ME352A: Theory of Mechanisms and Machines

Bonus Assignment – Implementation in computer program

Title: Plotting possible configurations of Watt's 6-bar linkage from open and crossed looping in MATLAB

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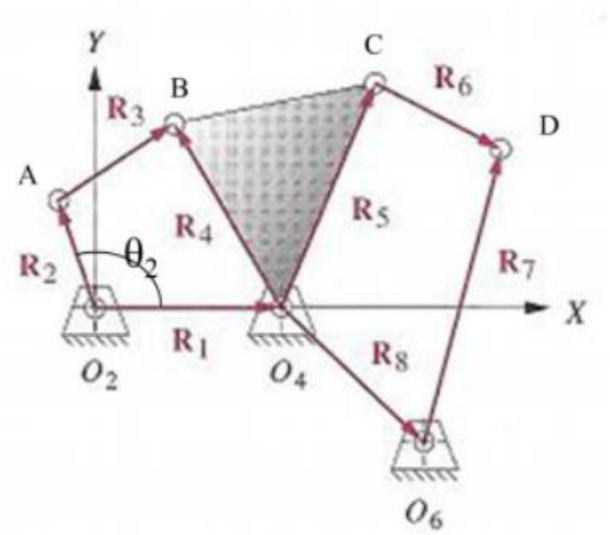
- **Figure**:



Where the required inputs are –

- R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8
- θ1 (Angle between Link 1 and the horizontal axis)
- θ8 (Angle between Link 8 and the horizontal axis)
- γ (Angle between link 4 and link 5)
- θ2 (Input angle)

- **Sample Cases:**

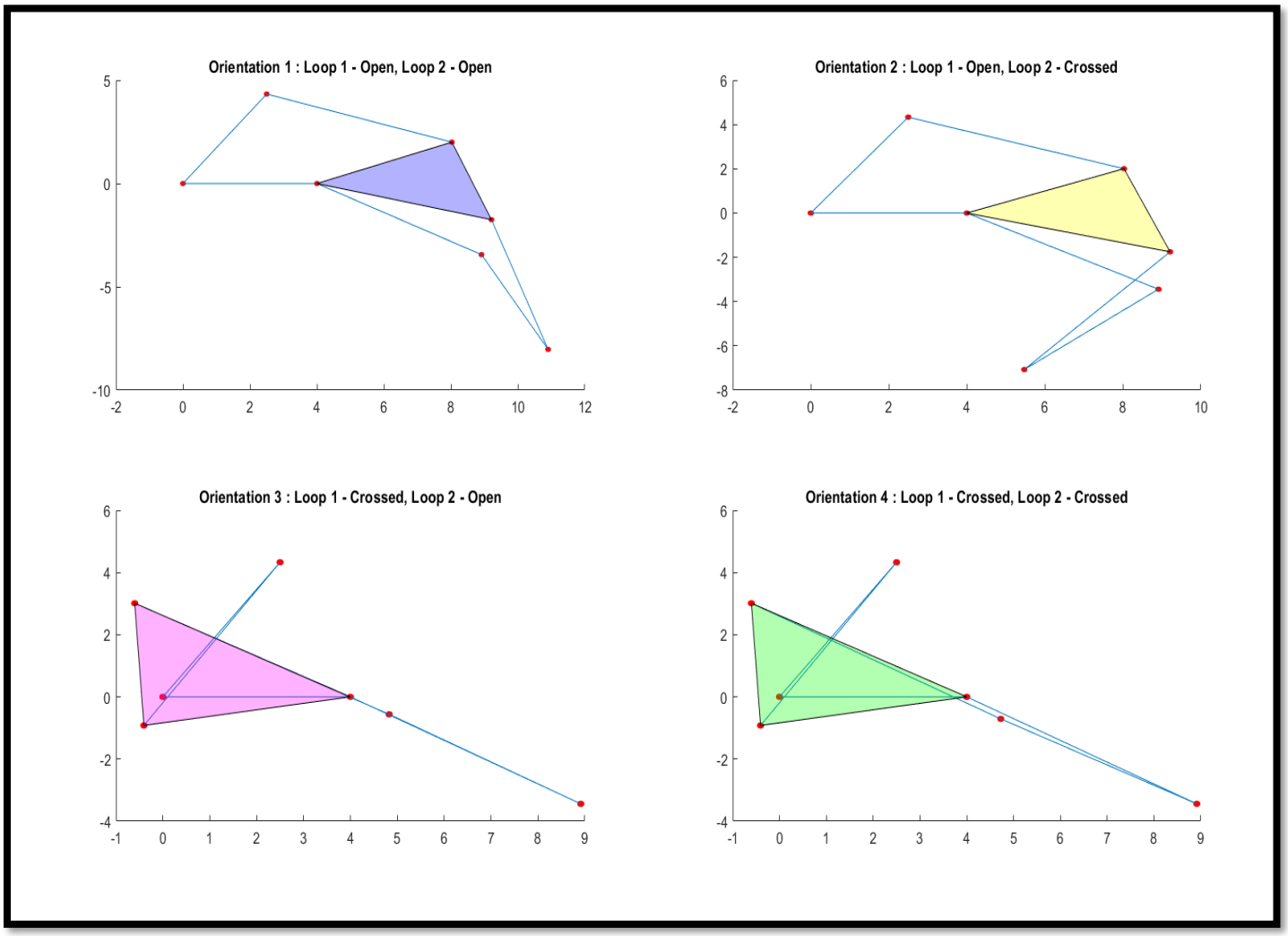
i) Input –

```
• Input all the angles in degrees only
  Input r1 = 4
  Input r2 = 5
  Input r3 = 6
  Input r4 = 4.5
  Input r5 = 5.5
  Input r6 = 6.5
  Input r7 = 5
  Input r8 = 6
  Input θ1 = 0
  Input θ8 = -35
  Input γ (the angle between r4 and r5) = 45
  Enter the input angle θ2 = 60
```

Output –

```
• The output angles given are in degrees
• There can be 4 orientations possible for the given inputs :

i)   Orientation 1 : Loop 1 - Open, Loop 2 - Open :
     θ3 = -22.83
     θ4 = 26.42
     θ5 = -18.58
     θ6 = -74.92
     θ7 = -66.56

ii)  Orientation 2 : Loop 1 - Open, Loop 2 - Crossed :
     θ3 = -22.83
     θ4 = 26.42
     θ5 = -18.58
     θ6 = -125.12
     θ7 = -133.48

iii) Orientation 3 : Loop 1 - Crossed, Loop 2 - Open :
     θ3 = -118.96
     θ4 = -168.21
     θ5 = -213.21
     θ6 = -33.36
     θ7 = 144.84

iv)  Orientation 4 : Loop 1 - Crossed, Loop 2 - Crossed :
     θ3 = -118.96
     θ4 = -168.21
     θ5 = -213.21
     θ6 = -34.93
     θ7 = 146.88
fx >>
```

Plots generated –



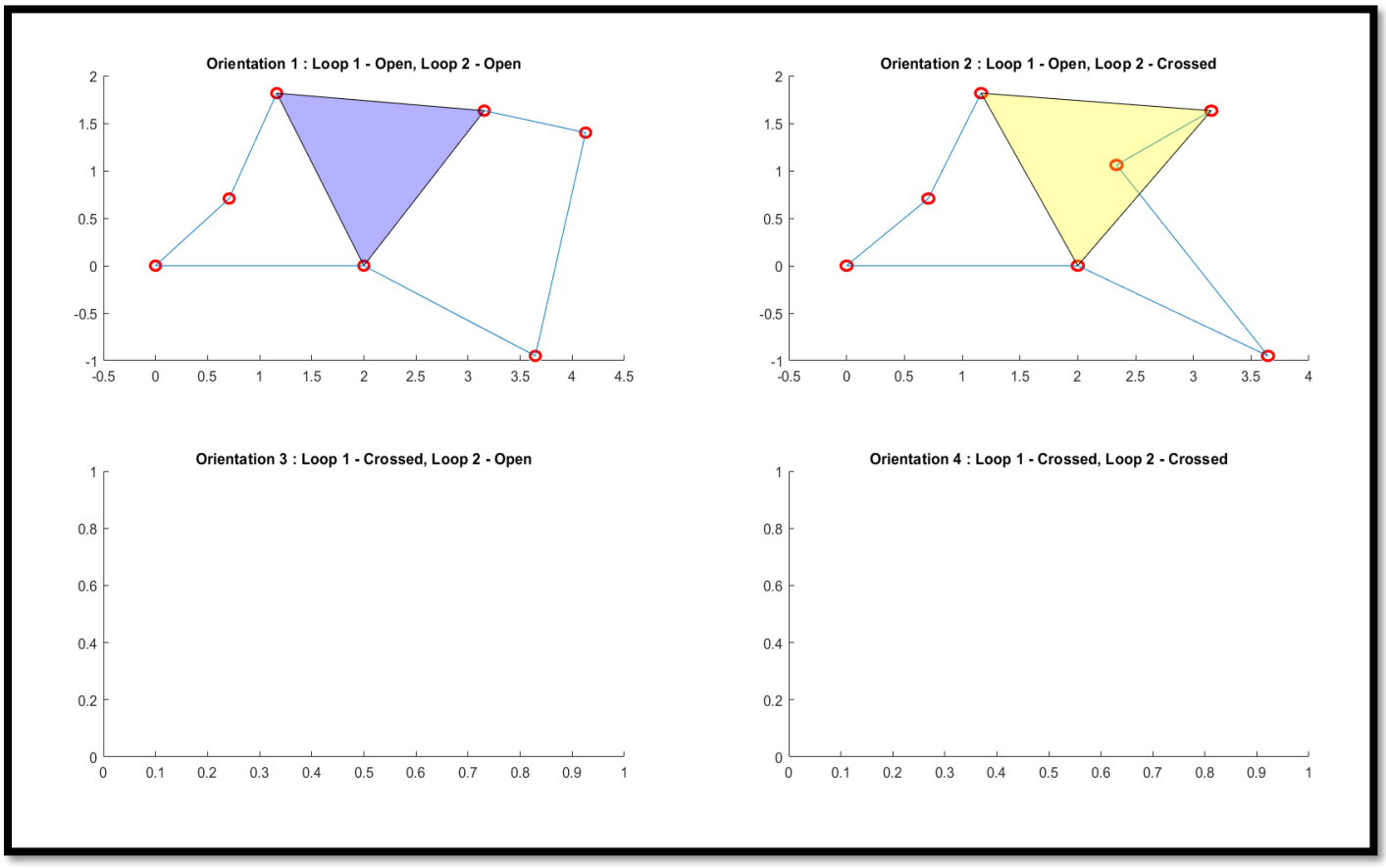
ii) Input –

```
• Input all the angles in degrees only
  Input r1 = 2
  Input r2 = 1
  Input r3 = 1.2
  Input r4 = 2
  Input r5 = 2
  Input r6 = 1
  Input r7 = 2.4
  Input r8 = 1.9
  Input θ1 = 0
  Input θ8 = -30
  Input γ (the angle between r4 and r5) = 60
  Enter the input angle θ2 = 45
```

Output –

```
• The output angles given are in degrees
• There can be 2 orientations possible for the given inputs :

i)   Orientation 1 : Loop 1 - Open, Loop 2 - Open :
     θ3 = 67.63
     θ4 = 114.71
     θ5 = 54.71
     θ6 = -13.39
     θ7 = 78.40

ii)  Orientation 2 : Loop 1 - Open, Loop 2 - Crossed :
     θ3 = 67.63
     θ4 = 114.71
     θ5 = 54.71
     θ6 = -145.12
     θ7 = 123.09

iii) Orientation 3 : Loop 1 - Crossed, Loop 2 - Open :
     This orientation is not possible for the provided input dimensions

iv)  Orientation 4 : Loop 1 - Crossed, Loop 2 - Crossed :
     This orientation is not possible for the provided input dimensions
fx >>
```

Plots generated –



iii) Input (garbage values) –

```
• Input all the angles in degrees only
  Input r1 = 50
  Input r2 = 5
  Input r3 = 4
  Input r4 = 30
  Input r5 = 12
  Input r6 = 16
  Input r7 = 25
  Input r8 = 40
  Input θ1 = 2
  Input θ8 = -20
  Input γ (the angle between r4 and r5) = 60
  Enter the input angle θ2 = 90
```

Output –

```
  • The output angles given are in degrees
  • There can be 0 orientations possible for the given inputs :

  i)   Orientation 1 : Loop 1 - Open, Loop 2 - Open :
       This orientation is not possible for the provided input dimensions

  ii)  Orientation 2 : Loop 1 - Open, Loop 2 - Crossed :
       This orientation is not possible for the provided input dimensions

  iii) Orientation 3 : Loop 1 - Crossed, Loop 2 - Open :
       This orientation is not possible for the provided input dimensions

  iv)  Orientation 4 : Loop 1 - Crossed, Loop 2 - Crossed :
       This orientation is not possible for the provided input dimensions
fx >>
```

No Plots generated !!

- **MATLAB Code:**

```
%% Code written for ME352A by : Abhinav Maheshwari, Roll No. 190028

%% taking the input

clear all;
clc;
fprintf('• Input all the angles in degrees only\n');
d=input('  Input r1 = ');
a=input('  Input r2 = ');
b=input('  Input r3 = ');
c=input('  Input r4 = ');
r_5=input('  Input r5 = ');
r_6=input('  Input r6 = ');
r_7=input('  Input r7 = ');
r_8=input('  Input r8 = ');
theta1=deg2rad(input('  Input θ1 = '));
theta8=deg2rad(input('  Input θ8 = '));
gamma=deg2rad(input('  Input γ (the angle between r4 and r5) = '));
theta2=deg2rad(input('  Enter the input angle θ2 = '));

%% code for calculation

%Calculation: angle θ3
k2=(c^2-(a^2+b^2+d^2)+2*a*d*cos(theta2-theta1))/(2*b);
A2=k2+a*cos(theta2)-d*cos(theta1);
B2=2*(d*sin(theta1)-a*sin(theta2));
C2=k2+d*cos(theta1)-a*cos(theta2);
D2=B2^2-4*A2*C2;
theta3_1=(2*atan((-1*B2+sqrt(D2))/(2*A2)));
theta3_2=(2*atan((-1*B2-sqrt(D2))/(2*A2)));

%Calculation: angle θ4
k1=(b^2-(a^2+c^2+d^2)+2*a*d*cos(theta2-theta1))/(2*c);
A1=k1+d*cos(theta1)-a*cos(theta2);
B1=2*(d*sin(theta1)-a*sin(theta2));
C1=k1+a*cos(theta2)-d*cos(theta1);
D1=B1^2-4*A1*C1;
theta4_1=(-2*atan((-1*B1+sqrt(D1))/(2*A1)));
theta4_2=(-2*atan((-1*B1-sqrt(D1))/(2*A1)));

```

```
%Calculation: angle θ5
theta5_1=(theta4_1-gamma);
theta5_2=(theta4_2-gamma);

%Calculation: angle θ6
k4=(r_7^2-(r_5^2+r_6^2+r_8^2)+2*r_5*r_8*cos(theta5_1-theta8))/(2*r_6);
A4=k4+r_5*cos(theta5_1)-r_8*cos(theta8);
B4=2*(r_8*sin(theta8)-r_5*sin(theta5_1));
C4=k4+r_8*cos(theta8)-r_5*cos(theta5_1);
D4=B4^2-4*A4*C4;
theta6_1=(2*atan((-1*B4+sqrt(D4))/(2*A4)));
theta6_2=(2*atan((-1*B4-sqrt(D4))/(2*A4)));

k4_1=(r_7^2-(r_5^2+r_6^2+r_8^2)+2*r_5*r_8*cos(theta5_2-theta8))/(2*r_6);
A4_1=k4_1+r_5*cos(theta5_2)-r_8*cos(theta8);
B4_1=2*(r_8*sin(theta8)-r_5*sin(theta5_2));
C4_1=k4_1+r_8*cos(theta8)-r_5*cos(theta5_2);
D4_1=B4_1^2-4*A4_1*C4_1;
theta6_1_1=(2*atan((-1*B4_1+sqrt(D4_1))/(2*A4_1)));
theta6_2_2=(2*atan((-1*B4_1-sqrt(D4_1))/(2*A4_1)));

%Calculation: angle θ7
k3=(r_6^2-(r_5^2+r_7^2+r_8^2)+2*r_5*r_8*cos(theta5_1-theta8))/(2*r_7);
A3=k3+r_8*cos(theta8)-r_5*cos(theta5_1);
B3=2*(r_8*sin(theta8)-r_5*sin(theta5_1));
C3=k3-r_8*cos(theta8)+r_5*cos(theta5_1);
D3=B3^2-4*A3*C3;
theta7_1=(-2*atan((-1*B3+sqrt(D3))/(2*A3)));
theta7_2=(-2*atan((-1*B3-sqrt(D3))/(2*A3)));

k3_1=(r_6^2-(r_5^2+r_7^2+r_8^2)+2*r_5*r_8*cos(theta5_2-theta8))/(2*r_7);
A3_1=k3_1+r_8*cos(theta8)-r_5*cos(theta5_2);
B3_1=2*(r_8*sin(theta8)-r_5*sin(theta5_2));
C3_1=k3_1-r_8*cos(theta8)+r_5*cos(theta5_2);
D3_1=B3_1^2-4*A3_1*C3_1;
theta7_1_1=(-2*atan((-1*B3_1+sqrt(D3_1))/(2*A3_1)));
theta7_2_2=(-2*atan((-1*B3_1-sqrt(D3_1))/(2*A3_1)));


%% Find the number of possible configurations

possible_configuration=4;
configuration_1=1;
configuration_2=1;
configuration_3=1;
configuration_4=1;
```

```
87
88  if(imag(theta3_2)~=0 || imag(theta4_2)~=0 || imag(theta5_2)~=0 || imag(theta6_2_2)~=0 || imag(theta7_2_2)~=0)
89      possible_configuration=possible_configuration-1;
90      configuration_1=0;
91  end
92  if(imag(theta3_2)~=0 || imag(theta4_2)~=0 || imag(theta5_2)~=0 || imag(theta6_1_1)~=0 || imag(theta7_1_1)~=0)
93      possible_configuration=possible_configuration-1;
94      configuration_2=0;
95  end
96  if(imag(theta3_1)~=0 || imag(theta4_1)~=0 || imag(theta5_1)~=0 || imag(theta6_2)~=0 || imag(theta7_2)~=0)
97      possible_configuration=possible_configuration-1;
98      configuration_3=0;
99  end
100 if(imag(theta3_1)~=0 || imag(theta4_1)~=0 || imag(theta5_1)~=0 || imag(theta6_1)~=0 || imag(theta7_1)~=0)
101     possible_configuration=possible_configuration-1;
102     configuration_4=0;
103 end
104
105 %% Output to be displayed on the console
106
107 fprintf('\n• The output angles given are in degrees\n');
108 fprintf('• There can be %i orientations possible for the given inputs :\n',possible_configuration);
109 fprintf('\ni)   Orientation 1 : Loop 1 - Open, Loop 2 - Open :\n');
110 if(configuration_1~=0)
111     fprintf('     θ3 = %.2f\n',rad2deg(theta3_2));
112     fprintf('     θ4 = %.2f\n',rad2deg(theta4_2));
113     fprintf('     θ5 = %.2f\n',rad2deg(theta5_2));
114     fprintf('     θ6 = %.2f\n',rad2deg(theta6_2_2));
115     fprintf('     θ7 = %.2f\n',rad2deg(theta7_2_2));
116 else
117     fprintf('     This orientation is not possible for the provided input dimensions\n');
118 end
119 fprintf('\nii)  Orientation 2 : Loop 1 - Open, Loop 2 - Crossed :\n');
120 if(configuration_2~=0)
121     fprintf('     θ3 = %.2f\n',rad2deg(theta3_2));
122     fprintf('     θ4 = %.2f\n',rad2deg(theta4_2));
123     fprintf('     θ5 = %.2f\n',rad2deg(theta5_2));
124     fprintf('     θ6 = %.2f\n',rad2deg(theta6_1_1));
125     fprintf('     θ7 = %.2f\n',rad2deg(theta7_1_1));
126 else
127     fprintf('     This orientation is not possible for the provided input dimensions\n');
128 end
129 fprintf('\niii) Orientation 3 : Loop 1 - Crossed, Loop 2 - Open :\n');
130  if(configuration_3~=0)
131      fprintf('     θ3 = %.2f\n',rad2deg(theta3_1));
132      fprintf('     θ4 = %.2f\n',rad2deg(theta4_1));
133      fprintf('     θ5 = %.2f\n',rad2deg(theta5_1));
134      fprintf('     θ6 = %.2f\n',rad2deg(theta6_2));
135      fprintf('     θ7 = %.2f\n',rad2deg(theta7_2));
136  else
137      fprintf('     This orientation is not possible for the provided input dimensions\n');
138  end
139  fprintf('\niv)  Orientation 4 : Loop 1 - Crossed, Loop 2 - Crossed :\n');
140  if(configuration_4~=0)
141      fprintf('     θ3 = %.2f\n',rad2deg(theta3_1));
142      fprintf('     θ4 = %.2f\n',rad2deg(theta4_1));
143      fprintf('     θ5 = %.2f\n',rad2deg(theta5_1));
144      fprintf('     θ6 = %.2f\n',rad2deg(theta6_1));
145      fprintf('     θ7 = %.2f\n',rad2deg(theta7_1));
146  else
147      fprintf('     This orientation is not possible for the provided input dimensions\n');
148  end
149
```

```
%% Code for plotting the output

if(configuration_1~=0 || configuration_2~=0 || configuration_3~=0 || configuration_4~=0)
    figure('units','normalized','outerposition',[0 0 1 1])
    plot_1=subplot(2,2,1);
    title('Orientation 1 : Loop 1 - Open, Loop 2 - Open');
    p1=[0;0];
    p2=[a*cos(theta2);a*sin(theta2)];
    p3=[a*cos(theta2)+b*cos(theta3_2);a*sin(theta2)+b*sin(theta3_2)];
    p4=[d*cos(theta1);d*sin(theta1)];
    p5=[d*cos(theta1)+r_5*cos(theta5_2);d*sin(theta1)+r_5*sin(theta5_2)];
    p6=[d*cos(theta1)+r_5*cos(theta5_2)+r_6*cos(theta6_2_2);d*sin(theta1)+r_5*sin(theta5_2)+r_6*sin(theta6_2_2)];
    p7=[d*cos(theta1)+r_8*cos(theta8);d*sin(theta1)+r_8*sin(theta8)];
    if(configuration_1~=0)
        p1_circle=viscircles(p1',0.05,'Color','r');
        p2_circle=viscircles(p2',0.05,'Color','r');
        p3_circle=viscircles(p3',0.05,'Color','r');
        p4_circle=viscircles(p4',0.05,'Color','r');
        p5_circle=viscircles(p5',0.05,'Color','r');
        p6_circle=viscircles(p6',0.05,'Color','r');
        p7_circle=viscircles(p7',0.05,'Color','r');
        link_a=line([p1(1) p2(1)],[p1(2) p2(2)]);
        link_b=line([p2(1) p3(1)],[p2(2) p3(2)]);
        link_c=line([p3(1) p4(1)],[p3(2) p4(2)]);
        link_d=line([p1(1) p4(1)],[p1(2) p4(2)]);
        link_e=line([p4(1) p5(1)],[p4(2) p5(2)]);
        link_f=line([p5(1) p6(1)],[p5(2) p6(2)]);
        link_g=line([p6(1) p7(1)],[p6(2) p7(2)]);
        link_h=line([p4(1) p7(1)],[p4(2) p7(2)]);
        link_i=line([p3(1) p5(1)],[p3(2) p5(2)]);
        patch([p3(1) p4(1) p5(1)],[p3(2) p4(2) p5(2)],'blue','FaceAlpha',.3);
    end
    plot_2=subplot(2,2,2);
    title('Orientation 2 : Loop 1 - Open, Loop 2 - Crossed');
    p1_1=[0;0];
    p2_2=[a*cos(theta2);a*sin(theta2)];
    p3_3=[a*cos(theta2)+b*cos(theta3_2);a*sin(theta2)+b*sin(theta3_2)];
    p4_4=[d*cos(theta1);d*sin(theta1)];
    p5_5=[d*cos(theta1)+r_5*cos(theta5_2);d*sin(theta1)+r_5*sin(theta5_2)];
    p6_6=[d*cos(theta1)+r_5*cos(theta5_2)+r_6*cos(theta6_1_1);d*sin(theta1)+r_5*sin(theta5_2)+r_6*sin(theta6_1_1)];
    p7_7=[d*cos(theta1)+r_8*cos(theta8);d*sin(theta1)+r_8*sin(theta8)];
    if(configuration_2~=0)
        p1_1_circle=viscircles(p1_1',0.05,'Color','r');
        p2_2_circle=viscircles(p2_2',0.05,'Color','r');
        p3_3_circle=viscircles(p3_3',0.05,'Color','r');
        p4_4_circle=viscircles(p4_4',0.05,'Color','r');
        p5_5_circle=viscircles(p5_5',0.05,'Color','r');
        p6_6_circle=viscircles(p6_6',0.05,'Color','r');
        p7_7_circle=viscircles(p7_7',0.05,'Color','r');
        link_a_a=line([p1_1(1) p2_2(1)],[p1_1(2) p2_2(2)]);
        link_b_b=line([p2_2(1) p3_3(1)],[p2_2(2) p3_3(2)]);
        link_c_c=line([p3_3(1) p4_4(1)],[p3_3(2) p4_4(2)]);
        link_d_d=line([p1_1(1) p4_4(1)],[p1_1(2) p4_4(2)]);
        link_e_e=line([p4_4(1) p5_5(1)],[p4_4(2) p5_5(2)]);
        link_f_f=line([p5_5(1) p6_6(1)],[p5_5(2) p6_6(2)]);
        link_g_g=line([p6_6(1) p7_7(1)],[p6_6(2) p7_7(2)]);
        link_h_h=line([p4_4(1) p7_7(1)],[p4_4(2) p7_7(2)]);
        link_i_i=line([p3_3(1) p5_5(1)],[p3_3(2) p5_5(2)]);
        patch([p3_3(1) p4_4(1) p5_5(1)],[p3_3(2) p4_4(2) p5_5(2)],'yellow','FaceAlpha',.3);
    end
```

```
    plot_3=subplot(2,2,3);
    title('Orientation 3 : Loop 1 - Crossed, Loop 2 - Open');
    p1_x=[0;0];
    p2_x=[a*cos(theta2);a*sin(theta2)];
    p3_x=[a*cos(theta2)+b*cos(theta3_1);a*sin(theta2)+b*sin(theta3_1)];
    p4_x=[d*cos(theta1);d*sin(theta1)];
    p5_x=[d*cos(theta1)+r_5*cos(theta5_1);d*sin(theta1)+r_5*sin(theta5_1)];
    p6_x=[d*cos(theta1)+r_5*cos(theta5_1)+r_6*cos(theta6_2);d*sin(theta1)+r_5*sin(theta5_1)+r_6*sin(theta6_2)];
    p7_x=[d*cos(theta1)+r_8*cos(theta8);d*sin(theta1)+r_8*sin(theta8)];
    if(configuration_3~=0)
        p1_x_circle=viscircles(p1_x',0.05,'Color','r');
        p2_x_circle=viscircles(p2_x',0.05,'Color','r');
        p3_x_circle=viscircles(p3_x',0.05,'Color','r');
        p4_x_circle=viscircles(p4_x',0.05,'Color','r');
        p5_x_circle=viscircles(p5_x',0.05,'Color','r');
        p6_x_circle=viscircles(p6_x',0.05,'Color','r');
        p7_x_circle=viscircles(p7_x',0.05,'Color','r');
        link_a_x=line([p1_x(1) p2_x(1)],[p1_x(2) p2_x(2)]);
        link_b_x=line([p2_x(1) p3_x(1)],[p2_x(2) p3_x(2)]);
        link_c_x=line([p3_x(1) p4_x(1)],[p3_x(2) p4_x(2)]);
        link_d_x=line([p1_x(1) p4_x(1)],[p1_x(2) p4_x(2)]);
        link_e_x=line([p4_x(1) p5_x(1)],[p4_x(2) p5_x(2)]);
        link_f_x=line([p5_x(1) p6_x(1)],[p5_x(2) p6_x(2)]);
        link_g_x=line([p6_x(1) p7_x(1)],[p6_x(2) p7_x(2)]);
        link_h_x=line([p4_x(1) p7_x(1)],[p4_x(2) p7_x(2)]);
        link_i_x=line([p3_x(1) p5_x(1)],[p3_x(2) p5_x(2)]);
        patch([p3_x(1) p4_x(1) p5_x(1)],[p3_x(2) p4_x(2) p5_x(2)],'magenta','FaceAlpha',.3);
    end
    plot_4=subplot(2,2,4);
    title('Orientation 4 : Loop 1 - Crossed, Loop 2 - Crossed');
    p1_y=[0;0];
    p2_y=[a*cos(theta2);a*sin(theta2)];
    p3_y=[a*cos(theta2)+b*cos(theta3_1);a*sin(theta2)+b*sin(theta3_1)];
    p4_y=[d*cos(theta1);d*sin(theta1)];
    p5_y=[d*cos(theta1)+r_5*cos(theta5_1);d*sin(theta1)+r_5*sin(theta5_1)];
    p6_y=[d*cos(theta1)+r_5*cos(theta5_1)+r_6*cos(theta6_1);d*sin(theta1)+r_5*sin(theta5_1)+r_6*sin(theta6_1)];
    p7_y=[d*cos(theta1)+r_8*cos(theta8);d*sin(theta1)+r_8*sin(theta8)];
    if(configuration_4~=0)
        p1_y_circle=viscircles(p1_y',0.05,'Color','r');
        p2_y_circle=viscircles(p2_y',0.05,'Color','r');
        p3_y_circle=viscircles(p3_y',0.05,'Color','r');
        p4_y_circle=viscircles(p4_y',0.05,'Color','r');
        p5_y_circle=viscircles(p5_y',0.05,'Color','r');
        p6_y_circle=viscircles(p6_y',0.05,'Color','r');
        p7_y_circle=viscircles(p7_y',0.05,'Color','r');
            link_a_y=line([p1_y(1) p2_y(1)],[p1_y(2) p2_y(2)]);
            link_b_y=line([p2_y(1) p3_y(1)],[p2_y(2) p3_y(2)]);
            link_c_y=line([p3_y(1) p4_y(1)],[p3_y(2) p4_y(2)]);
            link_d_y=line([p1_y(1) p4_y(1)],[p1_y(2) p4_y(2)]);
            link_e_y=line([p4_y(1) p5_y(1)],[p4_y(2) p5_y(2)]);
            link_f_y=line([p5_y(1) p6_y(1)],[p5_y(2) p6_y(2)]);
            link_g_y=line([p6_y(1) p7_y(1)],[p6_y(2) p7_y(2)]);
            link_h_y=line([p4_y(1) p7_y(1)],[p4_y(2) p7_y(2)]);
            link_i_y=line([p3_y(1) p5_y(1)],[p3_y(2) p5_y(2)]);
            patch([p3_y(1) p4_y(1) p5_y(1)],[p3_y(2) p4_y(2) p5_y(2)],'green','FaceAlpha',.3);
        end
    end
```