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1. Inverse Dynamics Control Algorithm

On the whole, we want to control the robot to move at the desired joint angle, and to achieve that goal, we need to get the torque that each joint needs to apply. For the real robot lab, we just need to give the torque to each joint and then it will move as required, and for the simulation, we need to create an model (actually already given to us) to represent the actual robot, and give the torque as input, and we will get the angle of all joints. This also can be called the inner loop. In order to get the torque, we need to use inner control loop. Because in the simulation we can easily get the value of angle and angular velocity, but if we approximate the angular acceleration. The error will be very large. So, we use PD gains and the desired angle, desired angular velocity and desired angular acceleration to calculate the acceleration.

2. Inverse Dynamics Control Code

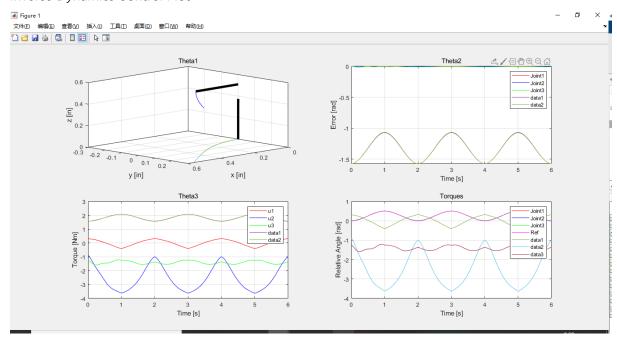
```
Kp = zeros(3,3);
Kp(1,1) = 200;
Kp(2,2) = 200;
Kp(3,3) = 200;

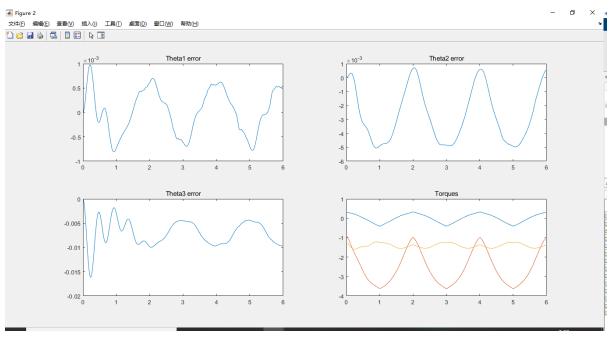
Kd = zeros(3,3);
Kd(1,1) = 2;
Kd(2,2) = 2;
Kd(3,3) = 3;

a_theta = Kp*(qd - q) + Kd * (dqd - dq) + ddqd;

u = DforController*a_theta + CforController*dq + GforController;
```

3. Inverse Dynamics Control Plot





4. Fast trajectory generation

```
elseif p.flag_ctrl == 4 || p.flag_ctrl == 5 || p.flag_ctr71 == 6 || p.flag_ctrl == 7
        % TODO: Create your fast trajectory here
        t_mod = mod(t, 2);
         if ((t_mod > 0) && (t_mod <= 0.33))</pre>
             qd = [-27*t_mod^3 + 13.5*t_mod^2;
                  -27*t_mod^3 + 13.5*t_mod^2 - pi/2;
                   -27*t_mod^3 + 13.5*t_mod^2 + pi/2;
             dqd = [-81*t_mod^2 + 27*t_mod;
                   -81*t_{mod}^2 + 27*t_{mod};
                   -81*t_mod^2 + 27*t_mod;
             ddqd = [-162*t_mod + 27;
                     -162*t_mod + 27;
                     -162*t_mod + 27;
         elseif ((t_mod > 0.33) && (t_mod < 1))
             qd = [0.5; 0.5 - pi/2; 0.5 + pi/2];
             dqd = [0.0; 0.0; 0.0];
             ddqd = [0.0; 0.0; 0.0];
         elseif ((t_mod \ge 1) && (t_mod \le 1.33))
             qd = [27*t_mod^3 - 94.5*t_mod^2 + 108*t_mod - 40]
                   27*t_mod^3 - 94.5*t_mod^2 + 108*t_mod - 40 - pi/2;
                   27*t_mod^3 - 94.5*t_mod^2 + 108*t_mod - 40 + pi/2;
             dqd = [81*t_mod^2 - 189*t_mod + 108;
                    81*t_mod^2 - 189*t_mod + 108;
                    81*t_mod^2 - 189*t_mod + 108];
             ddqd = [162*t_mod - 189;
                     162*t_mod - 189;
                     162*t_mod - 189];
         else
             qd = [0.0; -0.5*pi; 0.5*pi];
             dqd = [0.0; 0.0; 0.0];
             ddqd = [0.0; 0.0; 0.0];
         end
           disp(t_mod);
           disp(qd);
           disp(dqd);
           disp(ddqd);
         traj_d = [qd; dqd; ddqd];
    end
end
```

5. Inverse + Fast trajectory

```
Kp = zeros(3,3);
  Kp(1, 1) = 200;
  Kp(2, 2) = 200;
 Kp(3,3) = 200;
 Kd = zeros(3,3);
 Kd(1,1) = 5;
 Kd(2,2) = 7;
 Kd(3,3) = 9;

    ✓ Figure 1
    文件(E) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)

                                                                                                                                                    ð
Theta1
                                                                                                                 Theta2
                                                                                                                               Joint1
Joint2
Joint3
data1
data2
                0.6
                                                                                    Error [rad]
1-
              0.4
<u>E</u>
N
                                                                 0.2
                                                0.6
                               y [in]
                                                         x [in]
                                                                                                                 Torque
                                                                                                                                         Joint1
Joint2
Joint3
Ref
data1
data2
data3
                                                                                     Relative Angle [rad]
               Torque [Nm]
                                                                                                                 3
Time [s]
文件(P) 編輯(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)
Theta2 error
                                                                                                                              △/∃७⊕⊖∂
                                          Theta1 error
               0.015
                                                                                     0.015
                0.01
                                                                                      0.01
               0.005
                                                                                     0.005
                                                                                     -0.005
               -0.005
                -0.01
                                                                                     -0.01
               -0.015
0
                                                                                     -0.015
                                          Theta3 error
                                                                                                                 Torques
               0.005
                -0.01
               -0.015
```

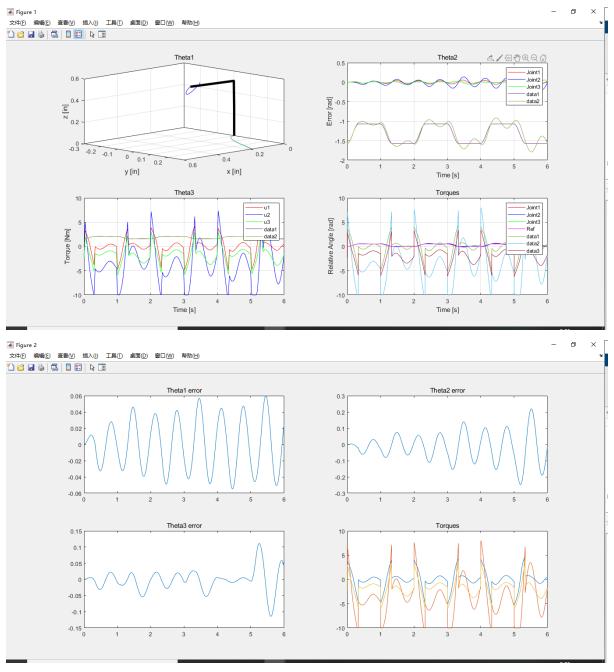
6. PD+Feedforward+Fast Trajectory

```
Kp = zeros(3,3);
   Kp(1, 1) = 200;
   Kp(2, 2) = 300;
   Kp(3,3) = 200;
   Kd = zeros(3,3);
   Kd(1,1) = 4;
   Kd(2, 2) = 12;
   Kd(3,3) = 6;
                                                                                                                                                 o
Figure 1
文件(F) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)
Theta1
                                                                                                               Theta2
                                                                                                                                      Joint1
Joint2
Joint3
data1
data2
                0.6
                                                                                  error [rad]
              0.4
<u>E</u>
N
                                                                0.2
                              0 0.1
                                               0.6
                                                                                                               3
Time [s]
                              y [in]
                                                        x [in]
                                                                                                               Torque
                                                                                   Relative Angle [rad]
               Torque [Nm]
                                           3
Time [s]
                                                                                                               3
Time [s]

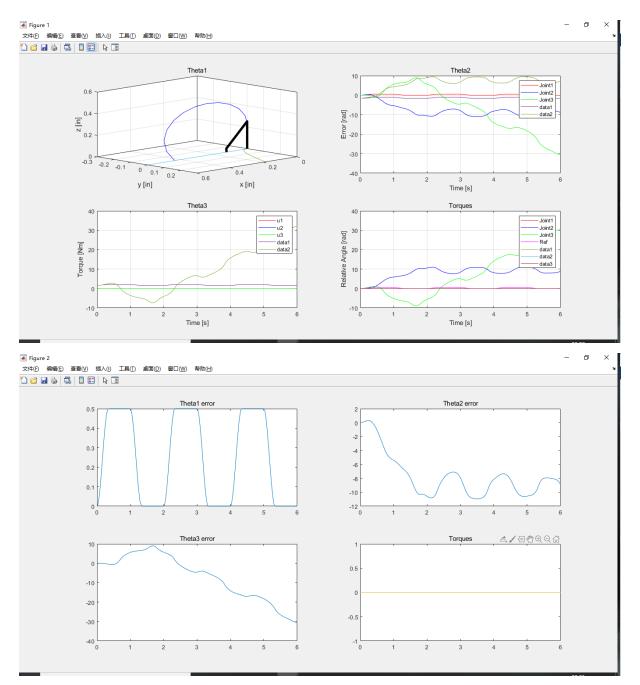
    ✓ Figure 2
    文件(P) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)

△/4®⊕9₩
                                                                                                             Theta2 error
                                         Theta1 error
                                                                                    0.02
                                                                                    0.01
                0.01
                                                                                    -0.01
                                                                                    -0.02
                -0.01
                                                                                    -0.03
                -0.02
                                                                                    -0.04
                -0.03 L
                                                                                    -0.05 L
                                    2
                                             3
                                                                                                        2
                                                                                                                 3
                                         Theta3 error
                                                                                                               Torques
                0.01
               0.005
               -0.005
               -0.01
               -0.015
                -0.02
               -0.025
```

7. Inverse + Fast trajectory + Mass



8. PD+Feedforward + Fast trajectory + Mass



9. Comparison of two control method

For a specific system, both PD+feedback control and Inverse control can have good control performance. However, if the model has some change both of the two control methods will have worse performance. But the inverse control performs much better than PD+feedback control. The inverse control still stable but has more overshoot and longer adjust time. But the PD+feedback control is unstable. In others words, inverse control has better robust character.