

## 2. Perform PD control simulation.

```
clc
clear all
close all
syms time
m1=10;
m2=5;
l=0.5;
tt01=30*pi/180;
tt02=150*pi/180;
ttf1=150*pi/180;
ttf2=30*pi/180;

a01=pi/6;
a02=5*pi/6;
a21=pi;
a22=-pi;
a31=-4*pi/3;
a32=4*pi/3;
g=9.81;
i=1;
deltat=0.01;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% P_D Controller %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
tt1_r=30*pi/180;
tt2_r=150*pi/180;
dtt1_r=0;
dtt2_r=0;
e1=0;
e2=0;

Kp1=9000;
Kp2=7800;
Kv1=0.1;
Kv2=2.5;
hold off;
for t=0:deltat:1
    tt1=a01+a21*t*t+a31*t^3;
    tt2=a02+a22*t*t+a32*t^3;
    dtt1=2*a21*t+3*a31*t^2;
    dtt2=2*a22*t+3*a32*t^2;
    ddt1=2*a21+6*a31*t;
    ddt2=2*a22+6*a32*t;

    tque1=-Kv1*dtt1_r+Kp1*e1;
    tque2=-Kv2*dtt2_r+Kp2*e2;

    T=[tque1;tque2];
    M=[1^2*m2+2*1^2*m2*cos(tt2_r)+1^2*(m1+m2)
        1^2*m2+1^2*m2*cos(tt2_r);1^2*m2+1^2*m2*cos(tt2_r) 1^2*m2];
```

```

V=[-m2*l^2*sin(tt2_r)*dtt2_r^2-
2*m2*l^2*sin(tt2_r)*dtt1_r*dtt2_r;m2*l^2*sin(tt2_r)*dtt1^2];

G=[m2*l*g*cos(tt1_r+tt2_r)+(m1+m2)*l*g*cos(tt1_r);m2*l*g*cos(tt1_r+tt2_r)];
Minv=M^-1;

ddtt=Minv*(T-V-G)
dtt1_r=ddtt(1)
dtt2_r=ddtt(2)
dtt1_r=dtt1_r+deltat*dtt1_r;
dtt2_r=dtt2_r+deltat*dtt2_r;
tt1_r=tt1_r+dtt1_r*deltat+0.5*deltat^2*dtt1_r;
tt2_r=tt2_r+dtt2_r*deltat+0.5*deltat^2*dtt2_r;
e1=tt1-tt1_r;
e2=tt2-tt2_r;

figure(1)
plot(t,tt1,'blue*');
hold on
plot(t,tt1_r,'red*');
hold on
plot(t,e1,'black*')
legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
title('PD Joint#1');

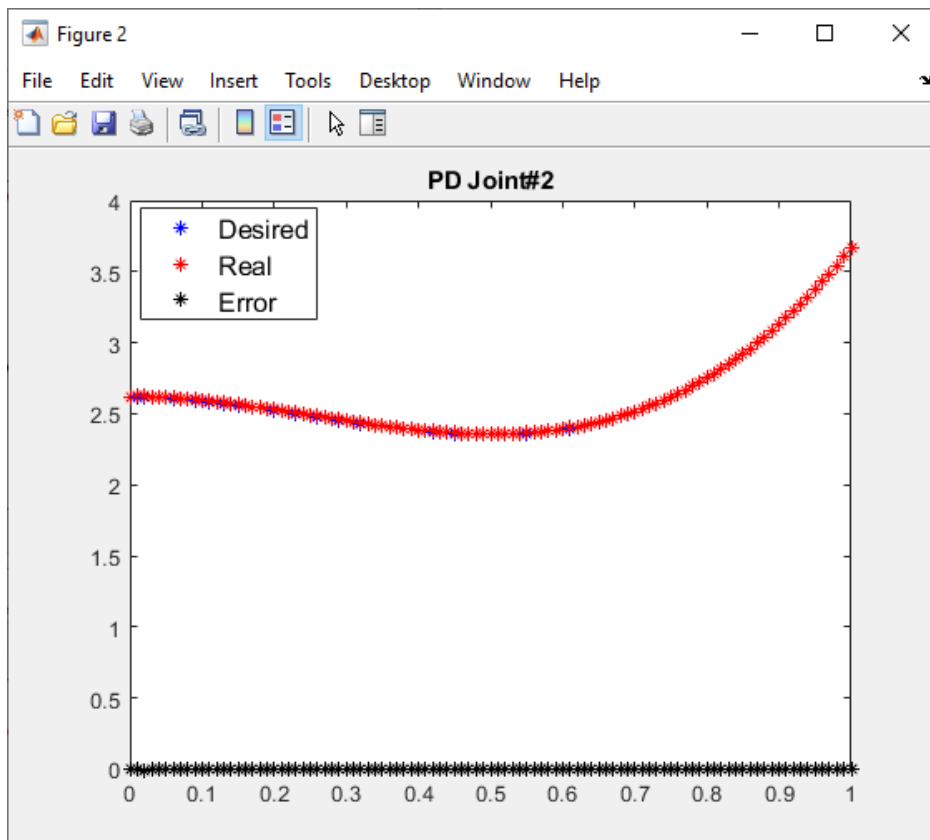
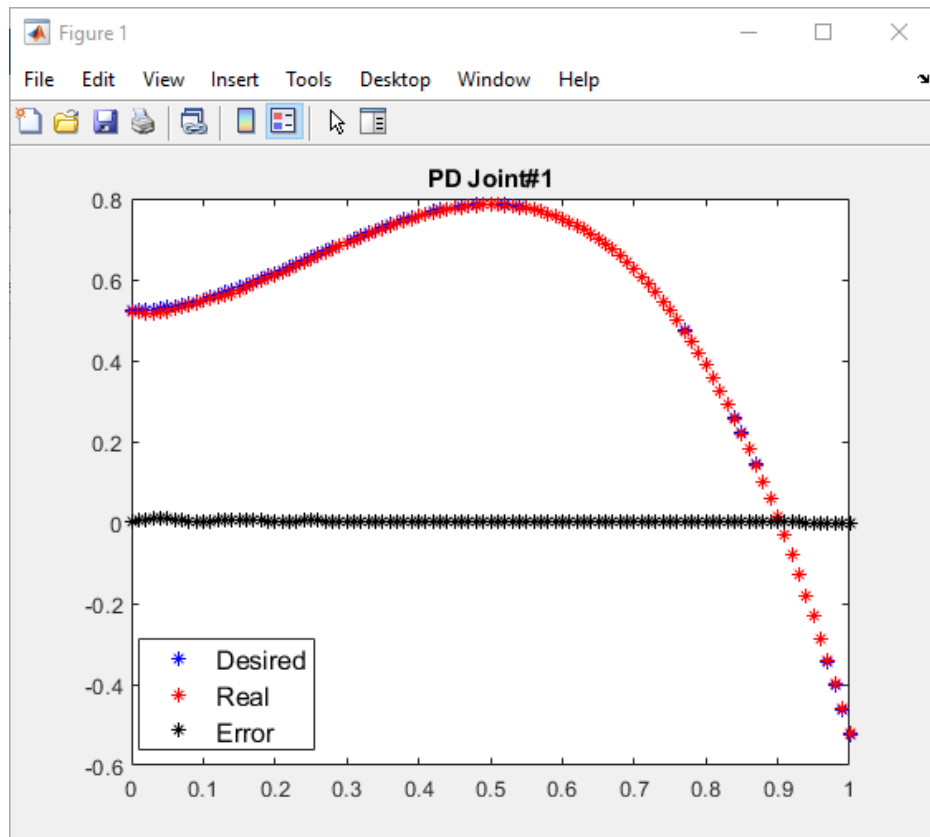
figure(2)
plot(t,tt2,'blue*');
hold on
plot(t,tt2_r,'red*');
hold on
plot(t,e2,'black*');
legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
title('PD Joint#2');

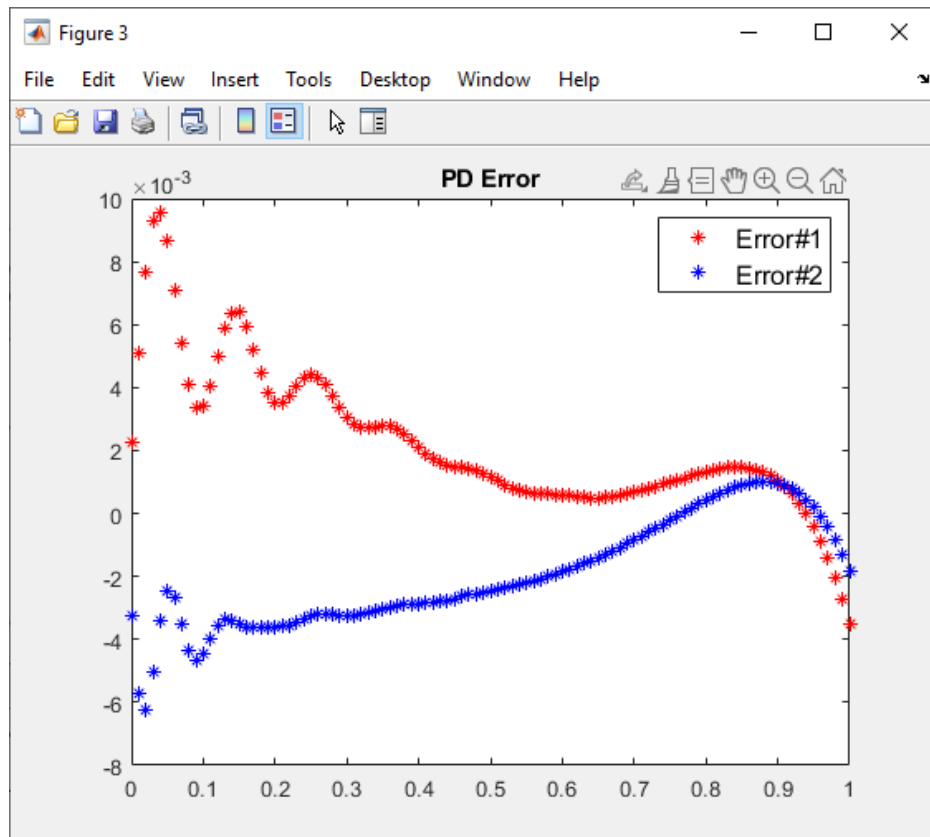
figure(3)
plot(t,e1,'red*')
hold on
plot(t,e2,'blue*');
legend({'Error#1', 'Error#2'}, 'FontSize', 12);
title('PD Error');

i=i+1;
end

```

The results obtained:





### 3. Perform PD + gravity control simulation.

Code in Matlab

```
tt1_r=30*pi/180;
tt2_r=150*pi/180;
dtt1_r=0;
dtt2_r=0;
e1=0;
e2=0;
Kp1=9000;
Kp2=7800;
Kv1=0.1;
Kv2=2.5;
for t=0:deltat:1
    tt1=a01+a21*t*t+a31*t^3;
    tt2=a02+a22*t*t+a32*t^3;
    dtt1=2*a21*t+3*a31*t^2;
    dtt2=2*a22*t+3*a32*t^2;
    ddt1=2*a21+6*a31*t;
    ddt2=2*a22+6*a32*t;
    g1=m2*l*g*cos(tt1+tt2)+(m1+m2)*l*g*cos(tt1);
    g2=m2*l*g*cos(tt1+tt2);

    tqe1=g1-Kv1*dtt1_r+Kp1*e1;
    tqe2=g2-Kv2*dtt2_r+Kp2*e2;
```

```

T=[tque1;tque2];
M=[1^2*m2+2*1^2*m2*cos(tt2_r)+1^2*(m1+m2)
1^2*m2+1^2*m2*cos(tt2_r);1^2*m2+1^2*m2*cos(tt2_r) 1^2*m2];
V=[-m2*1^2*sin(tt2_r)*dtt2_r^2-
2*m2*1^2*sin(tt2_r)*dtt1_r*dtt2_r;m2*1^2*sin(tt2_r)*dtt1^2];
G=[m2*1*g*cos(tt1_r+tt2_r)+(m1+m2)*1*g*cos(tt1_r);m2*1*g*cos(tt1_r+tt2_r)];
Minv=M^-1;
ddtt=Minv*(T-V-G)
ddtt1_r=ddtt(1)
ddtt2_r=ddtt(2)
dtt1_r=dtt1_r+deltat*ddtt1_r;
dtt2_r=dtt2_r+deltat*ddtt2_r;
tt1_r=tt1_r+dtt1_r*deltat+0.5*deltat^2*ddtt1_r;
tt2_r=tt2_r+dtt2_r*deltat+0.5*deltat^2*ddtt2_r;
e1=tt1-tt1_r;
e2=tt2-tt2_r;

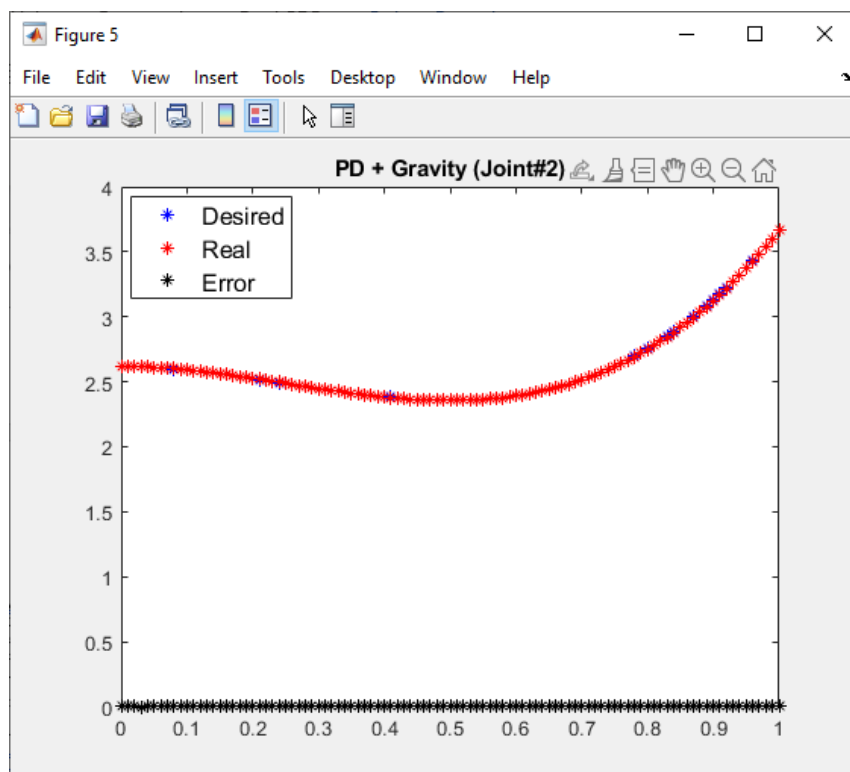
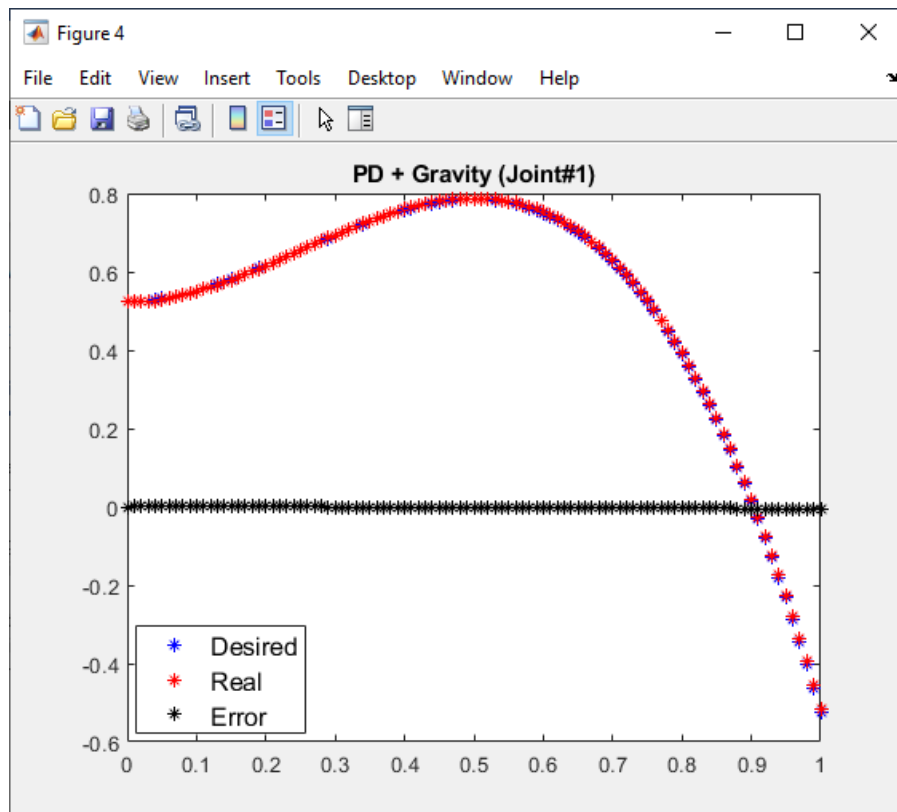
figure(4)
plot(t,tt1,'blue*');
hold on
plot(t,tt1_r,'red*');
hold on
plot(t,e1,'black*')
legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
title('PD + Gravity (Joint#1)');

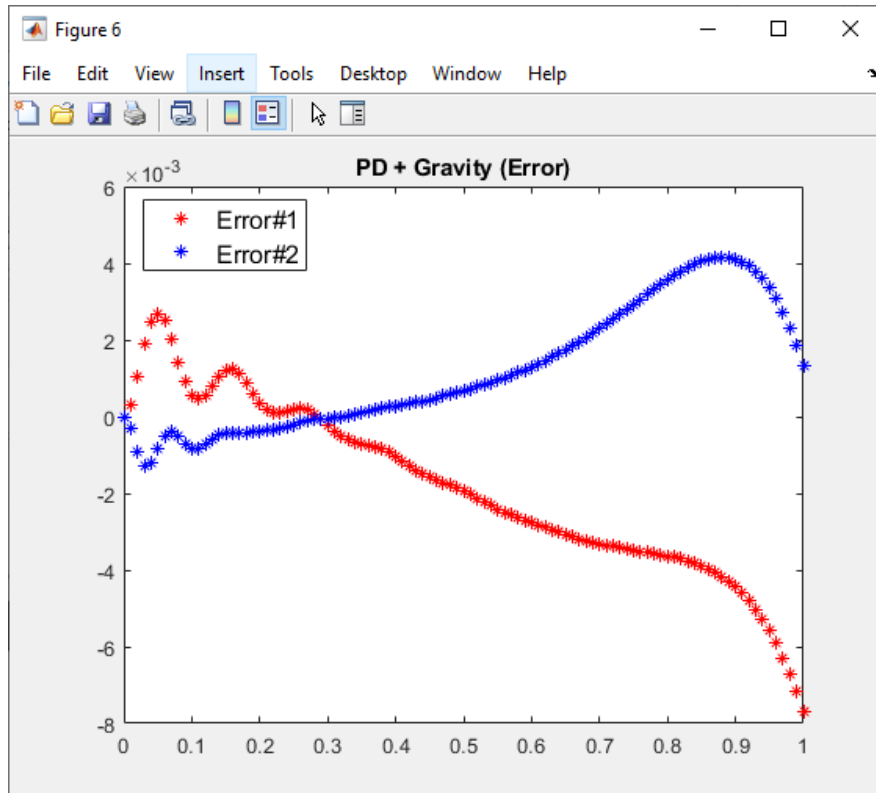
figure(5)
plot(t,tt2,'blue*');
hold on
plot(t,tt2_r,'red*');
hold on
plot(t,e2,'black*')
legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
title('PD + Gravity (Joint#2)');

figure(6)
plot(t,e1,'red*')
hold on
plot(t,e2,'*')
hold on
legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
title('PD + Gravity (Error)');

i=i+1;
end

```





#### 4. Perform computed torque control simulation.

Code in Matlab

```
tt1_r=30*pi/180;
tt2_r=150*pi/180;
dtt1_r=0;
dtt2_r=0;
e1=0;
e2=0;
de1=0;
de2=0;
Kp1=7800;
Kp2=5800;
Kv1=0.1;
Kv2=0.5;

for t=0:deltat:1
    tt1=a01+a21*t*t+a31*t^3;
    tt2=a02+a22*t*t+a32*t^3;
    dtt1=2*a21*t+3*a31*t^2;
    dtt2=2*a22*t+3*a32*t^2;
    ddt1=2*a21+6*a31*t;
    ddt2=2*a22+6*a32*t;

    tqe_c1=ddt1+Kp1*e1+Kv1*de1
    tqe_c2=ddt2+Kp2*e2+Kv2*de2
```

```

    alpha=[l^2*m2+2*l^2*m2*cos(tt2)+l^2*(m1+m2)
1^2*m2+l^2*m2*cos(tt2);l^2*m2+l^2*m2*cos(tt2) 1^2*m2];
    M=alpha;

    V=[-m2*l^2*sin(tt2_r)*dtt2_r^2-
2*m2*l^2*sin(tt2_r)*dtt1_r*dtt2_r;m2*l^2*sin(tt2_r)*dtt1^2];

G=[m2*l*g*cos(tt1_r+tt2_r)+(m1+m2)*l*g*cos(tt1_r);m2*l*g*cos(tt1_r+tt2_r)];
    beta=V+G;
    T=alpha*[tque_c1;tque_c2]+beta
    ddt=M\ (T-V-G);

    ddt1_r=ddt(1);
    ddt2_r=ddt(2);
    dtt1_r=dtt1_r+deltat*ddt1_r;
    dtt2_r=dtt2_r+deltat*ddt2_r;
    tt1_r=tt1_r+dtt1_r*deltat+0.5*deltat^2*ddt1_r;
    tt2_r=tt2_r+dtt2_r*deltat+0.5*deltat^2*ddt2_r;
    e1=tt1-tt1_r;
    e2=tt2-tt2_r;
    de1=ddt1-dtt1_r;
    de2=ddt2-dtt2_r;

    figure(7)
    plot(t,tt1,'blue*');
    hold on
    plot(t,tt1_r,'red*');
    hold on
    plot(t,e1,'black*')
    legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
    title('Torque Control (Joint#1)');

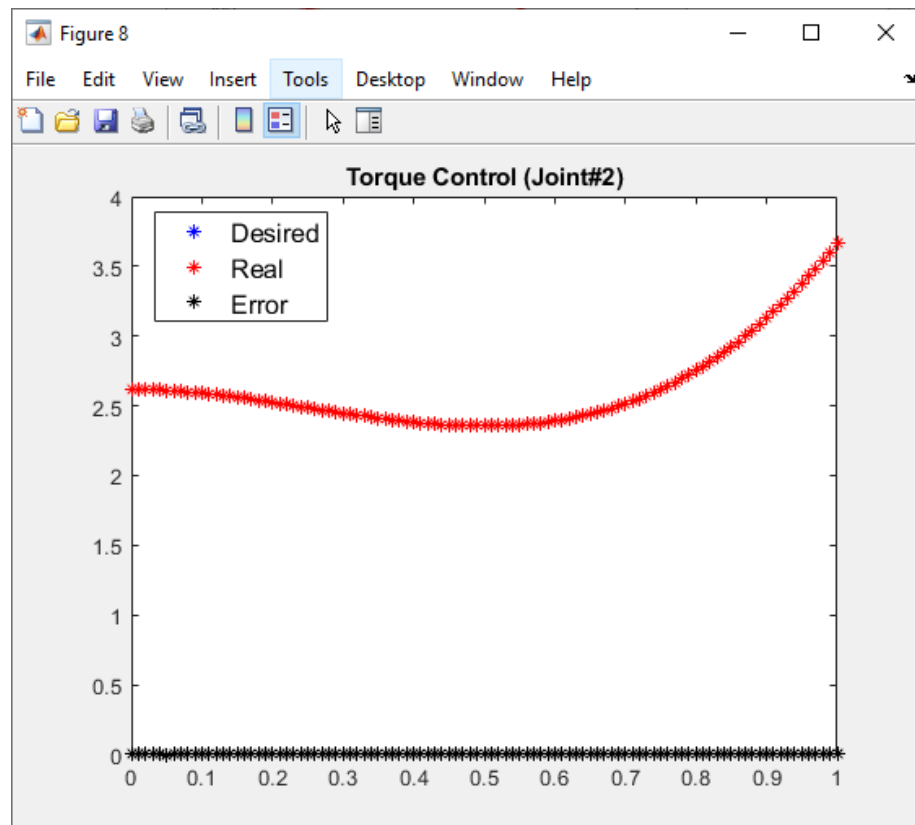
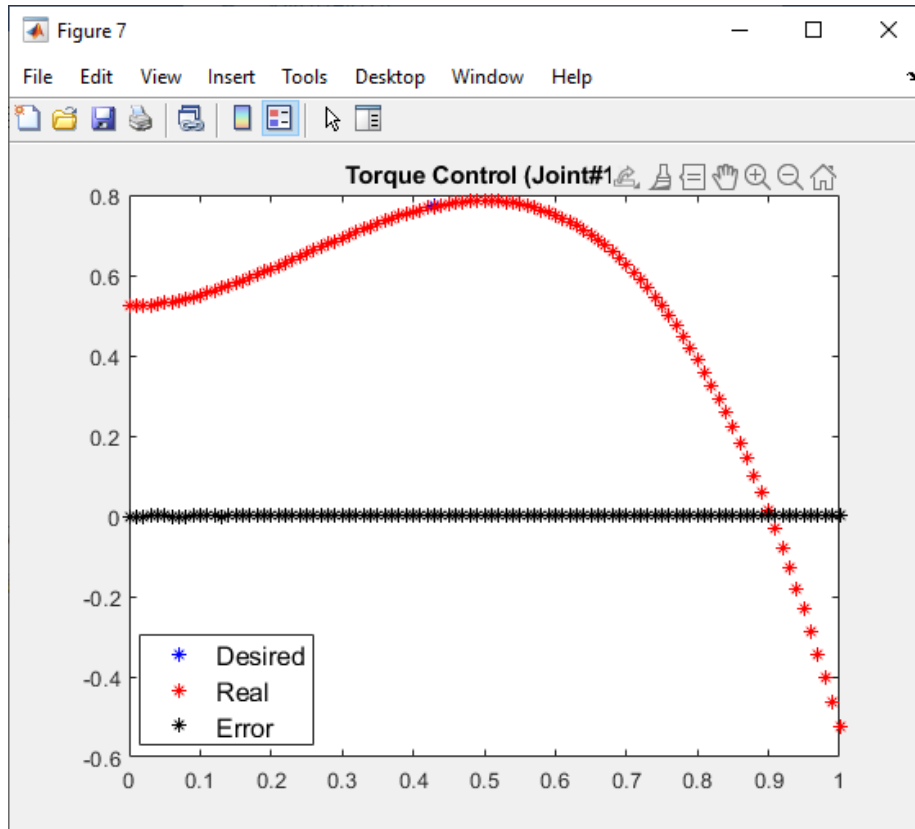
    figure(8)
    plot(t,tt2,'blue*');
    hold on
    plot(t,tt2_r,'red*');
    hold on
    plot(t,e2,'black*')
    legend({'Desired', 'Real', 'Error'}, 'FontSize', 12);
    title('Torque Control (Joint#2)');

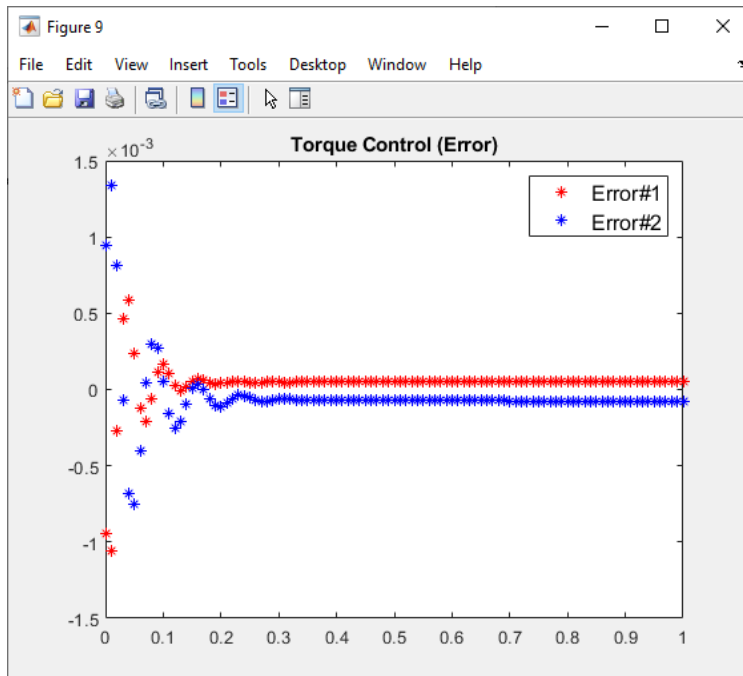
    figure(9)
    plot(t,e1,'red*')
    hold on
    plot(t,e2,'blue*')
    legend({'Error#1', 'Error#2'}, 'FontSize', 12);
    title('Torque Control (Error)');

    i=i+1;
end

```







5. Compare errors of 3 cases above.

