Department of Electronic and Telecommunication Engineering
UNIVERSITY OF MORATUWA
Faculty of Engineering

EN4563 : Robotics

Torque Simulation

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This is submitted as partial fulfillment for the module EN4563 : Robotics
Department of Electronic and Telecommunication Engineering
University of Moratuwa

Assignment: Torque Simulation of a 2link planar Robot Manipulator

EN4563 Robotics

Dept. of Electronic and Telecommunication Engineering

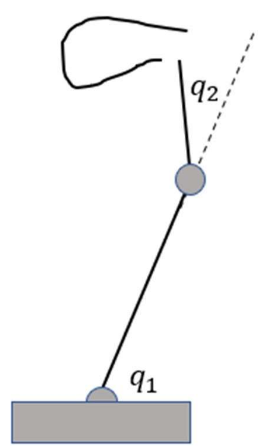
University of Moratuwa

To be submitted by 20th Feb 2023

Use a 2-link planar robot manipulator with horizontal axes and draw on the vertical plane the first letter of your name. Simulate the joint torques through the motion and present the following torque profiles.

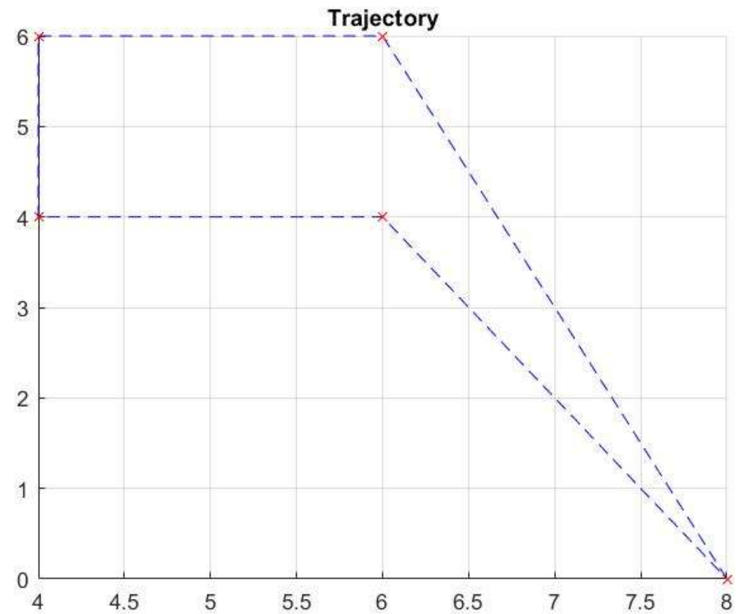
1. Inertial torque of each joint due to its own inertia
2. Coupled torque
3. Centripetal torque
4. Coriolis torque
5. Gravity torque

Use your own trajectory planning, and assume other parameters as link mass, and length. Disregard motor and gearbox.

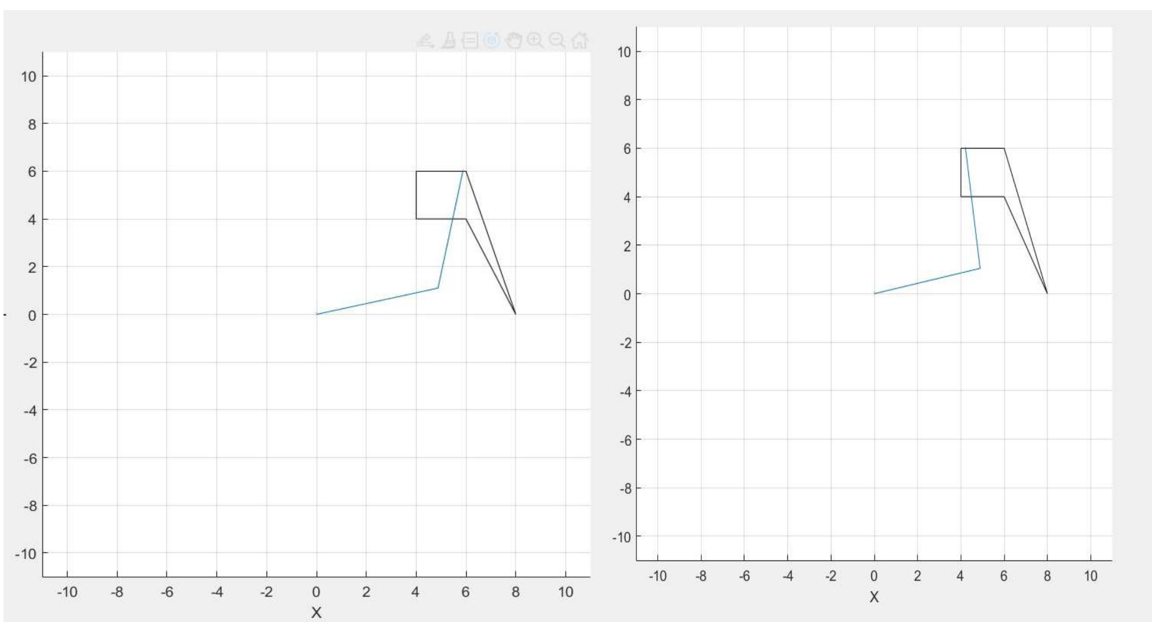


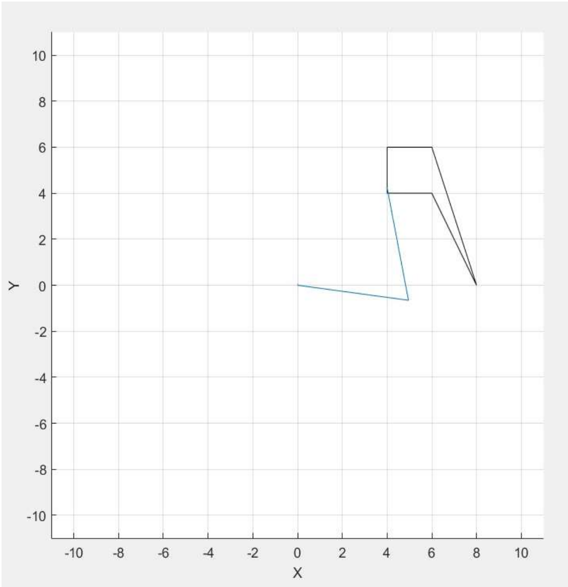
First Letter : C

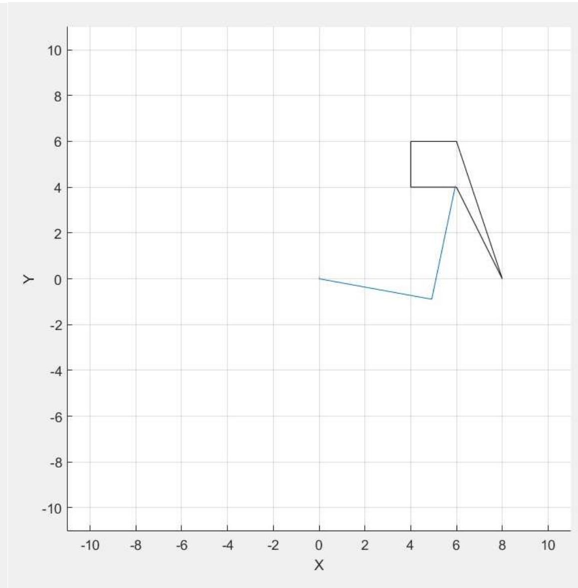
Find Coordinates of edges and generate trajectory.



Plot letter C using Two Link Planar Robot



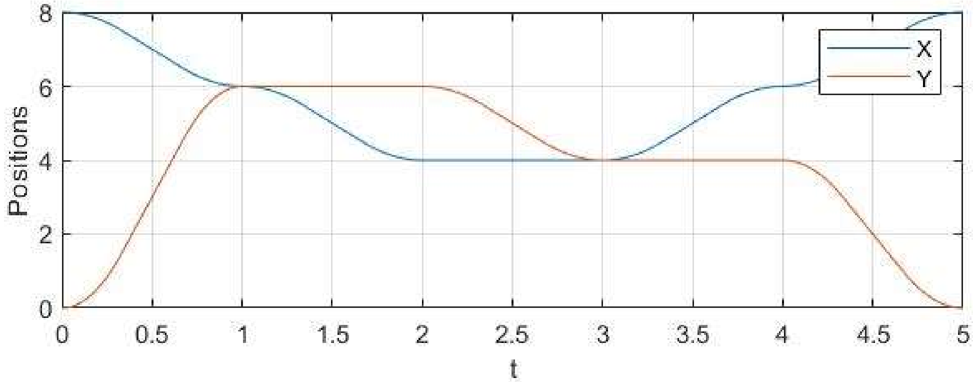


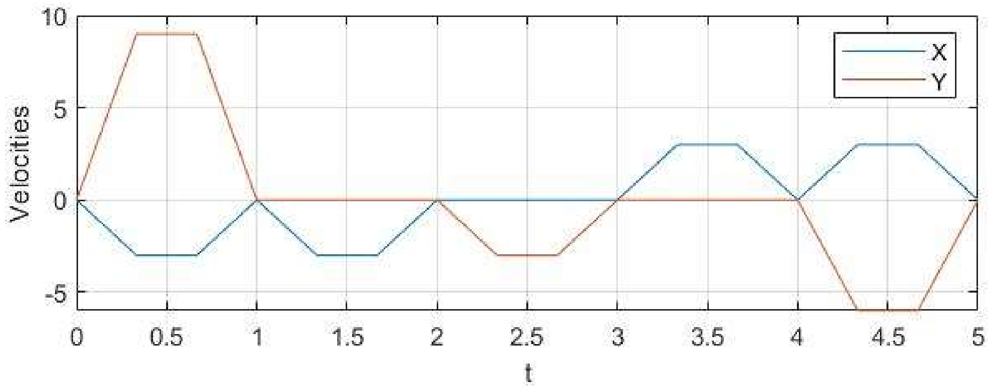


Using End Effector positions and velocities calculate

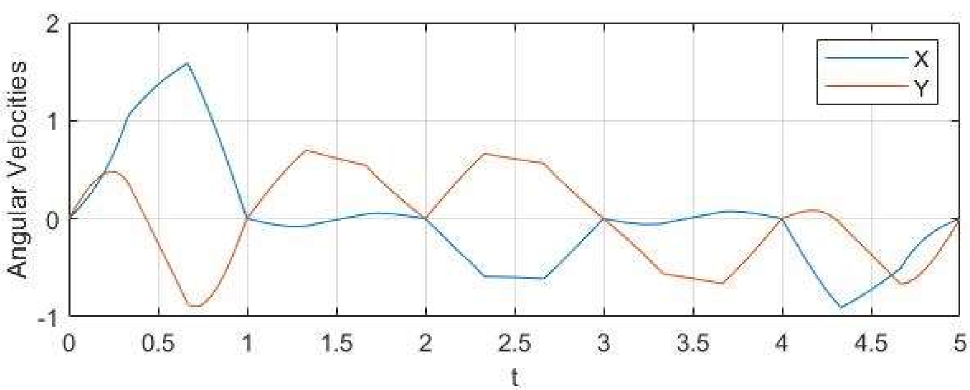
- Joint angles
- Angular velocities
- Angular accelerations
- Centripetal forces
- Coriolis forces
- Gravity forces
- Inertial forces

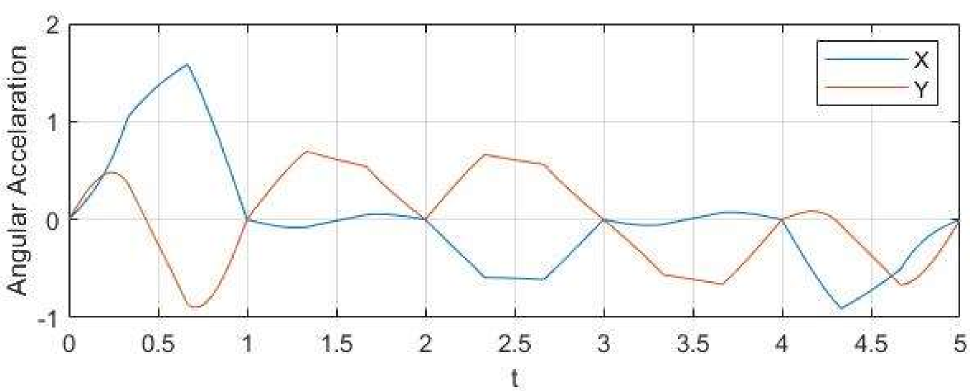
End effector position and velocity



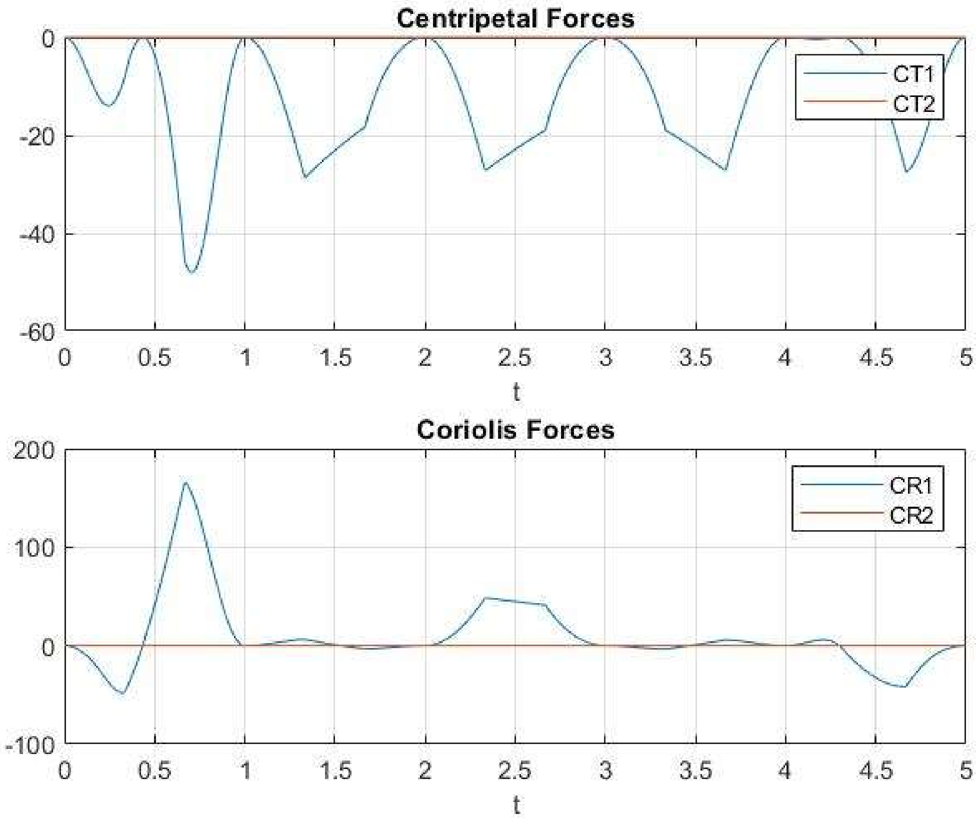


Angular velocities and acceleration

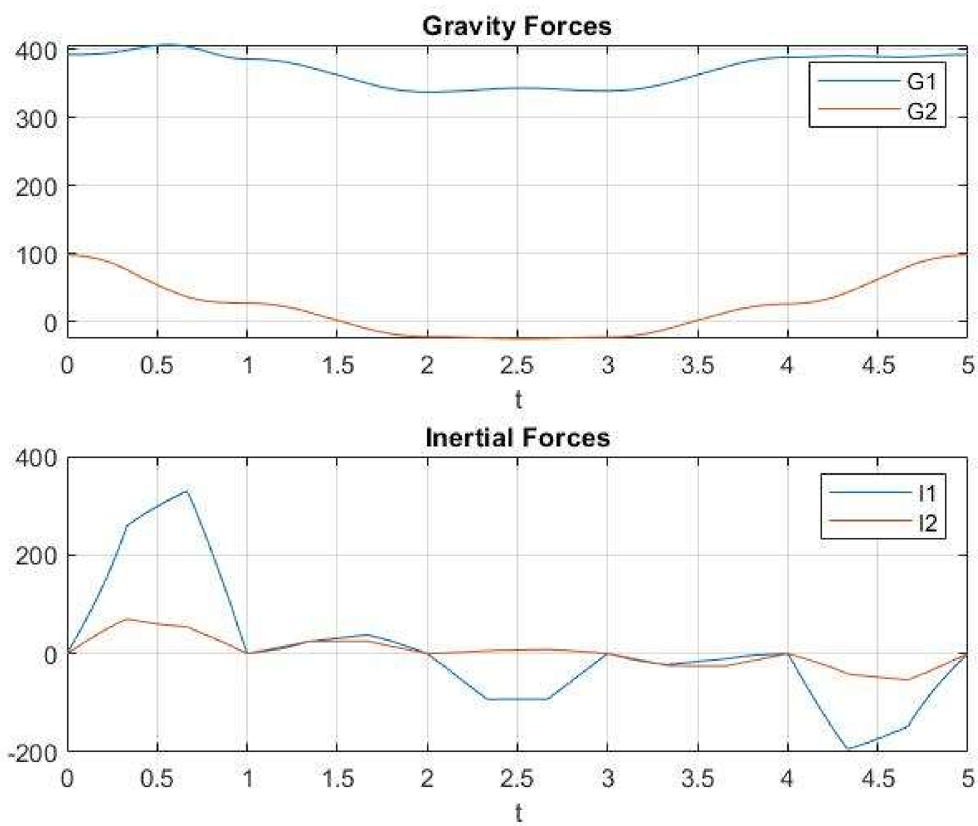




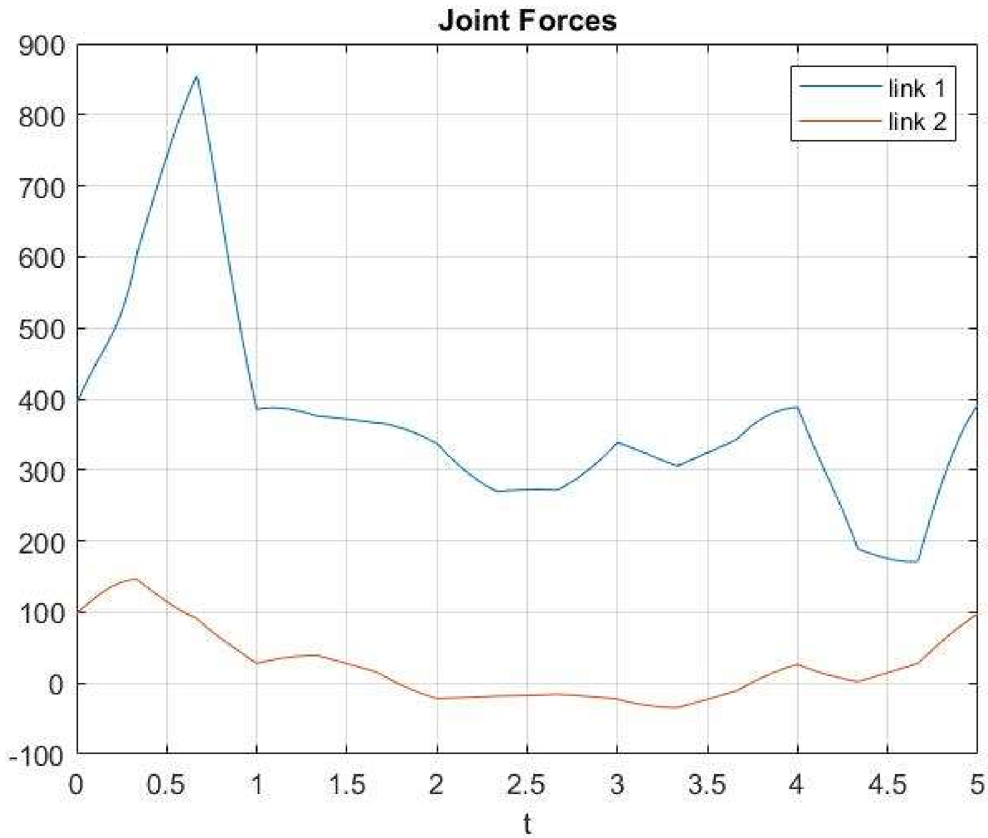
Centripetal and Coriolis forces/torques.



Gravity and Inertial forces/torques

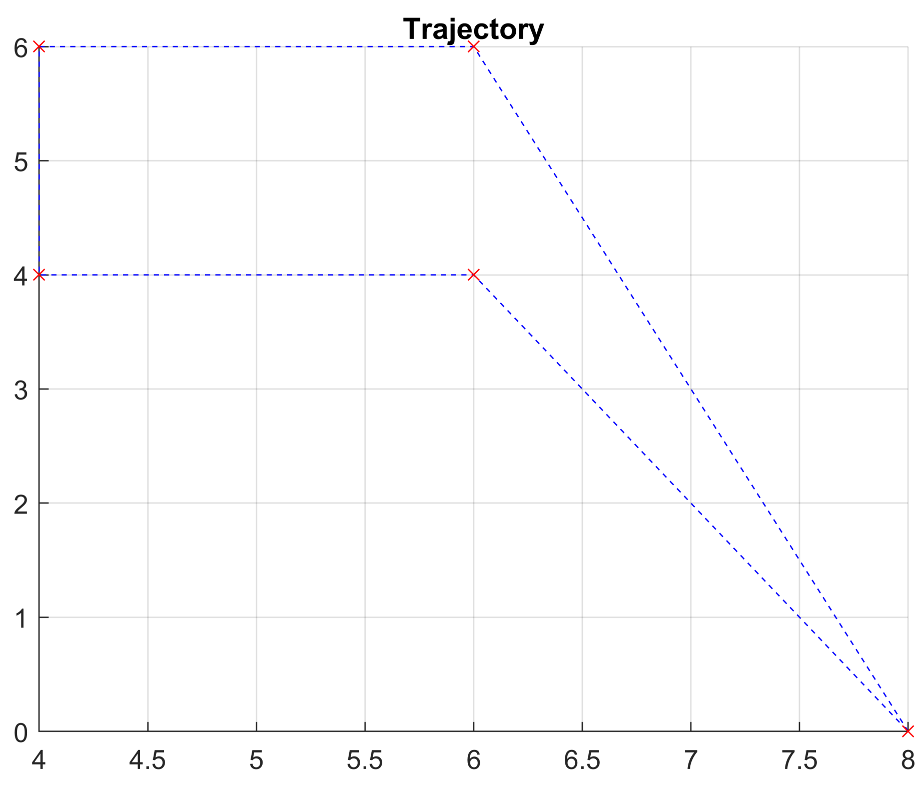


Joint forces for the link 1 and link 2



Source code : https://github.com/CSham31/Torque-Simulation

```
clear all;
close all;

%Coordinates
%start_end_pos=[8 0 0];
%coordinate=[[6 6]; [5 6 ]; [5 5 ]; [6 5];];

%Find Coordinates of edges and generate trajectory.

coordinate=[8 6 4 4 6 8; 0 6 6 4 4 0];
no_of_samples=1000;

%trajectory
[q, qd, qdd, tvec, pp] = trapveltraj(coordinate, no_of_samples);

figure;
hold on;
grid on;
title("Trajectory");
plot(q(1,:),q(2,:),'--b',coordinate(1,:),coordinate(2,:),'xr')
```



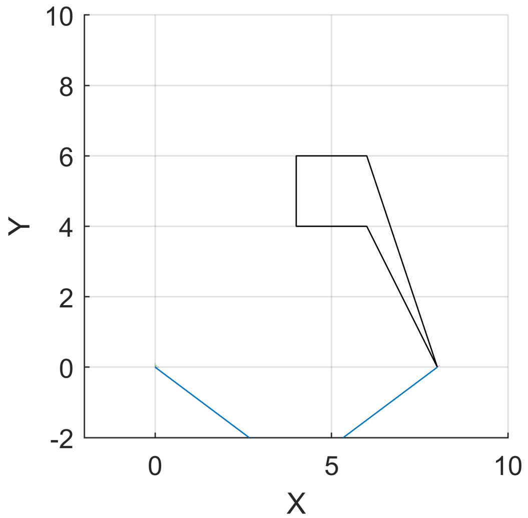

```
%creating two link planar robot

% Start with a blank rigid body tree model
robot = rigidBodyTree('DataFormat','column','MaxNumBodies',3);

% Specify arm lengths for the robot arm
l1=5;
```

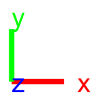
```
l2=5;

% Add |'link1'| body with |'joint1'| joint.
body = rigidBody('link1');
joint = rigidBodyJoint('joint1', 'revolute');
setFixedTransform(joint,trvec2tform([0 0 0]));
joint.JointAxis = [0 0 1];
body.Joint = joint;
addBody(robot, body, 'base');

% Add |'link2'| body with |'joint2'| joint.
body = rigidBody('link2');
joint = rigidBodyJoint('joint2','revolute');
setFixedTransform(joint, trvec2tform([l1,0,0]));
joint.JointAxis = [0 0 1];
body.Joint = joint;
addBody(robot, body, 'link1');

% Add |'tool'| end effector with |'fix1'| fixed joint.
body = rigidBody('tool');
joint = rigidBodyJoint('fix1','fixed');
setFixedTransform(joint, trvec2tform([l2, 0, 0]));
body.Joint = joint;
addBody(robot, body, 'link2');

% Show details of the robot to validate the input properties. The robot
% should have two non-fixed joints for the rigid bodies and a fixed body
% for the end-effector.
showdetails(robot);
```

```
--------------------
Robot: (3 bodies)

 Idx     Body Name     Joint Name     Joint Type     Parent Name(Idx)   Children Name(s)
 ---     ---------     ----------     ----------     ----------------   ----------------
   1         link1         joint1       revolute              base(0)   link2(2)
   2         link2         joint2       revolute             link1(1)   tool(3)
   3          tool           fix1          fixed             link2(2)
--------------------
```

```
% Pre-allocate configuration solutions as a matrix |qs|.
count=length(tvec);
q0 = homeConfiguration(robot);
ndof = length(q0);
qs = zeros(count, ndof);
x=transpose(q(1,:));
y=transpose(q(2,:));
z=transpose(zeros(size(tvec)));

points=[x,y,z];
% Create the inverse kinematics solver. Because the _xy_ Cartesian points are the
% only important factors of the end-effector pose for this workflow,
% specify a non-zero weight for the fourth and fifth elements of the
% |weight| vector. All other elements are set to zero.

ik = inverseKinematics('RigidBodyTree', robot);
```

```
weights = [0, 0, 0, 1, 1, 0];
endEffector = 'tool';

qInitial = q0; % Use home configuration as the initial guess
for i = 1:count
    % Solve for the configuration satisfying the desired end effector
    % position
    point = points(i,:);

    qSol = ik(endEffector,trvec2tform(point),weights,qInitial);
    % Store the configuration
    qs(i,:) = qSol;
    % Start from prior solution
    qInitial = qSol;
end

figure
show(robot,qs(1,:)');
view(2)
ax = gca;
ax.Projection = 'orthographic';
hold on
plot(points(:,1),points(:,2),'k')
axis([-2 10 -2 10])

framesPerSecond = 15;
r = rateControl(framesPerSecond);
for i = 1:count
    show(robot,qs(i,:)','PreservePlot',false);
    drawnow
    waitfor(r);
end
```



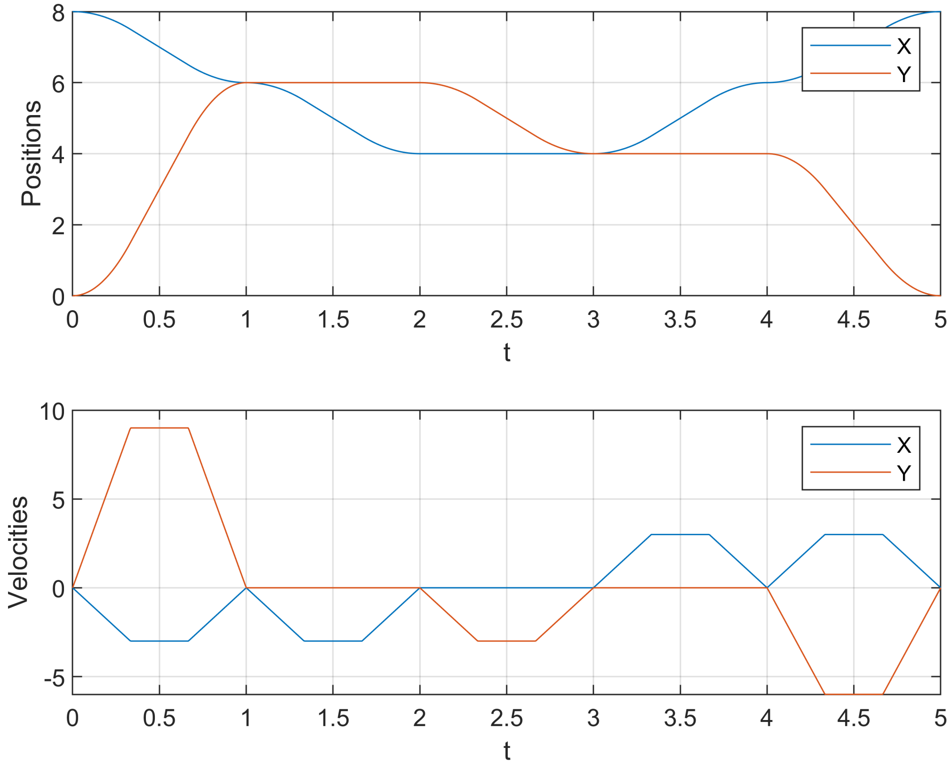



```
%variables for further calculation
density =1;
g=9.8;

m1=density*l1;
m2=density*l2;
%angular velocity
w_1=zeros(2,no_of_samples);

prev_w1=0;
prev_w2=0;

%angular accelaration
a_acc=zeros(2,no_of_samples);

%centripetal forces/torques
ctp_f=zeros(2,no_of_samples);

%coriolis forces/torques
crl_f=zeros(2,no_of_samples);

%gravity forces/torques
grv_f=zeros(2,no_of_samples);

%inertial forces/torques
int_f=zeros(2,no_of_samples);
```

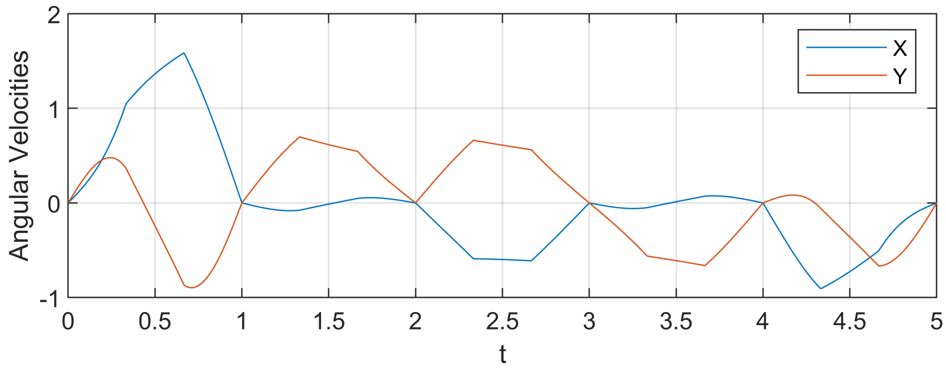
```
%joint forces/torques
joint_f=zeros(2,no_of_samples);

for i=1:no_of_samples

    %end effector position
    x2=q(1,i);
    y2=q(2,i);

    %end effector velocity
    Vx=qd(1,i);
    Vy=qd(2,i);

    %inverse kinematics
    theta_2= acos((x2^2 + y2^2 - l1^2 - l2^2)/(2*l1*l2));
    theta_1=atan2(y2,x2) - atan2((l2*sin(theta_2)),(l1 + l2*cos(theta_2)));

    %forward kinematics
    x1 = l1*cos(theta_1);
    y1 = l1*sin(theta_1);


    x2 = x1+(l2*cos(theta_2+theta_1));
    y2 = y1+(l2*sin(theta_2+theta_1));

    %jarcobian matrix
    jacobian = [[-(l1*sin(theta_1))-(l2*sin(theta_1+theta_2)), -(l1*sin(theta_1+theta_2))];
            [ (l1*cos(theta_1))+(l2*cos(theta_1+theta_2)),  (l2*cos(theta_1+theta_2))]];

    %angular velocity
    w = pinv(jacobian)*[Vx; Vy];

    w1 = w(1,1);
    w2 = w(2,1);
    w_1(1,i)=w1;
    w_1(2,i)=w2;

    %angular accelaration
    a_acc1=w1-prev_w1;
    a_acc2=w2-prev_w2;
    a_acc(1,i)=a_acc1;
    a_acc(2,i)=a_acc2;

    %christoffel symbols
    %c111=c112=c212=c122=c222=0
    %c211=c121=c221=-0.5*m2*l1*l2*sin(q2)

    c221=-0.5*m2*l1*l2*sin(theta_2);

    C = [[0 c221];[0 0]]*[w1^2; w2^2];
    ctp_f1= C(1,1);
    ctp_f2= C(2,1);
    ctp_f(1,i)=ctp_f1;
    ctp_f(2,i)=ctp_f2;
```

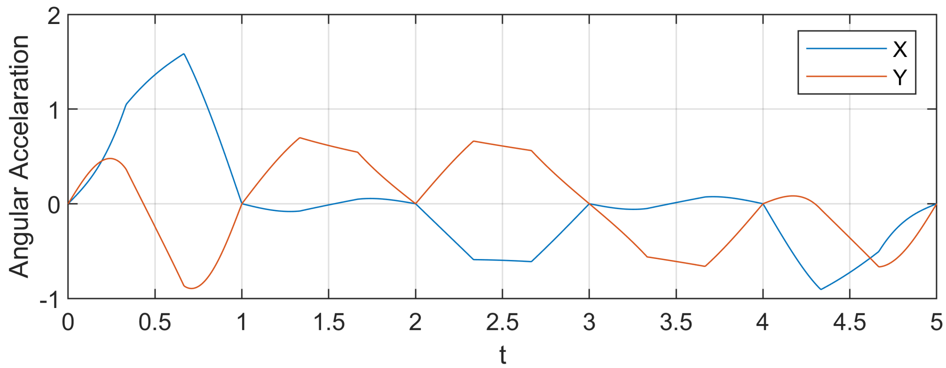
```
    %coriolis torques
    crl_f1=-1*m2*l1*l2*sin(theta_2)*w1*w2;
    crl_f2=0;
    crl_f(1,i)=crl_f1;
    crl_f(2,i)=crl_f2;

    %gravity torques
    grv_f1=0.5*m1*g*l1*cos(theta_1)+m2*g*(l1*cos(theta_1)+0.5*l2*cos(theta_1+theta_2));
    grv_f2=0.5*m2*g*l2*cos(theta_1+theta_2);
    grv_f(1,i)=grv_f1;
    grv_f(2,i)=grv_f2;

    %inertial torques
    M = [[ (m1*(l1^2)/3) + m2*((l1^2)+(l2^2/3)+(l1*l2*cos(theta_2))) m2*(((l2^2)/3)+(l1*l2*cos(
        [ m2*((l2^2/3)+(l1*l2*cos(theta_2)/2))                                                   (

    I=M*[a_acc1; a_acc2];
    int_f1=I(1,1);
    int_f2=I(2,1);
    int_f(1,i)=int_f1;
    int_f(2,i)=int_f2;

    %joint torques
    j1=ctp_f1+crl_f1+grv_f1+int_f1;
    j2=ctp_f2+ctp_f2+grv_f2+int_f2;
    joint_f(1,i)=j1;
    joint_f(2,i)=j2;

    %animate

end
```

```
%generating figures

figure;

subplot(2,1,1)
plot(tvec, q)
grid on
xlabel('t')
ylabel('Positions')
legend('X','Y')

subplot(2,1,2)
plot(tvec, qd)
grid on
xlabel('t')
ylabel('Velocities')
legend('X','Y')
```

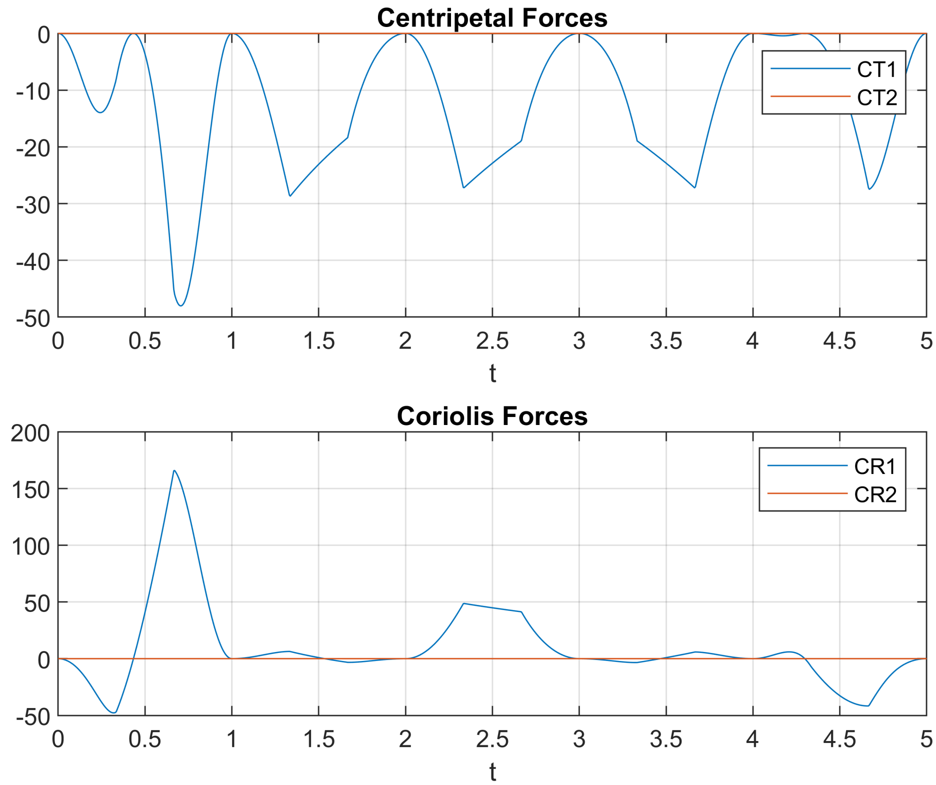



```
figure;

subplot(2,1,1)
plot(tvec, w_1)
grid on
xlabel('t')
ylabel('Angular Velocities')
legend('X','Y')

subplot(2,1,2)
plot(tvec, a_acc)
grid on
xlabel('t')
ylabel('Angular Accelaration')
legend('X','Y')
```

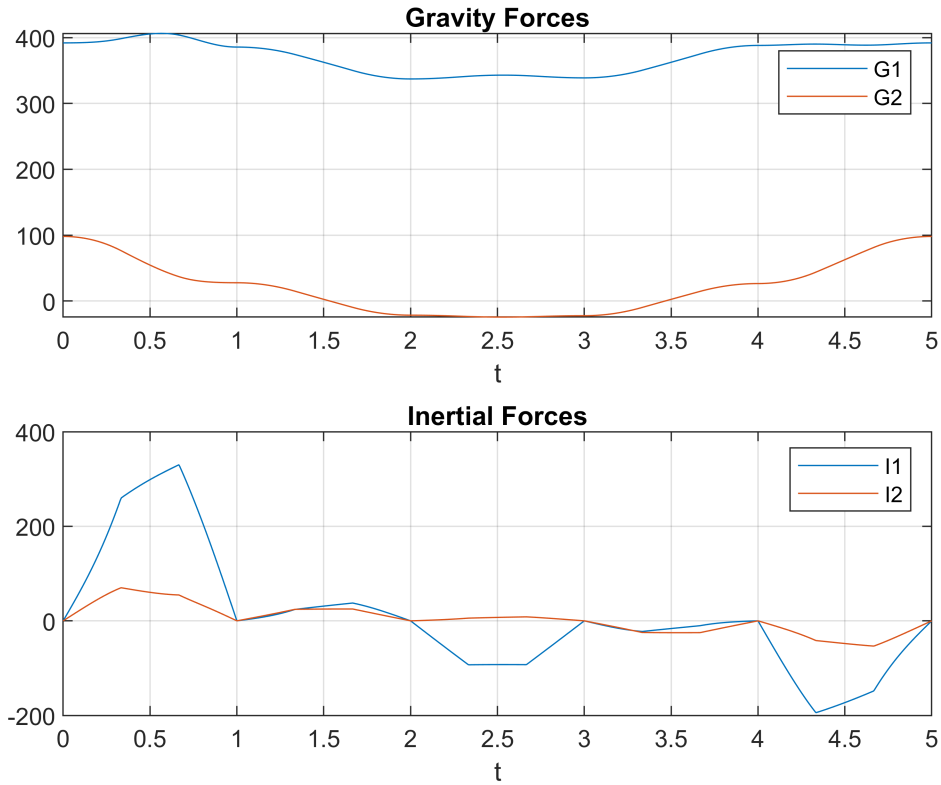




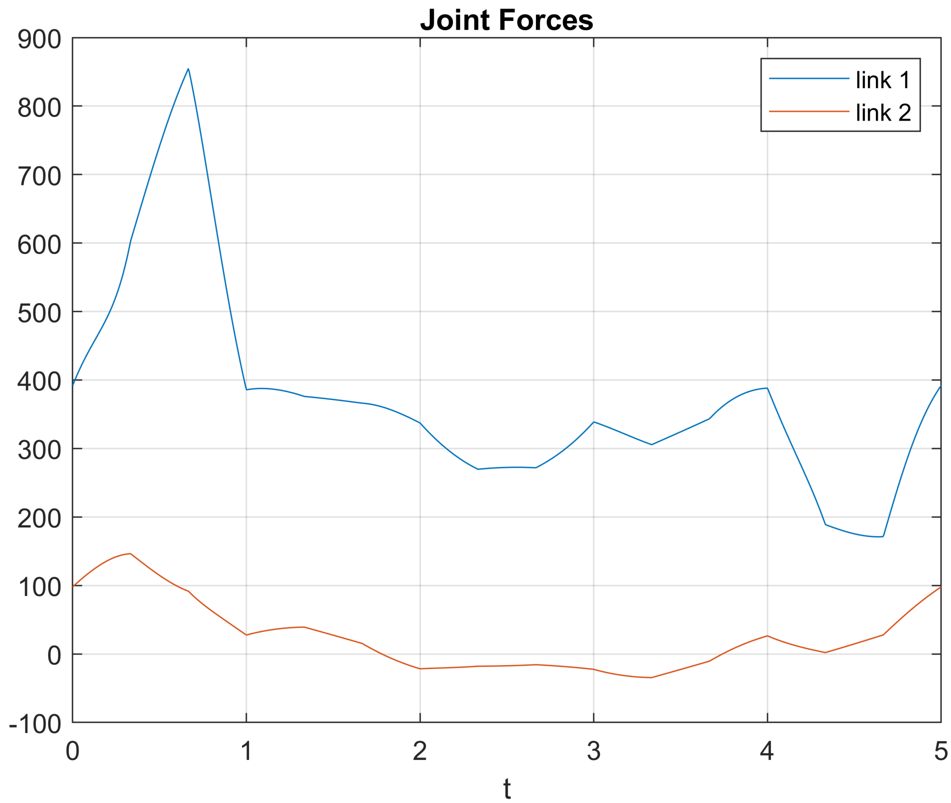

```
figure;

subplot(2,1,1)
plot(tvec, ctp_f)
grid on
xlabel('t')
title('Centripetal Forces')
legend('CT1','CT2')

subplot(2,1,2)
plot(tvec, crl_f)
grid on
xlabel('t')
title('Coriolis Forces')
legend('CR1','CR2')
```




```
figure;

subplot(2,1,1)
plot(tvec, grv_f)
grid on
xlabel('t')
title('Gravity Forces')
legend('G1','G2')

subplot(2,1,2)
plot(tvec, int_f)
grid on
xlabel('t')
title('Inertial Forces')
legend('I1','I2')
```




```
figure;

plot(tvec, joint_f)
grid on
xlabel('t')
title('Joint Forces')
legend('link 1','link 2')
```


Joint Forces
900
800
700
600
500
400
300
200
100
0
-100
0
1
2
3
4
5
t
link 1
link 2