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%-------------------------------------------------------------------------
%-------------------------------------------------------------------------
% COURSE:   RBE502 ROBOT CONTROL
%
% ASSIGNMENT:TERM PROJECT
%
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%
% DATE:     04/27/2019
%-------------------------------------------------------------------------
% TITLE: Open_Manipulator_Dynamic Model
%-------------------------------------------------------------------------

clear all
clc
```

OpenManipulator Parameters

```
l1 = 0.077; %m
l2 = 0.130; %m
l3 = 0.124; %m
l4 = 0.126; %m

lc1 = 0.077/2; %m (estimate)
lc2 = 0.130/2; %m (estimate)
lc3 = 0.124/2; %m (estimate)
lc4 = 0.126/2; %m (estimate)

m1 = 0.14; %kg (estimate)
m2 = 0.14; %kg (estimate)
m3 = 0.14; %kg (estimate)
m4 = 0.14; %kg (estimate)

I1 = 0.12; %kg*m^2 (estimate)
```

```
I2 = 0.12; %kg*m^2 (estimate)
I3 = 0.12; %kg*m^2 (estimate)
I4 = 0.12; %kg*m^2 (estimate)

g = 9.8; %m/s^2
```

Input: Enter Desired Position

```
% Joint angles are in degrees

% i) Take the input from the user for the desired end-effector
 position

Xd = 0.31729; % input('Enter desired X for end-effector(m)0.31729: ');
Yd = 0.0;     % input('Enter desired Y for end-effector(m)0.0: ');
Zd = 0.1411;  % input('Enter desired Z for end-effector(m)0.1411: ');
elb_pos = 1;  % input('Enter elbow position 1 (0 - elbow down, 1 -
 elbow up):');
```

Output: Desired Joint Variables

```
%Desired joint variables corresponding to the end-effector position
[theta1i, theta2i, theta3i, theta4i] = invKin([Xd Yd Zd elb_pos], l1,
 l2, l3, l4);
```

Move Arm Function

```
%End Effector is middle of gripper arm of OpenManipulator

[T4, X4, end_eff_x4, end_eff_y4, end_eff_z4 torque4] = moveArmU([.119,
 0, 0.1206 1],...
[0.1411, 0, .31729 1]);


% Comparing joint 3 torques
figure('Name','OpenManipulator:MATLAB Joint Torques Vs. Time 12');
plot(T4, torque4(1,1:size(T4,1)), 'g-');
hold on
plot(T4, torque4(2,1:size(T4,1)), 'r-');
plot(T4, torque4(3,1:size(T4,1)), 'b-');
plot(T4, torque4(4,1:size(T4,1)), 'm-');
ylim([-6 6]);
grid on
xlabel('Time in Seconds');
ylabel('Torque (Nm)');
legend('Theta 1', 'Theta 2', 'Theta 3', 'Theta 4','Location','Best');
title('OpenManipulator:MATLAB Joint Torques Vs. Time 12');
hold off

%Comparing end-effector X error
figure('Name','End-Effector X Position Error Control law PID');
```

```
plot(T4,Xd - end_eff_x4, 'r--');
xlabel('Time (seconds)');
ylabel('Position Error (meters)');
legend('PID: End Effector X Position Error');
title('End-Effector X Position Error Control law PID');

% Comparing end-effector Y error
figure('Name','End-Effector Y Position Error Control Law PID');
plot(T4,Yd - end_eff_y4, 'r--');
xlabel('Time (seconds)');
ylabel('Position Error (meters)');
legend('U: End Effector Y Position Error');
title('End-Effector Y Position Error Control Law PID');

% Comparing end-effector Z error
figure('Name','End-Effector Z Position Error Control Law PID');
plot(T4, Zd - end_eff_z4, 'r--');
xlabel('Time (seconds)');
ylabel('Position error (meters)');
legend('PID: End effector Z Position Error');
title('End-Effector Z Position Error Control Law PID');
```

MoveArmU

```
function [T, X, end_eff_x, end_eff_y, end_eff_z torque] =
 moveArmU(initial_config,...
 final_config)

l1 = 0.077; %m
l2 = 0.130; %m
l3 = 0.124; %m
l4 = 0.126; %m

lc1 = 0.077/2; %m
lc2 = 0.130/2; %m
lc3 = 0.124/2; %m
lc4 = 0.126/2; %m

m1 = 0.14; %kg
m2 = 0.14; %kg
m3 = 0.14; %kg
m4 = 0.14; %kg

I1 = 0.12; %kg*m^2
I2 = 0.12; %kg*m^2
I3 = 0.12; %kg*m^2
I4 = 0.12; %kg*m^2

   % Gains

    Kp = [100 0 0 0; 0 100 0 0; 0 0 100 0; 0 0 0 100];
    Kv = [100 0 0 0; 0 70 0 0; 0 0 70 0; 0 0 0 70];
    Ki = [100 0 0 0; 0 100 0 0; 0 0 100 0; 0 0 0 100];
```

```
g = 9.8; %m/s^2

[theta1i, theta2i, theta3i, theta4i] = invKin(initial_config, l1, l2,
 l3, l4);

[theta1f, theta2f, theta3f, theta4f] = invKin1(final_config, l1, l2,
 l3, l4);

x0 = [theta1i, theta2i, theta3i, theta4i, 0, 0, 0, 0]; % Initial
 Condition
xd = [theta1f, theta2f, theta3f, theta4f, 0, 0, 0, 0]; % Desired
 Condition

tf=11.979;

% ode15 solves the differential equation and returns X with respect to
 T.

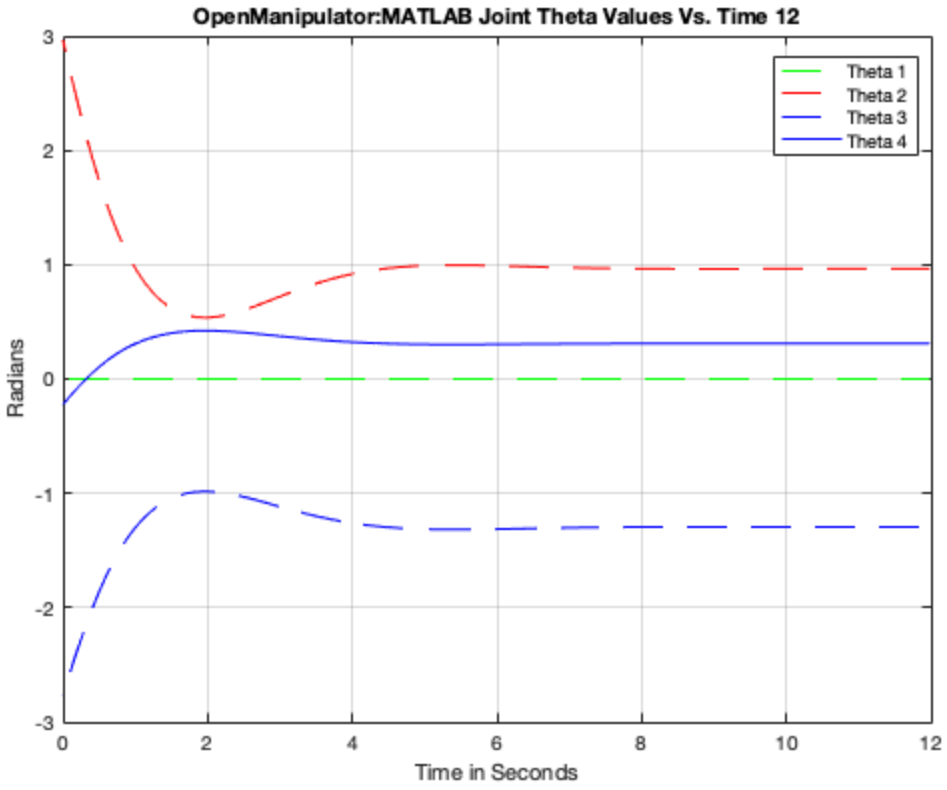
global torque
global t_old; % Time old
t_old = 0;
global dt; % Time dt for integration
dt = 0;
global ie; % Integrated error
ie = [0;0;0;0];

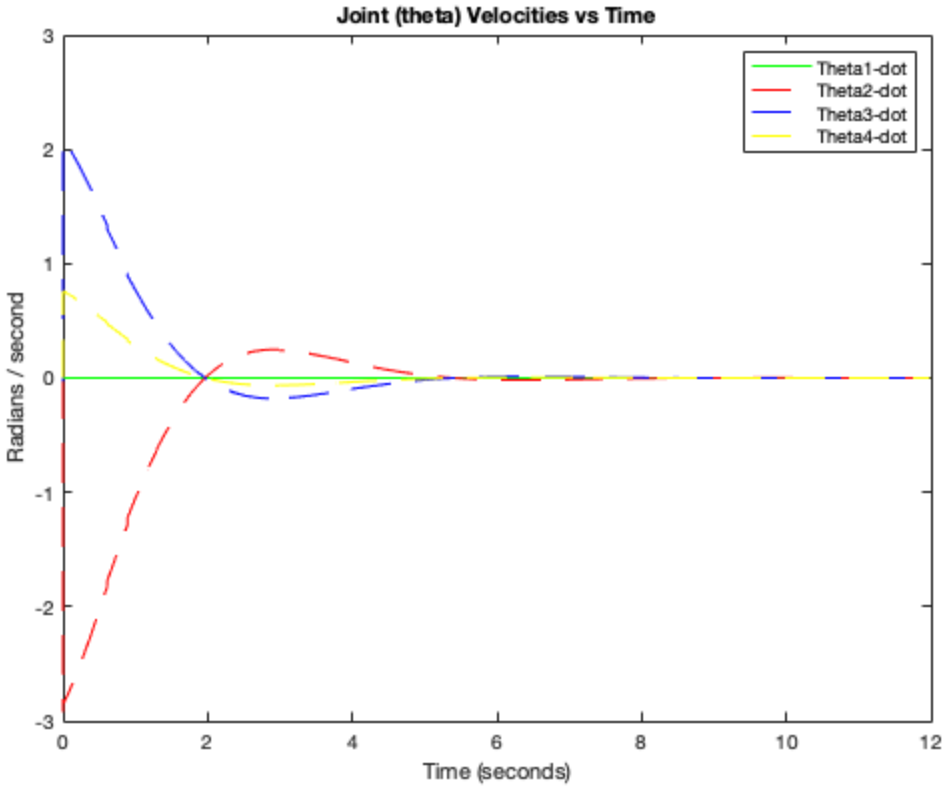
torque = [];
%opts = odeset('RelTol',1e-3);
[T,X] = ode15s(@(t,x)planarArmODE(t,x),[0 tf],x0);

% Joint Angles vs Time
figure('Name','OpenManipulator:MATLAB Joint Theta Values Vs. Time
 12');
plot(T, X(:,1),'g--');
hold on
grid on
plot(T, X(:,2),'r--');
plot(T, X(:,3),'b--');
plot(T, X(:,4),'b-');
xlabel('Time in Seconds');
ylabel('Radians');
legend('Theta 1', 'Theta 2', 'Theta 3', 'Theta 4','Location','Best');
title('OpenManipulator:MATLAB Joint Theta Values Vs. Time 12');

% Joint Velocities vs Time
figure('Name','PID: Joint (theta) Velocities vs Time');
plot(T, X(:,5),'g-');
hold on
plot(T, X(:,6),'r--');
plot(T, X(:,7),'b--');
plot(T, X(:,8),'y--');
xlabel('Time (seconds)');
```

```
ylabel('Radians / second');
legend('Theta1-dot', 'Theta2-dot', 'Theta3-dot','Theta4-dot');
title('Joint (theta) Velocities vs Time');
```





OpenManipulator Joint Space Positions

```
%X(:,1) Theta 1
%X(:,2) Theta 2
%X(:,3) Theta 3
%X(:,4) Theta 4

%Base Position
base_om_x = 0;
base_om_y = 0;
base_om_z = 0;

%Joint 1 Position
joint_1_x = 0;
joint_1_y = 0;
joint_1_z = l1;

%Joint 2 Position
joint_2_x = l2.*cos(X(:,2)).*cos(X(:,1));
joint_2_y = l2.*cos(X(:,2)).*sin(X(:,1));
joint_2_z = l1 + l2.*sin(X(:,2));

%Joint 3 Position
joint_3_x = (l2.*cos(X(:,2))+l3.*cos(X(:,2)+X(:,3))).*cos(X(:,1));
joint_3_y = (l2.*cos(X(:,2))+l3.*cos(X(:,2)+X(:,3))).*sin(X(:,1));
```

```
joint_3_z = l1 + l2.*sin(X(:,2))+l3.*sin(X(:,2)+X(:,3));

%End Effector Position
end_eff_x =
 (l2.*cos(X(:,2))+l3.*cos(X(:,2)+X(:,3))+l4.*cos(X(:,2)+X(:,3)+X(:,4))).*cos(X(:,1
end_eff_y =
 (l2.*cos(X(:,2))+l3.*cos(X(:,2)+X(:,3))+l4.*cos(X(:,2)+X(:,3)+X(:,4))).*sin(X(:,1
end_eff_z = l1 +
 l2.*sin(X(:,2))+l3.*sin(X(:,2)+X(:,3))+l4.*sin(X(:,2)+X(:,3)+X(:,4));
```

OpenManipulator Stick Model Positions

```
% Initial Position
line1_x = [0 joint_1_x(1,1) joint_2_x(1,1) joint_3_x(1,1)
 end_eff_x(1,1)];
line1_y = [0 joint_1_y(1,1) joint_2_y(1,1) joint_3_y(1,1)
 end_eff_y(1,1)];
line1_z = [0 joint_1_z(1,1) joint_2_z(1,1) joint_3_z(1,1)
 end_eff_z(1,1)];

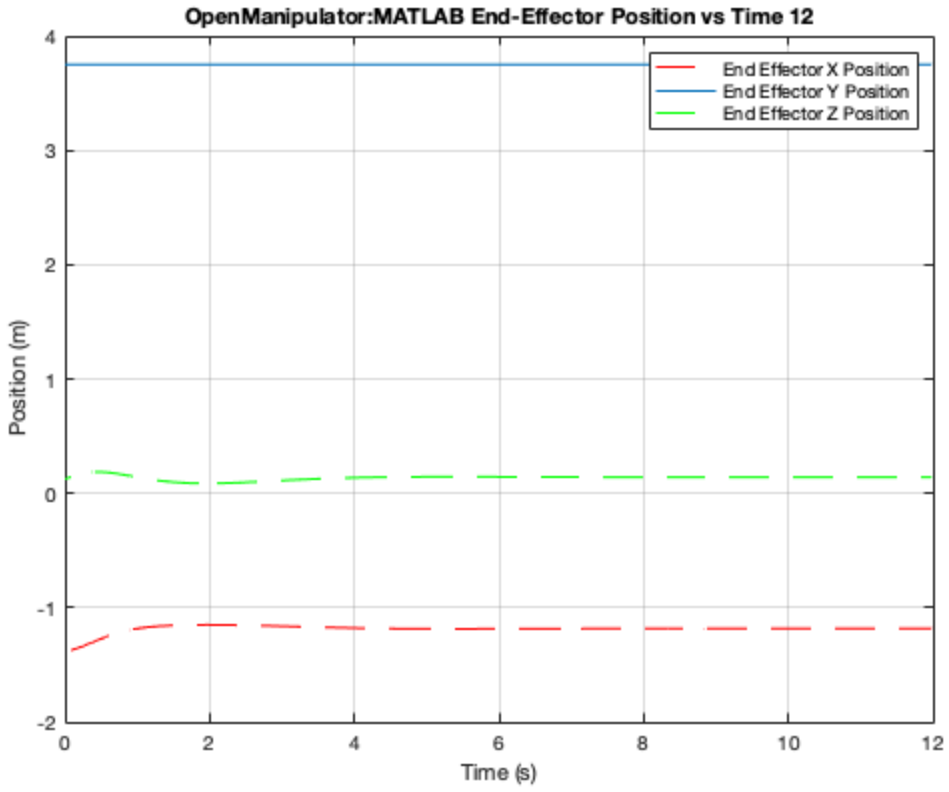
%Final Position
line3_x = [0 joint_1_x(end,1) joint_2_x(end,1) joint_3_x(end,1)
 end_eff_x(end,1)];
line3_y = [0 joint_1_y(end,1) joint_2_y(end,1) joint_3_y(end,1)
 end_eff_y(end,1)];
line3_z = [0 joint_1_z(end,1) joint_2_z(end,1) joint_3_z(end,1)
 end_eff_z(end,1)];

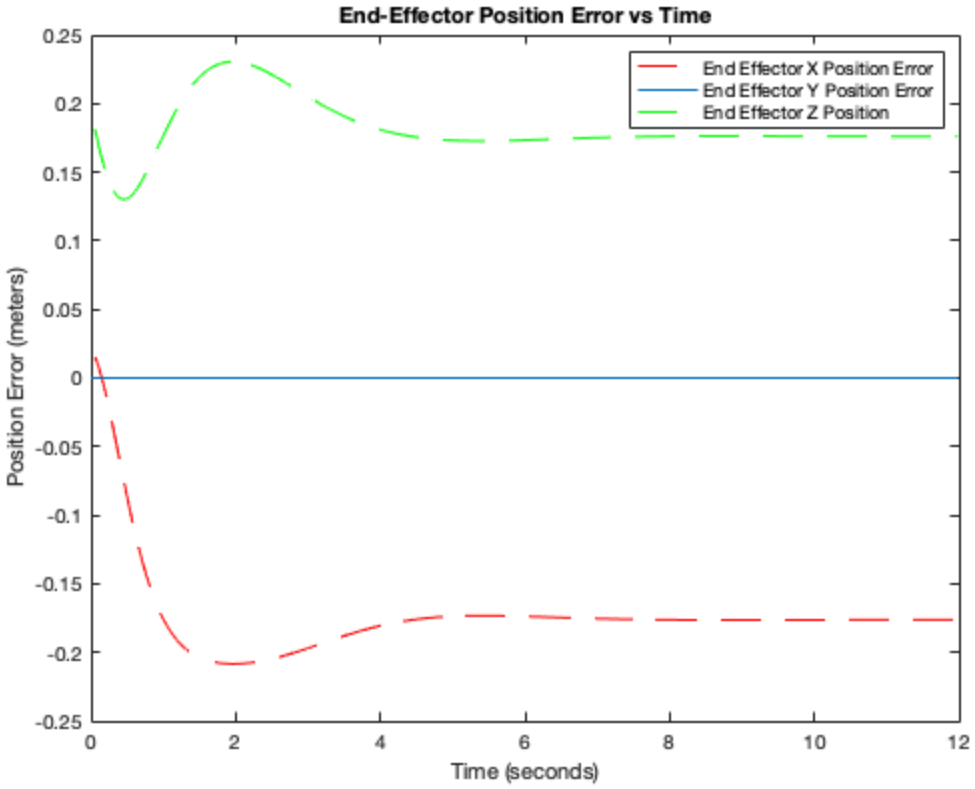
%End-Effector Position vs Time
figure('Name', 'OpenManipulator:MATLAB End-Effector Position vs Time
 12')
plot(T, (end_eff_x-1.5), 'r--', T, (end_eff_y+3.75), T,
 end_eff_z, 'g--');
grid on
xlabel('Time (s)');
ylabel('Position (m)');
legend('End Effector X Position', 'End Effector Y Position', 'End
 Effector Z Position')
title('OpenManipulator:MATLAB End-Effector Position vs Time 12');

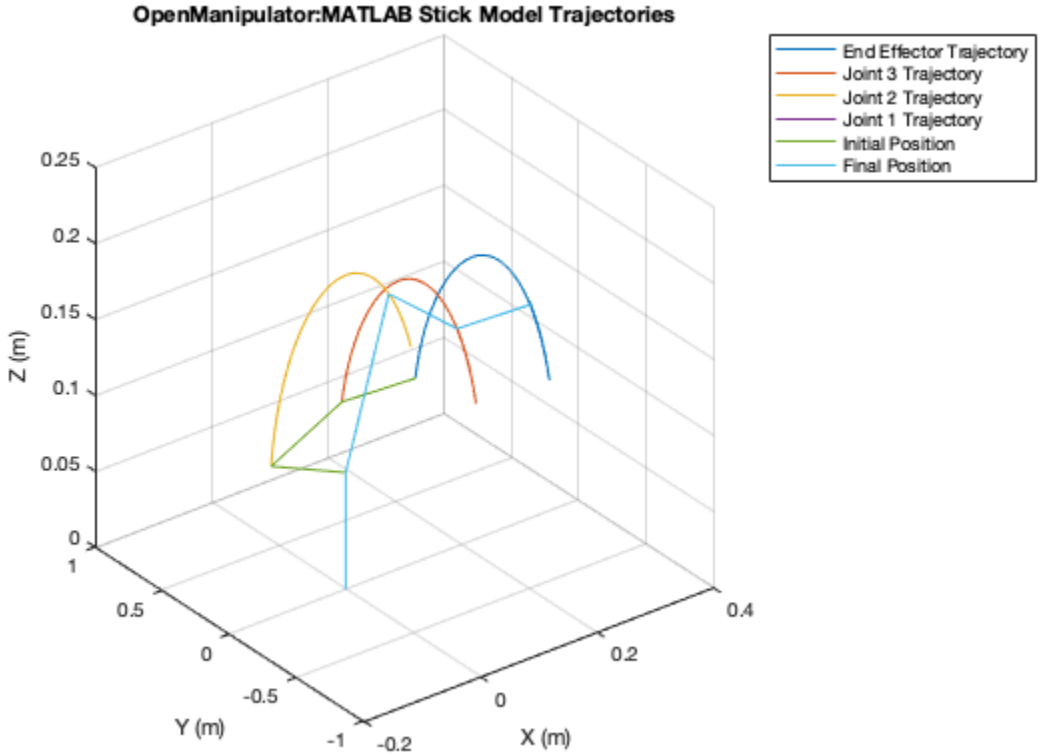
% End-effector position Error vs Time
figure('Name', 'PID: End-effector Position Error vs Time')
plot(T, final_config(1,1) - end_eff_x, 'r--', T, final_config(1,2) -
 end_eff_y, T, final_config(1,3) - end_eff_z, 'g--');
xlabel('Time (seconds)');
ylabel('Position Error (meters)');
legend('End Effector X Position Error', 'End Effector Y Position
 Error', 'End Effector Z Position')
title('End-Effector Position Error vs Time');

%Stick model Trajectories
figure('Name', 'OpenManipulator:MATLAB Stick Model Trajectories')
```

```
plot3(end_eff_x, end_eff_y, end_eff_z, joint_3_x, joint_3_y,
 joint_3_z, joint_2_x, joint_2_y, joint_2_z, joint_1_x, joint_1_y,
 joint_1_z, line1_x, line1_y, line1_z, line3_x, line3_y, line3_z);
grid on
xlabel('X (m)');
ylabel('Y (m)');
zlabel('Z (m)');
legend('End Effector Trajectory','Joint 3 Trajectory','Joint 2
 Trajectory','Joint 1 Trajectory', 'Initial Position', 'Final
 Position')
title('OpenManipulator:MATLAB Stick Model Trajectories');
```




End-Effector Position Error vs Time
End Effector X Position Error
End Effector Y Position Error
End Effector Z Position
Position Error (meters)
Time (seconds)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
2
4
6
8
10
12


OpenManipulator:MATLAB Stick Model Trajectories
End Effector Trajectory
Joint 3 Trajectory
Joint 2 Trajectory
Joint 1 Trajectory
Initial Position
Final Position
Z (m)
0.25
0.2
0.15
0.1
0.05
0
Y (m)
1
0.5
0
-0.5
-1
X (m)
-0.2
0
0.2
0.4

PlanarArmODE Function

```
function dx = planarArmODE(t,x)

 theta_d = xd(1, 1:4)'; % Desired Set-Point Position
 dtheta_d = xd(1, 5:8)'; % Desired velocity (Derivative of theta_d)

 ddtheta_d = [0;0;0;0];

 theta = x(1:4,1);
 dtheta = x(5:8,1);
 global Mmat Cmat gmat

 %Calculated Inverse Kinematics with Separate M File and subbed in
 (TBD)
 %See MCG Calculation File for Proposed Values:

M10 = (l2^2*m3)/2 + (l2^2*m4)/2 + (l3^2*m4)/2 + (lc2^2*m2)/2 +
 (lc3^2*m3)/2 + (lc4^2*m4)/2 + (lc4^2*m4*cos(2*x(2) + 2*x(3) +
 2*x(4)))/2 + (l2^2*m3*cos(2*x(2)))/2 + (l2^2*m4*cos(2*x(2)))/2
 - (lc2^2*m2*cos(2*x(1)))/2 + (lc2^2*m2*cos(2*x(2)))/2 +
 (l3^2*m4*cos(2*x(2) + 2*x(3)))/2 - (lc2^2*m2*cos(2*x(1) - 2*x(2)))/4
 - (lc2^2*m2*cos(2*x(1) + 2*x(2)))/4 + (lc3^2*m3*cos(2*x(2) +
 2*x(3)))/2 + l2*lc4*m4*cos(x(3) + x(4)) + l2*lc4*m4*cos(2*x(2) +
 x(3) + x(4)) + l2*l3*m4*cos(2*x(2) + x(3)) + l2*lc3*m3*cos(2*x(2) +
 x(3)) + l3*lc4*m4*cos(2*x(2) + 2*x(3) + x(4)) + l2*l3*m4*cos(x(3)) +
 l2*lc3*m3*cos(x(3)) + l3*lc4*m4*cos(x(4));

M11 =(lc2^2*m2*sin(2*x(1))*sin(2*x(2)))/2;

M12 = 0;

M13 = 0;

M20 =(lc2^2*m2*sin(2*x(1))*sin(2*x(2)))/2;

M21 = l2^2*m3 + l2^2*m4 + l3^2*m4 + lc2^2*m2 + lc3^2*m3 + lc4^2*m4
 + (lc2^2*m2*cos(2*x(1)))/2 - (lc2^2*m2*cos(2*x(1))*cos(2*x(2)))/2 +
 2*l2*l3*m4*cos(x(3)) + 2*l2*lc3*m3*cos(x(3)) + 2*l3*lc4*m4*cos(x(4))
 + 2*l2*lc4*m4*cos(x(3))*cos(x(4)) - 2*l2*lc4*m4*sin(x(3))*sin(x(4));

M22 = m4*l3^2 + 2*m4*cos(x(4))*l3*lc4 + l2*m4*cos(x(3))*l3 + m3*lc3^2
 + l2*m3*cos(x(3))*lc3 + m4*lc4^2 + l2*m4*cos(x(3) + x(4))*lc4;

M23 =lc4^2*m4 + l2*lc4*m4*cos(x(3) + x(4)) + l3*lc4*m4*cos(x(4));

M30 = 0;

M31 = m4*l3^2 + 2*m4*cos(x(4))*l3*lc4 + l2*m4*cos(x(3))*l3 + m3*lc3^2
 + l2*m3*cos(x(3))*lc3 + m4*lc4^2 + l2*m4*cos(x(3) + x(4))*lc4;

M32 = m4*l3^2 + 2*m4*cos(x(4))*l3*lc4 + m3*lc3^2 + m4*lc4^2;
```

```
M33 = m4*lc4^2 + l3*m4*cos(x(4))*lc4;

M40 = 0;

M41 =lc4^2*m4 + l2*lc4*m4*cos(x(3) + x(4)) + l3*lc4*m4*cos(x(4));

M42 =m4*lc4^2 + l3*m4*cos(x(4))*lc4;

M43 =lc4^2*m4;

C1 =(lc2^2*m2*sin(2*x(1) - 2*x(2))*x(6)^2)/4 + (lc2^2*m2*sin(2*x(1)
 + 2*x(2))*x(6)^2)/4 + (lc2^2*m2*sin(2*x(1))*x(6)^2)/2 -
 l3^2*m4*sin(2*x(2) + 2*x(3))*x(5)*x(6) - l3^2*m4*sin(2*x(2) +
 2*x(3))*x(5)*x(7) - lc2^2*m2*sin(2*x(1) - 2*x(2))*x(5)*x(6) +
 lc2^2*m2*sin(2*x(1) + 2*x(2))*x(5)*x(6) - lc3^2*m3*sin(2*x(2)
 + 2*x(3))*x(5)*x(6) - lc3^2*m3*sin(2*x(2) + 2*x(3))*x(5)*x(7)
 - lc4^2*m4*sin(2*x(2) + 2*x(3) + 2*x(4))*x(5)*x(6)
 - lc4^2*m4*sin(2*x(2) + 2*x(3) + 2*x(4))*x(5)*x(7) -
 l2^2*m3*sin(2*x(2))*x(5)*x(6) - l2^2*m4*sin(2*x(2))*x(5)*x(6) -
 lc2^2*m2*sin(2*x(2))*x(5)*x(6) - 2*l2*lc4*m4*sin(2*x(2) + x(3) +
 x(4))*x(5)*x(6) - l2*lc4*m4*sin(2*x(2) + x(3) + x(4))*x(5)*x(7)
 - 2*l2*l3*m4*sin(2*x(2) + x(3))*x(5)*x(6) - l2*l3*m4*sin(2*x(2)
 + x(3))*x(5)*x(7) - 2*l2*lc3*m3*sin(2*x(2) + x(3))*x(5)*x(6) -
 l2*lc3*m3*sin(2*x(2) + x(3))*x(5)*x(7) - 2*l3*lc4*m4*sin(2*x(2)
 + 2*x(3) + x(4))*x(5)*x(6) - 2*l3*lc4*m4*sin(2*x(2) +
 2*x(3) + x(4))*x(5)*x(7) - l2*l3*m4*sin(x(3))*x(5)*x(7) -
 l2*lc3*m3*sin(x(3))*x(5)*x(7) - l2*lc4*m4*sin(x(3) + x(4))*x(5)*x(7);

C2 =(lc2^2*m2*sin(2*x(1) + 2*x(2))*x(6)^2)/2 - (lc2^2*m2*sin(2*x(1)
 - 2*x(2))*x(6)^2)/2 - l2*l3*m4*sin(x(3))*x(7)^2 -
 l2*lc3*m3*sin(x(3))*x(7)^2 - l2*lc4*m4*sin(x(3) + x(4))*x(7)^2
 + lc2^2*m2*sin(2*x(1) - 2*x(2))*x(5)*x(6) + lc2^2*m2*sin(2*x(1)
 + 2*x(2))*x(5)*x(6) - lc2^2*m2*sin(2*x(1))*x(5)*x(6) -
 2*l2*l3*m4*sin(x(3))*x(6)*x(7) - 2*l2*lc3*m3*sin(x(3))*x(6)*x(7) -
 2*l3*lc4*m4*sin(x(4))*x(6)*x(8) - 2*l3*lc4*m4*sin(x(4))*x(7)*x(8)
 - 2*l2*lc4*m4*sin(x(3) + x(4))*x(6)*x(7) - 2*l2*lc4*m4*sin(x(3) +
 x(4))*x(6)*x(8) - 2*l2*lc4*m4*sin(x(3) + x(4))*x(7)*x(8);

C3 =l2*l3*m4*sin(x(3))*x(6)^2 + l2*lc3*m3*sin(x(3))*x(6)^2 +
 l2*lc4*m4*sin(x(3) + x(4))*x(6)^2 - l2*l3*m4*sin(x(3))*x(6)*x(7)
 - l2*lc3*m3*sin(x(3))*x(6)*x(7) - 2*l3*lc4*m4*sin(x(4))*x(6)*x(8)
 - 2*l3*lc4*m4*sin(x(4))*x(7)*x(8) - l2*lc4*m4*sin(x(3) +
 x(4))*x(6)*x(7);

C4 =l3*lc4*m4*sin(x(4))*x(6)^2 + l3*lc4*m4*sin(x(4))*x(7)^2 +
 l2*lc4*m4*sin(x(3) + x(4))*x(6)^2 + 2*l3*lc4*m4*sin(x(4))*x(6)*x(7)
 - l3*lc4*m4*sin(x(4))*x(6)*x(8) - l3*lc4*m4*sin(x(4))*x(7)*x(8) -
 l2*lc4*m4*sin(x(3) + x(4))*x(6)*x(8);

G1 = (lc2^2*m2*sin(2*x(1) - 2*x(2))*x(5)^2)/2 + (lc2^2*m2*sin(2*x(1) +
 2*x(2))*x(5)^2)/2 + lc2^2*m2*sin(2*x(1))*x(5)^2 - lc4^2*m4*sin(2*x(2)
 + 2*x(3) + 2*x(4))*x(5)*x(8) - l2*lc4*m4*sin(2*x(2) + x(3) +
 x(4))*x(5)*x(8) - l3*lc4*m4*sin(2*x(2) + 2*x(3) + x(4))*x(5)*x(8) -
 l3*lc4*m4*sin(x(4))*x(5)*x(8) - l2*lc4*m4*sin(x(3) + x(4))*x(5)*x(8);
```

```
G2 = (l3^2*m4*sin(2*x(2) + 2*x(3))*x(5)^2)/2 - (lc2^2*m2*sin(2*x(1)
 - 2*x(2))*x(5)^2)/4 + (lc2^2*m2*sin(2*x(1) + 2*x(2))*x(5)^2)/4
 + (lc3^2*m3*sin(2*x(2) + 2*x(3))*x(5)^2)/2 + g*lc4*m4*cos(x(2)
 + x(3) + x(4)) + g*l3*m4*cos(x(2) + x(3)) + g*lc3*m3*cos(x(2)
 + x(3)) + (lc4^2*m4*sin(2*x(2) + 2*x(3) + 2*x(4))*x(5)^2)/2 +
 (l2^2*m3*sin(2*x(2))*x(5)^2)/2 + (l2^2*m4*sin(2*x(2))*x(5)^2)/2
 + (lc2^2*m2*sin(2*x(2))*x(5)^2)/2 + g*l2*m3*cos(x(2)) +
 g*l2*m4*cos(x(2)) + g*lc2*m2*cos(x(2)) + l3*lc4*m4*sin(2*x(2)
 + 2*x(3) + x(4))*x(5)^2 - l3*lc4*m4*sin(x(4))*x(8)^2 -
 l2*lc4*m4*sin(x(3) + x(4))*x(8)^2 + l2*lc4*m4*sin(2*x(2) +
 x(3) + x(4))*x(5)^2 + l2*l3*m4*sin(2*x(2) + x(3))*x(5)^2 +
 l2*lc3*m3*sin(2*x(2) + x(3))*x(5)^2;

G3 = (l3^2*m4*sin(2*x(2) + 2*x(3))*x(5)^2)/2 + (lc3^2*m3*sin(2*x(2)
 + 2*x(3))*x(5)^2)/2 + g*lc4*m4*cos(x(2) + x(3) + x(4))
 + g*l3*m4*cos(x(2) + x(3)) + g*lc3*m3*cos(x(2) + x(3))
 + (lc4^2*m4*sin(2*x(2) + 2*x(3) + 2*x(4))*x(5)^2)/2
 + l3*lc4*m4*sin(2*x(2) + 2*x(3) + x(4))*x(5)^2 +
 (l2*l3*m4*sin(x(3))*x(5)^2)/2 + (l2*lc3*m3*sin(x(3))*x(5)^2)/2 -
 l3*lc4*m4*sin(x(4))*x(8)^2 + (l2*lc4*m4*sin(x(3) + x(4))*x(5)^2)/2 +
 (l2*lc4*m4*sin(2*x(2) + x(3) + x(4))*x(5)^2)/2 + (l2*l3*m4*sin(2*x(2)
 + x(3))*x(5)^2)/2 + (l2*lc3*m3*sin(2*x(2) + x(3))*x(5)^2)/2;

G4 = g*lc4*m4*cos(x(2) + x(3) + x(4)) + (lc4^2*m4*sin(2*x(2)
 + 2*x(3) + 2*x(4))*x(5)^2)/2 + (l3*lc4*m4*sin(2*x(2) +
 2*x(3) + x(4))*x(5)^2)/2 + (l3*lc4*m4*sin(x(4))*x(5)^2)/2 +
 (l2*lc4*m4*sin(x(3) + x(4))*x(5)^2)/2 + (l2*lc4*m4*sin(2*x(2) + x(3)
 + x(4))*x(5)^2)/2;

 Mmat = [M10 M11 M12 M13; M20 M21 M22 M23;M30 M31 M32 M33; M40 M41 M42
 M43];

 Cmat = [C1; C2; C3; C4];

 gmat = [G1; G2; G3; G4];

 invM = inv(Mmat);

 invMC = invM*Cmat;

 invMg = invM*gmat;

 tau = PIDControl(theta_d,dtheta_d,ddtheta_d,theta,dtheta,t);

 torque =[torque, tau];

 dx=zeros(8,1);

 dx(1) = x(5); %dtheta1
 dx(2) = x(6); %dtheta2
 dx(3) = x(7); %dtheta3
 dx(4) = x(8); %dtheta4
```

```
 dx(5:8) = -invMC.* x(5:8) +invM*tau - invMg;

end

 function tau =
 PIDControl(theta_d,dtheta_d,ddtheta_d,theta,dtheta,t_now)
 dt = t_now - t_old; % Find the time dt for integration
 t_old = t_now;
 e = theta_d - theta; % position error
 de = dtheta_d - dtheta; % velocity error
 ie = ie + (e .* dt); % integrated error
 tau = Kp*e + Kv*de + Ki*ie;
 end

disp('Finish.');

Finish.

end
```

Inverse Kinematics of the 4DOF Robot Manipulator

```
function [theta1, theta2, theta3, theta4] =
 invKin(arm_pose,l1,l2,l3,l4)
 x = arm_pose(1,1); % Get X coordinate of end-effector
 y = arm_pose(1,2); % Get Y coordinate of end-effector
 z = arm_pose(1,3); % Get Z coordinate of end-effector

 elbow_up = arm_pose(1,4); % Get elbow configuration

  theta1 = real(atan(y./x));

 x_3 = x - l4*cos(theta1);
 y_3 = y - l4*sin(theta1);
 z_3 = z;

 x_1 = 0;
 y_1 = 0;
 z_1 = l1;

 D = ((x_3 - x_1)^2 + (z_3 - z_1)^2 - l2^2 - l3^2)/(2*l2*l3);

 theta3 = real(atan(sqrt(1-D^2)/D))+2.4187+0.6926;

 if (elbow_up == 1)

 theta3 = -theta3;

 end

 theta2 = atan((z_3-z_1)/(x_3 - x_1)) - atan((l3*sin(theta3))/
(l2+l3*cos(theta3)))+3.1174;
```

```
 theta4 = -(theta3+theta2)-.02299;

end

function [theta1, theta2, theta3, theta4] =
 invKin1(arm_pose,l1,l2,l3,l4)
 x = arm_pose(1,1); % Get X coordinate of end-effector
 y = arm_pose(1,2); % Get Y coordinate of end-effector
 z = arm_pose(1,3); % Get Z coordinate of end-effector

 elbow_up = arm_pose(1,4); % Get elbow configuration

  theta1 = real(atan(y./x));

 x_3 = x - l4*cos(theta1);
 y_3 = y - l4*sin(theta1);
 z_3 = z;

 x_1 = 0;
 y_1 = 0;
 z_1 = l1;

 D = ((x_3 - x_1)^2 + (z_3 - z_1)^2 - l2^2 - l3^2)/(2*l2*l3);

 theta3 = atan(sqrt(1-D^2)/D)+0.6463;

 if (elbow_up == 1)

 theta3 = -theta3;

 end

 theta2 = atan((z_3-z_1)/(x_3 - x_1)) - atan((l3*sin(theta3))/
(l2+l3*cos(theta3)))-1.1726;

 theta4 = -(theta3+theta2)-.0199;

end
```

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