Appendix

[A-1] Optimize design of the four links mechanism (in Matlab Language)

```
function main
% Public variables
x0=[1;1;1];
A=[]; %Local variable
b=[];
Aeq=[];
Beq=[];
lb=[0,0,0];
ub=[2,2,2];
x1=[];  % Reserved for output
options = optimset('outputfcn',@outfun, 'display', 'iter', 'Algorithm','active-set');
x=fmincon(@fun,x0,A,b,Aeq,Beq,lb,ub,@nonlcon,options);
end

function stop = outfun(x,optimValues,state)
   stop = false;
     switch state
         case 'iter'
                calTimes = 0;
                l1=1;l2=x(1,1);l3=x(2,1);l4=x(3,1);
g1=68*pi/180;

                    while g1<108*pi/180
                         a=l4-l1*cos(g1);
                         b=-l1*sin(g1);
                         c=(power(a,2)+power(b,2)+power(l3,2)-power(l2,2))./(2*l3);
                         g3=2*atan((b+power(power(a,2)+power(b,2)-power(c,2),0.5))./(a-c));
                         g0=g3-82.2*pi/180;     % 82.2 is a const  for plot robot hand
                         g00=g3-46.3*pi/180;   % 46.3 is a const for plot robot hand

m=[0,l1*cos(g1),l3*cos(g3)+l4,l4,0,l4,2.78*l3*cos(g3)+l4,4.2*cos(g00)+1.2,4.1*cos(g0)+1.2];
                         n=[0,l1*sin(g1),l3*sin(g3),0,0,0,2.78*l3*sin(g3),4.2*sin(g00),4.1*sin(g0)];
                         plot(m,n)
                         axis equal
                         hold on
                         g1=g1+39*pi/180;
                    end

                      calTimes = calTimes + 1
                      title(['Calculate times;', int2str(calTimes)])
                      pause(2)
                      axis equal
                      hold on
          x1 = [ x1; x];
     end
end

% Objective function
function f=fun(x)
% a1, b1, c1 are A, B, C in Eq (4)
 a1=x(3)-0.3746;
 b1=-0.9272;
 c1=(a1^2+b1^2+x(2)^2-x(1)^2)/(2*x(2));

%j1 and j2 are theta1 and theta 2 in Eq (6)
 j1=2*atan((b1+(a1^2+b1^2-c1^2)^0.5)/(a1-c1));
 a2=x(3)+0.309;
 b2=-0.951;
```

```
 c2=(a2^2+b2^2+x(2)^2-x(1)^2)/(2*x(2));
 j2=2*atan((b2+(a2^2+b2^2-c2^2)^0.5)/(a2-c2));
 f=abs(j2-j1-13*pi/36);
end

% Constrain function
function [g,ceq]=nonlcon(x)
    j=68*pi/180:108*pi/180;
    a1=x(3)-0.3746;
    b1=-0.9272;
    c1=(a1^2+b1^2+x(2)^2-x(1)^2)/(2*x(2));
    j1=2*atan((b1+(a1^2+b1^2-c1^2)^0.5)/(a1-c1));
    g=[abs(x(1)^2+x(2)^2-1-x(3)^2+2*x(3)*0.3746)/(2*x(1)*x(2))-0.087;…
        -abs(x(1)^2+x(2)^2-1-x(3)^2+2*x(3)*0.3746)/(2*x(1)*x(2));…
        j1-pi/2;…
        80*pi/180-j1;…
       -0.309-(1+x(3)^2-(x(1)+x(2))^2)/2*x(3)];
    ceq=0; % not used, therefore set to 0
end
```