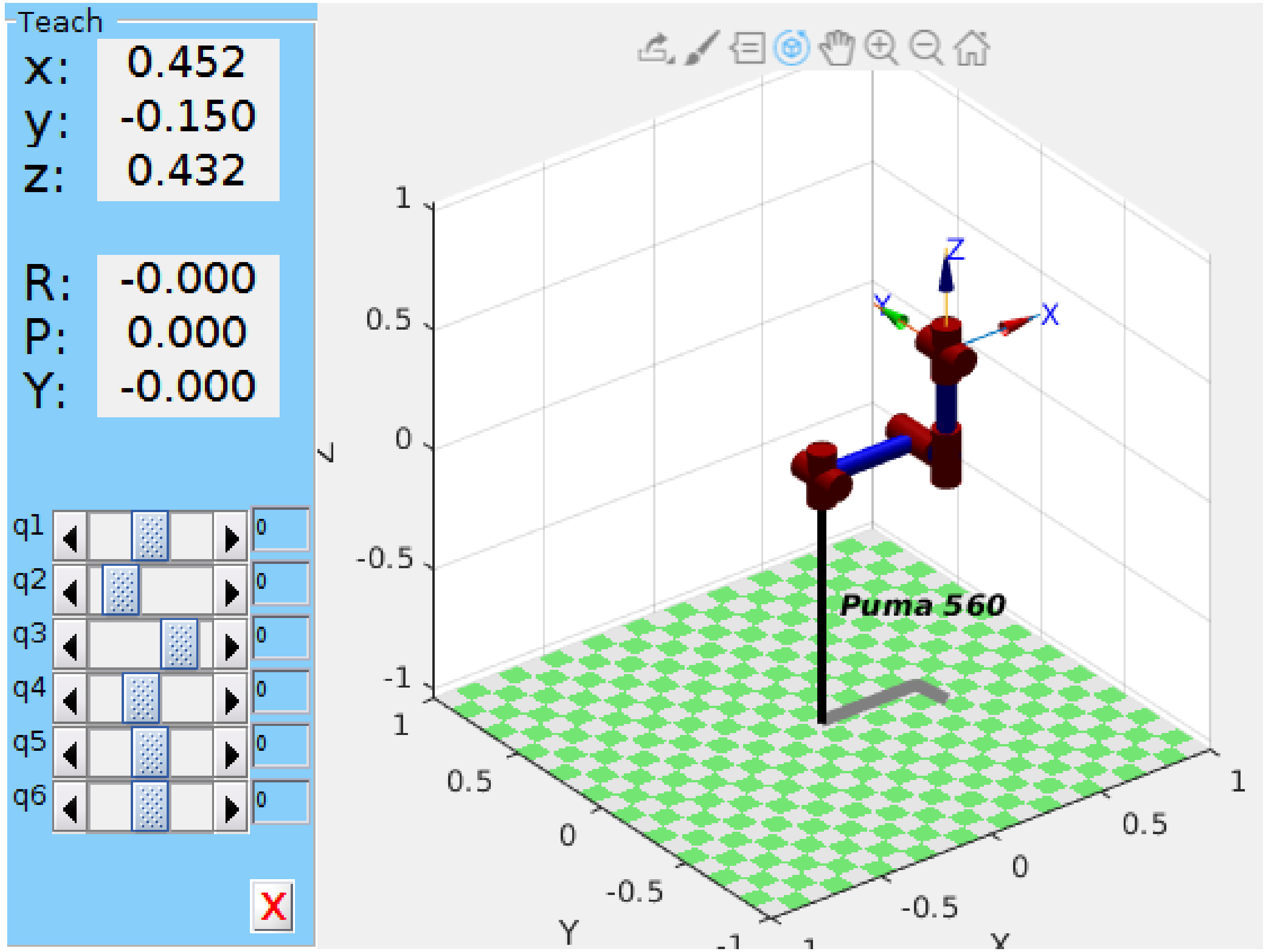
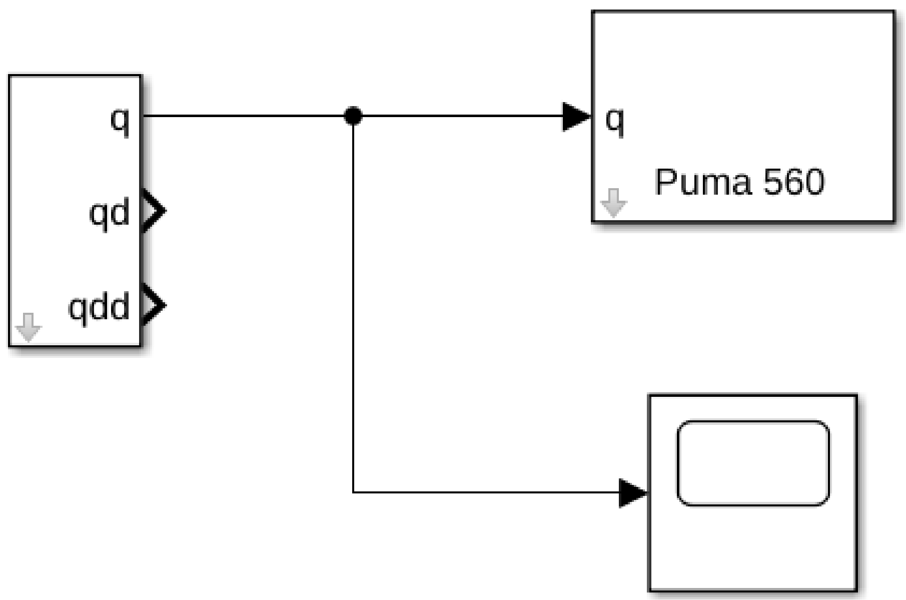
MATLAB EXERCISES

SARIM MEHDI

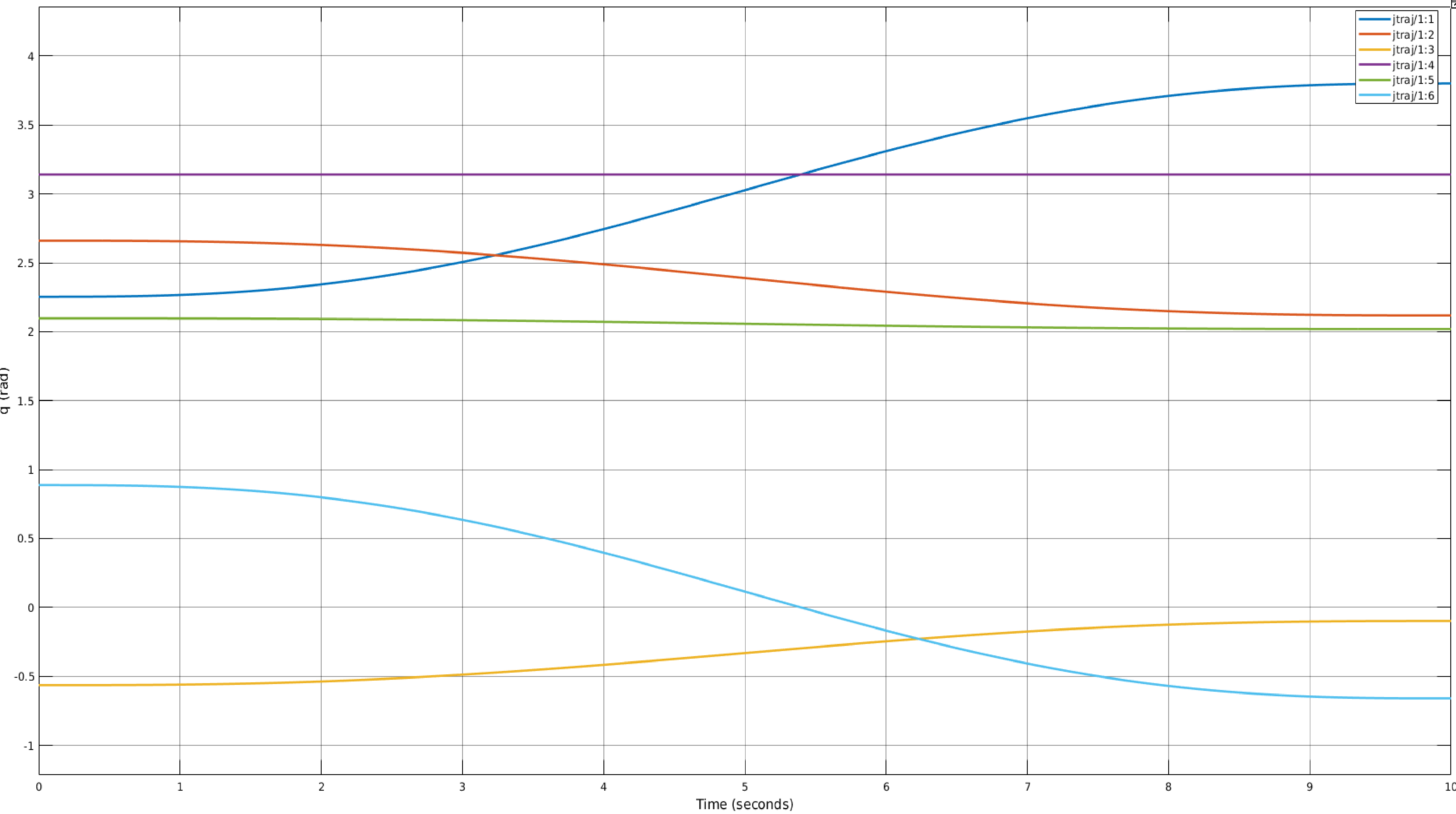


JOINT SPACE TRAJECTORY FOR A PUMA 560

LINE TRAJECTORY

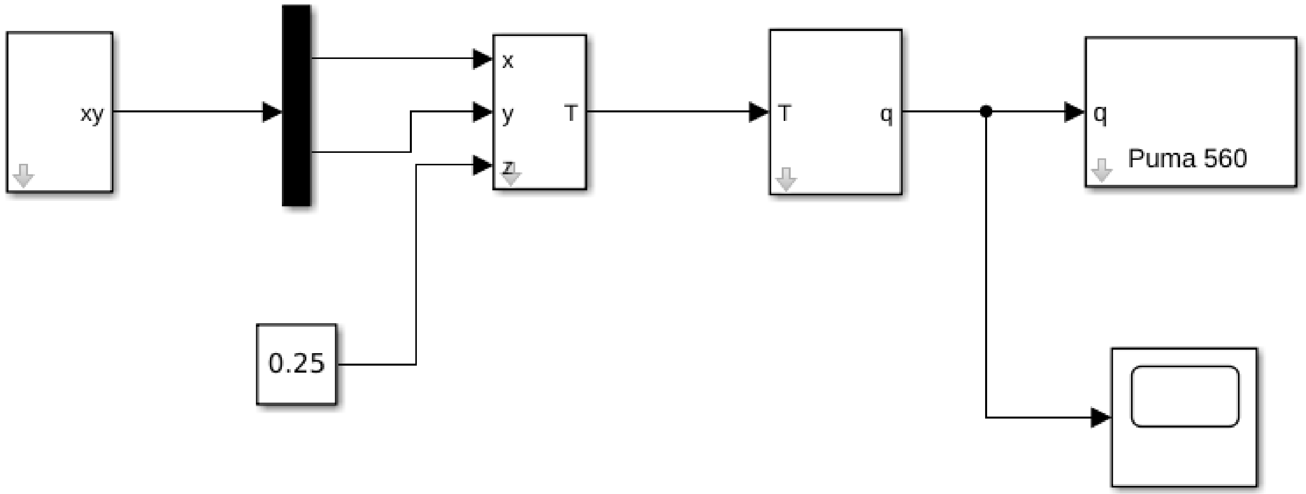


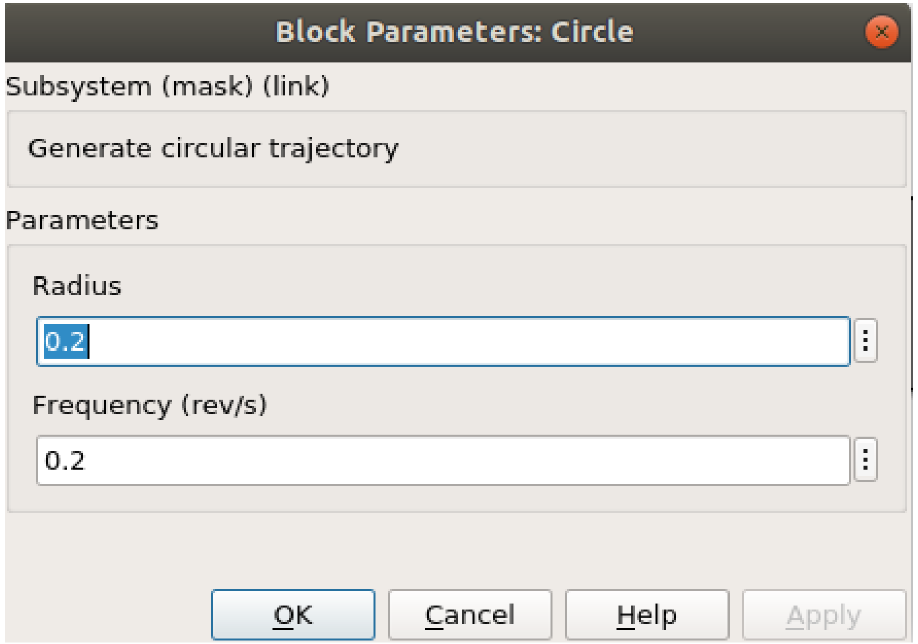

```
%LINE
T1 = transl(0.6, -0.5, 0.0); % START
T2 = transl(0.4, 0.5, 0.2); % DESTINATION
res=20;
TTl=ctraj(T1,T2,res);
qq=ikine6s(p560,TTl);
```

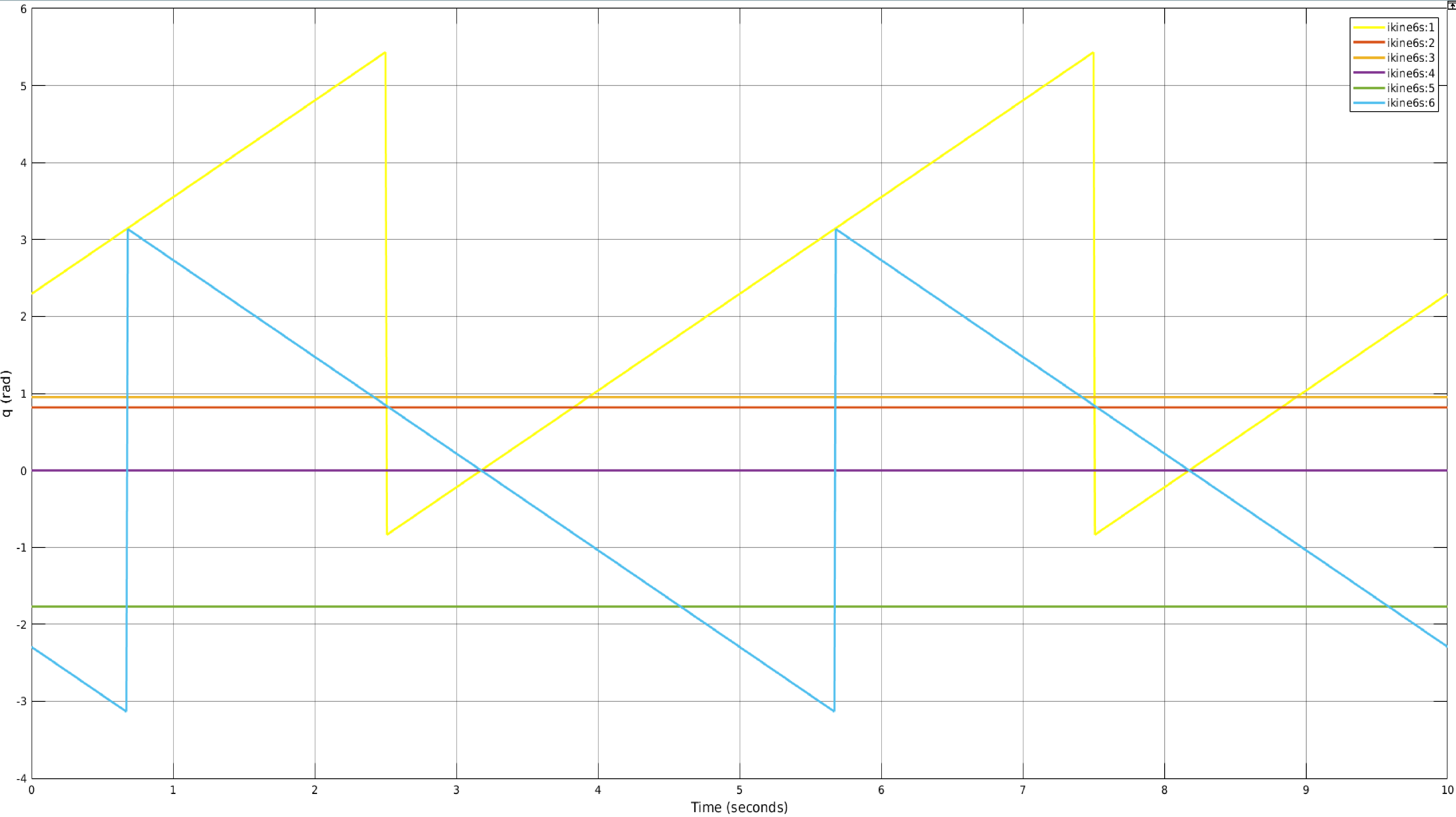


jtraj/1:1
jtraj/1:2
jtraj/1:3
jtraj/1:4
jtraj/1:5
jtraj/1:6
q (rad)
Time (seconds)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
1
2
3
4
5
6
7
8
9
10

JOINT SPACE TRAJECTORY FOR A PUMA 560







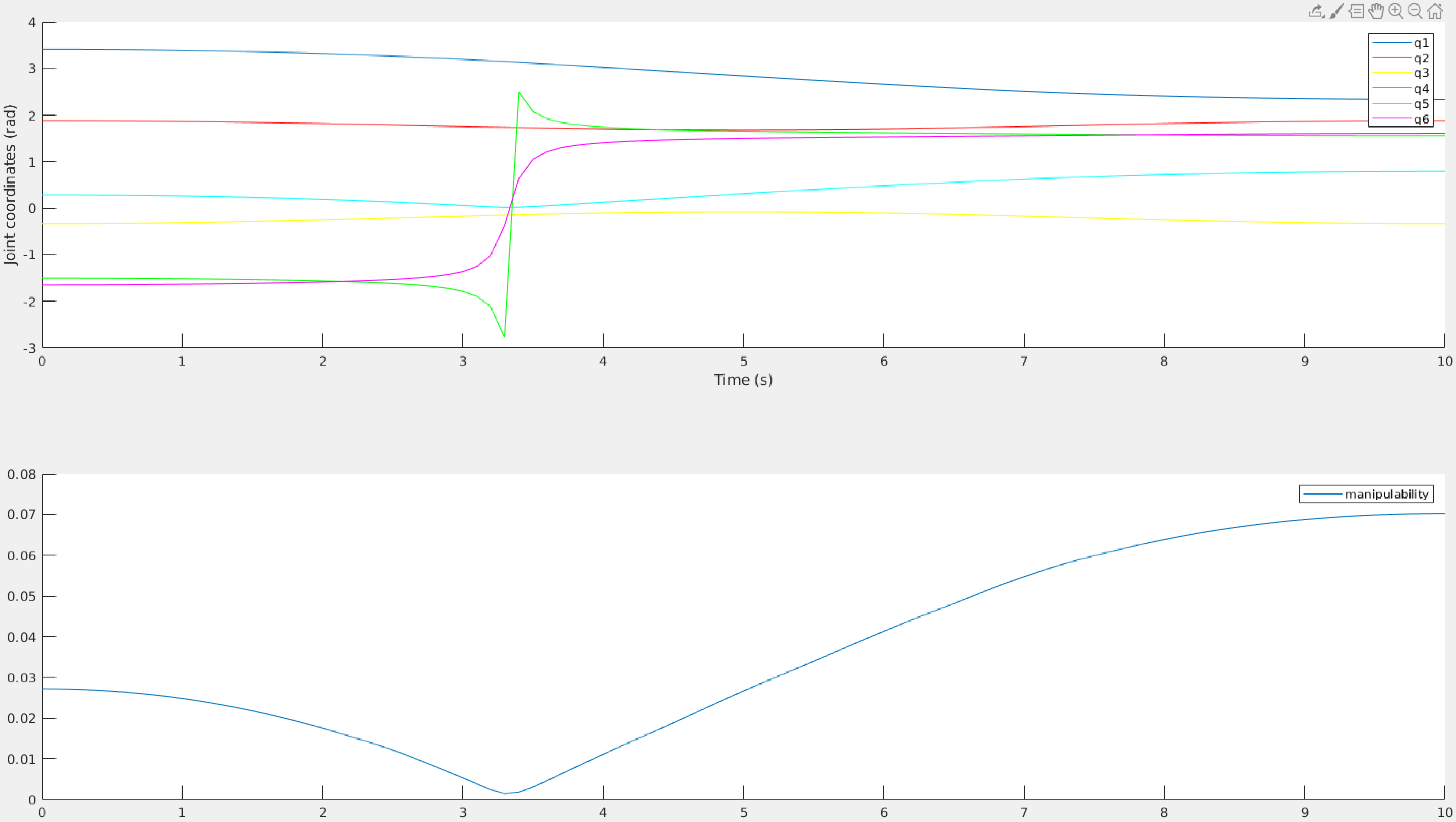
ikine6s:1
ikine6s:2
ikine6s:3
ikine6s:4
ikine6s:5
ikine6s:6
q (rad)
Time (seconds)
6
5
4
3
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5
6
7
8
9
10

SINGULARITY

```
t = [0:t_res:10];
Ts = ctraj(T1, T2, length(t));
q = p560.ikine6s(Ts);
m = p560.maniplty(q);
[rows, cols] = size(q);
colors = ['b', 'r', 'y', 'g', 'c', 'm'];
figure;
subplot(2,1,1);
xlabel('Time (s)');
ylabel('Joint coordinates (rad)');
hold on
plot(t, q(:,1))
for i=2:cols
    hold on; plot(t, q(:,i), colors(i))
end
legend('q1', 'q2', 'q3', 'q4', 'q5', 'q6')
xlabel('Time (s)');
ylabel('Joint coordinates (rad)');
subplot(2,1,2);
hold on; plot(t, m)
legend('manipulability')
```

WRIST SINGULARITY

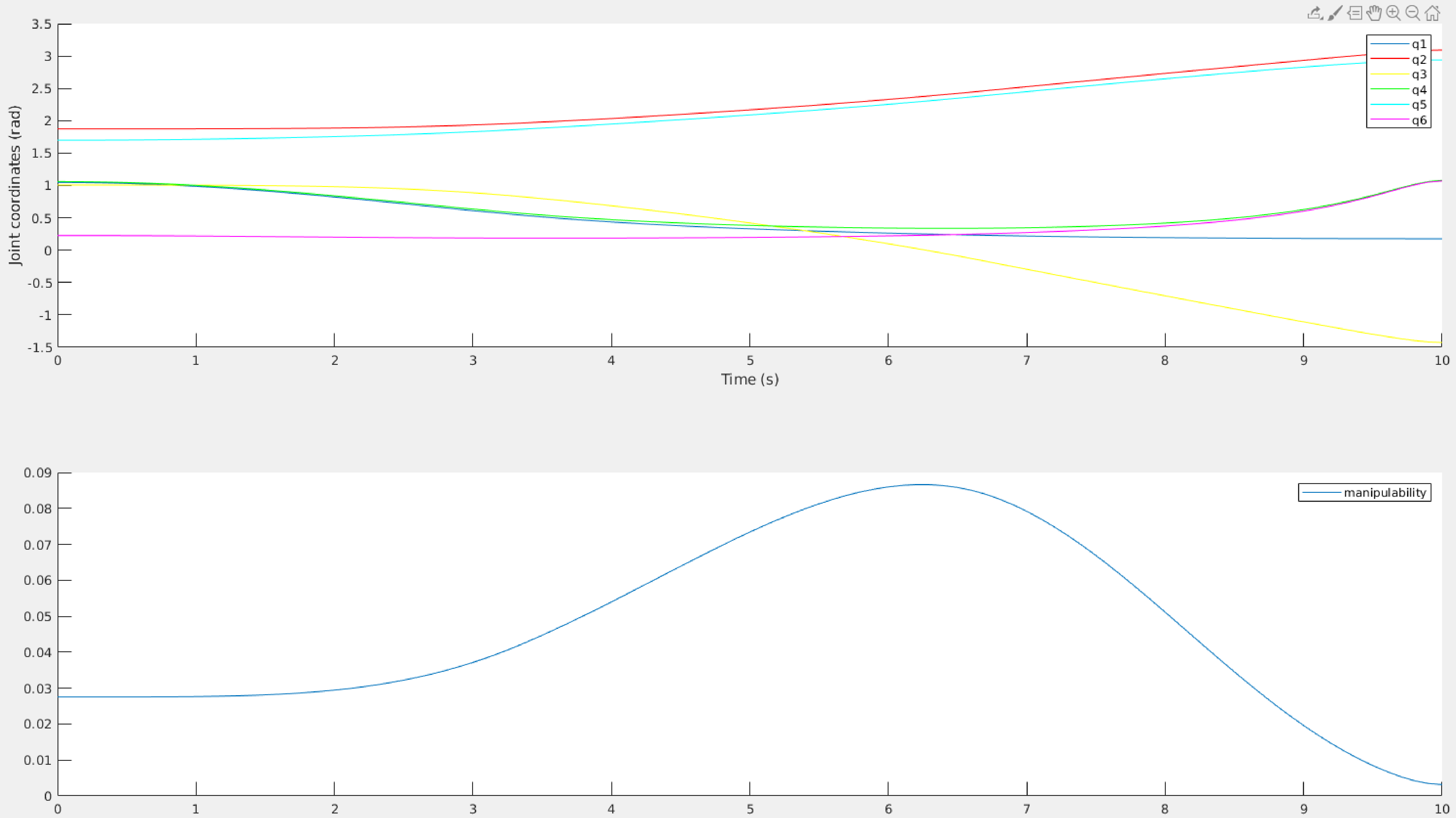
- T1 = SE3(0.5, 0.3, 0.44) * SE3.Ry(pi/2);
- T2 = SE3(0.5, -0.3, 0.44) * SE3.Ry(pi/2);
- At time 3.4s, q5 is almost zero and q4 and q6 have a sudden increase.
- This is also at the exact time when the manipulability drops to a very low value. Axes of joints 4 and 6 become coincident. Robot cannot move in the direction of axis of joint 5 In order for the endpoint to follow a line through the singularity, joints 4 and 6 must simultaneously rotate 90 degrees.



Joint coordinates (rad)
Time (s)
q1
q2
q3
q4
q5
q6
manipulability

ELBOW SINGULARITY

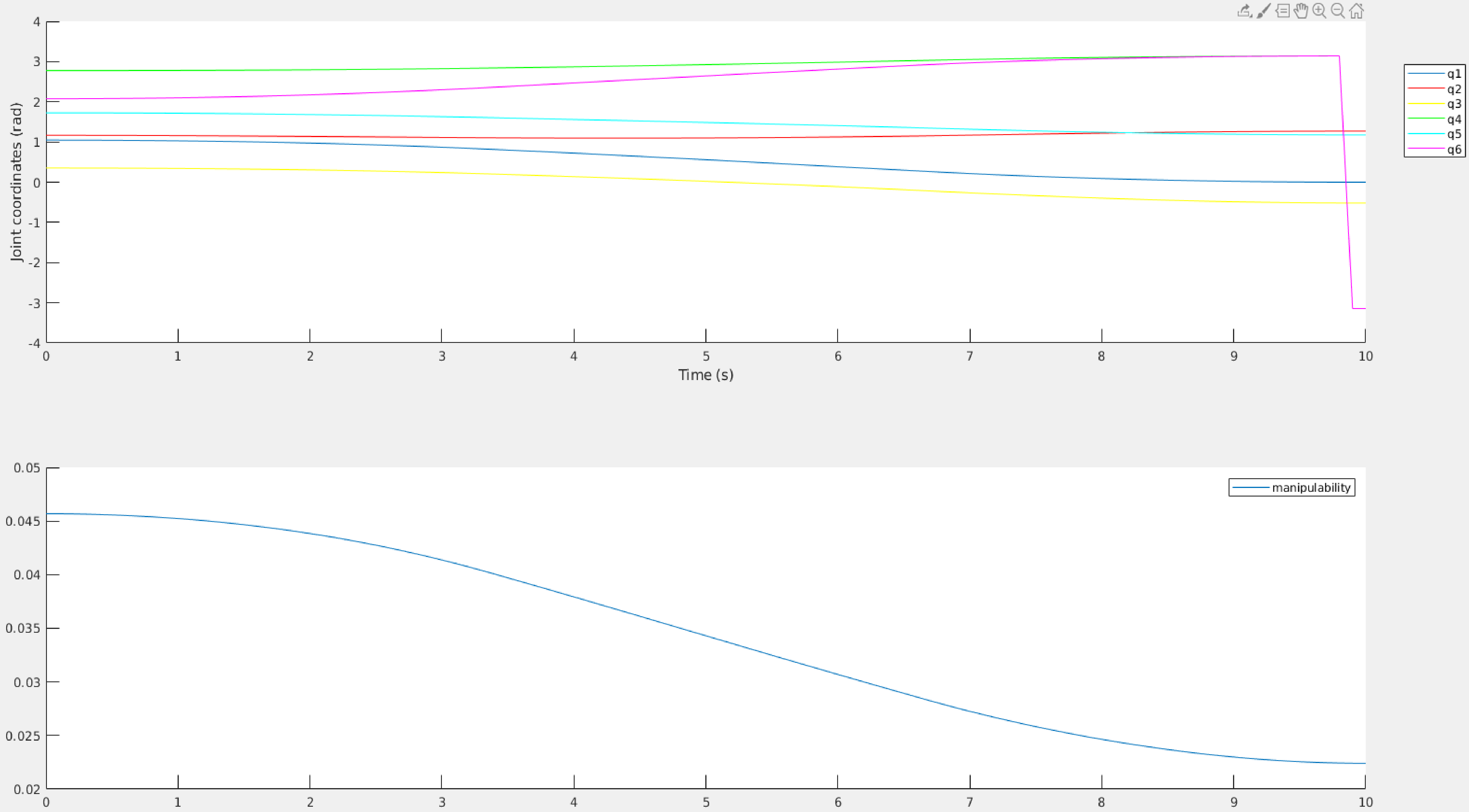
- T1 = SE3(0, -0.3, 0) * SE3.Ry(pi/2);
- T2 = SE3(-0.823, -0.3, 0) * SE3.Ry(pi/2); %elbow singularity
- It occurs when the arm is fully stretched. It is determined by q3. We can see the manipulability drop as q3 drops to a value close to -1.



Joint coordinates (rad)
Time (s)
q1
q2
q3
q4
q5
q6
manipulability

SHOULDER SINGULARITY

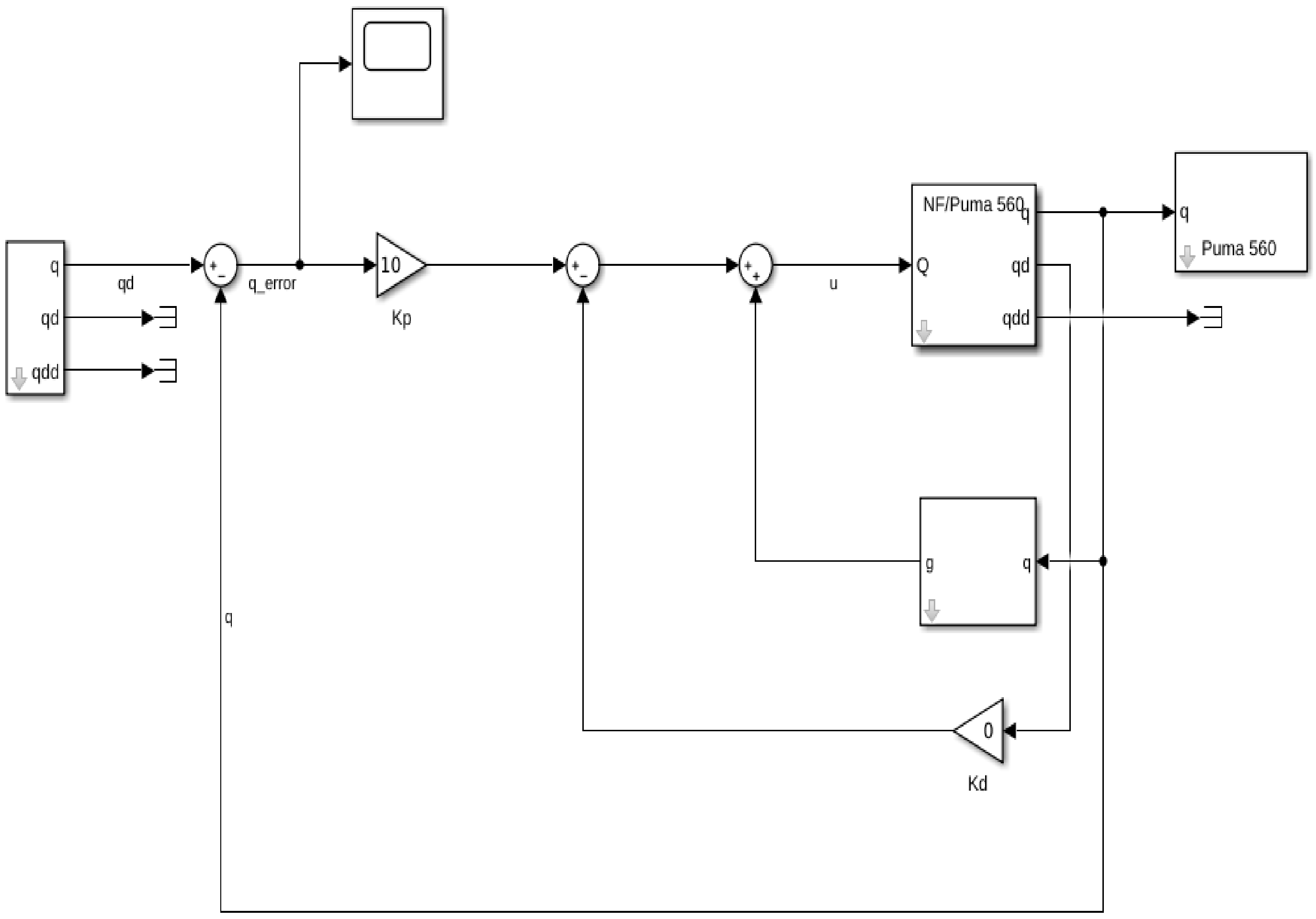
- T1 = SE3(0, -0.3, 0.44) * SE3.Ry(0.42);
- T2 = SE3(-0.154, -0.15, 0.741) * SE3.Ry(0.42);
- 1 and 4 must rotate in opposite direction. Both joints 4 and 6 drop from 3.14 to -3.14 at singularity.

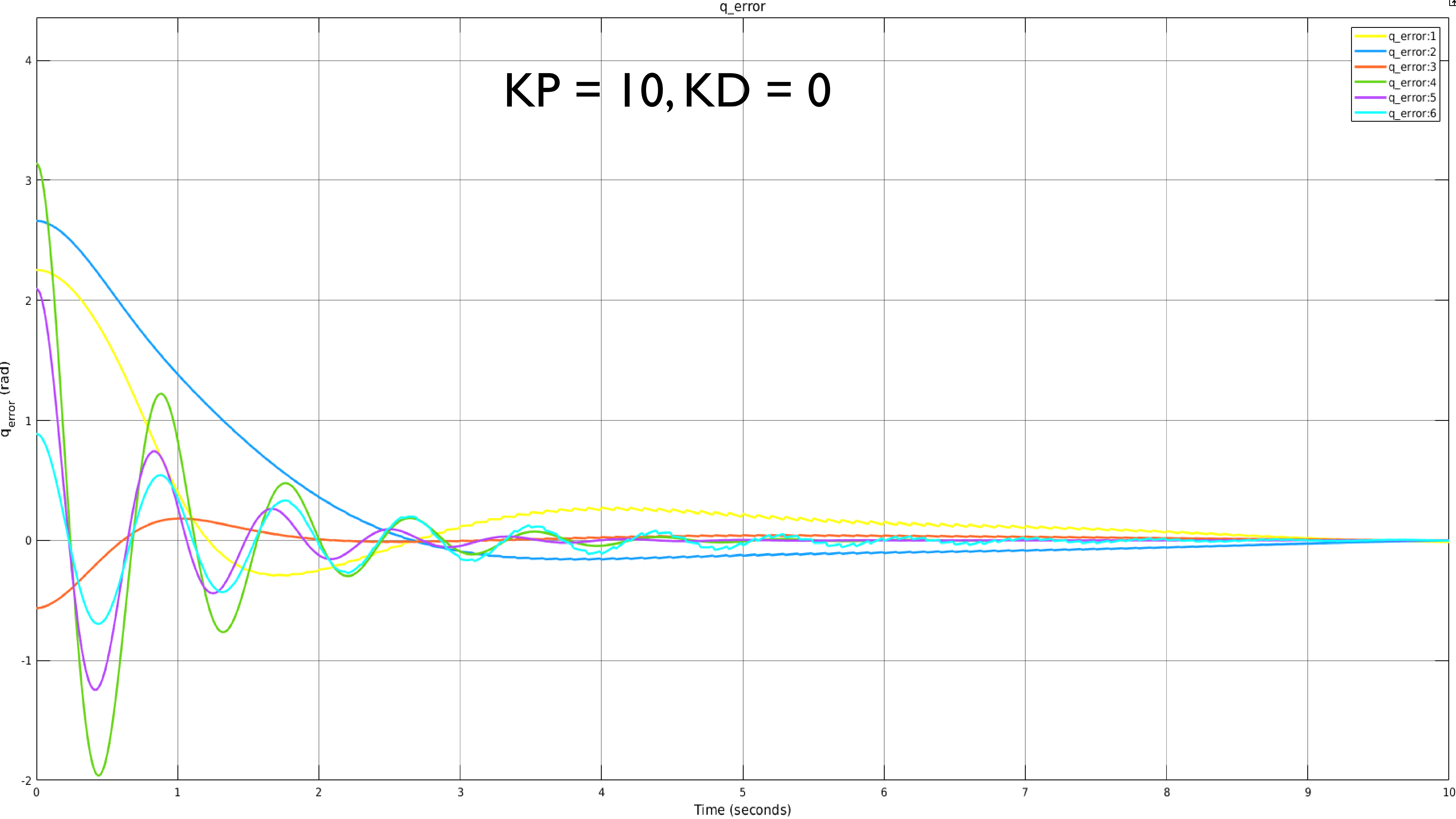


Joint coordinates (rad)
Time (s)
q1
q2
q3
q4
q5
q6
manipulability

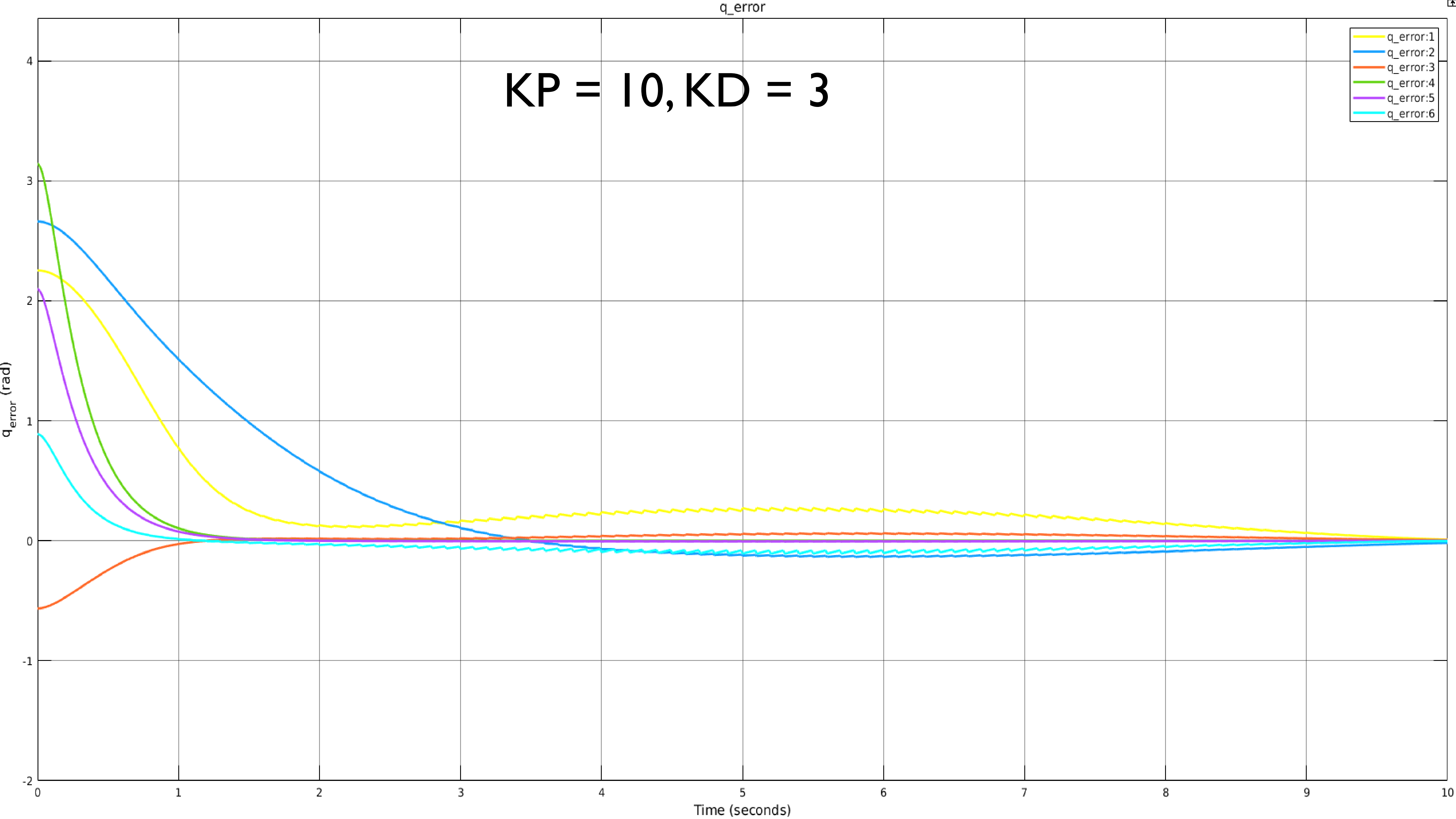
PD CONTROL +GRAVITY COMPENSATION

PD + GRAVITY COMPENSATION

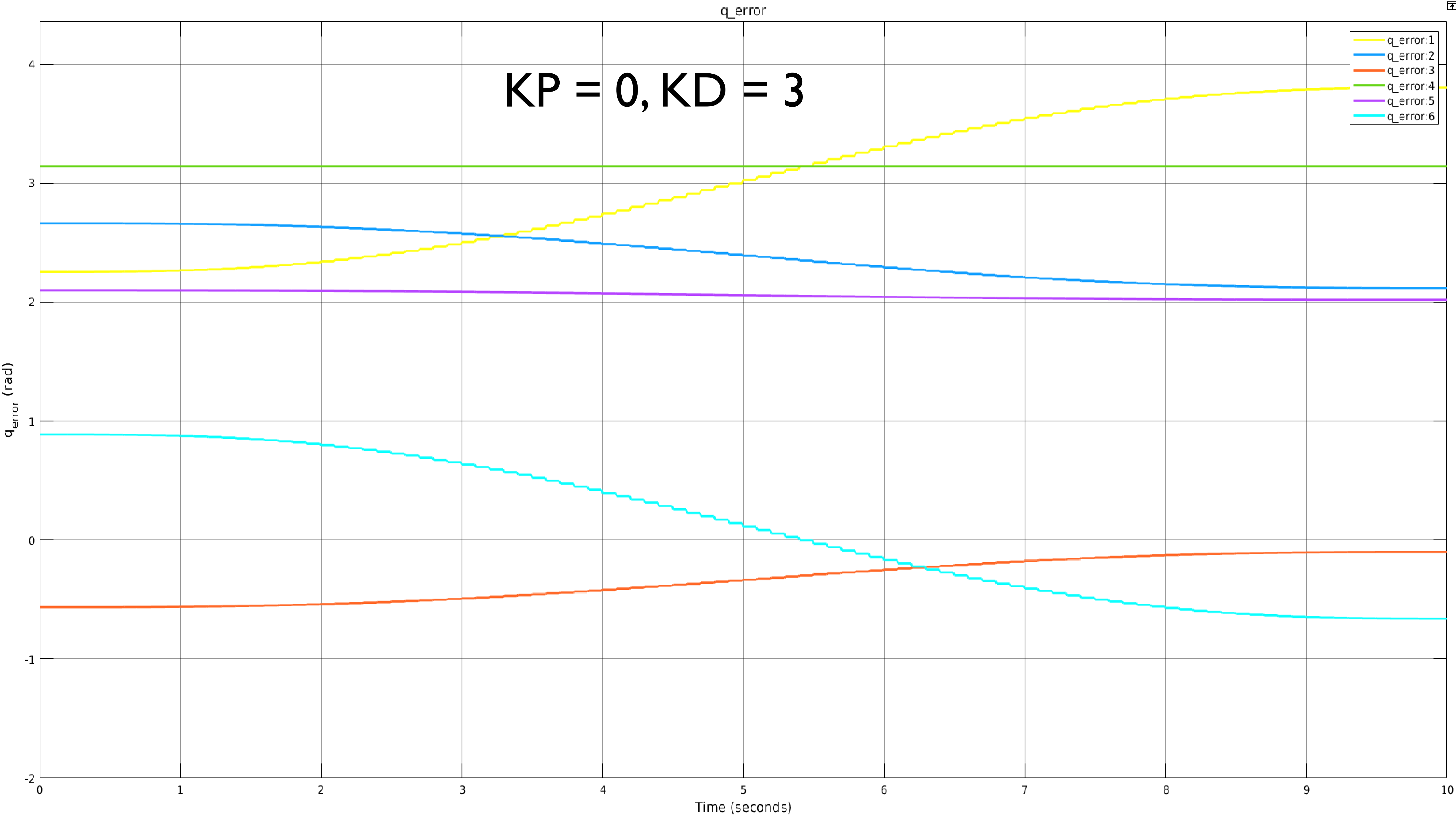




q_error
KP = 10, KD = 0
q_error:1
q_error:2
q_error:3
q_error:4
q_error:5
q_error:6
q_{error} (rad)
Time (seconds)
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10

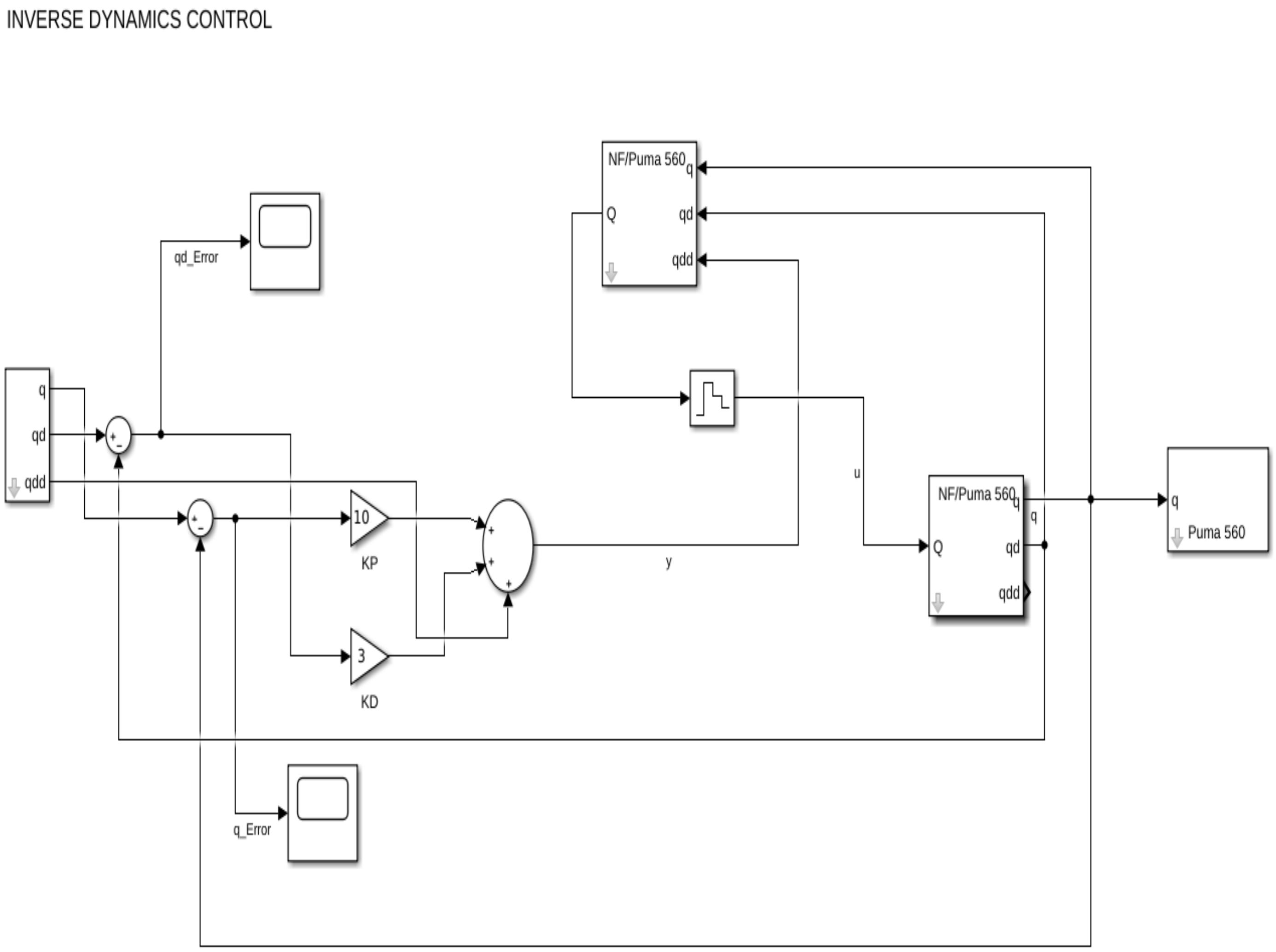


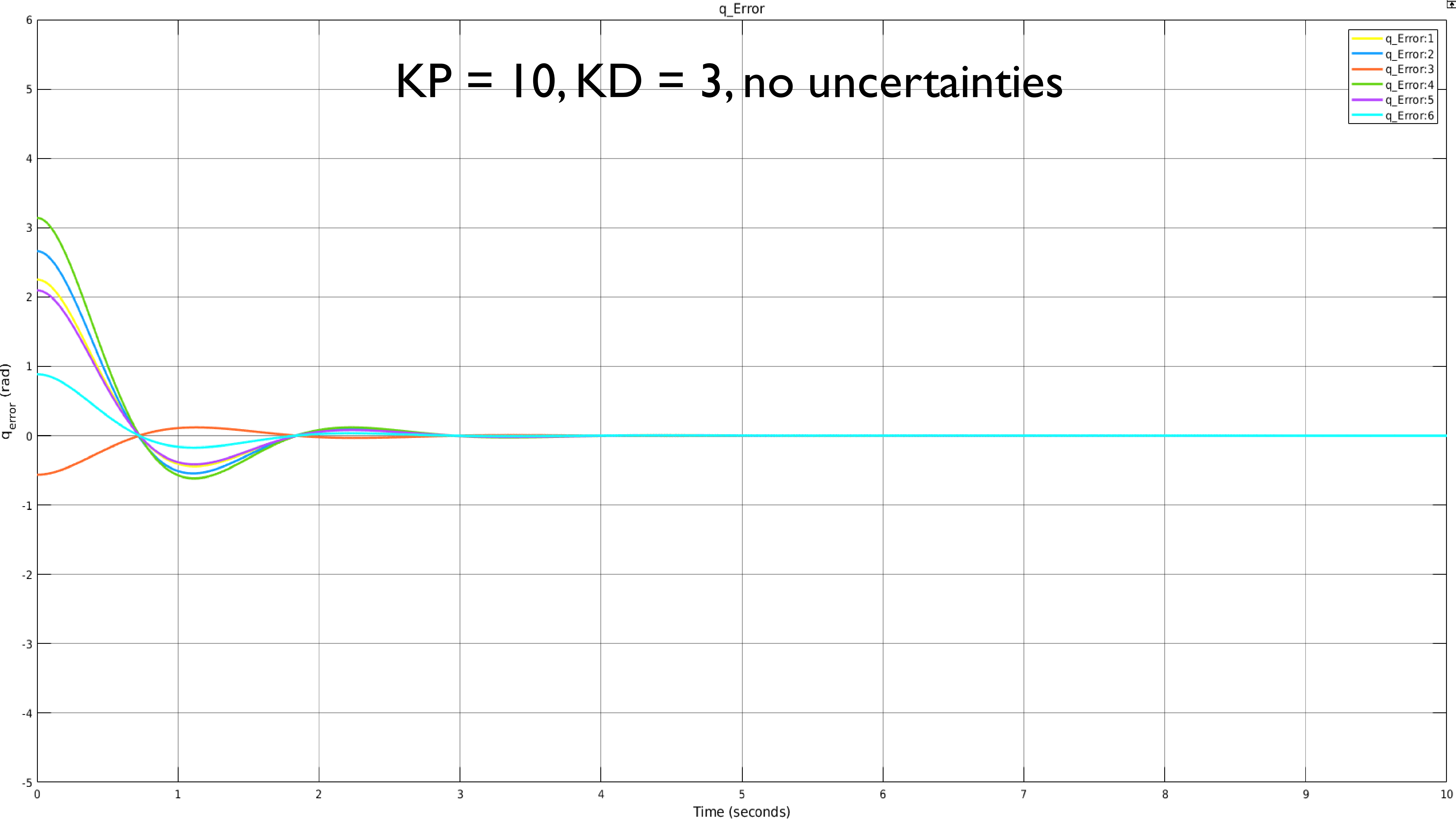
q_error
KP = 10, KD = 3
q_error:1
q_error:2
q_error:3
q_error:4
q_error:5
q_error:6
4
3
2
1
0
-1
-2
q_{error} (rad)
0
1
2
3
4
5
6
7
8
9
10
Time (seconds)



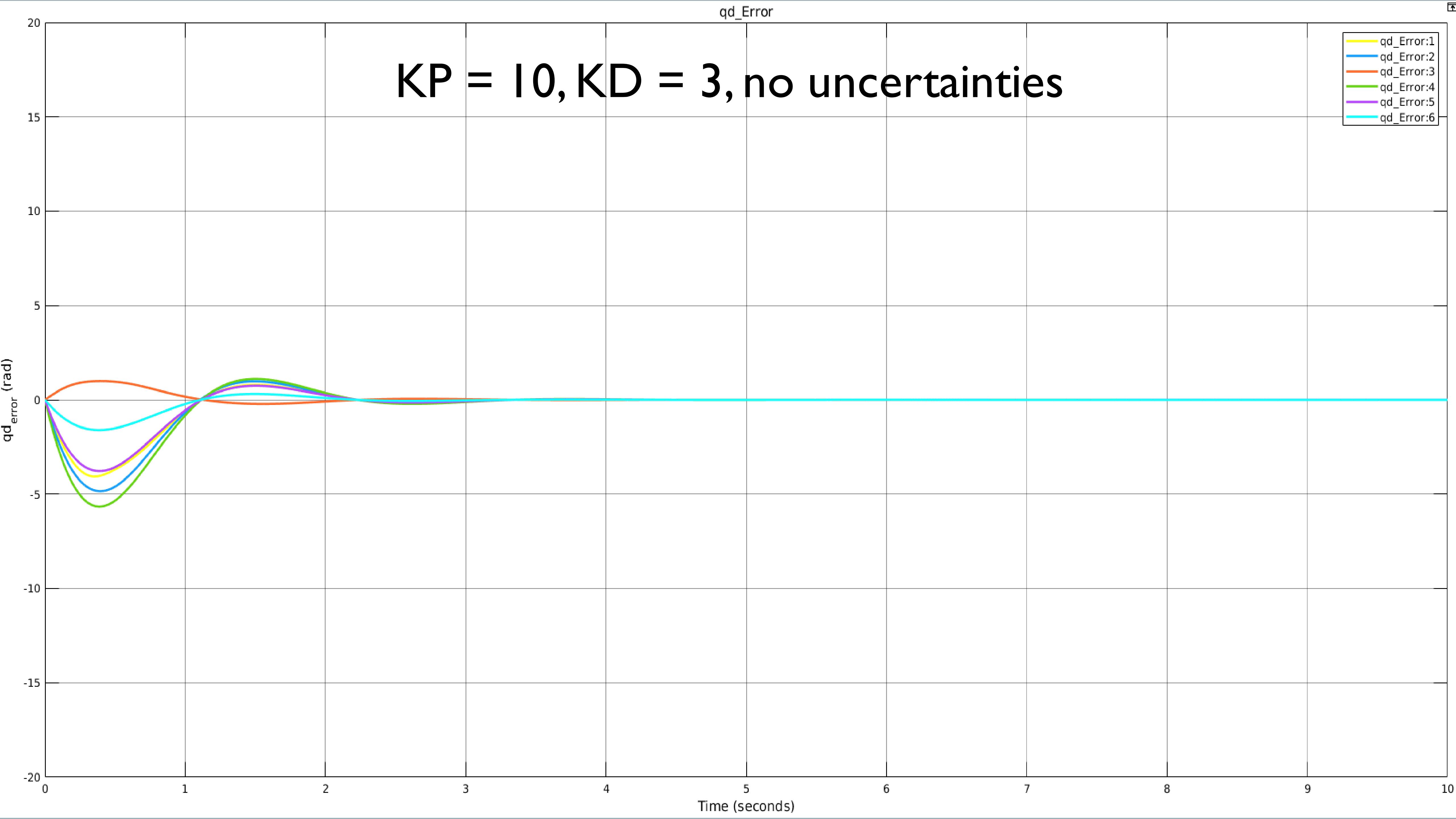
q_error
KP = 0, KD = 3
q_error:1
q_error:2
q_error:3
q_error:4
q_error:5
q_error:6
q_{error} (rad)
Time (seconds)
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10

INVERSE DYNAMICS CONTROL

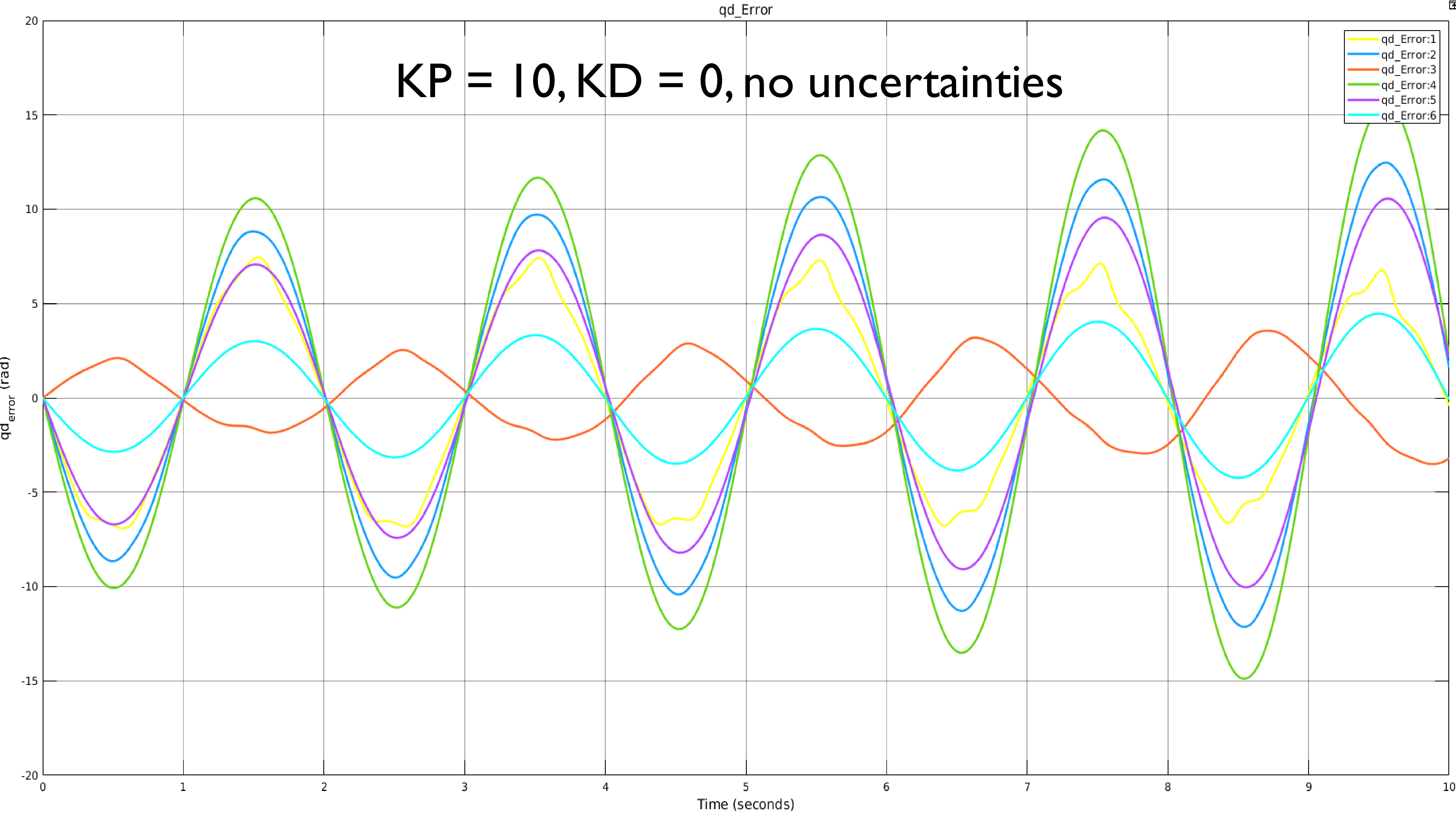




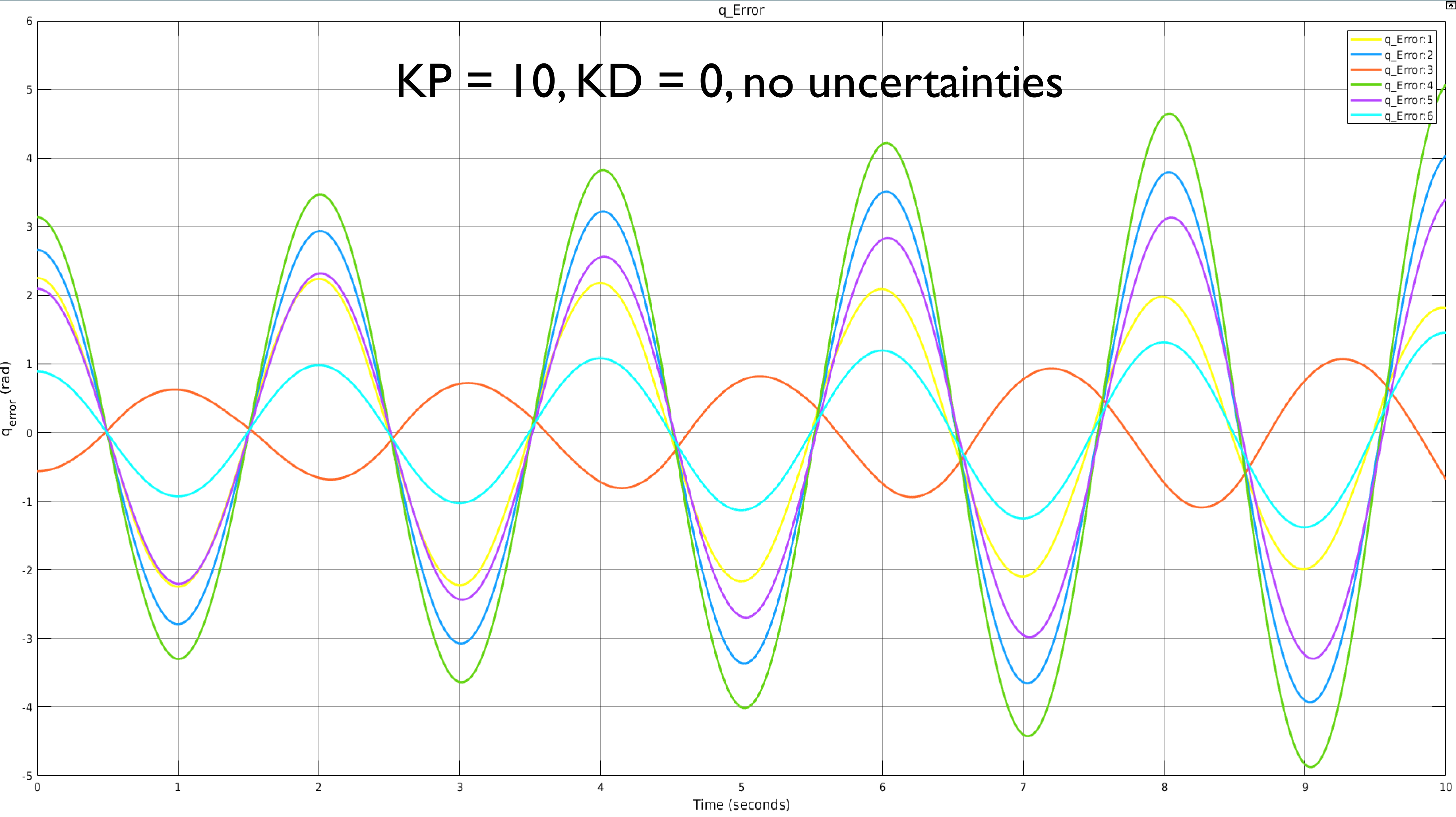
q_Error
KP = 10, KD = 3, no uncertainties
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
q_{error} (rad)
0
1
2
3
4
5
6
7
8
9
10
Time (seconds)



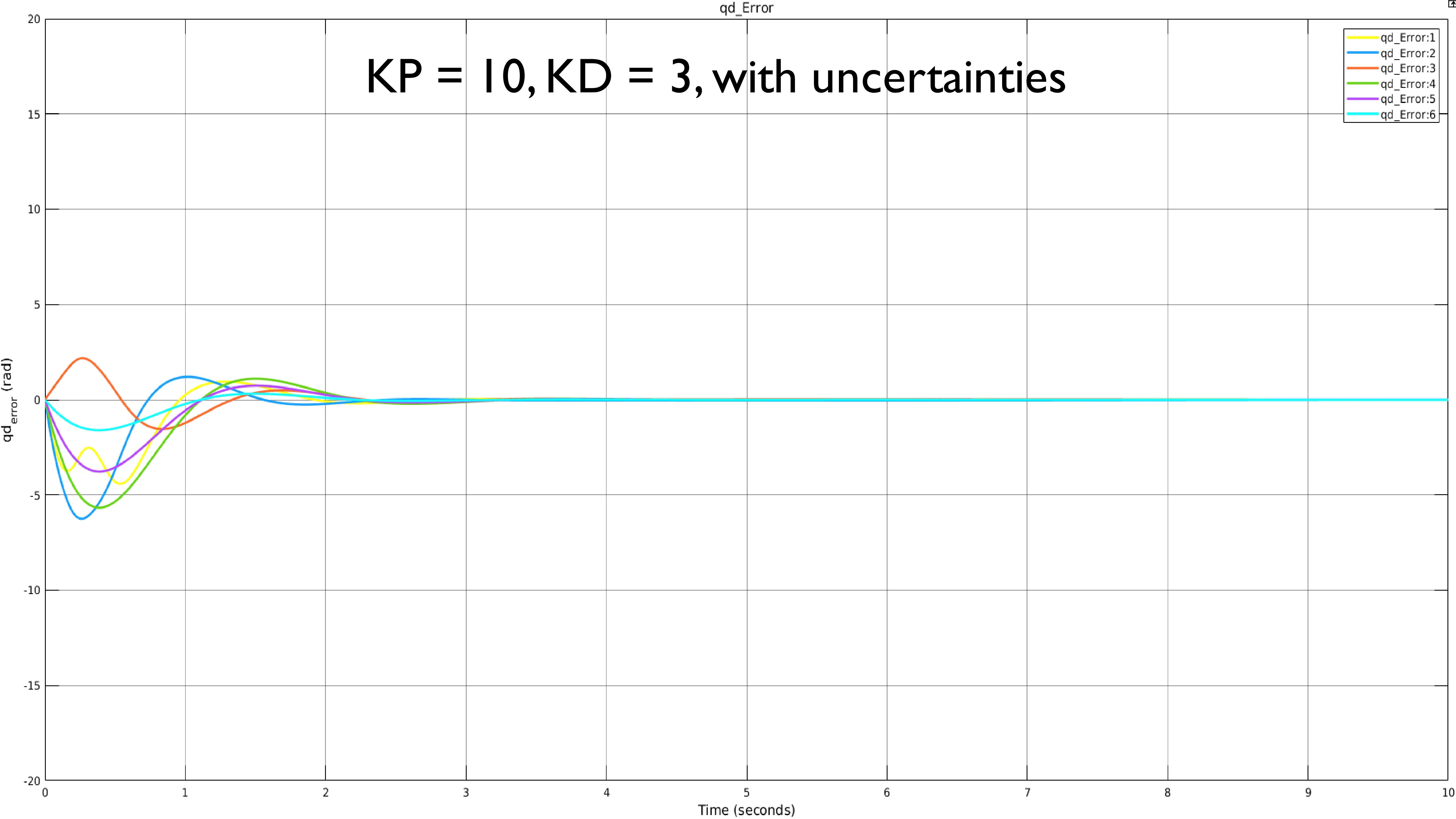
qd_Error
KP = 10, KD = 3, no uncertainties
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
qd_error (rad)
Time (seconds)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10



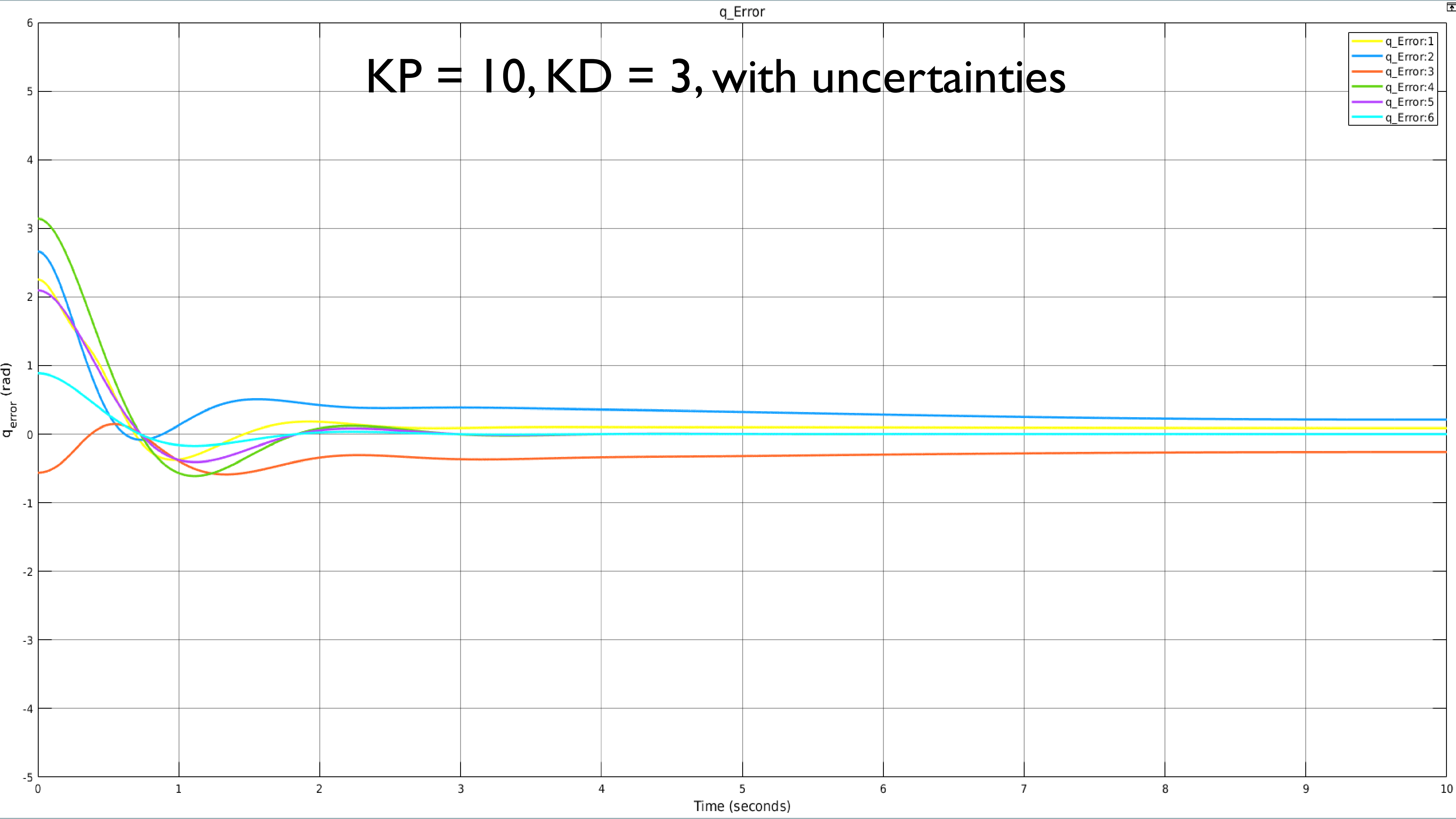
qd_Error
KP = 10, KD = 0, no uncertainties
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10
qd_{error} (rad)
Time (seconds)



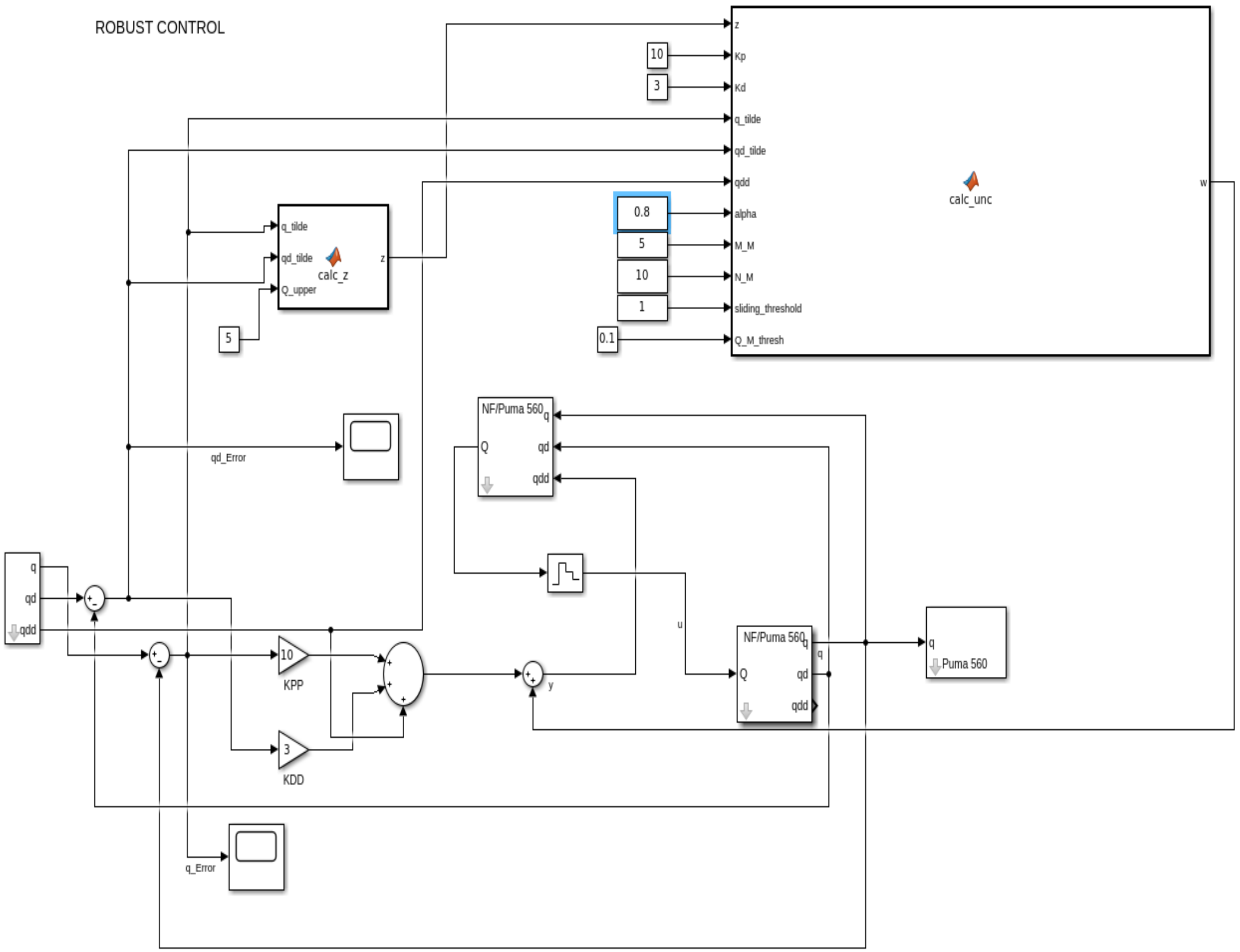
q_Error
KP = 10, KD = 0, no uncertainties
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
q_{error} (rad)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10
Time (seconds)



qd_Error
KP = 10, KD = 3, with uncertainties
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
20
15
10
5
0
-5
-10
-15
-20
qd_{error} (rad)
0
1
2
3
4
5
6
7
8
9
10
Time (seconds)


q_Error
KP = 10, KD = 3, with uncertainties
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
q_{error} (rad)
Time (seconds)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10

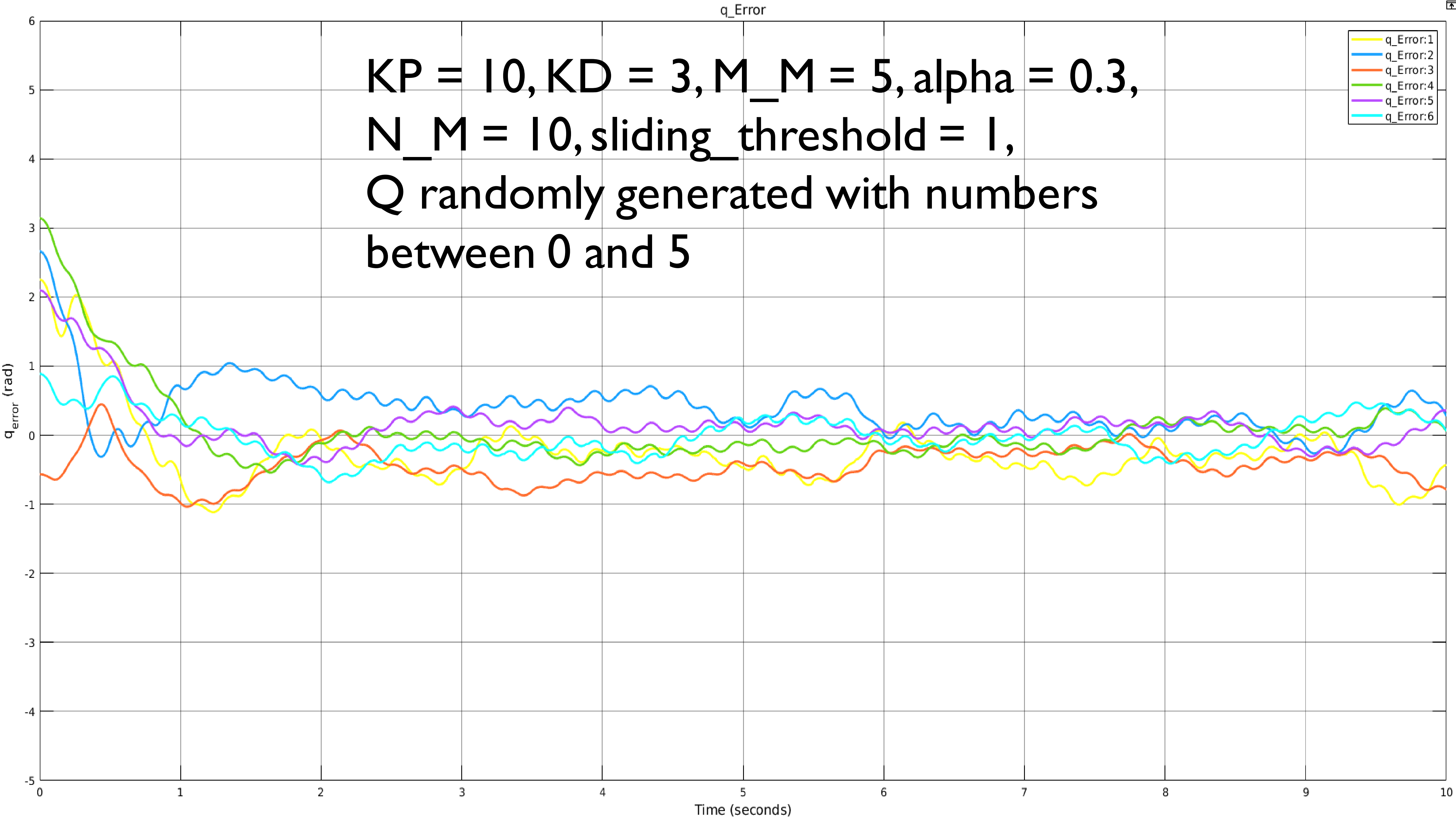
ROBUST SLIDING MODE CONTROL



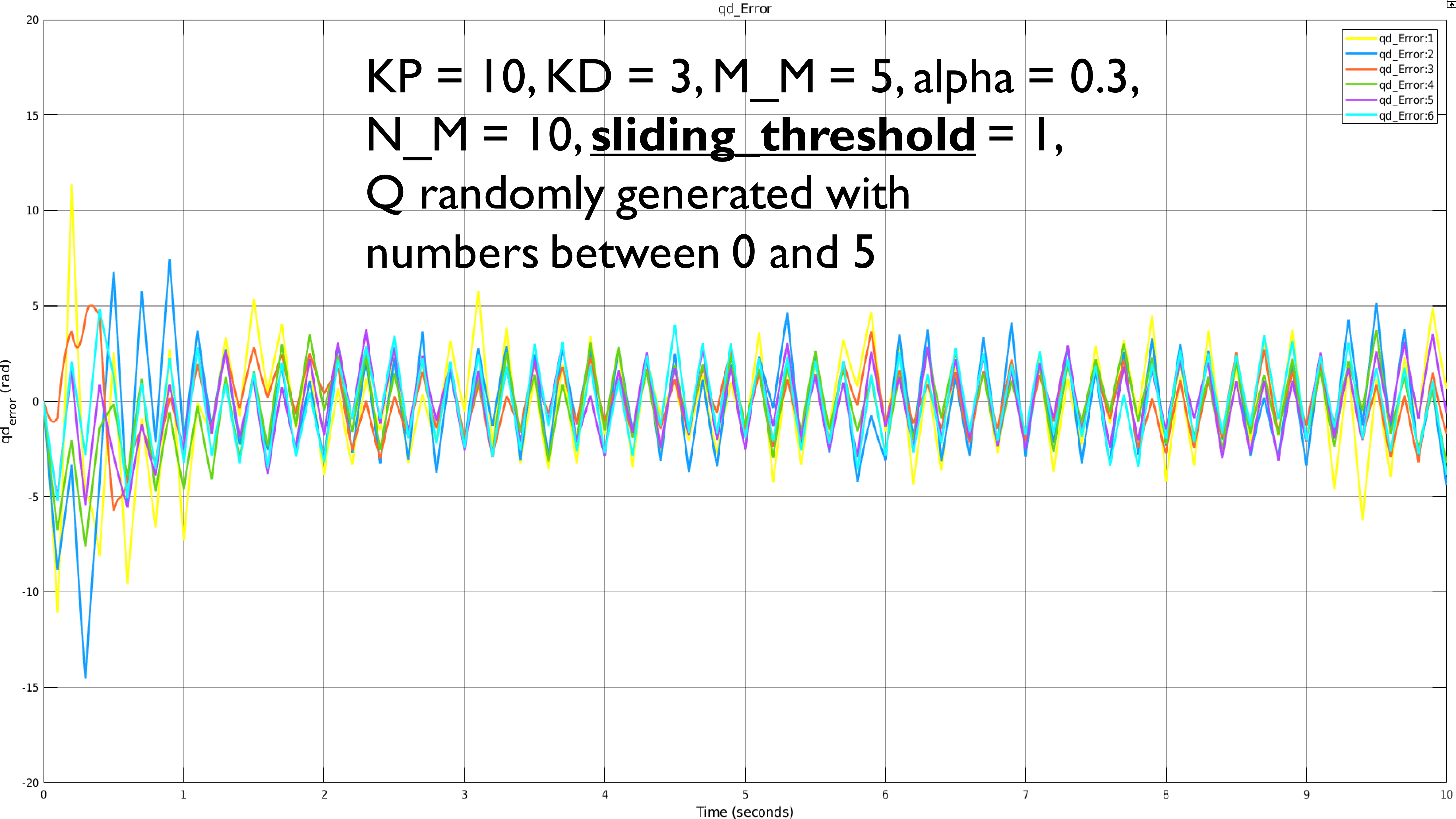
ROBUST SLIDING MODE CONTROL

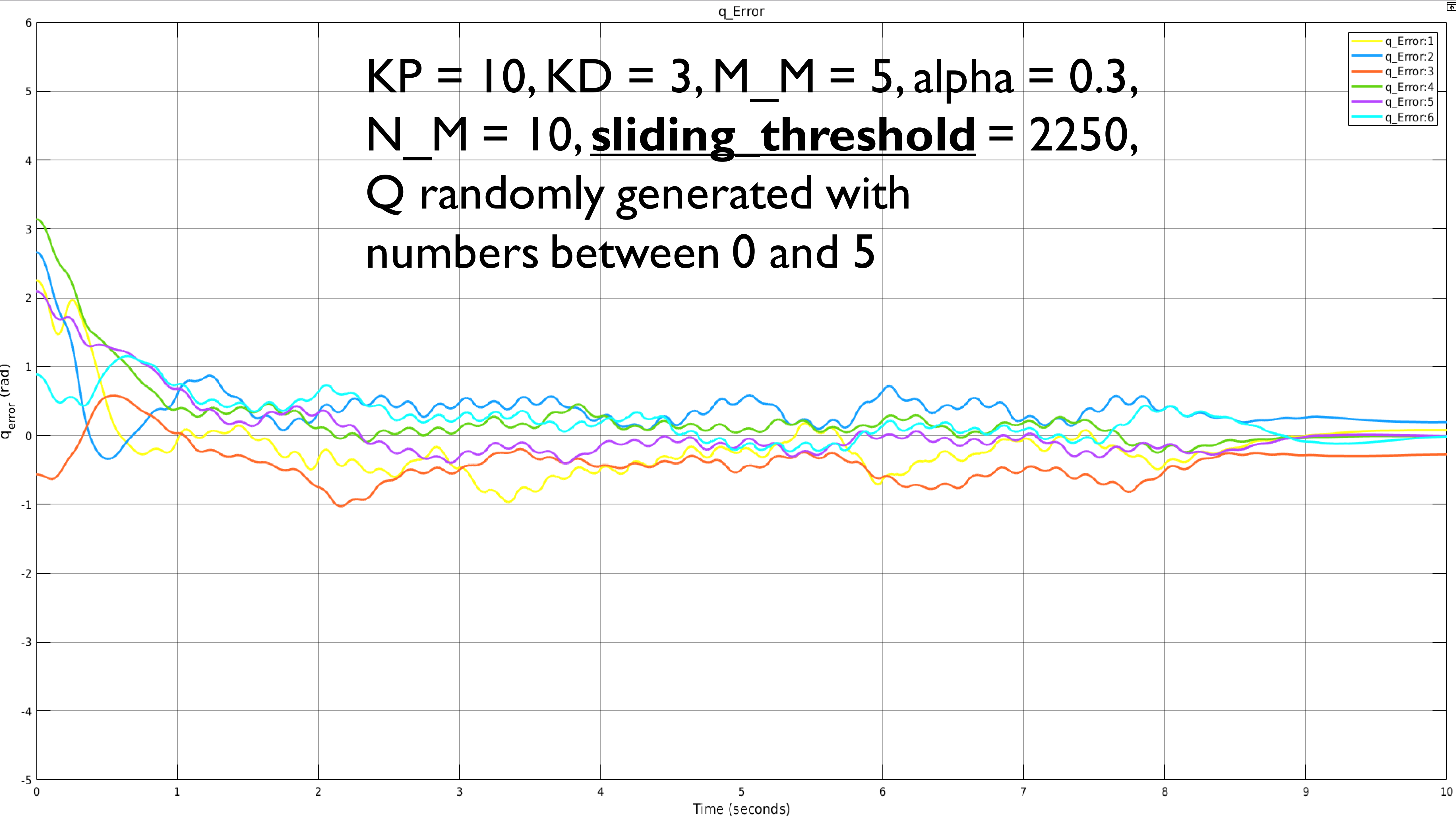
```
function w = calc_unc(z, Kp, Kd, q_tilde, qd_tilde, qdd, alpha, M_M, N_M,...
    sliding_threshold, Q_M_thresh)
    K = [eye(6)*Kp eye(6)*Kd];
    epsilon = [q_tilde; qd_tilde];
    Q_M = max(abs(qdd)) + Q_M_thresh;
    rho = (1/(1-alpha))*(alpha*Q_M + alpha*norm(K)*norm(epsilon) + M_M*N_M);
    z_unit_vector = z/norm(z);
    if norm(z) >= sliding_threshold
        w = rho * z_unit_vector;
    else
        w = rho * z * (1/sliding_threshold);
    end
end
```

```
function z = calc_z(q_tilde, qd_tilde, Q_upper)
D = [eye(6)*0; eye(6)];
A = 0 + (0+Q_upper) * rand(12);
Q = A*A.';
epsilon = [q_tilde; qd_tilde];
z = transpose(D) * Q * epsilon;
end
```

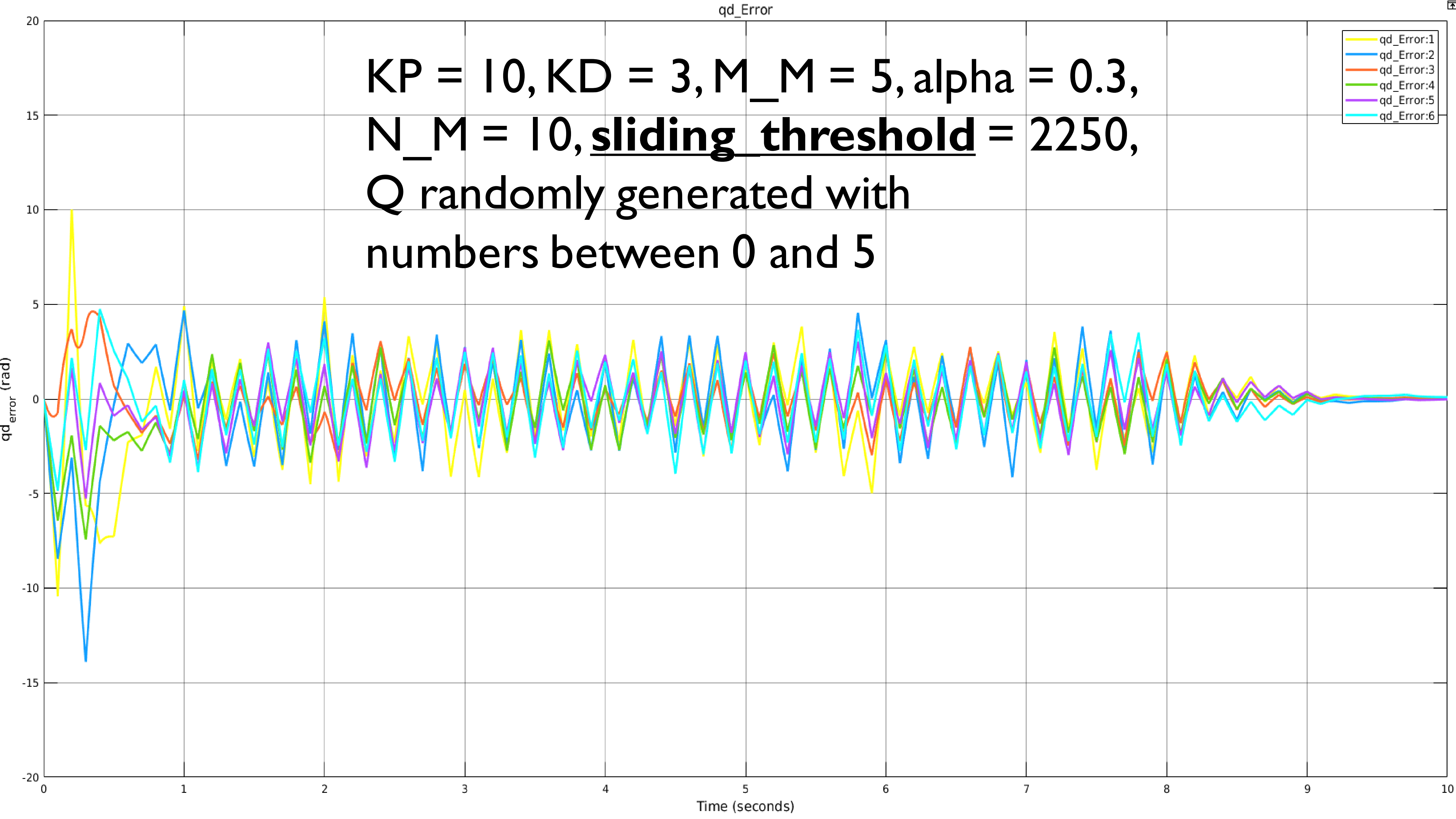

q_Error
KP = 10, KD = 3, M_M = 5, alpha = 0.3,
N_M = 10, sliding_threshold = 1,
Q randomly generated with numbers
between 0 and 5
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10
Time (seconds)
q_{error} (rad)

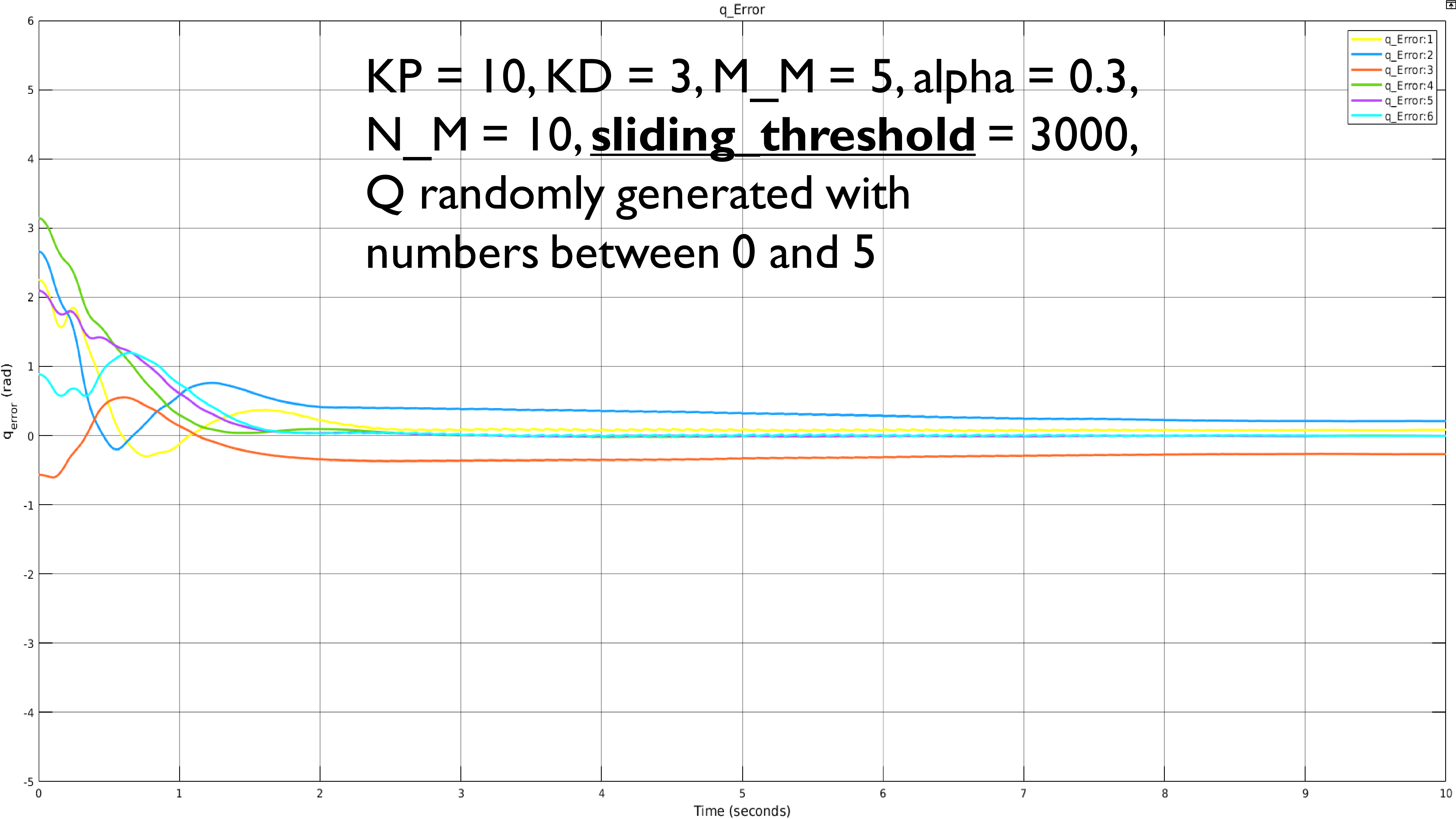
KP = 10, KD = 3, M_M = 5, alpha = 0.3,
N_M = 10, **sliding_threshold** = 1,
Q randomly generated with
numbers between 0 and 5



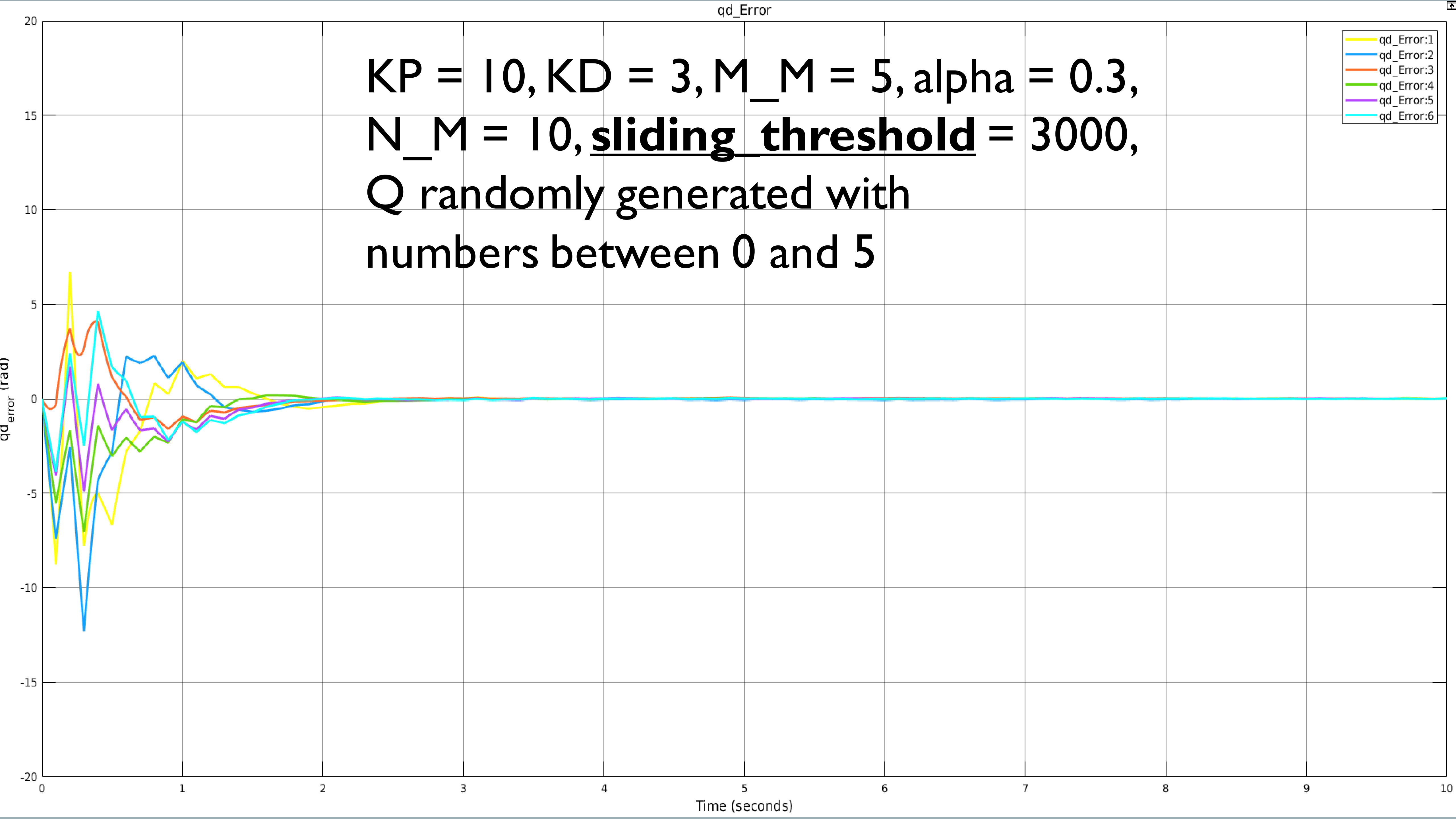


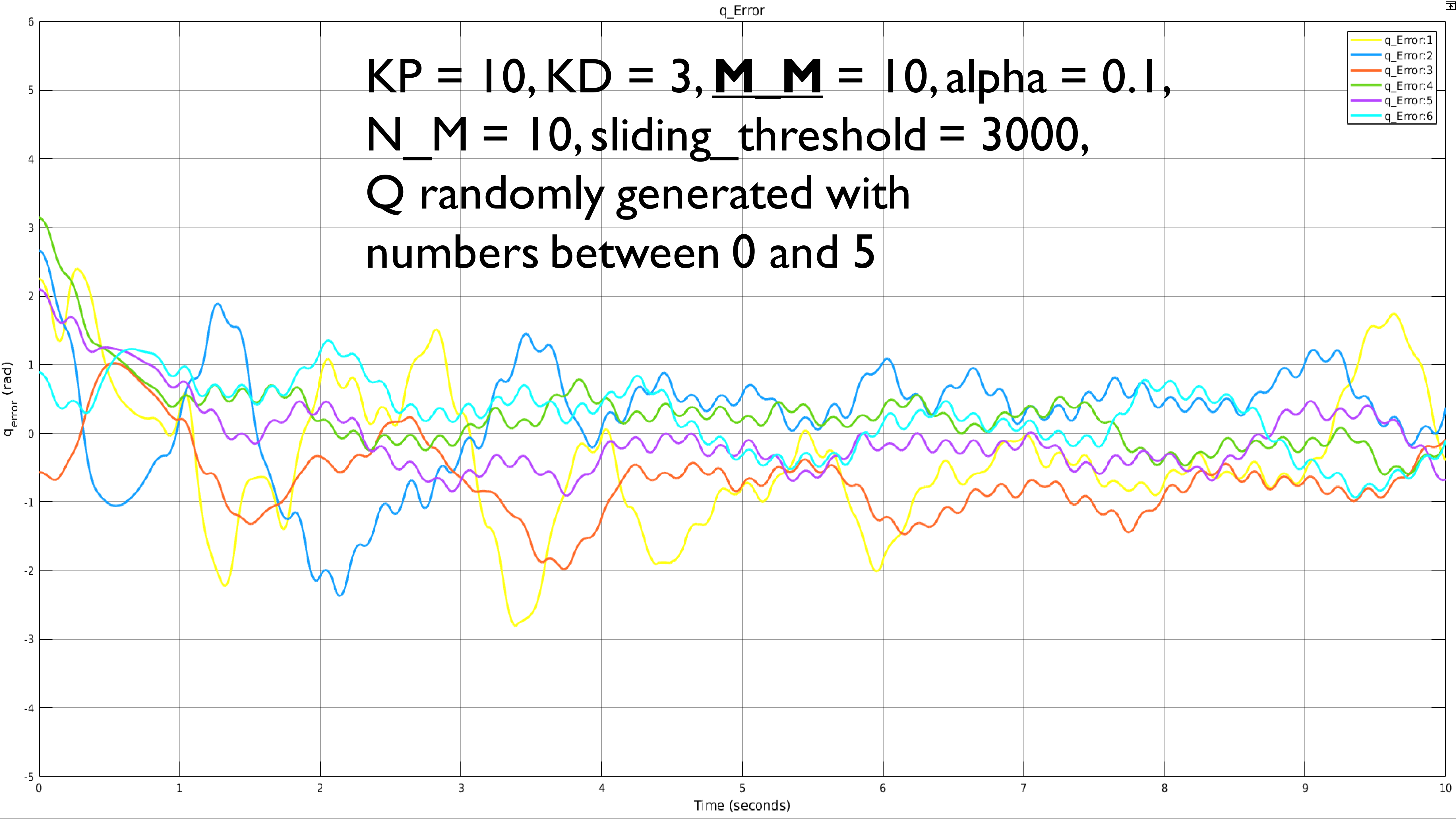
KP = 10, KD = 3, M_M = 5, alpha = 0.3, N_M = 10, **sliding_threshold** = 2250, Q randomly generated with numbers between 0 and 5

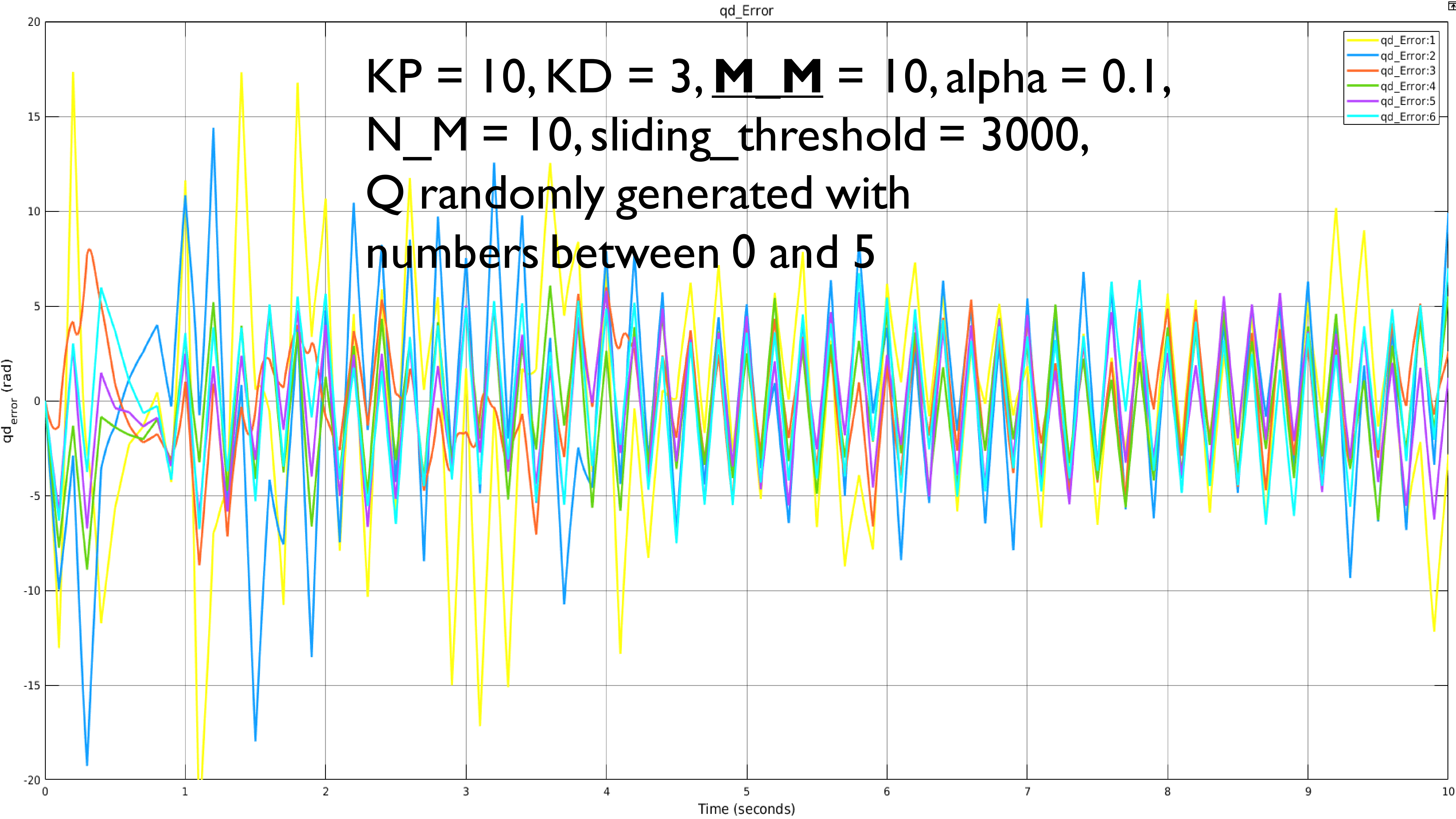

qd_Error
KP = 10, KD = 3, M_M = 5, alpha = 0.3,
N_M = 10, **sliding_threshold** = 2250,
Q randomly generated with
numbers between 0 and 5
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
qd_{error} (rad)
Time (seconds)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10

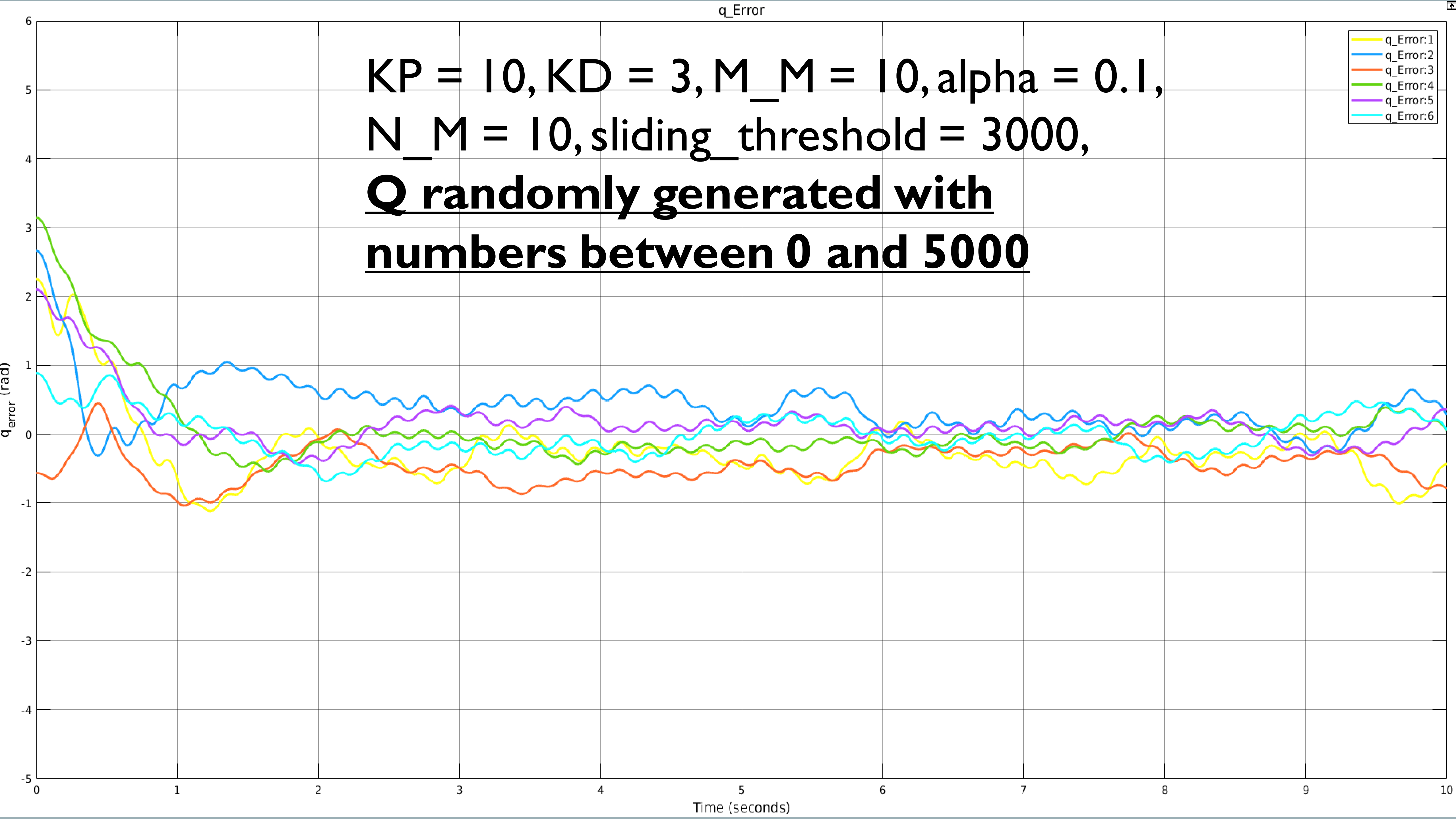


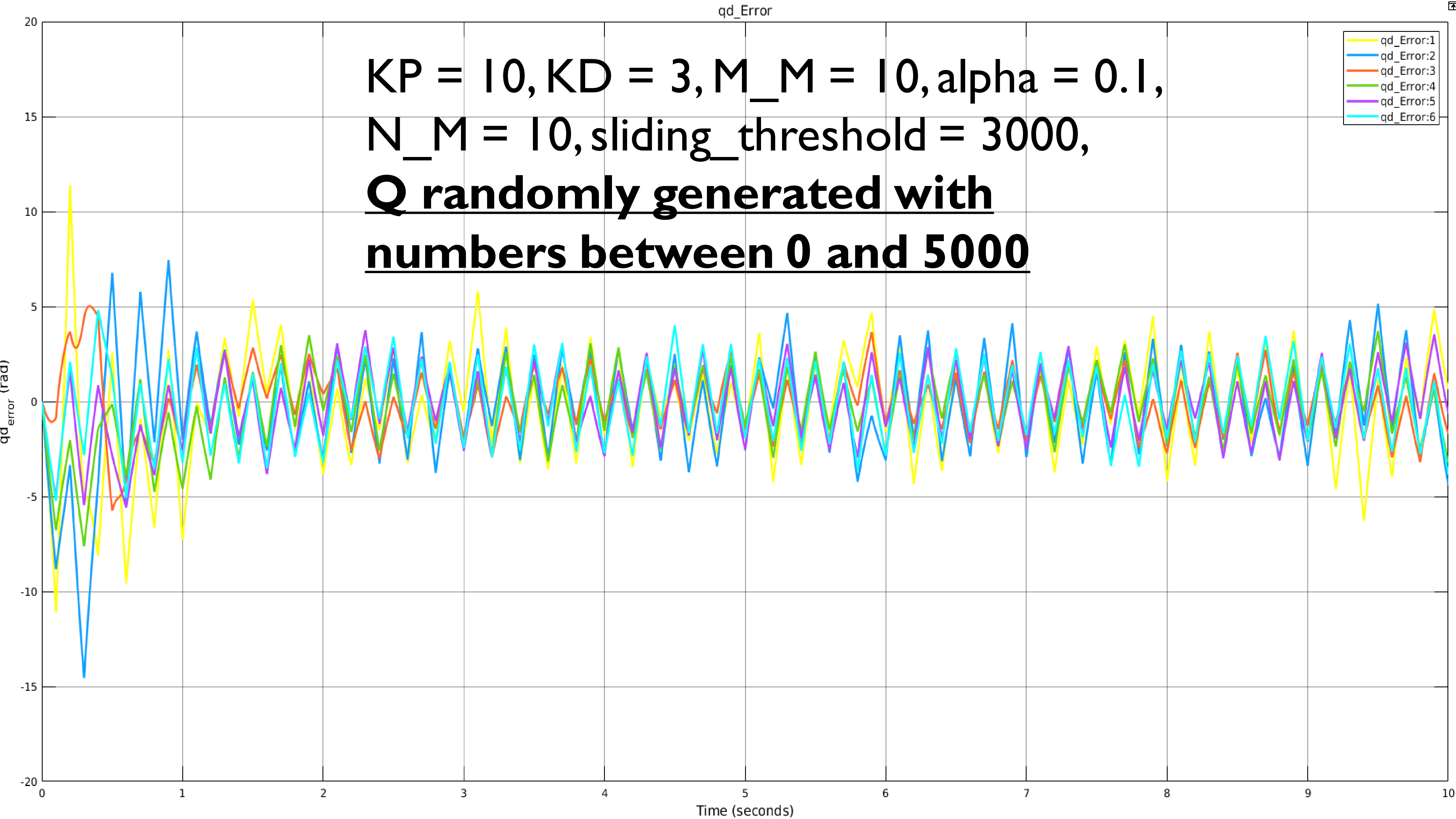
KP = 10, KD = 3, M_M = 5, alpha = 0.3, N_M = 10, **<u>sliding_threshold</u>** = 3000, Q randomly generated with numbers between 0 and 5

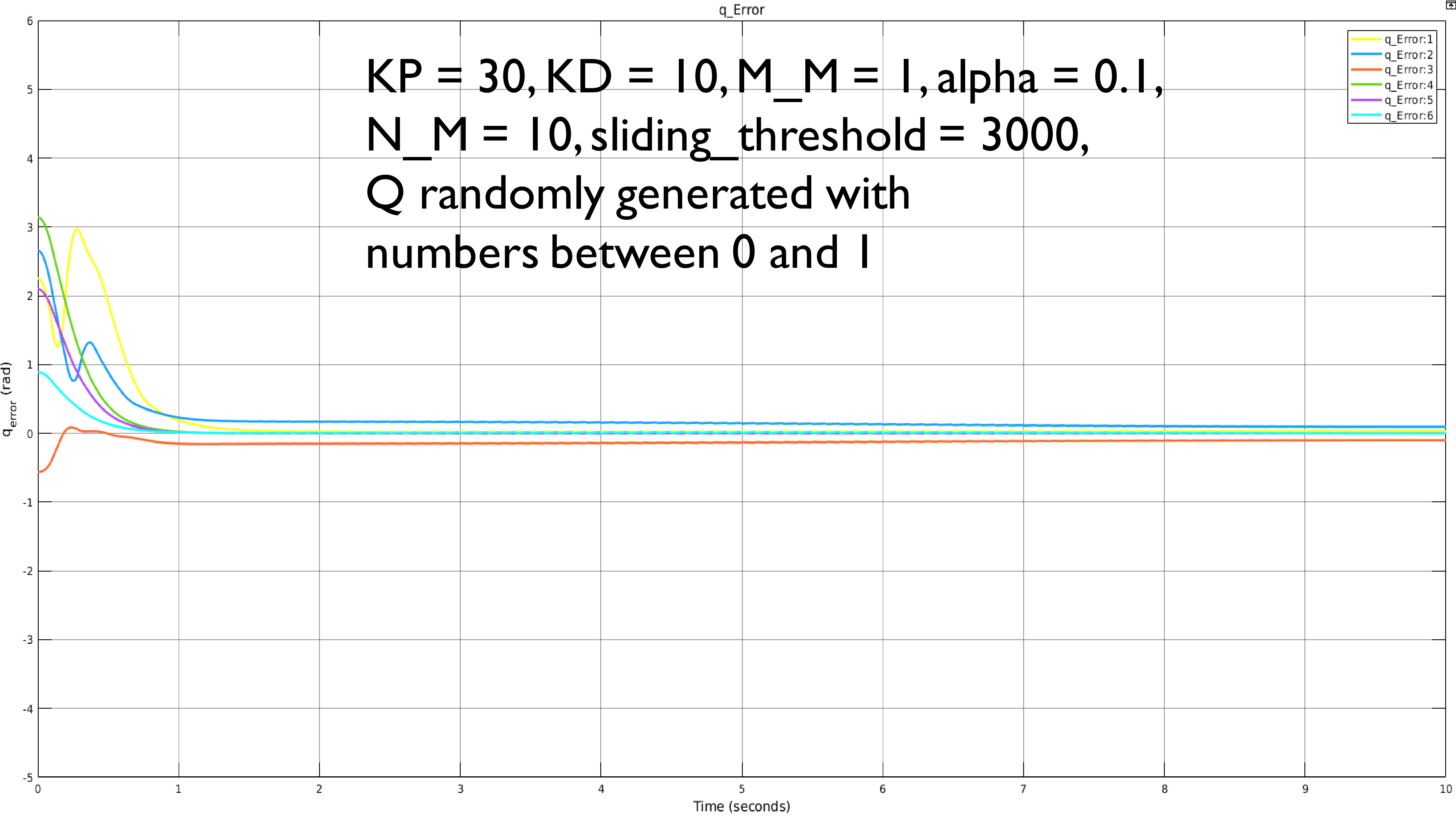

qd_Error
KP = 10, KD = 3, M_M = 5, alpha = 0.3,
N_M = 10, **sliding_threshold** = 3000,
Q randomly generated with
numbers between 0 and 5
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
qd_{error} (rad)
Time (seconds)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10

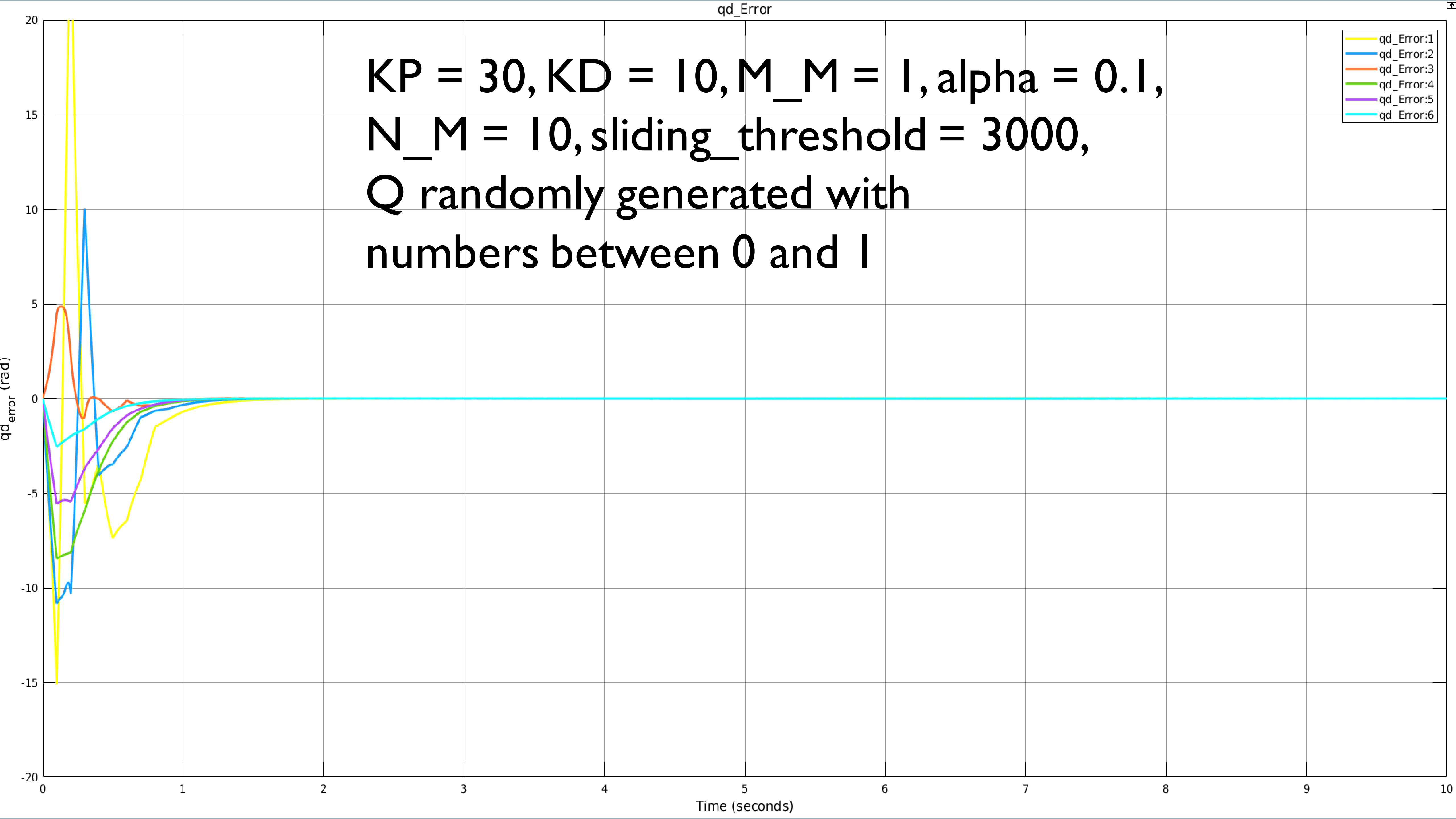

q_Error
KP = 10, KD = 3, M_M = 10, alpha = 0.1,
N_M = 10, sliding_threshold = 3000,
Q randomly generated with
numbers between 0 and 5
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
q_error (rad)
Time (seconds)


qd_Error
KP = 10, KD = 3, M_M = 10, alpha = 0.1,
N_M = 10, sliding_threshold = 3000,
Q randomly generated with
numbers between 0 and 5
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
qd error (rad)
Time (seconds)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10

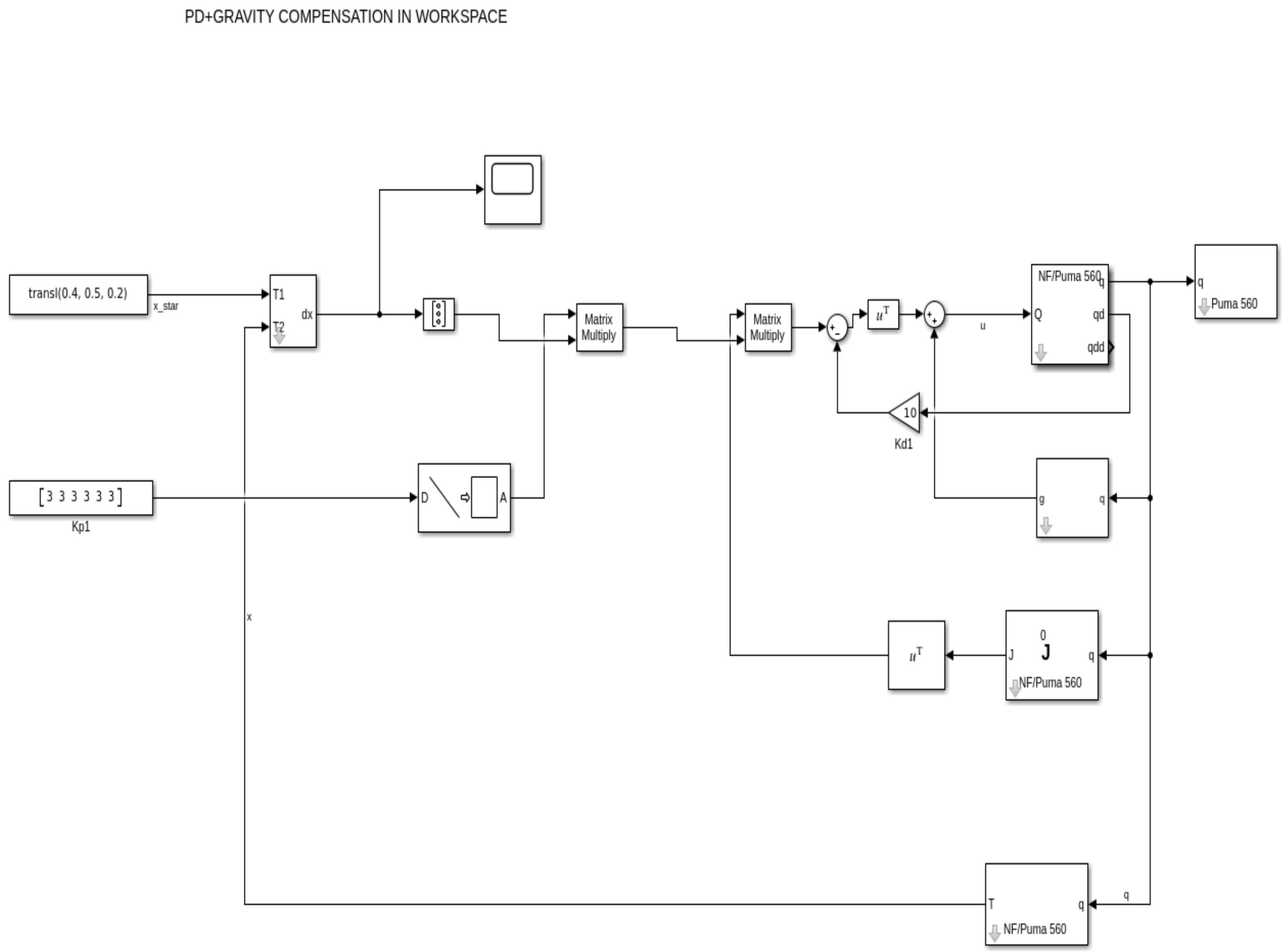

q_Error
KP = 10, KD = 3, M_M = 10, alpha = 0.1,
N_M = 10, sliding_threshold = 3000,
Q randomly generated with
numbers between 0 and 5000
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
q_error (rad)
Time (seconds)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10


qd_Error
KP = 10, KD = 3, M_M = 10, alpha = 0.1,
N_M = 10, sliding_threshold = 3000,
Q randomly generated with
numbers between 0 and 5000
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
qd_error (rad)
Time (seconds)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10


q_Error
KP = 30, KD = 10, M_M = 1, alpha = 0.1,
N_M = 10, sliding_threshold = 3000,
Q randomly generated with
numbers between 0 and 1
q_Error:1
q_Error:2
q_Error:3
q_Error:4
q_Error:5
q_Error:6
q_error (rad)
Time (seconds)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10


qd_Error
KP = 30, KD = 10, M_M = 1, alpha = 0.1,
N_M = 10, sliding_threshold = 3000,
Q randomly generated with
numbers between 0 and 1
qd_Error:1
qd_Error:2
qd_Error:3
qd_Error:4
qd_Error:5
qd_Error:6
qd_{error} (rad)
Time (seconds)

PD CONTROL + GRAVITY COMPENSATION IN WORKSPACE



PD CONTROL + GRAVITY COMPENSATION IN WORKSPACE

$$V(x) = \frac{1}{2}\,\dot{q}^{\,T} M(q)\,\dot{q} + \frac{1}{2}\,\tilde{x}^{\,T} K_p\,\tilde{x}$$

$$\dot{V}(x) = \frac{1}{2}\,\dot{q}^{\,T}\,\dot{M}\,\dot{q} + \dot{q}^{\,T} M\,\ddot{q} + \dot{\tilde{x}}^{\,T} K_p\,\tilde{x}$$

$$\dot{V}(x) = \frac{1}{2}\,\dot{q}^{\,T}\,\dot{M}\,\dot{q} + \dot{q}^{\,T}(u - C\dot{q} - D\dot{q} - g) - \dot{x}^{\,T} K_p\,\tilde{x}$$

$$\dot{V}(x) = \frac{1}{2}\,\dot{q}^{\,T}\,\dot{M}\,\dot{q} - \dot{q}^{\,T} C\dot{q} + \dot{q}^{\,T}(u - D\dot{q} - g) - \dot{x}^{\,T} K_p\,\tilde{x}$$

$$\dot{V}(x) = \dot{q}^{\,T}(u - D\dot{q} - g) - \dot{x}^{\,T} K_p\,\tilde{x}$$

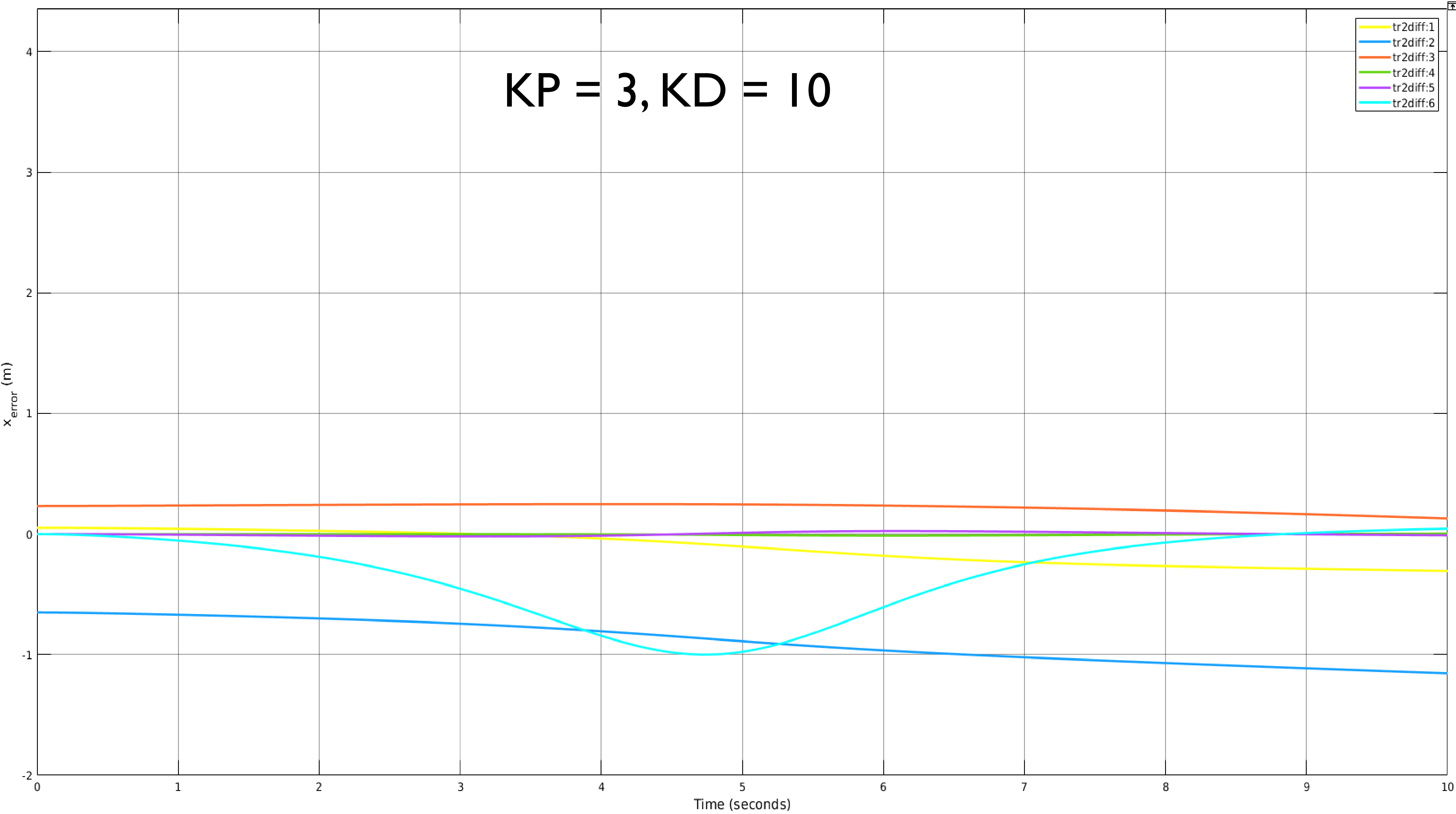
$$\left(\frac{1}{2}\,\dot{q}^{\,T}\,\dot{M}\,\dot{q} - \dot{q}^{\,T} C\dot{q} = 0 \quad \text{due to Christoffel Symbols}\right)$$

$$\dot{x} = J\dot{q}$$

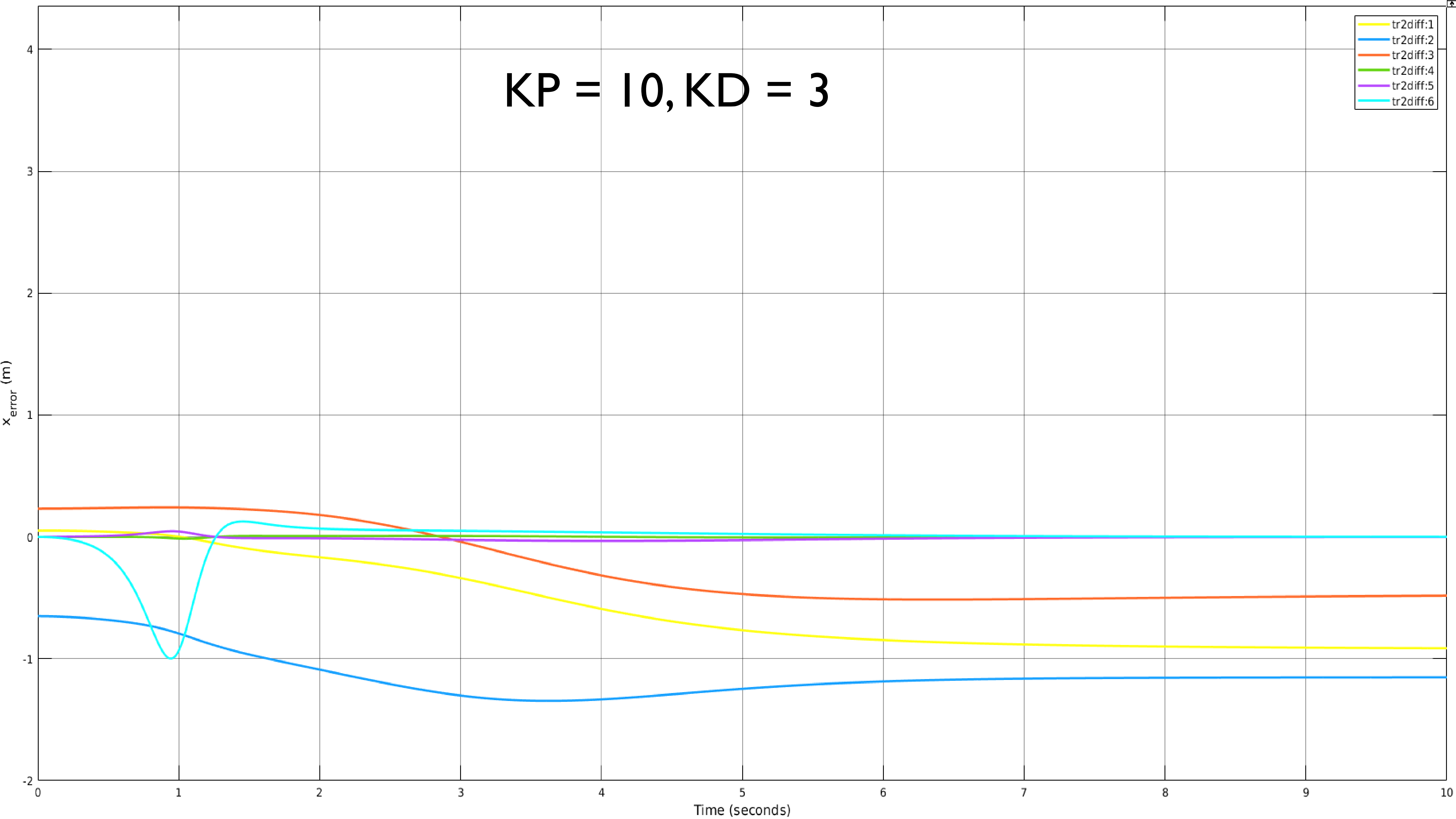
$$u = J^T(K_p\,\tilde{x}) - K_d\,\dot{q} + g$$

$$\dot{V}(x) = -\dot{q}\,D\dot{q} - \dot{q}\,K_d\,\dot{q} \le 0$$

$$\forall\,\dot{q} \text{ not equal to } 0$$



KP = 3, KD = 10
tr2diff:1
tr2diff:2
tr2diff:3
tr2diff:4
tr2diff:5
tr2diff:6
x_{error} (m)
Time (seconds)
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10



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9
10