);0 0 0 1];
% extract 6 components from 4x4 Td matrix to Jacobian 1st column
J1 = [Td(1,4), Td(2,4), Td(3,4), Td(3,2), Td(1,3), Td(2,1)]'
```

```
J1 =
```

$$\left(\begin{array}{c} \sigma_1 - \cos(q_2)\sin(q_1) - \sigma_3 \\ \cos(q_1)\cos(q_2) + \sigma_4 - \sigma_2 \\ 0 \\ 0 \\ -\frac{\cos(q_2+q_3)\ (\cos(q_2)\sin(q_1)\sin(q_3) + \cos(q_3)\sin(q_1)\sin(q_2))}{\sigma_7+\sigma_6} - \frac{\sin(q_2+q_3)\ (\sigma_1 - \cdots}{\sigma_7+\sigma_6} \\ \frac{\sin(q_1)^2}{\cos(q_1)^2+\sin(q_1)^2} + \frac{\cos(q_2+q_3)\cos(q_1)\ (\sigma_4-\sigma_2)}{\sigma_5} + \frac{\sin(q_2+q_3)\cos(q_1)\ (\cos(q_1)\cos(q_2)\sin(q_3) + \cos\cdots}{\sigma_5} \end{array}\right.$$

where

$$\sigma_1 = \sin(q_1)\sin(q_2)\sin(q_3)$$

$$\sigma_2 = \cos(q_1)\sin(q_2)\sin(q_3)$$

$$\sigma_3 = \cos(q_2)\cos(q_3)\sin(q_1)$$

$$\sigma_4 = \cos(q_1)\cos(q_2)\cos(q_3)$$

$$\sigma_5 = \sigma_7\cos(q_1)^2 + \sigma_7\sin(q_1)^2 + \sigma_6\cos(q_1)^2 + \sigma_6\sin(q_1)^2$$

$$\sigma_6 = \sin(q_2+q_3)^2$$

$$\sigma_7 = \cos(q_2+q_3)^2$$

```
% diff by q2
Td=Rz(q1)*Tz(L1)*Ryd(q2)*Tx(L2)*Ry(q3)*Tx(L3)*...
    [R^-1 zeros(3,1);0 0 0 1];
% extract 6 components from 4x4 Td matrix to Jacobian 2nd column
J2 = [Td(1,4), Td(2,4), Td(3,4), Td(3,2), Td(1,3), Td(2,1)]'
```

```
J2 =
```

$$
\left(\begin{array}{c}
-\cos(q_1)\sin(q_2) - \sigma_4 - \sigma_3 \\
-\sin(q_1)\sin(q_2) - \sigma_2 - \sigma_1 \\
\sigma_5 - \sigma_6 - \cos(q_2) \\
-\frac{\cos(q_2+q_3)\sin(q_1)\ (\sigma_6 - \sigma_5)}{\sigma_7} - \frac{\sin(q_2+q_3)\sin(q_1)\ (\cos(q_2)\sin(q_3) + \cos(q_3)\sin(q_2))}{\sigma_7} \\
\frac{\cos(q_2+q_3)\ (\cos(q_1)\cos(q_2)\cos(q_3) - \cos(q_1)\sin(q_2)\sin(q_3))}{\sigma_9 + \sigma_8} + \frac{\sin(q_2+q_3)\ (\sigma_4 + \sigma_3)}{\sigma_9 + \sigma_8} \\
-\frac{\cos(q_2+q_3)\cos(q_1)\ (\sigma_2 + \sigma_1)}{\sigma_7} - \frac{\sin(q_2+q_3)\cos(q_1)\ (\sin(q_1)\sin(q_2)\sin(q_3) - \cos(q_2)\cos(q_3)\sin(q_1)}{\sigma_7}
\end{array}\right)
$$

where

$\sigma_1 = \cos(q_3)\sin(q_1)\sin(q_2)$

$\sigma_2 = \cos(q_2)\sin(q_1)\sin(q_3)$

$\sigma_3 = \cos(q_1)\cos(q_3)\sin(q_2)$

$\sigma_4 = \cos(q_1)\cos(q_2)\sin(q_3)$

$\sigma_5 = \sin(q_2)\sin(q_3)$

$\sigma_6 = \cos(q_2)\cos(q_3)$

$\sigma_7 = \sigma_9\cos(q_1)^2 + \sigma_9\sin(q_1)^2 + \sigma_8\cos(q_1)^2 + \sigma_8\sin(q_1)^2$

$\sigma_8 = \sin(q_2+q_3)^2$

$\sigma_9 = \cos(q_2+q_3)^2$

```
% diff by q3
Td=Rz(q1)*Tz(L1)*Ry(q2)*Tx(L2)*Ryd(q3)*Tx(L3)*...
    [R^-1 zeros(3,1);0 0 0 1];
% extract 6 components from 4x4 Td matrix to Jacobian 2nd column
J3 = [Td(1,4), Td(2,4), Td(3,4), Td(3,2), Td(1,3), Td(2,1)]'
```

```
J3 =
```

$$
\left(\begin{array}{c}
-\sigma_4 - \sigma_3 \\
-\sigma_2 - \sigma_1 \\
\sigma_5 - \sigma_6 \\
-\frac{\cos(q_2+q_3)\sin(q_1)\ (\sigma_6 - \sigma_5)}{\sigma_7} - \frac{\sin(q_2+q_3)\sin(q_1)\ (\cos(q_2)\sin(q_3) + \cos(q_3)\sin(q_2))}{\sigma_7} \\
\frac{\cos(q_2+q_3)\ (\cos(q_1)\cos(q_2)\cos(q_3) - \cos(q_1)\sin(q_2)\sin(q_3))}{\sigma_9 + \sigma_8} + \frac{\sin(q_2+q_3)\ (\sigma_4 + \sigma_3)}{\sigma_9 + \sigma_8} \\
-\frac{\cos(q_2+q_3)\cos(q_1)\ (\sigma_2 + \sigma_1)}{\sigma_7} - \frac{\sin(q_2+q_3)\cos(q_1)\ (\sin(q_1)\sin(q_2)\sin(q_3) - \cos(q_2)\cos(q_3)\sin(q_1)}{\sigma_7}
\end{array}\right.
$$

where

$$\sigma_1 = \cos(q_3)\sin(q_1)\sin(q_2)$$

$$\sigma_2 = \cos(q_2)\sin(q_1)\sin(q_3)$$

$$\sigma_3 = \cos(q_1)\cos(q_3)\sin(q_2)$$

$$\sigma_4 = \cos(q_1)\cos(q_2)\sin(q_3)$$

$$\sigma_5 = \sin(q_2)\sin(q_3)$$

$$\sigma_6 = \cos(q_2)\cos(q_3)$$

$$\sigma_7 = \sigma_9\cos(q_1)^2 + \sigma_9\sin(q_1)^2 + \sigma_8\cos(q_1)^2 + \sigma_8\sin(q_1)^2$$

$$\sigma_8 = \sin(q_2+q_3)^2$$

$$\sigma_9 = \cos(q_2+q_3)^2$$

```
% Full Jacobian 3x3
Jq = [simplify(J1), simplify(J2), simplify(J3)]
```

```
Jq =
```

$$\begin{pmatrix} -\sin(q_1)\,\sigma_2 & -\cos(q_1)\,\sigma_1 & -\sin(q_2+q_3)\cos(q_1) \\ \cos(q_1)\,\sigma_2 & -\sin(q_1)\,\sigma_1 & -\sin(q_2+q_3)\sin(q_1) \\ 0 & -\cos(q_2+q_3)-\cos(q_2) & -\cos(q_2+q_3) \\ 0 & -\sin(q_1) & -\sin(q_1) \\ 0 & \cos(q_1) & \cos(q_1) \\ 1 & 0 & 0 \end{pmatrix}$$

where

$$\sigma_1 = \sin(q_2+q_3)+\sin(q_2)$$

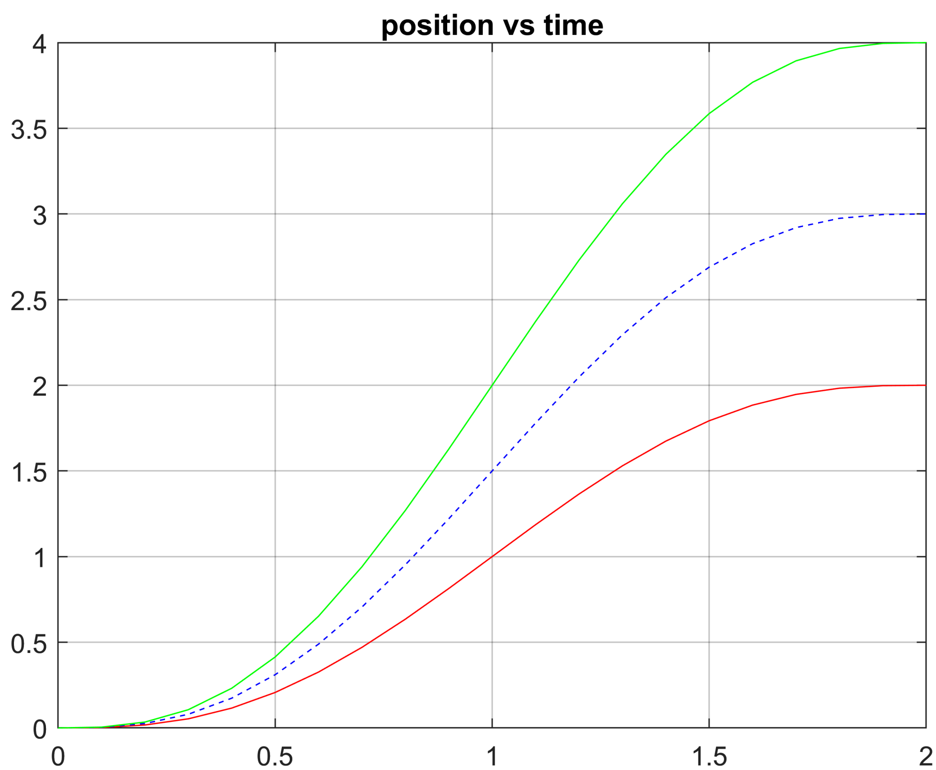
$$\sigma_2 = \cos(q_2+q_3)+\cos(q_2)$$

Trajectory

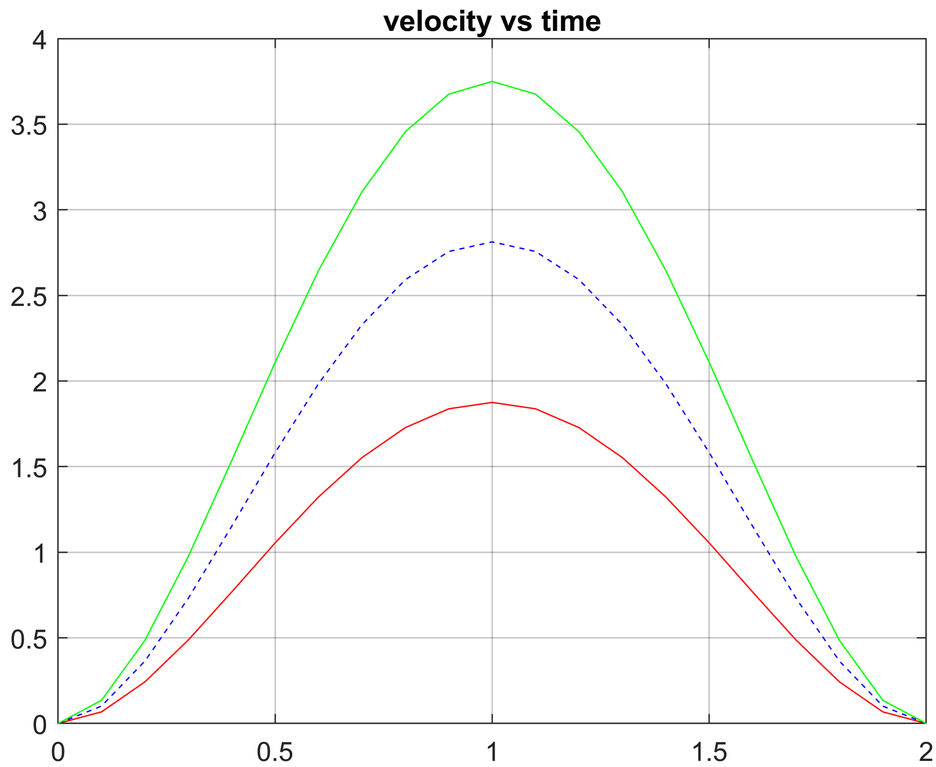
Task 1

```
% Q2
% define the initial and final conditions


t0 = 0; tf = 2;
q0 = [0 0 0]; qf = [2 3 4];
v0 = 0; vf = 0;
acc0 = 0; accf = 0;
tf = 2;
q_all=zeros(21,3);
v_all= zeros(21,3);
acc_all=zeros(21,3);

for i=1:3
%Given:
A = [1 t0 t0^2 t0^3 t0^4 t0^5
     0 1 2*t0 3*t0^2 4*t0^3 5*t0^4
     0 0 2 6*t0 12*t0^2 20*t0^3
     1 tf tf^2 tf^3 tf^4 tf^5
     0 1 2*tf 3*tf^2 4*tf^3 5*tf^4
     0 0 2 6*tf 12*tf^2 20*tf^3];
c = [q0(i);v0;acc0;qf(i);vf;accf];
b = A\c;
% assign the results to the coefficients
a0 = b(1); a1 = b(2); a2 = b(3); a3 = b(4); a4 = b(5); a5 = b(6);


t = 0:0.1:2;
q = a0+a1.*t+a2.*t.^2+a3.*t.^3+a4.*t.^4+a5.*t.^5;
v = a1+2*a2.*t+3*a3.*t.^2+4*a4.*t.^3+5*a5.*t.^4;
```

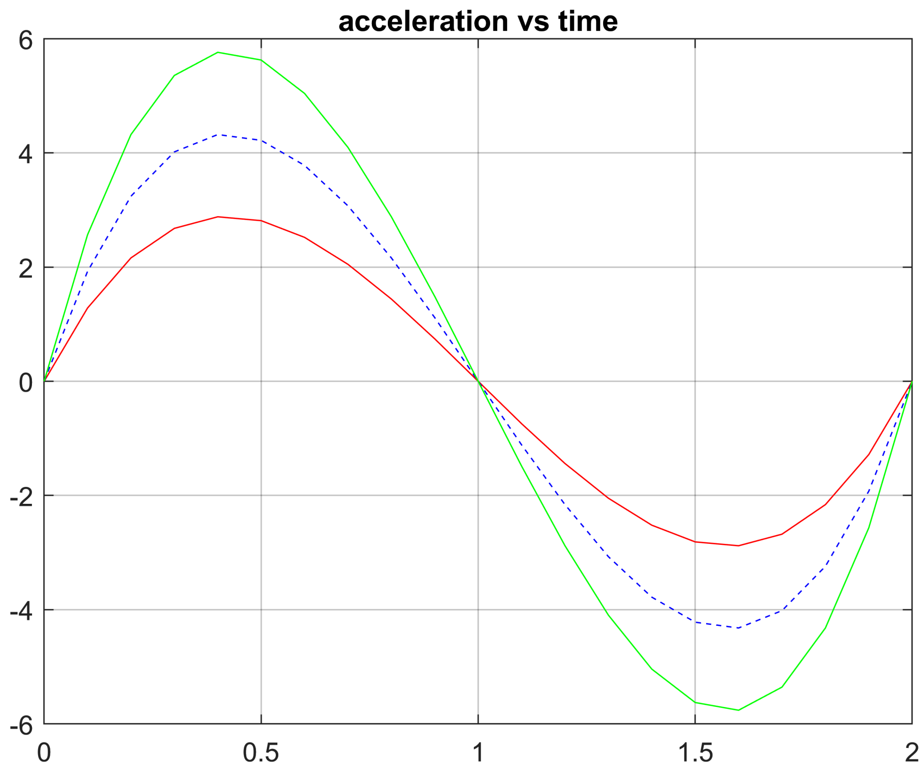
```
acc = 2*a2+6*a3.*t+12*a4.*t.^2+20*a5.*t.^3;

q_all(:,i) = q;
v_all(:,i) = v;
acc_all(:,i)  = acc ;
end

figure
plot(t,q_all(:,1),'r-',t,q_all(:,2),'b--',t,q_all(:,3),'g-')
title('position vs time')
grid on
```




```
figure
plot(t,v_all(:,1),'r-',t,v_all(:,2),'b--',t,v_all(:,3),'g-')
title('velocity vs time')
grid on
```




```
figure
plot(t,acc_all(:,1),'r-',t,acc_all(:,2),'b--',t,acc_all(:,3),'g-')
title('acceleration vs time')
grid on
```



Task 2

```
Calculate Joint Trajectory (Trapezoidal) for PTP Given

q(t) from q(0) = (0, 0, 0) to q(2) = (2, 3, 4)

Controller command interpretation frequency f = 100 Hz

Maximum joint velocity = 1 rad/s

Maximum joint acceleration = 10 rad/s2
```

$$q(t) = \begin{cases} a_{10} + a_{11}t + a_{12}t^2 & 0 \le t \le t_a \\ a_{20} + a_{21}t & t_a < t < t_f - t_a \\ a_{30} + a_{31}t + a_{32}t^2 & t_f - t_a < t < t_f \end{cases}$$

where t_a and $t_f - t_a$ is the period when the joint moves in constant velocity and they computed as follows:

$$t_a = \frac{v_{\max}}{a_{\max}}$$

$$t_f = \frac{q_f - q_0}{v_{\max}} + t_a$$

```
clear all
close all;clc;
q0 = [0 0 0]; qf = [2 3 4]; v_max = [1 1 1]; a_max = [10 10 10];
v0= [0 0 0];
dt = 0.01;
n = 0;

while (floor(dt*10^n)~=dt*10^n)
    n=n+1;
end
E = 1*10^-n;
ta = v_max./a_max;

delta_q = (qf(:)-q0(:));
tf = (delta_q(:))./v_max + ta;
taw=delta_q ./v_max;

if rem(ta,dt)~=0
    ta_new = round(ta,n)+E;
else
    ta_new = round(ta,n);
end
 tf = (qf(:)-q0(:))./v_max(:)  + ta_new(:);

if rem(tf,dt)~=0
    tf_new = round(tf,n)+E;
else
    tf_new = round(tf,n);
end

ta_new=max(ta_new)
```

```
ta_new = 0.1000
```

```
tf_new=max(tf_new)
```

```
tf_new = 4.1000
```

```
v_old =((qf(:)-q0(:))./(tf-ta));
a_old = v_old/ta;

v = ((qf(:)-q0(:))./(tf_new-ta_new))
```

```
v = 3×1
    0.5000
    0.7500
    1.0000
```

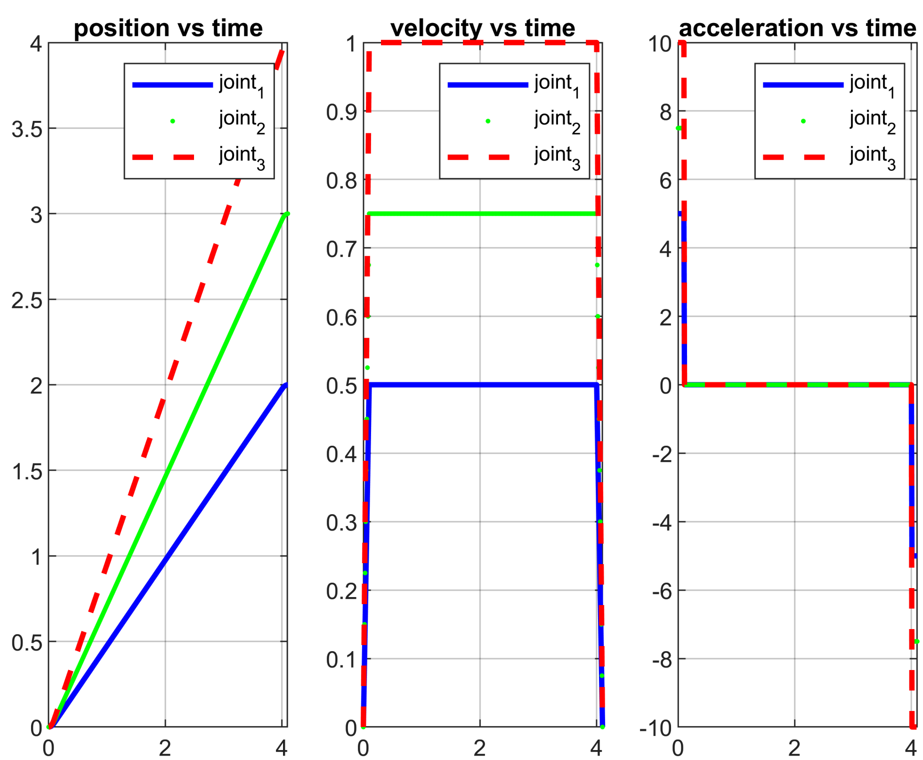
```
a = v/ta_new
```

```
a = 3×1
    5.0000
    7.5000
   10.0000
```

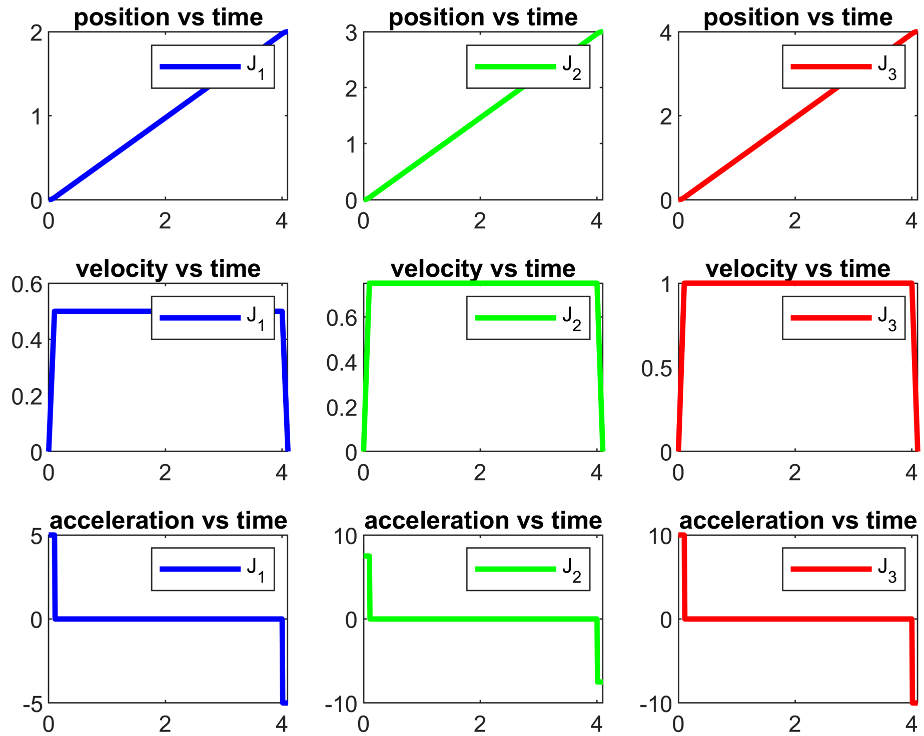
```
% all joints - coefficients:
for i =1:3

% t0 --> ta:
a10 = q0(i);
a11 = v0(i);
a12 = 0.5*a(i);

% ta --> tf-ta:
a20 = q0(i) + 0.5*a(i)*ta_new^2 - v(i)*ta_new;
a21 = v(i);

% tf-ta --> tf:
a30 = qf(i) - 0.5*a(i)*tf_new^2;
a31 = a(i)*tf_new;
a32 = -0.5*a(i);

 b(i,:) = [a10; a11; a12; a20; a21; a30; a31; a32];
end

t = 0:dt:tf_new;
v=zeros(3,length(t));
for i=1:3

q(i,:) = (b(i,1)+b(i,2).*t+b(i,3).*t.^2).*(t<=ta_new)...
    +(b(i,4)+b(i,5).*t).*(t>ta_new).*(t<=(tf_new-ta_new))...
    +(b(i,6)+b(i,7).*t+b(i,8).*t.^2).*(t>(tf_new-ta_new)).*(t<=tf_new);

v(i,:) = (b(i,2)+2*b(i,3).*t).*(t<=ta_new)...
    +(b(i,5)).*(t>ta_new).*(t<=(tf_new-ta_new))...
    +(b(i,7)+2*b(i,8).*t).*(t>(tf_new-ta_new)).*(t<=tf_new);

acc(i,:) = (2*b(i,3)).*(t<=ta_new)...
    +(0).*(t>ta_new).*(t<=(tf_new-ta_new))...
    +(2*b(i,8)).*(t>(tf_new-ta_new)).*(t<=tf_new);

end
```

```
figure
subplot(1,3,1)
plot(t,q(1,:),'b-','linewidth',2)
hold on
plot(t,q(2,:),'g.','linewidth',2)
```

```
hold on
plot(t,q(3,:),'r--','linewidth',2)
grid on
title('position vs time')
legend('joint_1','joint_2','joint_3')
axis([0 tf_new -inf inf])

subplot(1,3,2)
plot(t,v(1,:),'b-','linewidth',2)
hold on
plot(t,v(2,:),'g.','linewidth',2)
hold on
plot(t,v(3,:),'r--','linewidth',2)
title('velocity vs time')
legend('joint_1','joint_2','joint_3')
grid on
axis([0 tf_new -inf inf])

subplot(1,3,3)
plot(t,acc(1,:),'b-','linewidth',2)
hold on
plot(t,acc(2,:),'g.','linewidth',2)
hold on
plot(t,acc(3,:),'r--','linewidth',2)
title('acceleration vs time')
legend('joint_1','joint_2','joint_3')
grid on
axis([0 tf_new -inf inf])
```

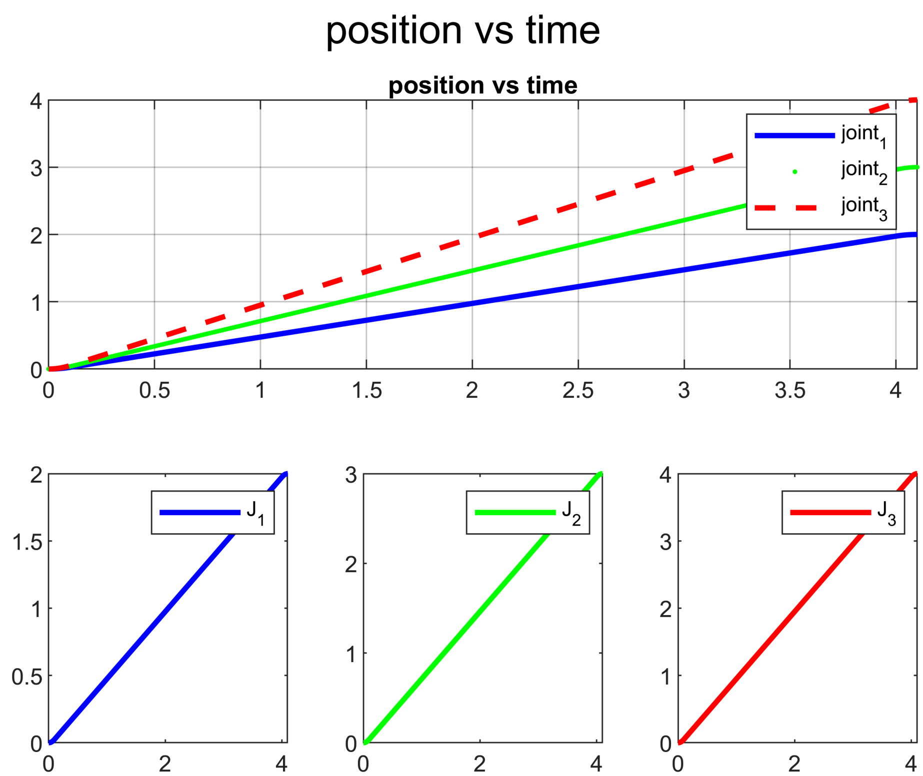


```
figure;
subplot(3,3,1);plot(t,q(1,:),'b-','linewidth',2);title('position vs time');legend('J_1');
subplot(3,3,2);plot(t,q(2,:),'g-','linewidth',2);title('position vs time');legend('J_2');
subplot(3,3,3);plot(t,q(3,:),'r-','linewidth',2 );title('position vs time');legend('J_3');

subplot(3,3,4);plot(t,v(1,:),'b-','linewidth',2);title('velocity vs time');legend('J_1');
subplot(3,3,5);plot(t,v(2,:),'g-','linewidth',2);title('velocity vs time');legend('J_2');
subplot(3,3,6);plot(t,v(3,:),'r-','linewidth',2 );title('velocity vs time');legend('J_3');

subplot(3,3,7);plot(t,acc(1,:),'b-','linewidth',2);title('acceleration vs time');legend('J_1');
subplot(3,3,8);plot(t,acc(2,:),'g-','linewidth',2);title('acceleration vs time');legend('J_2');
subplot(3,3,9);plot(t,acc(3,:),'r-','linewidth',2 );title('acceleration vs time');legend('J_3')
hold off
```

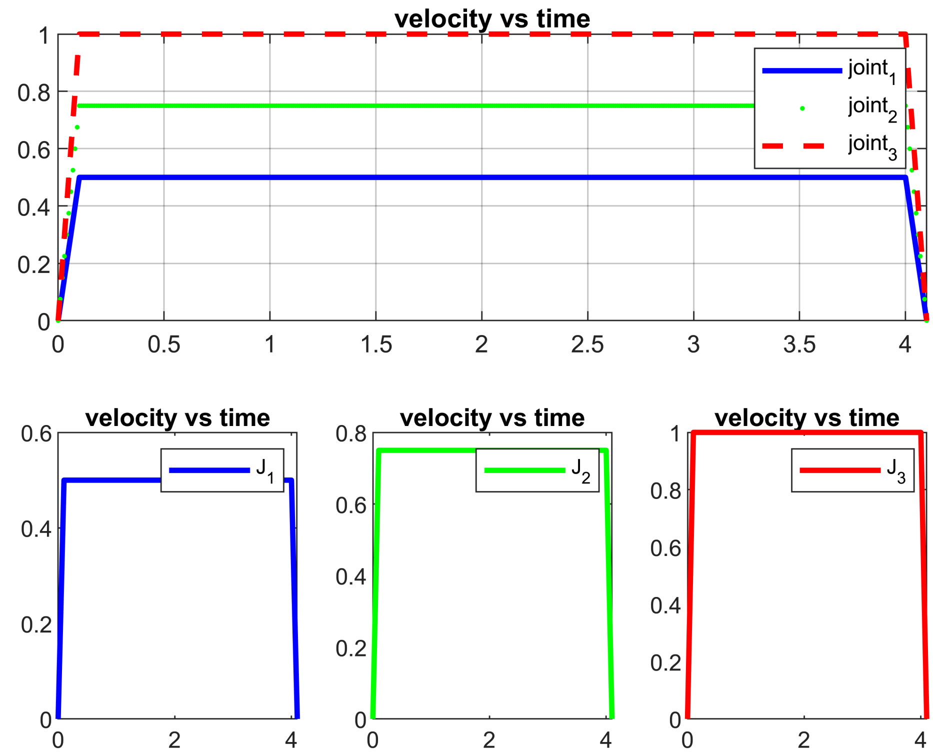



```
figure
subplot(2,3,1:3)
plot(t,q(1,:),'b-','linewidth',2)
hold on
plot(t,q(2,:),'g.','linewidth',2)
hold on
plot(t,q(3,:),'r--','linewidth',2)
grid on
```

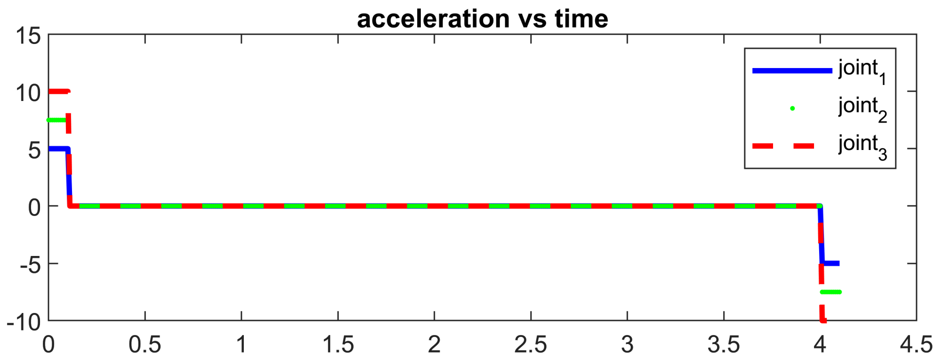
```
title('position vs time')
legend('joint_1','joint_2','joint_3')
axis([0 tf_new -inf inf])

subplot(2,3,4);plot(t,q(1,:),'b-','linewidth',2);sgtitle('position vs time');legend('J_1');
subplot(2,3,5);plot(t,q(2,:),'g-','linewidth',2);sgtitle('position vs time');legend('J_2');
subplot(2,3,6);plot(t,q(3,:),'r-','linewidth',2 );sgtitle('position vs time');legend('J_3');
```

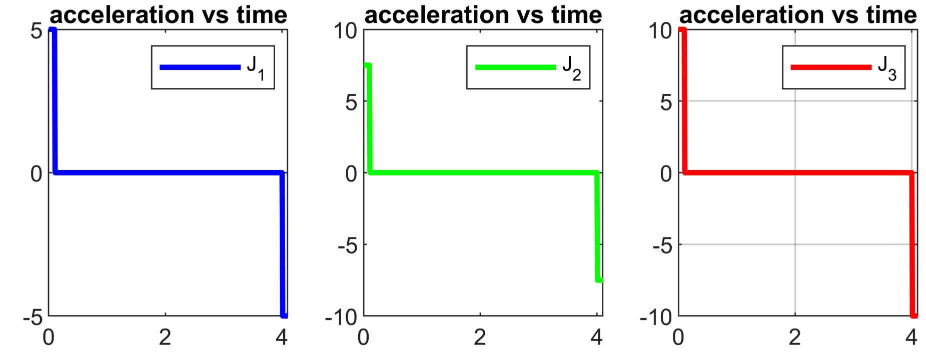



```
figure;
subplot(2,3,1:3)
plot(t,v(1,:),'b-','linewidth',2)
hold on
plot(t,v(2,:),'g.','linewidth',2)
hold on
plot(t,v(3,:),'r--','linewidth',2)
title('velocity vs time')
legend('joint_1','joint_2','joint_3')
grid on
axis([0 tf_new -inf inf])

subplot(2,3,4);plot(t,v(1,:),'b-','linewidth',2);title('velocity vs time');legend('J_1');
subplot(2,3,5);plot(t,v(2,:),'g-','linewidth',2);title('velocity vs time');legend('J_2');
subplot(2,3,6);plot(t,v(3,:),'r-','linewidth',2 );title('velocity vs time');legend('J_3');
```




```
figure;
subplot(2,3,1:3)
plot(t,acc(1,:),'b-','linewidth',2)
hold on
plot(t,acc(2,:),'g.','linewidth',2)
hold on
plot(t,acc(3,:),'r--','linewidth',2)
title('acceleration vs time')
legend('joint_1','joint_2','joint_3')

subplot(2,3,4);plot(t,acc(1,:),'b-','linewidth',2);title('acceleration vs time');legend('J_1');
subplot(2,3,5);plot(t,acc(2,:),'g-','linewidth',2);title('acceleration vs time');legend('J_2');
subplot(2,3,6);plot(t,acc(3,:),'r-','linewidth',2 );title('acceleration vs time');legend('J_3')
grid on
axis([0 tf_new -inf inf])
```





Task 3

Joint trajectory for the following commands: LIN – p1 = (1, 0, 1) to p2 = (√2/2, √2/2, 1.2) (trapezoidal)

- Controller command interpretation frequency – f = 100 Hz
- Maximum linear velocity – 1 m/s
- Maximum linear acceleration – 10 m/s2

```
clear all;
p1 = [ 1, 0, 1];
p2 = [sqrt(2)/2 sqrt(2)/2 1.2];
v_max = [1 1 1]; a_max = [10 10 10];
v0= [0 0 0];
dt = 0.01;
n = 0;
N = 100;

while (floor(dt*10^n)~=dt*10^n)
    n=n+1;
end
E = 1*10^-n;
```

```
ta = v_max./a_max
```

```
ta = 1×3
    0.1000    0.1000    0.1000
```

```
delta_p = (p2(:)-p1(:));
```

we will calcualate for the controller frequancy and recalculate the time by using maximum time

```
if rem(ta,dt)~=0
    ta_new = round(ta,n)+E;
else
    ta_new = round(ta,n);
end

 tf = (delta_p(:))./v_max(:)  + ta_new(:);

if rem(tf,dt)~=0
    tf_new = round(tf,n)+E;
else
    tf_new = round(tf,n);
end


ta_new=max(ta_new)
```

```
ta_new = 0.1000
```

```
tf_new=max(tf_new)
```

```
tf_new = 0.8200
```

```
% v_old =((p2(:)-p1(:))./(tf-ta));
% a_old = v_old/ta;
%
% v = ((p2(:)-p1(:))./(tf_new-ta_new))
% a = v/ta_new

t_lin = linspace(0,tf_new,N);
```

we will then calculate all the waypoints positions and velocities that would make the straight line path between the given points in cartesian coordinates

```
% positions
% x = ((p2(1)-p1(1))/tf_new).*t+p1(1);
% y = ((p2(2)-p1(2))/tf_new).*t+p1(2);
% z = ((p2(3)-p1(3))/tf_new).*t+p1(3);
    waypnts = [((p2(:)-p1(:))./tf_new).*t_lin+p1(:)]';
% velocities
% vx = ((p2(1)-p1(1))/tf_new);
% vy = ((p2(2)-p1(2))/tf_new);
% vz = ((p2(3)-p1(3))/tf_new);
    vel = ((p2(:)-p1(:))/tf_new);
m = -1; % 1 elbow up, -1 elbow down
```

we then calculate these waypoints from the cartesian space to the joint space getting joint andles and velocities using robot inverse kinematiks and jacobian matrix

```
for i=1:N
    waypnt = waypnts(i,:);
    jointangles(i,:) = InverseKinematics(waypnt);
    if i == 1 || i==N
        jointVelocity(i,:) = [0 0 0];
    else
        J = Jacobian(jointangles(i,:));
        jointVelocity(i,:) =  (J\vel)';
    end
end
```

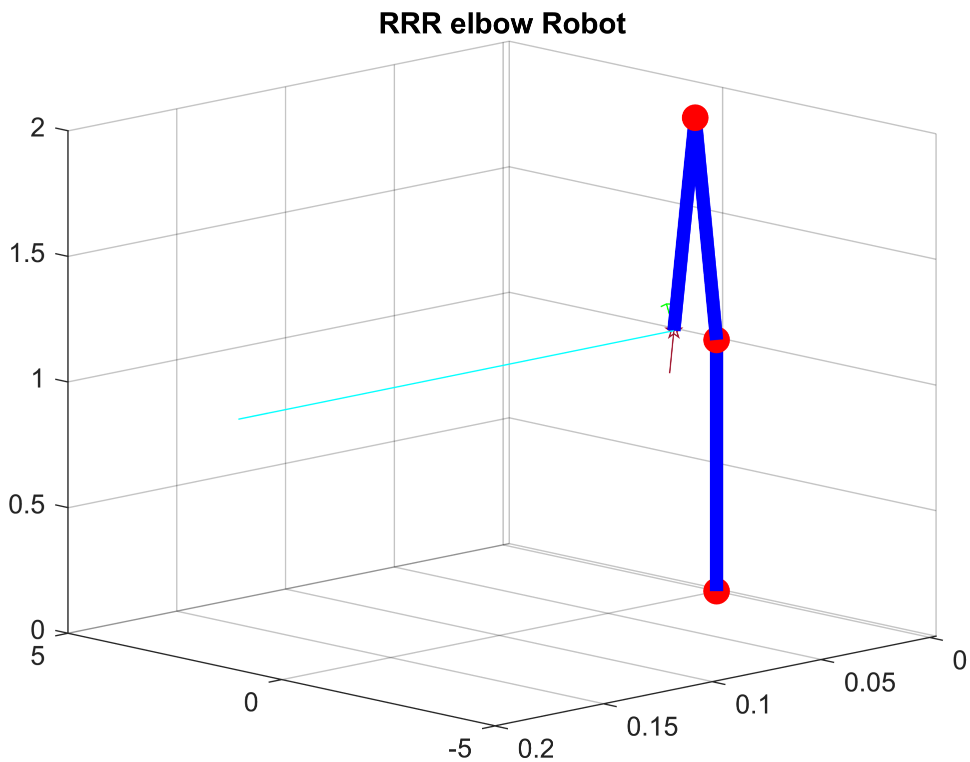
we calculate the position ,velocity and acceleration for each joint for each waypoint and store there values.

```
n = 15;
num=0;
Q = [];
Vel = [];
Acc = [];
acc =[];
vel =[];
for i=1:N-1
    t1 = t_lin(i); t2 = t_lin(i+1);
    A = [1 t1 t1^2 t1^3
        0 1 2*t1 3*t1^2
        1 t2 t2^2 t2^3
        0 1 2*t2 3*t2^2];
    for j = 1:3
         q1 = jointangles(i,j);
         q2 = jointangles(i+1,j);
         v1 = jointVelocity(i,j);
         v2 = jointVelocity(i+1,j);
         c = [q1;v1;q2;v2];
         b = A\c;
         t = linspace(t1,t2,n);
         q(j,:) = b(1)+b(2).*t+b(3).*t.^2+b(4).*t.^3;
         vel(j,:) = b(2)+2*b(3).*t+3*b(4).*t.^2;
         acc(j,:) = 2* b(3)+6* b(4).*t;

    end
    Q = [Q q];
    Vel = [Vel vel];
    Acc = [Acc acc];

end
```

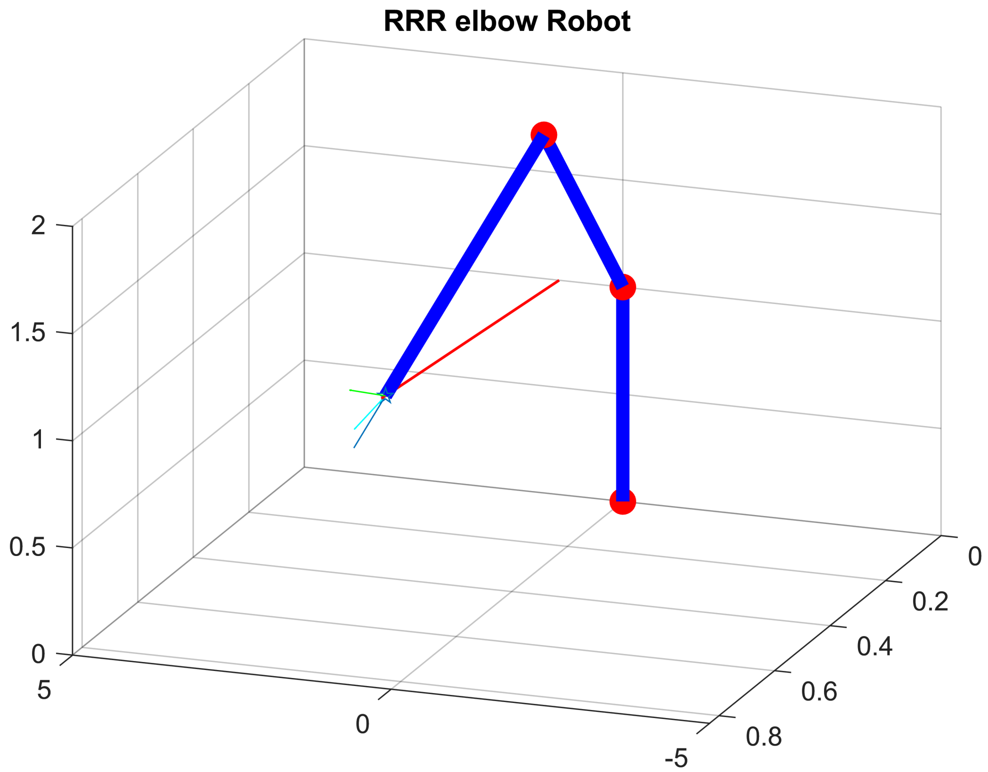
we check our solution by getting the forward kinematics for the joints and calculate the path and its velocity and acceleration from the jacobian and visualize the robot motion

```
cartTrajectory = ForwardKinematics(Q');
```

```
for i=1:length(Q)
   jac= Jacobian(Q(:,i)');
   CartVelocity(:,i)= jac * Vel(:,i);
   CartAcceleration(i,:)= jac * Acc(:,i);


end
CartAcceleration=CartAcceleration';
cartTrajectory=cartTrajectory';
figure;

hold on
for i=1:50:length(Q)
   draw_myrobot([1 1 1],Q(:,i)')
```




```
   pause(0.01)
   cla
   plot3(waypnts(:,1),waypnts(:,2),waypnts(:,3),'r-','linewidth',1)
  end
 draw_myrobot([1 1 1],Q(:,i)')
```

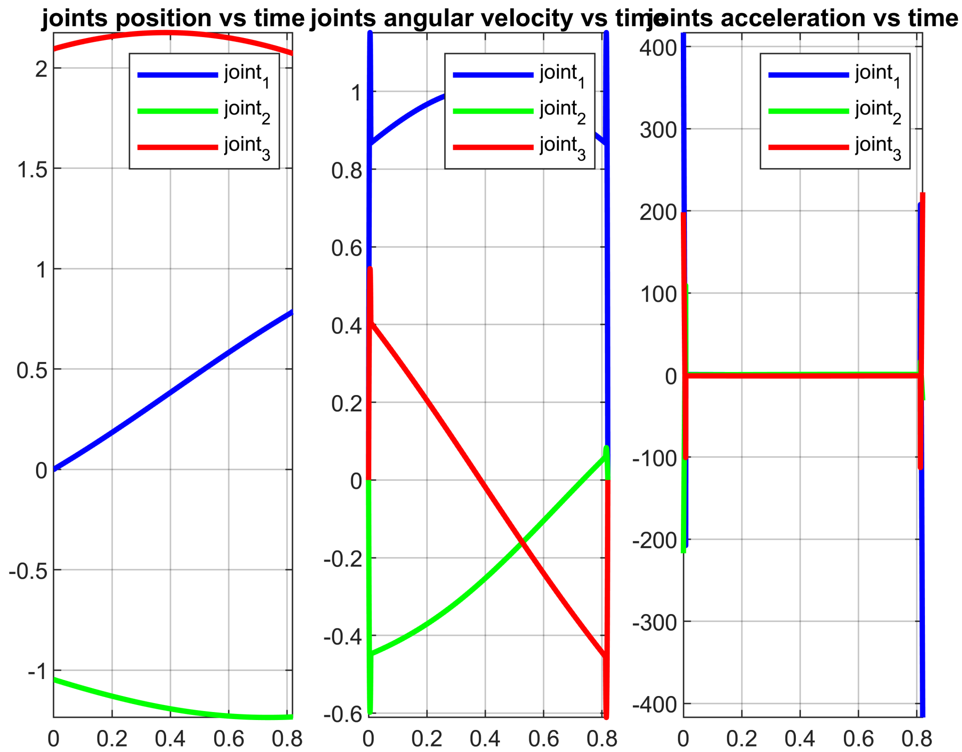



```
  num=n*N-n;
t  = linspace(0,tf_new,num);
```

these graphs draw the relation between all the joints position velocity and acceleration and also the linear position , velocity and acceleration of the end-effector motion.

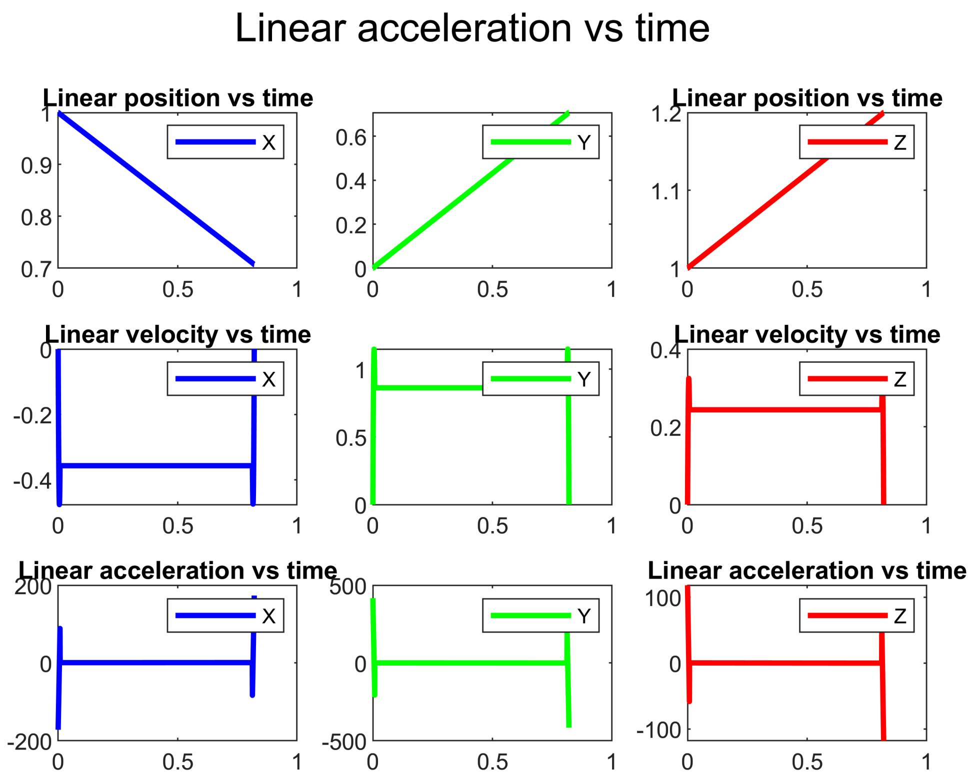
```
figure
subplot(1,3,1)
plot(t,Q(1,:),'b-','linewidth',2)
hold on
plot(t,Q(2,:),'g-','linewidth',2)
hold on
plot(t,Q(3,:),'r-','linewidth',2)
grid on
title('joints position vs time')
legend('joint_1','joint_2','joint_3')
axis([0 tf_new -inf inf])

subplot(1,3,2)
plot(t,Vel(1,:),'b-','linewidth',2)
hold on
plot(t,Vel(2,:),'g-','linewidth',2)
hold on
plot(t,Vel(3,:),'r-','linewidth',2)
title('joints angular velocity vs time')
legend('joint_1','joint_2','joint_3')
```

```
grid on
axis([0 tf_new -inf inf])

subplot(1,3,3)
plot(t,Acc(1,:),'b-','linewidth',2)
hold on
plot(t,Acc(2,:),'g-','linewidth',2)
hold on
plot(t,Acc(3,:),'r-','linewidth',2)
title('joints acceleration vs time')
legend('joint_1','joint_2','joint_3')
grid on
axis([0 tf_new -inf inf])
```



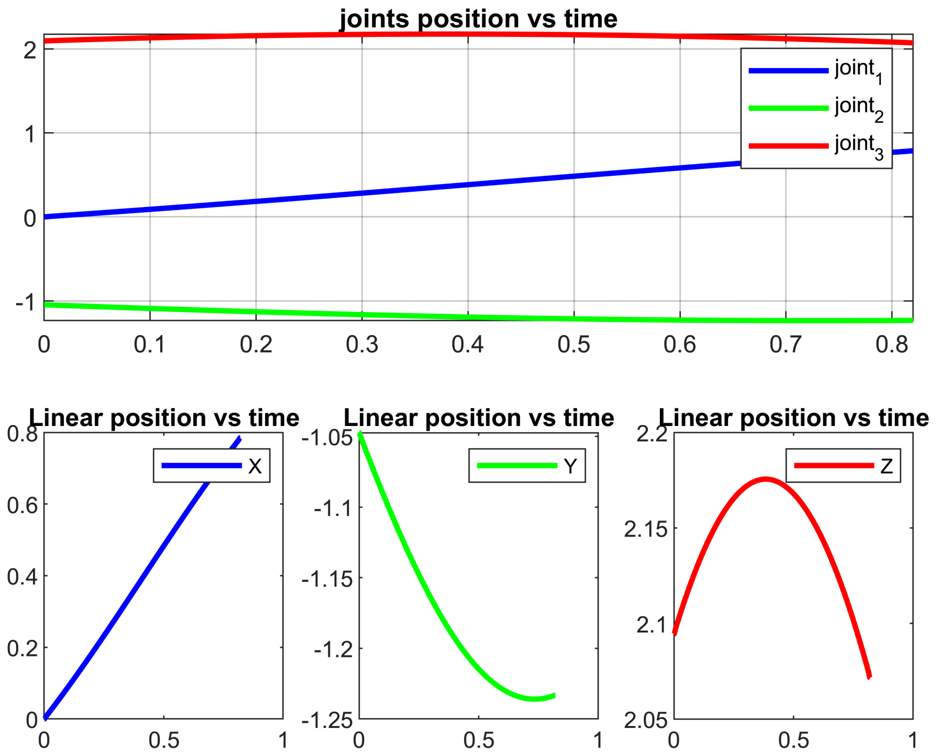

```
figure;
subplot(3,3,1);plot(t,cartTrajectory(1,:),'b-','linewidth',2);title('Linear position vs time');
subplot(3,3,2);plot(t,cartTrajectory(2,:),'g-','linewidth',2);sgtitle('Linear position vs time'
subplot(3,3,3);plot(t,cartTrajectory(3,:),'r-','linewidth',2 );title('Linear position vs time')

subplot(3,3,4);plot(t,CartVelocity(1,:),'b-','linewidth',2);title('Linear velocity vs time');le
subplot(3,3,5);plot(t,CartVelocity(2,:),'g-','linewidth',2);sgtitle('Linear velocity vs time');
subplot(3,3,6);plot(t,CartVelocity(3,:),'r-','linewidth',2 );title('Linear velocity vs time');l

subplot(3,3,7);plot(t,CartAcceleration(1,:),'b-','linewidth',2);title('Linear acceleration vs t
subplot(3,3,8);plot(t,CartAcceleration(2,:),'g-','linewidth',2);sgtitle('Linear acceleration vs
subplot(3,3,9);plot(t,CartAcceleration(3,:),'r-','linewidth',2 );title('Linear acceleration vs
```

```
hold off
```

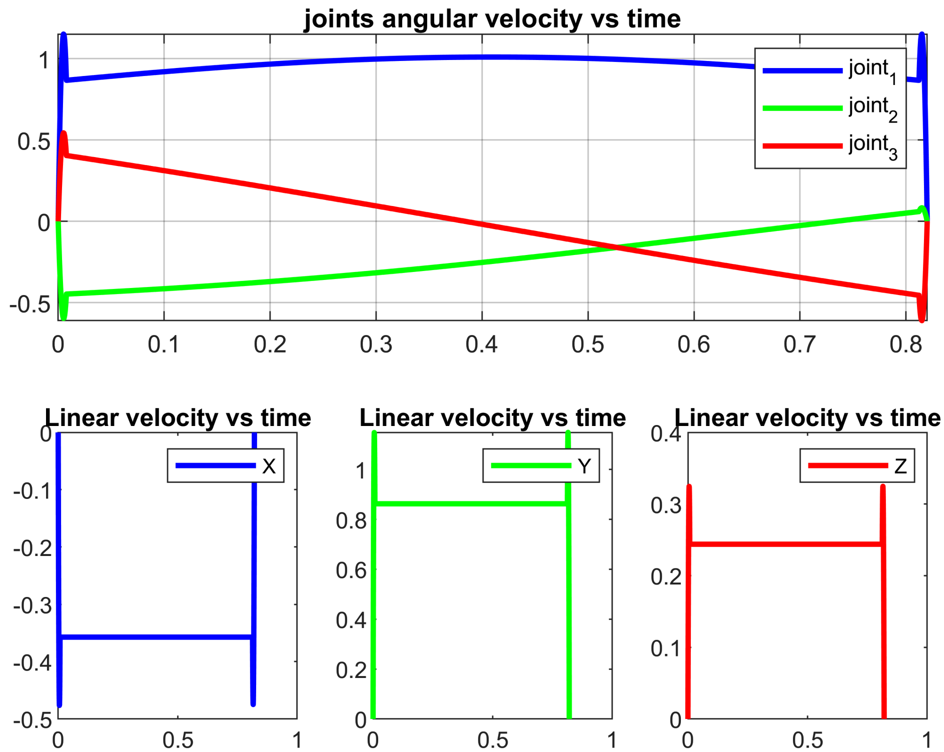



```

```

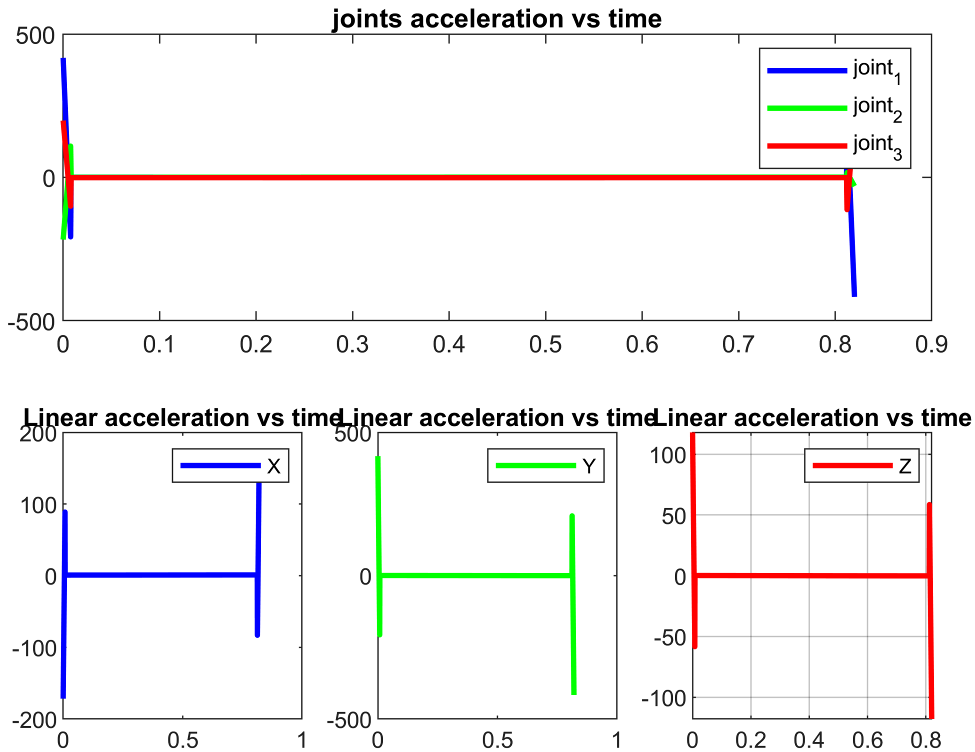
```
figure
subplot(2,3,1:3)
plot(t,Q(1,:),'b-','linewidth',2)
hold on
plot(t,Q(2,:),'g-','linewidth',2)
hold on
plot(t,Q(3,:),'r-','linewidth',2)
grid on
title('joints position vs time')
legend('joint_1','joint_2','joint_3')
axis([0 tf_new -inf inf])

subplot(2,3,4);plot(t,Q(1,:),'b-','linewidth',2);title('Linear position vs time');legend('X');
subplot(2,3,5);plot(t,Q(2,:),'g-','linewidth',2);title('Linear position vs time');legend('Y');
subplot(2,3,6);plot(t,Q(3,:),'r-','linewidth',2 );title('Linear position vs time');legend('Z');
```




```
figure;
subplot(2,3,1:3)
plot(t,Vel(1,:),'b-','linewidth',2)
hold on
plot(t,Vel(2,:),'g-','linewidth',2)
hold on
plot(t,Vel(3,:),'r-','linewidth',2)
title('joints angular velocity vs time')
legend('joint_1','joint_2','joint_3')
grid on
axis([0 tf_new -inf inf])

subplot(2,3,4);plot(t,CartVelocity(1,:),'b-','linewidth',2);title('Linear velocity vs time');le
subplot(2,3,5);plot(t,CartVelocity(2,:),'g-','linewidth',2);title('Linear velocity vs time');le
subplot(2,3,6);plot(t,CartVelocity(3,:),'r-','linewidth',2 );title('Linear velocity vs time');l
```




```
figure;
subplot(2,3,1:3)
plot(t,Acc(1,:),'b-','linewidth',2)
hold on
plot(t,Acc(2,:),'g-','linewidth',2)
hold on
plot(t,Acc(3,:),'r-','linewidth',2)
title('joints acceleration vs time')
legend('joint_1','joint_2','joint_3')

subplot(2,3,4);plot(t,CartAcceleration(1,:),'b-','linewidth',2);title('Linear acceleration vs t
subplot(2,3,5);plot(t,CartAcceleration(2,:),'g-','linewidth',2);title('Linear acceleration vs t
subplot(2,3,6);plot(t,CartAcceleration(3,:),'r-','linewidth',2 );title('Linear acceleration vs
grid on
axis([0 tf_new -inf inf])
```


joints acceleration vs time
joint$_1$
joint$_2$
joint$_3$
500
0
-500
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Linear acceleration vs time
X
200
100
0
-100
-200
0
0.5
1
Linear acceleration vs time
Y
500
0
-500
0
0.5
1
Linear acceleration vs time
Z
100
50
0
-50
-100
0
0.2
0.4
0.6
0.8