Table of Contents


```
syms q1 q2 q1d q2d
question4_func(q1, q2, q1d, q2d)
function []= question4_func(q1, q2, q1d, q2d)
```

```
clc
%clear all;
close all;

I1=1;  I2 = 1; m1=0.5; r1=0.15; m2=0.5; r2=.15; l1=0.3; l2=0.3;

a = I1+I2+m1*r1^2+ m2*(l1^2+ r2^2);
b = m2*l1*r2;
d = I2+ m2*r2^2;

global Mmat_symb Cmat_symb G_matrix_symb
```

Model equations

```
Mmat_symb = [a+2*b*cos(q1), d+b*cos(q1);  d+b*cos(q1), d];
Cmat_symb = [-b*sin(q1)*q2d, -b*sin(q1)*(q1d+q2d); b*sin(q2)*q1d,0];
g = 9.81;
G_matrix_symb = [(m1*r1 + m2*l1)*g * sin(q1) + m2 * r2 * g * sin(q1 +
 q2);...
    m2 * r2 * g * sin(q1 + q2)];
```

```
%xd = input('X coordinate ');
%yd = input('Y coordinate ');
```

position calculations

```
posi = [0.300,0.450]
posf = [-0.300,0.450]
```

```
[qi1,qi2] = twoDOFIK(posi(1),posi(2),1);
[qf1,qf2] = twoDOFIK(posf(1),posf(2),-1);
```

```
x0= [qi1,qi2,0,0]; % Initial Condition - Format:
[theta1,theta2,dtheta1,dtheta2]


tf=10;
```

```
posi =

    0.3000    0.4500
```

```
posf =

   -0.3000    0.4500
```

Solve the closed-loop system nonlinear differential equation (PlanarArmODE) via ode45

```
%%ode45 solves the differential equation and returns X with respect to
 T.
global torque
torque=[];

[T,X] = ode45(@(t,x)planarArmODE(t,x),[0 tf],x0);

temp = ones(length(X(:,1)));

[x,y] = twoDOFFK([X(:,1),X(:,2)],l1,l2);
poses = [x,y];
linkx = l1*cos(X(:,1));
linky = l1*sin(X(:,1)) ;
links = [linkx,linky];


error_joints = [temp * qf1 - X(:,1),temp * qf1 - X(:,2)];
error_task = sqrt((posf(1)-x).^2 + (posf(2)-y).^2) ;

task_velocity = diff(poses);
```

```
t =

     0
```

```
t =

   4.6897e-06
```

```
t =
```

```
   7.0346e-06

t =

   1.8759e-05

t =

   2.0843e-05

t =

   2.3449e-05

t =

   2.3449e-05

t =

   4.6897e-05

t =

   5.8622e-05

t =

   1.1724e-04

t =

   1.2767e-04

t =

   1.4069e-04

t =

   1.4069e-04
```

```
t =

   2.5794e-04

t =

   3.1656e-04

t =

   6.0967e-04

t =

   6.6178e-04

t =

   7.2691e-04

t =

   7.2691e-04

t =

    0.0013

t =

    0.0016

t =

    0.0031

t =

    0.0033

t =

    0.0037
```

```
t =

    0.0037

t =

    0.0061

t =

    0.0073

t =

    0.0134

t =

    0.0144

t =

    0.0158

t =

    0.0158

t =

    0.0191

t =

    0.0207

t =

    0.0289

t =

    0.0304
```

```
t =

    0.0322

t =

    0.0322

t =

    0.0369

t =

    0.0393

t =

    0.0511

t =

    0.0532

t =

    0.0559

t =

    0.0559

t =

    0.0621

t =

    0.0652

t =
```

```
    0.0806

t =

    0.0834

t =

    0.0868

t =

    0.0868

t =

    0.0947

t =

    0.0986

t =

    0.1183

t =

    0.1218

t =

    0.1262

t =

    0.1262

t =

    0.1362

t =
```

```
    0.1412

t =

    0.1662

t =

    0.1706

t =

    0.1761

t =

    0.1761

t =

    0.1890

t =

    0.1955

t =

    0.2276

t =

    0.2333

t =

    0.2405

t =

    0.2405
```

```
t =

    0.2576

t =

    0.2662

t =

    0.3091

t =

    0.3167

t =

    0.3262

t =

    0.3262

t =

    0.3509

t =

    0.3632

t =

    0.4247

t =

    0.4356

t =

    0.4493
```

```
t =

    0.4493

t =

    0.4886

t =

    0.5082

t =

    0.6064

t =

    0.6238

t =

    0.6456

t =

    0.6456

t =

    0.4752

t =

    0.4881

t =

    0.5527

t =

    0.5642
```

```
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    0.5786

t =

    0.5786

t =

    0.6044

t =

    0.6173

t =

    0.6820

t =

    0.6935

t =

    0.7078

t =

    0.7078

t =

    0.7318

t =

    0.7438

t =
```

```
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t =

    0.8144

t =

    0.8277

t =

    0.8277

t =

    0.8488

t =

    0.8593

t =

    0.9121

t =

    0.9215

t =

    0.9332

t =

    0.9332

t =

    0.9531

t =
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```
    0.9631

t =

    1.0130

t =

    1.0218

t =

    1.0329

t =

    1.0329

t =

    1.0523

t =

    1.0620

t =

    1.1104

t =

    1.1190

t =

    1.1298

t =

    1.1298
```

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t =

    1.1548

t =

    1.1966

t =

    1.2040

t =

    1.2133

t =

    1.2133

t =

    1.2349

t =

    1.2457

t =

    1.2998

t =

    1.3094

t =

    1.3214
```

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t =

    1.3459

t =

    1.3581

t =

    1.4193

t =

    1.4302

t =

    1.4438

t =

    1.4438

t =

    1.4698

t =

    1.4828

t =

    1.5476

t =

    1.5592
```

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t =

    1.5736

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t =

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t =

    1.6917

t =

    1.7064

t =

    1.7064

t =

    1.7332

t =

    1.7466

t =
```

```
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t =

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t =

    1.8404

t =

    1.8660

t =

    1.8788

t =

    1.9428

t =

    1.9542

t =

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t =

    1.9684

t =

    1.9913

t =
```

```
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    2.0600

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    2.0702

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    2.0829

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t =

    2.1134

t =

    2.1642

t =

    2.1732

t =

    2.1845

t =

    2.1845
```

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t =

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t =

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t =

    2.3145

t =

    2.3145

t =

    2.3547

t =

    2.3748

t =

    2.4751

t =

    2.4930

t =

    2.5153
```

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t =

    2.7707

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t =

    2.5572

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t =

    2.6395
```

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    2.6551

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t =

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    2.7793

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t =

    2.7949

t =

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t =
```

```
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    2.9364

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    2.9755

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    3.0667

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    3.0910

t =
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    3.3138
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t =

    3.4552

t =

    3.4894

t =

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t =

    3.5920

t =

    3.6072

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t =

    3.7989

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t =

    3.6590

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    3.7236
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t =
```

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t =

    4.0698

t =

    4.0809

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    4.0948

t =

    4.0948

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    4.1192

t =
```

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    4.2169

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    4.3460
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    4.4538

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    4.5886

t =

    4.6119

t =

    4.6236

t =

    4.6819

t =

    4.6922
```

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    4.7052

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    4.8182

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t =

    4.8545

t =
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```
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    4.9392

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t =

    4.9828

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t =

    5.0683

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t =

    5.0844

t =

    5.1342

t =
```

```
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t =

    5.3057

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t =

    5.3334

t =

    5.1136

t =

    5.1282

t =

    5.2012

t =

    5.2142

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    5.2304

t =

    5.2304
```

```
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    5.3602

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t =

    5.3764

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    5.4143

t =

    5.4332

t =

    5.5279

t =

    5.5447

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    5.5658
```

```
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t =

    5.5024

t =

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t =

    5.5181

t =

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t =

    5.5606

t =

    5.6315

t =

    5.6441
```

```
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t =

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    5.7706

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t =

    5.7983

t =

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```

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    6.0070

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    5.8804

t =

    5.8895

t =

    5.9009

t =

    5.9009

t =

    5.9215

t =
```

```
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    5.9831

t =

    5.9922

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t =

    6.0036

t =

    6.0281

t =

    6.0403

t =

    6.1016

t =

    6.1125

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    6.1261

t =

    6.1261
```

```
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    6.1739

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t =

    6.2676

t =

    6.2853

t =

    6.2853

t =

    6.1491

t =

    6.1606

t =

    6.2180

t =

    6.2282

t =

    6.2410
```

```
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    6.2410

t =

    6.2640

t =

    6.2754

t =

    6.3329

t =

    6.3431

t =

    6.3559

t =

    6.3559

t =

    6.3779

t =

    6.3889

t =

    6.4439

t =

    6.4537
```

```
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    6.4659

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t =

    6.5022

t =

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t =

    6.5733

t =

    6.5868

t =

    6.5868

t =

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t =

    6.6306

t =
```

```
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    6.7166

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    6.7328

t =

    6.7328

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    6.6095

t =

    6.6209

t =

    6.6779

t =

    6.6880

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    6.7006

t =

    6.7006

t =

    6.7234

t =
```

```
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t =

    6.7918

t =

    6.8019

t =

    6.8145

t =

    6.8145

t =

    6.8421

t =

    6.8559

t =

    6.9248

t =

    6.9370

t =

    6.9523

t =

    6.9523
```

```
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t =

    6.9968

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t =

    7.0841

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    7.1005

t =

    7.1005

t =

    7.1269

t =

    7.1401

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    7.2061

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    7.2178

t =

    7.2325
```

```
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    7.2325

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    7.2616

t =

    7.2761

t =

    7.3487

t =

    7.3616

t =

    7.3778

t =

    7.3778

t =

    7.4068

t =

    7.4213

t =

    7.4939

t =

    7.5068
```

```
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t =

    7.5229

t =

    7.3978

t =

    7.4079

t =

    7.4580

t =

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    7.4780

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    7.5081

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```

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```

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    7.8662

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    7.7761

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    7.7867

t =

    7.7867
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    7.8716

t =

    7.8822

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    7.8822

t =

    7.9048

t =

    7.9161

t =

    7.9726

t =

    7.9826

t =

    7.9952
```

```
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    7.9952

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t =

    8.0474

t =

    8.1345

t =

    8.1500

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    8.1693

t =

    8.1693

t =

    8.0195

t =

    8.0316

t =

    8.0922

t =

    8.1030
```

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t =

    8.1165

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    8.1408

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t =

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t =

    8.2378

t =

    8.2378

t =

    8.2694

t =

    8.2852

t =
```

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    8.3959

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    8.5573

t =

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    8.5977

t =

    8.5977

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    8.4912

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    8.5103

t =

    8.5198

t =

    8.5675

t =

    8.5759

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    8.5865

t =

    8.5865
```

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    8.6837

t =

    8.6945

t =

    8.7080

t =

    8.7080

t =

    8.7318

t =

    8.7437

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t =

    8.8138

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    8.8270
```

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    8.9247

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    8.9479

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    9.0175

t =

    9.0279
```

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    9.0408

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    9.1649

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    9.1649

t =

    9.2013

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    9.2196

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```

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    9.3471

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    9.1920

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    9.2056

t =

    9.2735

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    9.2856

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    9.3006

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    9.3006

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    9.3278

t =
```

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    9.4093

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t =

    9.4364

t =

    9.4619

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    9.4746

t =

    9.5383

t =

    9.5496

t =

    9.5638

t =

    9.5638
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t =

    9.6272

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    9.7328

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    9.7516

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    9.7750

t =

    9.7750

t =

    9.5853

t =

    9.5960

t =

    9.6498

t =

    9.6594

t =

    9.6713
```

```
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t =

    9.6928

t =

    9.7036

t =

    9.7573

t =

    9.7669

t =

    9.7788

t =

    9.7788

t =

    9.8009

t =

    9.8119

t =

    9.8669

t =

    9.8767
```

```
t =

    9.8890


t =

    9.8890


t =

    9.9112


t =

    9.9223


t =

    9.9778


t =

    9.9877


t =

    10


t =

    10
```

Plot Data

```
figure('Name','Model');
plot([0,links(end,1),poses(end,1)],
[0,links(end,2),poses(end,2)],'r-');
hold on
plot([0,links(1,1),poses(1,1)],[0,links(1,2),poses(1,2)],'b-');
hold on

figure('Name','Task Error');
plot(T, error_task,'r-');
```

```
hold on

figure('Name','Positions red is x');
plot(T, x,'r-');
hold on
plot(T, y,'b-');
hold on

figure('Name','Theta_1 Error');
plot(T, error_joints(:,1),'r-');
hold on

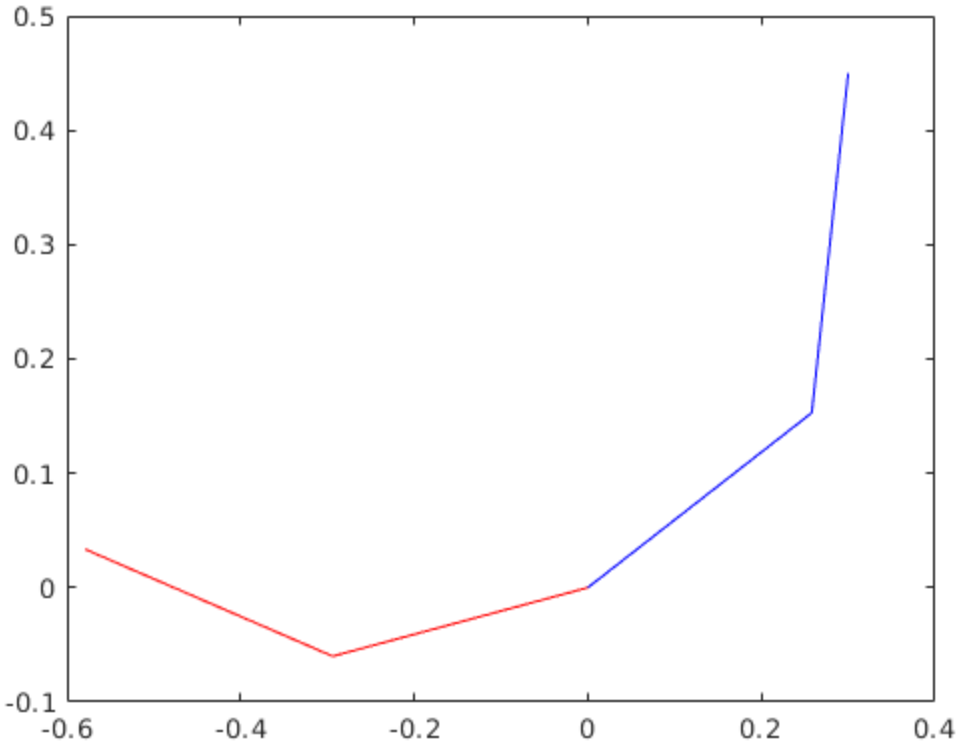
figure('Name','Theta_2 Error');
plot(T, error_joints(:,2),'r-');
hold on

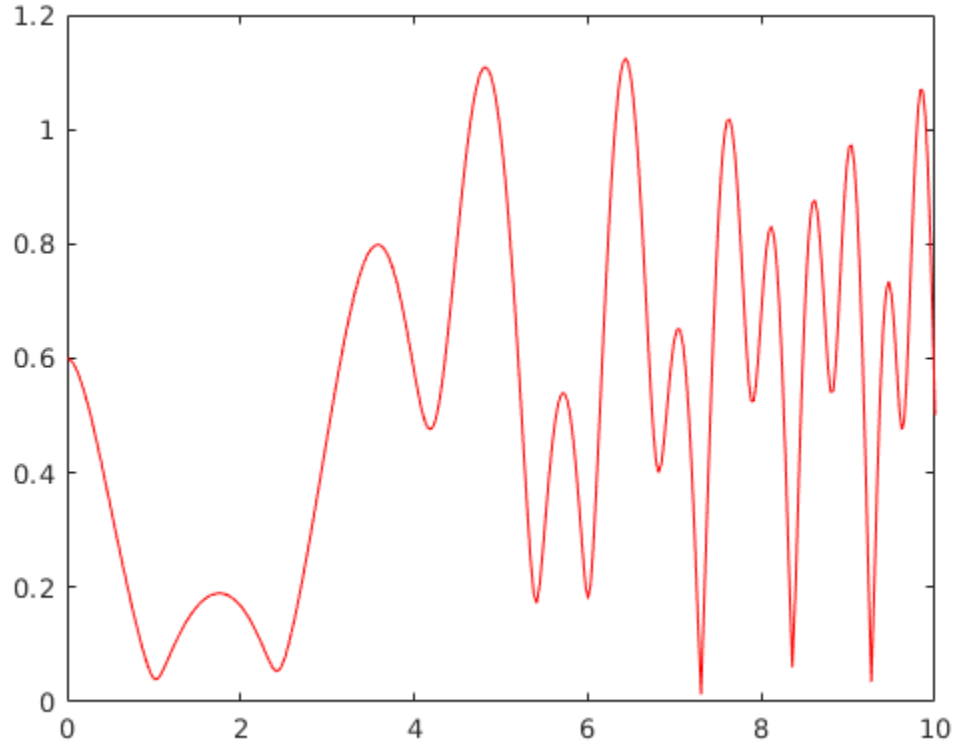
figure('Name','Theta_1 Position');
plot(T, X(:,1),'r-');
hold on

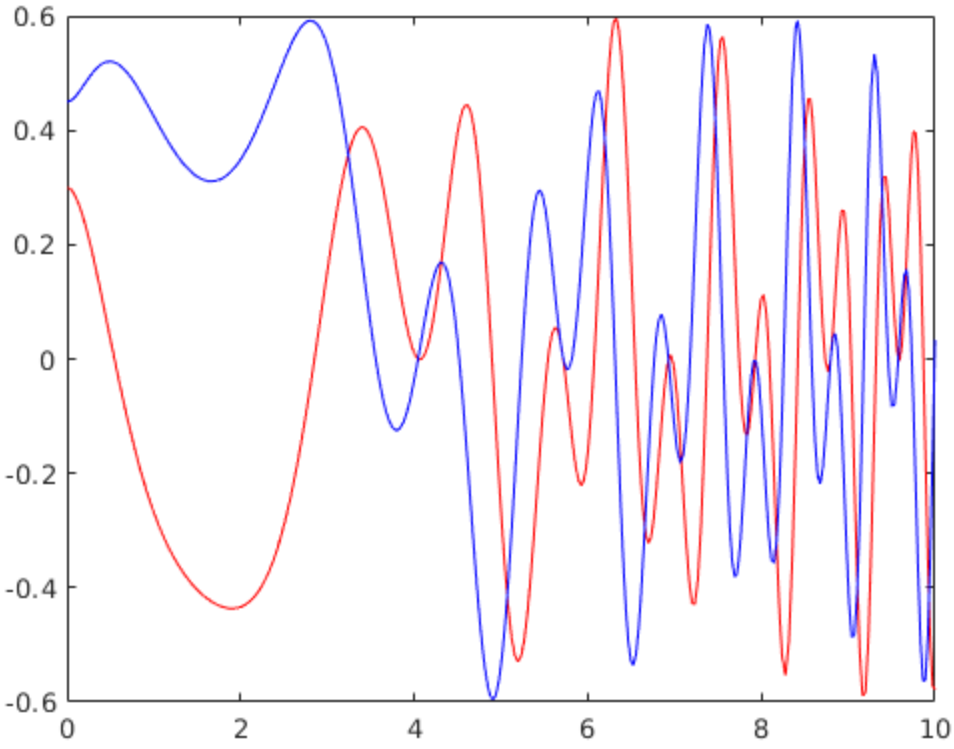
figure('Name','Theta_1 Velocity ');
plot(T, [0;diff(X(:,1))],'r-');
hold on
%}
figure('Name','Theta_2 under PD SetPoint Control');
plot(T, X(:,2),'r--');
hold on
figure('Name','Theta_2 Velocity ');
plot(T, [0;diff(X(:,2))],'r-');
hold on

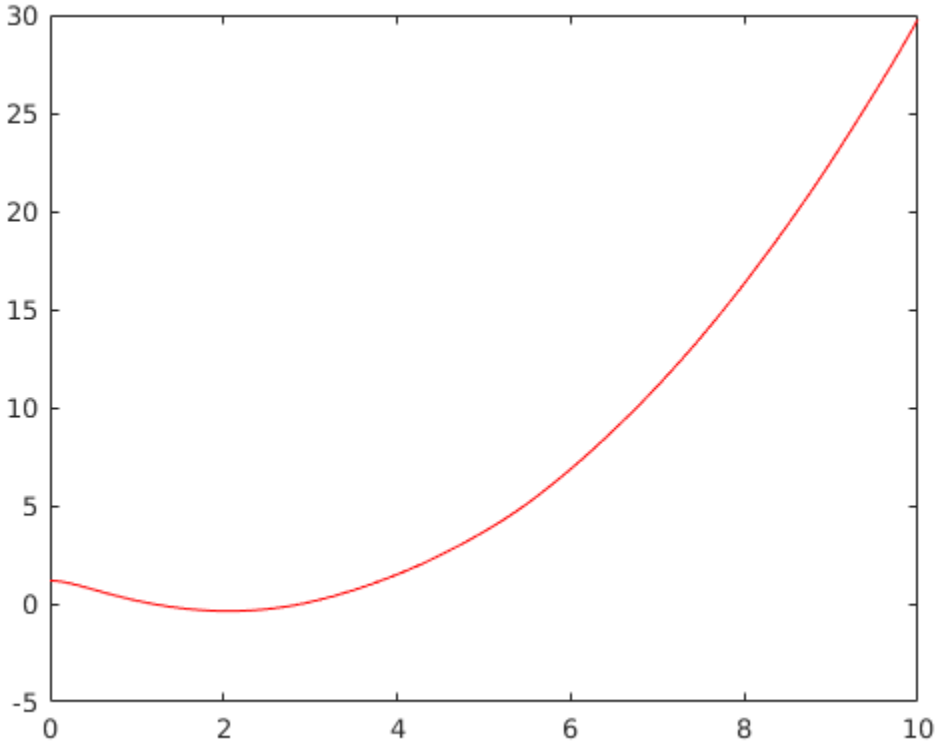
figure('Name','Input_PD control');
plot(T, torque(1,1:size(T,1)),'-' );
hold on
plot(T, torque(2,1:size(T,1)),'r--');

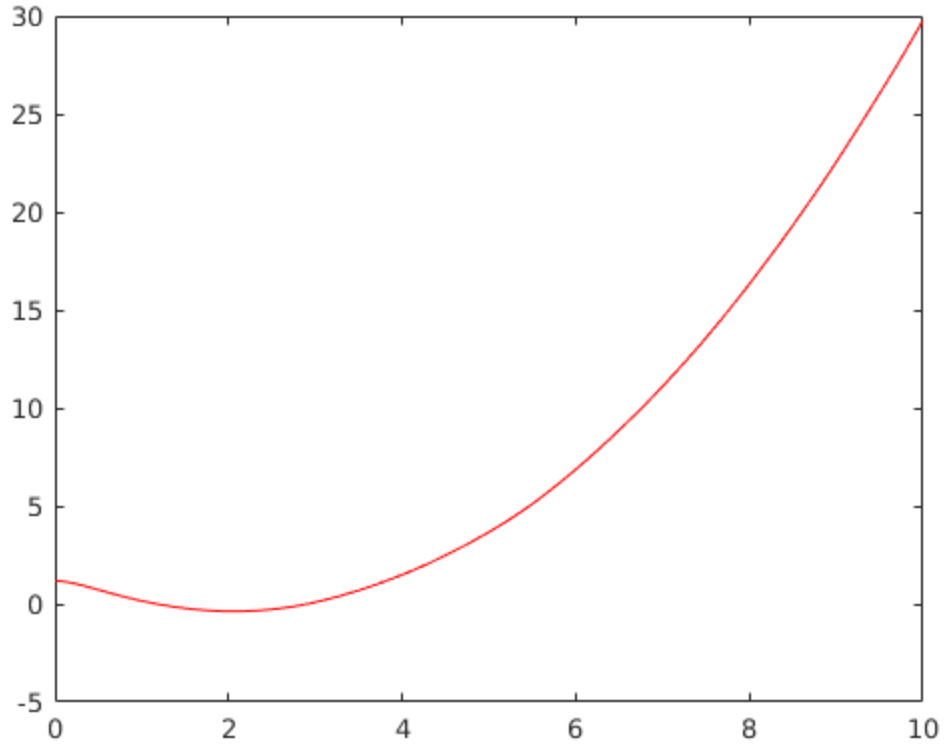
torque=[];
```

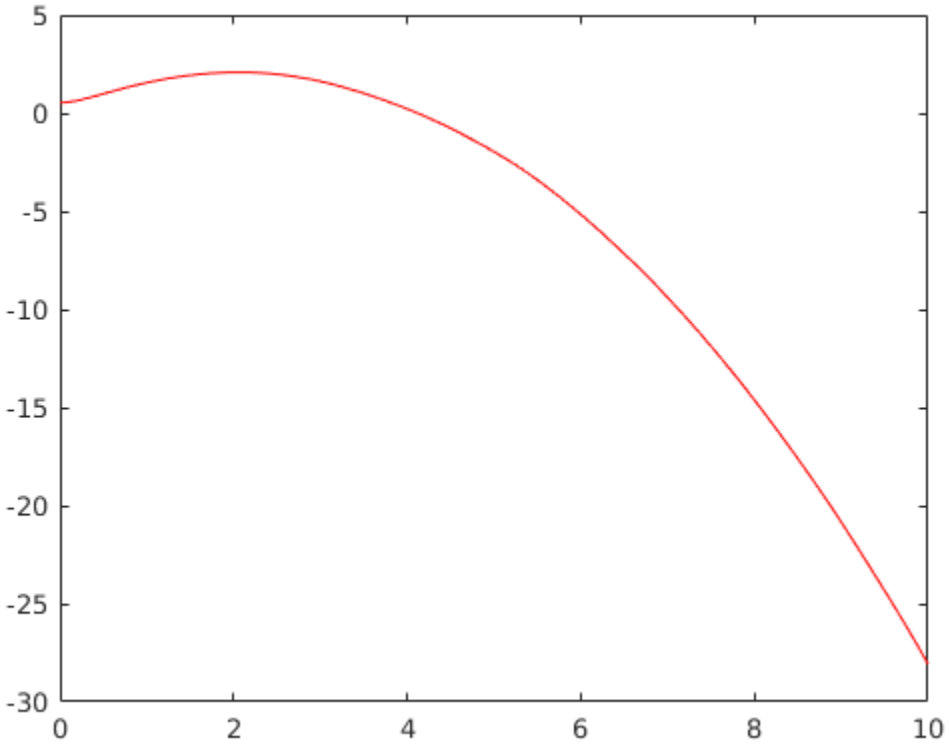

0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.6
-0.4
-0.2
0
0.2
0.4

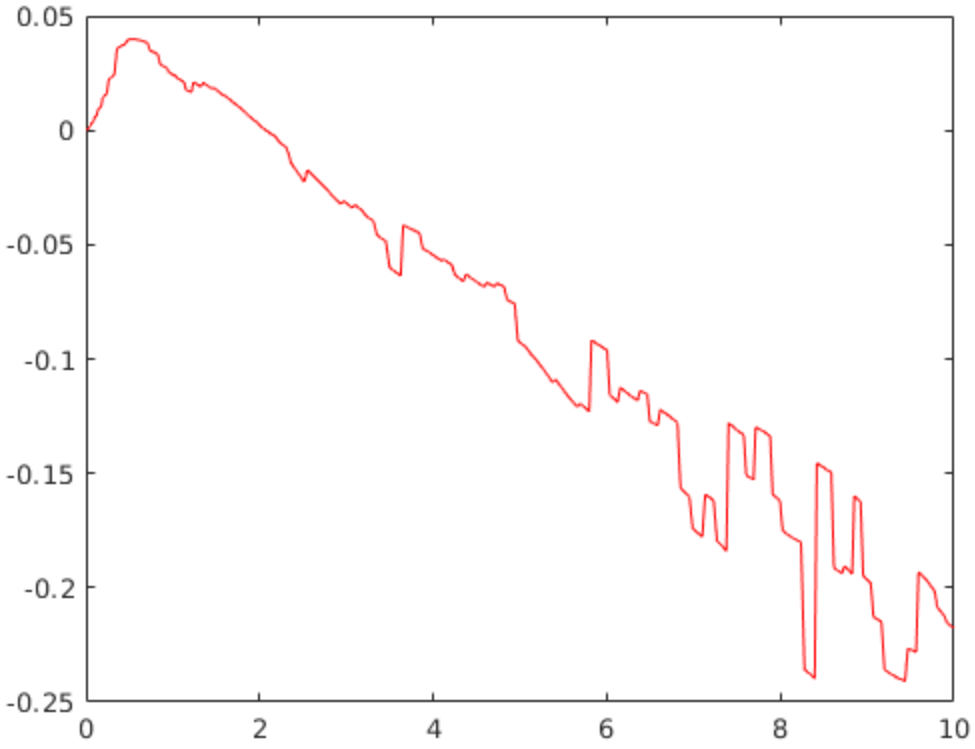

1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10

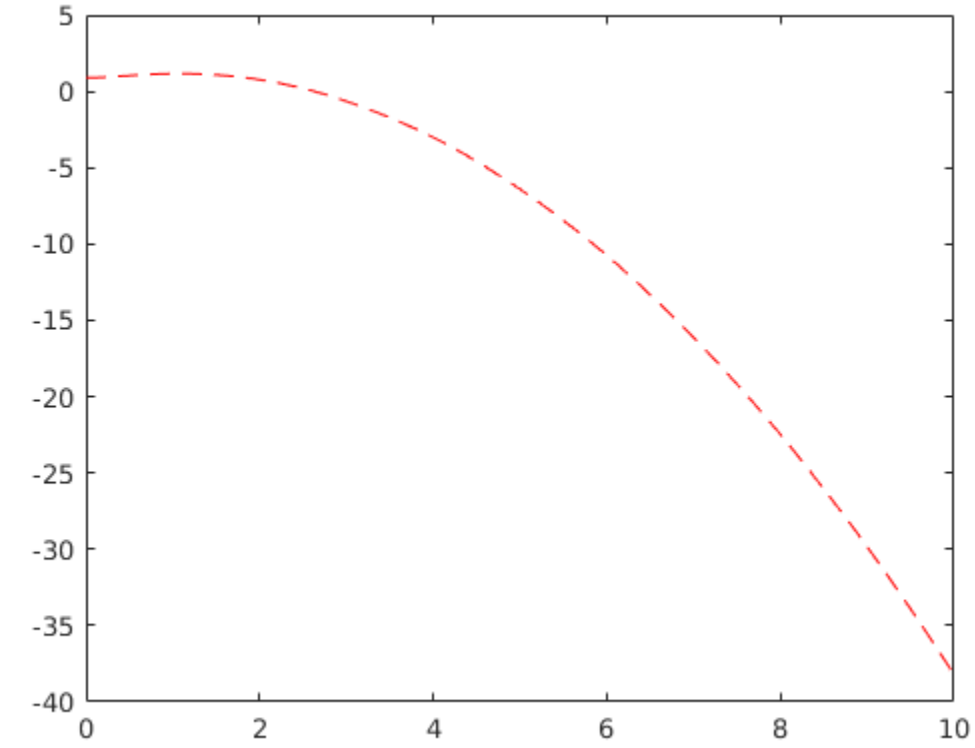

0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
2
4
6
8
10

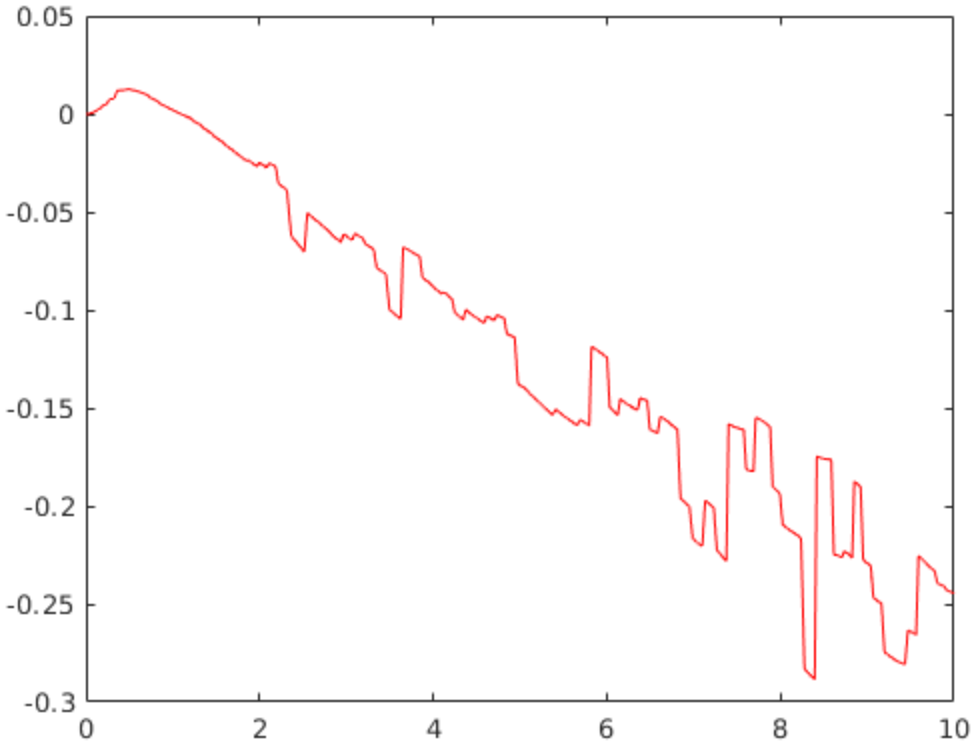

30
25
20
15
10
5
0
-5
0
2
4
6
8
10

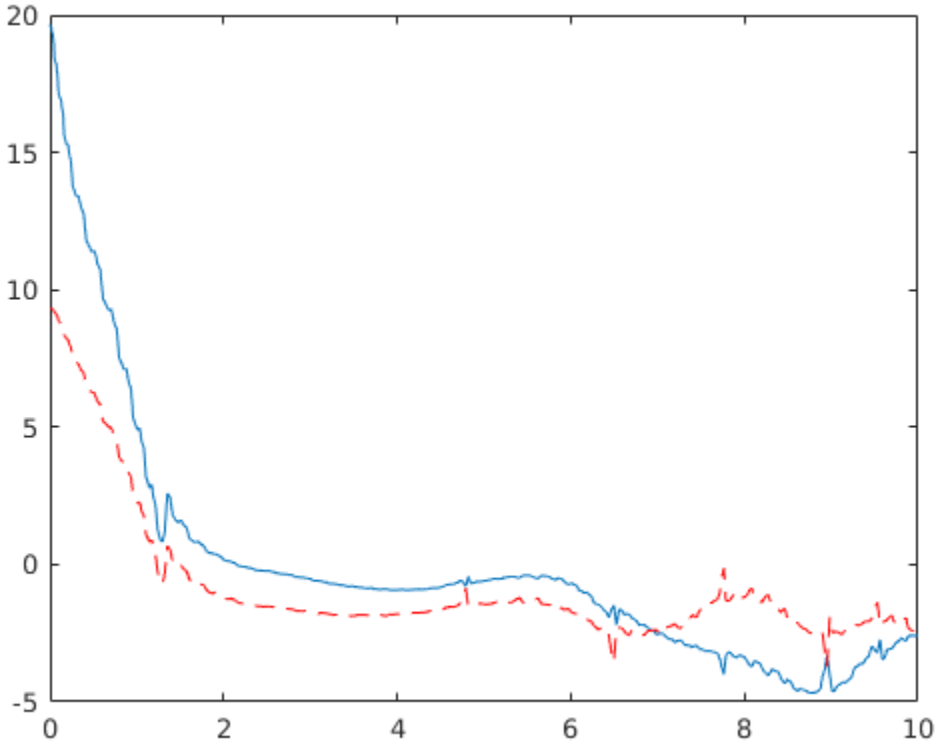

30
25
20
15
10
5
0
-5
0
2
4
6
8
10


5
0
-5
-10
-15
-20
-25
-30
0
2
4
6
8
10


0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
2
4
6
8
10


5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
2
4
6
8
10


0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
0
2
4
6
8
10


20
15
10
5
0
-5
0
2
4
6
8
10

Definging Functions

```
        function [q1,q2] = twoDOFIK(x,y,direction)
            q2 = direction * acos((x^2 + y^2 -l1^2 - l2^2)/(2*l1*l2));
            B = atan2((l2*sin(q2)),(l1 + l2*cos(q2)));
            Y = atan2(y,x);
            q1 = Y - direction * B;
        end
        function [x,y] = twoDOFFK(data,l1,l2)
            q1 = data(:,1);
            q2 = data(:,2);

            x = l1 * cos(q1) + l2*cos(q1 + q2);
            y = l1 * sin(q1) + l2*sin(q1 + q2);
        end
        function dx = planarArmODE(t,x)
            theta_d=[qf1;-qf2]; % Desired Set-Point Position
            dtheta_d=[0;0]; % Desired velocity (Derivative of theta_d)
            ddtheta_d=[0;0];
            theta= x(1:2,1);
            dtheta= x(3:4,1);

            t
            Mmat = subs(Mmat_symb,[q1;q2;q1d;q2d],x(:,1));
            Cmat = subs(Cmat_symb,[q1;q2;q1d;q2d],x(:,1));
            G_matrix = subs(G_matrix_symb,[q1;q2;q1d;q2d],x(:,1));

            Mmat_D = subs(Mmat_symb,[q1;q2;q1d;q2d],[theta_d;dtheta_d]);
            Cmat_D = subs(Cmat_symb,[q1;q2;q1d;q2d],[theta_d;dtheta_d]);
            G_matrix_D = subs(G_matrix_symb,[q1;q2;q1d;q2d],
    [theta_d;dtheta_d]);
    %        tau =
     Computed_Torque(theta_d,dtheta_d,ddtheta_d,theta,dtheta,t);
            tau = PDControl(theta_d,dtheta_d,theta,dtheta,t)...
                + Mmat_D*ddtheta_d + Cmat_D * dtheta_d + G_matrix_D;



            torque =[torque, tau];
            dx=zeros(4,1);
            dx(1) = x(3); %dtheta1
            dx(2) = x(4); %dtheta2
            dx(3:4) =   Mmat\(tau-Cmat*x(3:4) - G_matrix);
            %dx(3:4) = tau
        end

    function tau =
     Computed_Torque(theta_d,dtheta_d,ddtheta_d,theta,dtheta,time)
        Kp=[1500,0;...
            0,14000];
        Kv=[77.46,0;...
            0,236.64];
```

```
    time
    e=theta_d-theta; % position error
    de = dtheta_d - dtheta; % velocity error

    tau = Kp*e + Kv*de + ddtheta_d;

end
 function tau = PDControl(theta_d,dtheta_d,ddtheta_d,theta,dtheta)
        Kp=10*eye(2);
        Kv=10*eye(2);
        e=theta_d-theta; % position error
        de = dtheta_d - dtheta; % velocity error
        tau = Kp*e + Kv*de;
    end

disp('Finish.');
```

```
Finish.
```

```
end
```

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