```
%%% MIE301 Lab 3: Optimizing mechanisms
%% part a
close all; % closes all figures
clear all; % clears all variables from memory
clc;       % clears all calculations from the Matlab workspace

% Plot Parameters: these will be used to set the axis limits on the figure
xmin= -20; % leftmost window edge
xmax= 70;  % rightmost window edge
ymin= -25; % bottom window edge
ymax= 75;  % top window edge

% Link Parameters
increments = 100; % number of theta2 configuration steps to calculate along
mechanism rotation %%%% YOU MAY WANT TO CHANGE THIS

max_rotation_theta2 = 360 *pi/180; % rotation limit of theta2, radians
theta2 = linspace(0,max_rotation_theta2,increments); % link 2 rotation into
'increments' number of angles

r1 = 19;          % link 1 length, cm
r2 = 10;          % link 2 length, cm
%r3 = 25;          % link 3 length, cm
r4 = 25;          % link 4 length, cm
re = 20;          % extension length, cm
a = 0.1 ;         % path slope tolerance
% Rotation time
theta2_dot = 60;                        % rotation rate, rpm
t_rev = 60/theta2_dot;                  % rotation time limit, seconds
time = linspace(0,t_rev,increments);    % link 2 rotation into 'increments' number
of times

% set up figure
figure(1);                              %create new figure
set(1,'WindowStyle','Docked')           %dock the figure
% 4-bar mechanism geometric constants: See textbook section 4.3.3 for derivation.
(Eq. 4.3-54)

% Hint: add a for-loop here to calculate mechanism motion and plot iterate over r3
% recommended range for r3 20:0.5:30

G = []';
r3 = 20:0.5:30;
for x=1:length(r3)
    h1 = r1/r2;
    h2 = r1/r3(x);
    h3 = r1/r4;
    h4 =(-r1^2-r2^2-(r3(x))^2+r4^2)/(2*r2*r3(x));
    h5 =(r1^2+r2^2-(r3(x))^2+r4^2)/(2*r2*r4);
```

```
        for i=1:increments                              % step through motion of the
mechanism
            hold off;

            %  geometric calculations (book eq. 4.3-56 to 4.3-62):
            d = -h1 +(1-h3)*cos(theta2(i)) +h5;
            b = -2*sin(theta2(i));
            e = h1 -(1+h3)*cos(theta2(i)) +h5;
            a_a = -h1 +(1+h2)*cos(theta2(i)) +h4;
            c = h1 -(1-h2)*cos(theta2(i)) +h4;

            theta3_1(i) = 2*atan(((-b-(b^2-4*a_a*c)^0.5)/(2*a_a))); %calculate
angle of link 3 (eq. 4.3-64)
            theta4_1(i) = 2*atan(((-b-(b^2-4*d*e)^0.5)/(2*d)));

            % Link Coordinates calculations:
            Ax(i) = 0;                                            % pivot point of link 2
position
            Ay(i) = 0;                                            % pivot point of link 2
position
            Bx(i) = r2*cos( theta2(i) );                          % point B position
            By(i) = r2*sin( theta2(i) );                          % point B position
            Cx(i,1) = Bx(i) + (r3(x)+re )*cos( theta3_1(i) );             % point C
position. We're going to store these for each extension value (indexed by j)
            Cy(i,1) = By(i) + (r3(x)+re )*sin( theta3_1(i) );             % point C
position
            Dx(i) = r1 + r4*cos( theta4_1(i) );                   % point D position
            Dy(i) = r4*sin( theta4_1(i) );                        % point D
position

            if (false) % put true here to draw the mechanism each time, false to
skip drawing that for increased simulation speed
                plot( [Ax(i) Bx(i)], [Ay(i), By(i)],'Color','r','LineWidth',3 ); %
draw link2
                hold on;
                plot( [Bx(i), Dx(i)], [ By(i), Dy(i)],'Color','b','LineWidth',3 );
% draw link3
                plot( [Dx(i), Cx(i,1)], [ Dy(i),
Cy(i,1)],'Color','b','LineWidth',3 ); % draw link3 extension to point C
                plot( [r1, Dx(i)], [ 0, Dy(i)],'Color','m','LineWidth',3 ); % draw
link4

                % Draw Base Pivots:
                recsz = 2.5;                                          % size of drawn
base pivot
                plot([0,recsz],[0,-recsz],'r');                       % draw base
pivot for link2
                plot([0,-recsz],[0,-recsz],'r');                      % draw base
pivot for link2
```

```
                plot(0,0,'ro','MarkerFaceColor','w');                % draw a small
circle at the base pivot point
                plot(Bx(i), By(i), 'bo','MarkerFaceColor','w');      % draw a small
circle at B
                text(Bx(i)+0.9, By(i), 'B','color','b');             % label point B

                plot([r1,r1+recsz],[0,-recsz],'r');                  % draw base
pivot for link4
                plot([r1,r1-recsz],[0,-recsz],'r');                  % draw base
pivot for link4
                plot(r1,0,'ro','MarkerFaceColor','w');               % draw a small
circle at the base pivot point
                plot(Dx(i), Dy(i), 'bo','MarkerFaceColor','w');      % draw a small
circle at D
                text(Dx(i)+0.9, Dy(i), 'D','color','b');             % label point D
                text(Cx(i,1)+0.9, Cy(i,1), 'C','color','b');         % label point C

                xlabel('x (cm)', 'fontsize', 15);   % axis label
                ylabel('y (cm)', 'fontsize', 15);   % axil label
                title('Lab3 - starter');            % add a title to the figure
                axis equal;                         % make sure the figure is not
stretched
                grid on;
                axis( [xmin xmax ymin ymax] );      % figure axis limits
            end
            %pause(0.1);                            % wait to proceed to next
configuration, seconds
        end
         %pause(.01); %pause after drawing the current and previous paths, seconds



    % compute slope on point c path
    for i=1:1:length(Cx)
        if i==1
        s(i)=(Cy(2)-Cy(end))/(Cx(2)-Cx(end));
        elseif i==length(Cx)
        s(i)=(Cy(1)-Cy(end-1))/(Cx(1)-Cx(end-1));
        else
        s(i)=(Cy(i+1)-Cy(i-1))/(Cx(i+1)-Cx(i-1));
        end
    end
    % get the very left and right points on point c path
    index_left=find(Cx==max(Cx));
    index_right=find(Cx==min(Cx));

    k = find(abs(s) < a); % find the poins with slope smaller than a
    k_bottom=k(k<index_right & k>index_left);% select the points at the bottom of
the path
```

```
    % compute length of straight portion

    g=0;
    k_start=k_bottom(1);
    k_end=k_bottom(end);
    for j=k_start:1:k_end-1
        g_=((Cx(j+1)-Cx(j))^2+(Cy(j+1)-Cy(j))^2)^0.5;
        g=g+g_;

    end

    % plot the point c path
    plot(Cx,Cy)

    G = [G; g];
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%
% todo: plot g as function r3

figure;
hold on;
grid on;
plot(r3, G',"Color",'black', 'LineWidth',1);
title('g vs Length of Link 3');
xlabel('r3: Length of Link 3 [cm]');
ylabel('g: Length of Approx. linear distance [cm]');
hold off;

[Max_g, i] = max(G)      % Maximum length of straight portion g
```

```
Max_g = 45.5359
i = 19
```

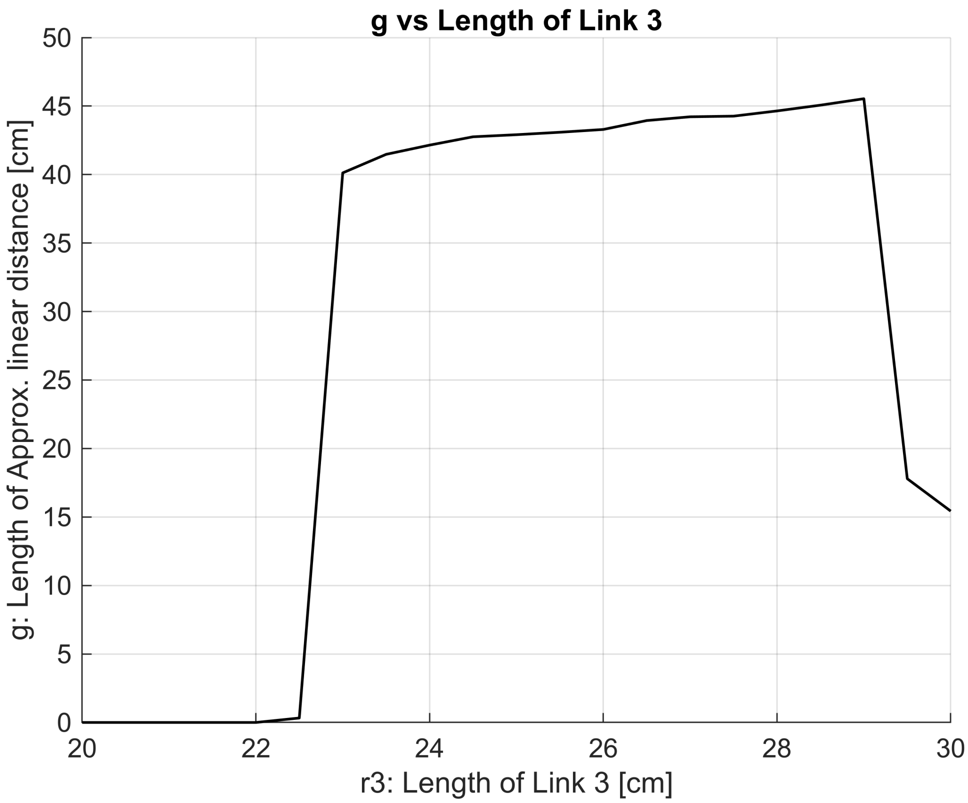
```
r3_for_max_g = r3(i)     % The length of link 3 corresponding to max g value
```

```
r3_for_max_g = 29
```

```

%k1 = r3
%k2 = G

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%
%% part b - Plot the optimized trace; with the straight line portion precisely
marked.
% Include the optimized mechanism links.
% first find the max g and its corresponding r3

h1 = r1/r2;
h2 = r1/r3_for_max_g;
h3 = r1/r4;
```

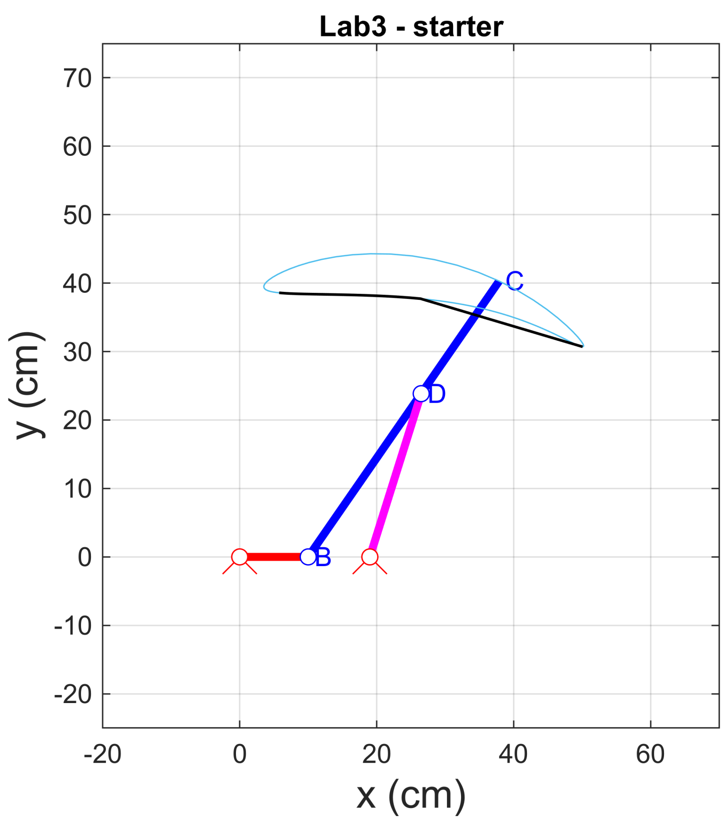
```
h4 =(-r1^2-r2^2-r3_for_max_g^2+r4^2)/(2*r2*r3_for_max_g);
h5 =(r1^2+r2^2-r3_for_max_g^2+r4^2)/(2*r2*r4);
    for i=1:increments                        % step through motion of the mechanism
        hold off;

        %  geometric calculations (book eq. 4.3-56 to 4.3-62):
        d = -h1 +(1-h3)*cos(theta2(i)) +h5;
        b = -2*sin(theta2(i));
        e = h1 -(1+h3)*cos(theta2(i)) +h5;
        a_a = -h1 +(1+h2)*cos(theta2(i)) +h4;
        c = h1 -(1-h2)*cos(theta2(i)) +h4;

        theta3_1(i) = 2*atan(((-b-(b^2-4*a_a*c)^0.5)/(2*a_a))); %calculate angle of
link 3 (eq. 4.3-64)
        theta4_1(i) = 2*atan(((-b-(b^2-4*d*e)^0.5)/(2*d)));

        % Link Coordinates calculations:
        Ax(i) = 0;                                        % pivot point of link 2
position
        Ay(i) = 0;                                        % pivot point of link 2
position
        Bx(i) = r2*cos( theta2(i) );                      % point B position
        By(i) = r2*sin( theta2(i) );                      % point B position
        Cx(i,1) = Bx(i) + (r3_for_max_g+re )*cos( theta3_1(i) );             %
point C position. We're going to store these for each extension value (indexed by j)
        Cy(i,1) = By(i) + (r3_for_max_g+re )*sin( theta3_1(i) );             %
point C position
        Dx(i) = r1 + r4*cos( theta4_1(i) );               % point D position
        Dy(i) = r4*sin( theta4_1(i) );                    % point D position

        if (true) % put true here to draw the mechanism each time, false to skip
drawing that for increased simulation speed
            plot( [Ax(i) Bx(i)], [Ay(i), By(i)],'Color','r','LineWidth',3 ); % draw
link2
            hold on;
            plot( [Bx(i), Dx(i)], [ By(i), Dy(i)],'Color','b','LineWidth',3 ); %
draw link3
            plot( [Dx(i), Cx(i,1)], [ Dy(i), Cy(i,1)],'Color','b','LineWidth',3 );
% draw link3 extension to point C
            plot( [r1, Dx(i)], [ 0, Dy(i)],'Color','m','LineWidth',3 ); % draw link4

            % Draw Base Pivots:
            recsz = 2.5;                                        % size of drawn
base pivot
            plot([0,recsz],[0,-recsz],'r');                     % draw base pivot
for link2
            plot([0,-recsz],[0,-recsz],'r');                    % draw base pivot
for link2
            plot(0,0,'ro','MarkerFaceColor','w');               % draw a small
circle at the base pivot point
```

```
            plot(Bx(i), By(i), 'bo','MarkerFaceColor','w');     % draw a small
circle at B
            text(Bx(i)+0.9, By(i), 'B','color','b');            % label point B

            plot([r1,r1+recsz],[0,-recsz],'r');                 % draw base pivot
for link4
            plot([r1,r1-recsz],[0,-recsz],'r');                 % draw base pivot
for link4
            plot(r1,0,'ro','MarkerFaceColor','w');              % draw a small
circle at the base pivot point
            plot(Dx(i), Dy(i), 'bo','MarkerFaceColor','w');     % draw a small
circle at D
            text(Dx(i)+0.9, Dy(i), 'D','color','b');            % label point D
            text(Cx(i,1)+0.9, Cy(i,1), 'C','color','b');        % label point C

            xlabel('x (cm)', 'fontsize', 15);   % axis label
            ylabel('y (cm)', 'fontsize', 15);   % axil label
            title('Lab3 - starter');            % add a title to the figure
            axis equal;                         % make sure the figure is not
stretched
            grid on;
            axis( [xmin xmax ymin ymax] );      % figure axis limits
        end
        pause(0.01);                            % wait to proceed to next
configuration, seconds
        hold on;
    end
```




```
    %pause(.01); %pause after drawing the current and previous paths, seconds



% compute slope on point c path
for i=1:1:length(Cx)
    if i==1
    s(i)=(Cy(2)-Cy(end))/(Cx(2)-Cx(end));
    elseif i==length(Cx)
    s(i)=(Cy(1)-Cy(end-1))/(Cx(1)-Cx(end-1));
    else
    s(i)=(Cy(i+1)-Cy(i-1))/(Cx(i+1)-Cx(i-1));
    end
end
% get the very left and right points on point c path
index_left=find(Cx==max(Cx));
index_right=find(Cx==min(Cx));

k = find(abs(s) < a); % find the points with slope smaller than a
k_bottom=k(k<index_right & k>index_left);% select the points at the bottom of the
path

% compute length of straight portion

g=0;
k_start=k_bottom(1);
```

```
k_end=k_bottom(end);
for j=k_start:1:k_end-1
    g_=((Cx(j+1)-Cx(j))^2+(Cy(j+1)-Cy(j))^2)^0.5;
    g=g+g_;
end

plot(Cx, Cy)

hold on
Cx_g = [];
Cy_g = [];
% plot the point c path, with the straight portion coloured differently
% Use k_bottom indices to get Cy values
for i=k_bottom
    Cx_g = [Cx_g; Cx(i)];
    Cy_g = [Cy_g; Cy(i)];
end
plot(Cx_g, Cy_g, 'LineWidth', 1, 'color', 'black')
```




```
%% part c - Input link angle?
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%
min_angle = 0;
max_angle = 0;
Cx_copy = [];
Cx_at_min_theta2 = Cx_g(1);
```

```
Cx_at_max_theta2 = Cx_g(end);

% Step through the possible theta2 values, calculate Cx and find which
% theta2 values give the endpoints of the straight path

for i=1:length(theta2)
    h1 = r1/r2;
    h2 = r1/r3_for_max_g;
    h3 = r1/r4;
    h4 =(-r1^2-r2^2-r3_for_max_g^2+r4^2)/(2*r2*r3_for_max_g);
    h5 =(r1^2+r2^2-r3_for_max_g^2+r4^2)/(2*r2*r4);

    d = -h1 +(1-h3)*cos(theta2(i)) +h5;
    b = -2*sin(theta2(i));
    e = h1 -(1+h3)*cos(theta2(i)) +h5;
    a_a = -h1 +(1+h2)*cos(theta2(i)) +h4;
    c = h1 -(1-h2)*cos(theta2(i)) +h4;

    theta3_1(i) = 2*atan(((-b-(b^2-4*a_a*c)^0.5)/(2*a_a)));

    Bx(i) = r2*cos( theta2(i) );
    Cx_copy(i) = Bx(i) + (r3_for_max_g+re )*cos( theta3_1(i) );
    if Cx_copy(i) == Cx_at_min_theta2
        min_angle = theta2(i)*180/pi
    elseif Cx_copy(i) == Cx_at_max_theta2
        max_angle = theta2(i)*180/pi
    end

end
```

```
min_angle = 43.6364
max_angle = 258.1818
```

```

%%% The Rightmost point of the staight portion of the path has angle
%%% min_angle = 43.6 degrees and max_angle = 258.2 degrees for increments =
%%% 100

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%
%% part d - Max and min speed and acceleration of the trace of point C through the
straight portion?
% Hint: distance between C(i+1) and C(i-1) devided by 2 delta_t can give
% you an approximation of speed at point C(i)
% acceleration = change in speed/change in time

speed = [];
accel = [];
dt = time(2);                                % Time units are all the same length,
defined above
for i=2:length(Cx_g)-1
```

```
    speed_value = abs(Cx_g(i+1) - Cx_g(i-1))/(2*dt);
    speed = [speed; speed_value];
end

for i=2:length(speed)-1
    accel_value = abs(speed(i+1) - speed(i-1))/(2*dt);
    accel = [accel; accel_value];
end

% Find the maximum values
maximum_speed_straight_path = max(speed)
```

```
maximum_speed_straight_path = 1.2158e+03
```

```
maximum_accel_straight_path = max(accel)
```

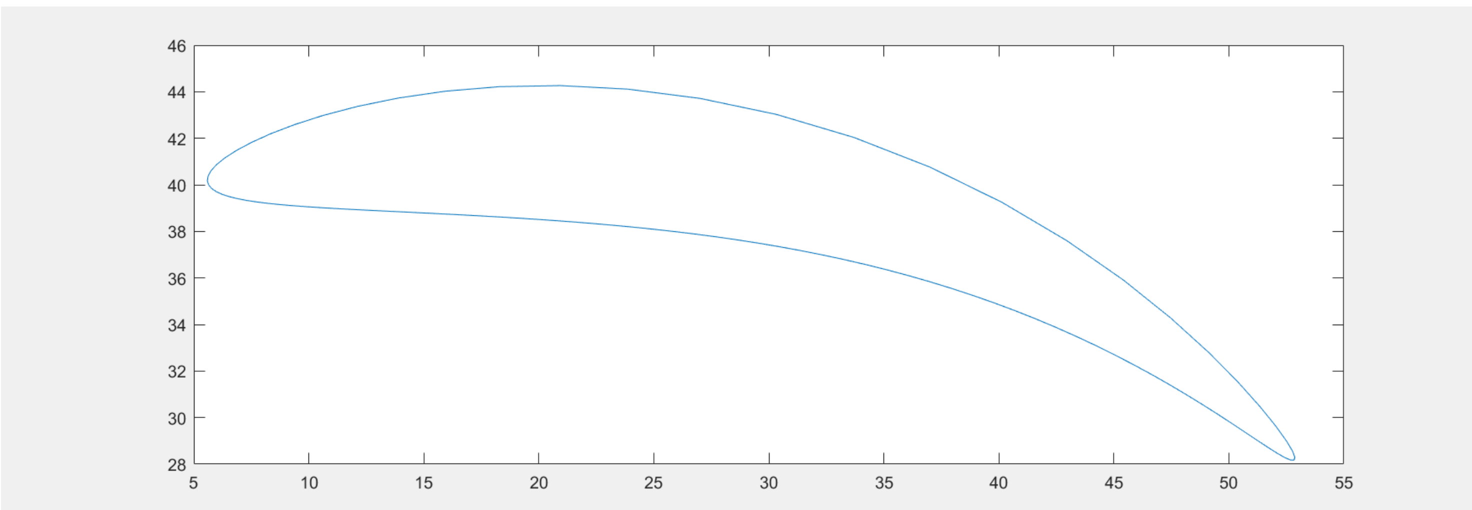
```
maximum_accel_straight_path = 5.5906e+04
```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%
%% part e - How does the tolerance (a) affect your optimized path length?

% Hint: Similar to part a, but add an outer loop and iterate over a instead of r3

increments = 500; % number of theta2 configuration steps to calculate along
mechanism rotation %%%% YOU MAY WANT TO CHANGE THIS

max_rotation_theta2 = 360 *pi/180; % rotation limit of theta2, radians
theta2 = linspace(0,max_rotation_theta2,increments); % link 2 rotation into
'increments' number of angles

r1 = 19;          % link 1 length, cm
r2 = 10;          % link 2 length, cm
r3 = 22;          % link 3 length, cm
r4 = 25;          % link 4 length, cm
re=20;            % extension length, cm
%a = 0.1 ;         % path slope tolerance
% Rotation time
theta2_dot = 60;                        % rotation rate, rpm
t_rev = 60/theta2_dot;                  % rotation time limit, seconds
time = linspace(0,t_rev,increments);    % link 2 rotation into 'increments' number
of times

% set up figure
figure(1);                         %create new figure
set(1,'WindowStyle','Docked')      %dock the figure

G_2 = [];
a = 0.05:0.005:0.15;
for k = 1:length(a)
```

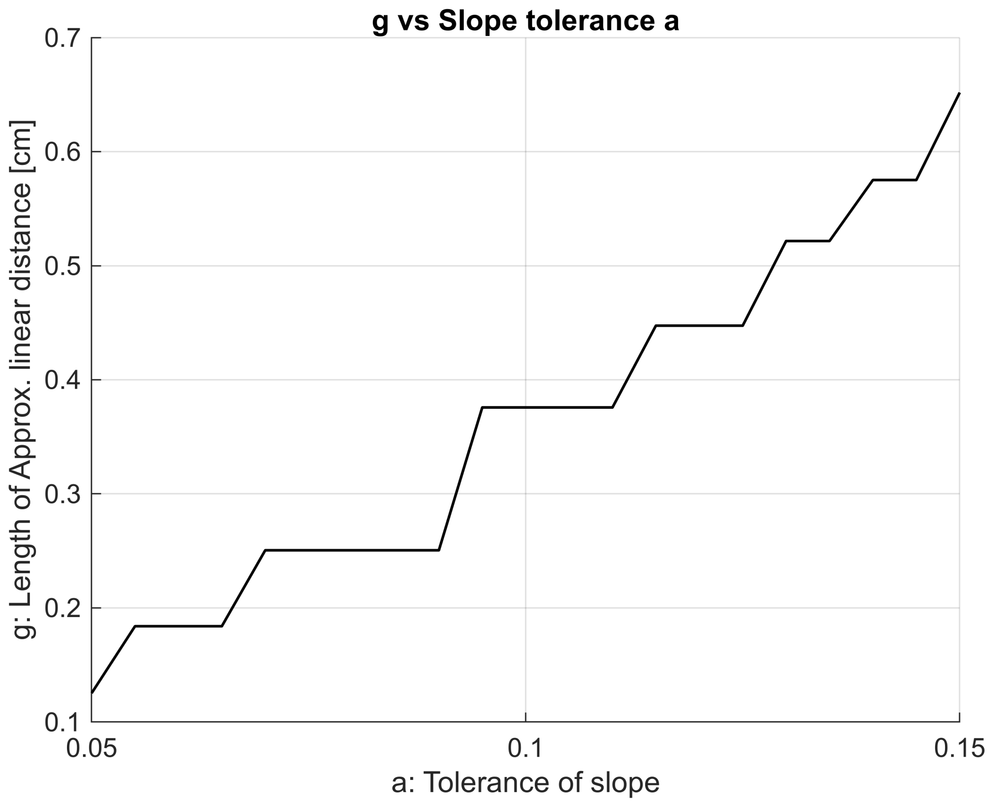
```
    h1 = r1/r2;
    h2 = r1/r3;
    h3 = r1/r4;
    h4 =(-r1^2-r2^2-r3^2+r4^2)/(2*r2*r3);
    h5 =(r1^2+r2^2-r3^2+r4^2)/(2*r2*r4);
        for i=1:increments                        % step through motion of the
mechanism
            hold off;

            %  geometric calculations (book eq. 4.3-56 to 4.3-62):
            d = -h1 +(1-h3)*cos(theta2(i)) +h5;
            b = -2*sin(theta2(i));
            e = h1 -(1+h3)*cos(theta2(i)) +h5;
            a_a = -h1 +(1+h2)*cos(theta2(i)) +h4;
            c = h1 -(1-h2)*cos(theta2(i)) +h4;

            theta3_1(i) = 2*atan(((-b-(b^2-4*a_a*c)^0.5)/(2*a_a))); %calculate
angle of link 3 (eq. 4.3-64)
            theta4_1(i) = 2*atan(((-b-(b^2-4*d*e)^0.5)/(2*d)));

            % Link Coordinates calculations:
            Ax(i) = 0;                                      % pivot point of link 2
position
            Ay(i) = 0;                                      % pivot point of link 2
position
            Bx(i) = r2*cos( theta2(i) );                    % point B position
            By(i) = r2*sin( theta2(i) );                    % point B position
            Cx(i,1) = Bx(i) + (r3+re )*cos( theta3_1(i) );            % point C
position. We're going to store these for each extension value (indexed by j)
            Cy(i,1) = By(i) + (r3+re )*sin( theta3_1(i) );            % point C
position
            Dx(i) = r1 + r4*cos( theta4_1(i) );             % point D position
            Dy(i) = r4*sin( theta4_1(i) );                  % point D
position

            if (false) % put true here to draw the mechanism each time, false to
skip drawing that for increased simulation speed
                plot( [Ax(i) Bx(i)], [Ay(i), By(i)],'Color','r','LineWidth',3 ); %
draw link2
                hold on;
                plot( [Bx(i), Dx(i)], [ By(i), Dy(i)],'Color','b','LineWidth',3 );
% draw link3
                plot( [Dx(i), Cx(i,1)], [ Dy(i),
Cy(i,1)],'Color','b','LineWidth',3 ); % draw link3 extension to point C
                plot( [r1, Dx(i)], [ 0, Dy(i)],'Color','m','LineWidth',3 ); % draw
link4

                % Draw Base Pivots:
                recsz = 2.5;                                    % size of drawn
base pivot
```

```
                plot([0,recsz],[0,-recsz],'r');                      % draw base
pivot for link2
                plot([0,-recsz],[0,-recsz],'r');                     % draw base
pivot for link2
                plot(0,0,'ro','MarkerFaceColor','w');                % draw a small
circle at the base pivot point
                plot(Bx(i), By(i), 'bo','MarkerFaceColor','w');      % draw a small
circle at B
                text(Bx(i)+0.9, By(i), 'B','color','b');             % label point B

                plot([r1,r1+recsz],[0,-recsz],'r');                  % draw base
pivot for link4
                plot([r1,r1-recsz],[0,-recsz],'r');                  % draw base
pivot for link4
                plot(r1,0,'ro','MarkerFaceColor','w');               % draw a small
circle at the base pivot point
                plot(Dx(i), Dy(i), 'bo','MarkerFaceColor','w');      % draw a small
circle at D
                text(Dx(i)+0.9, Dy(i), 'D','color','b');             % label point D
                text(Cx(i,1)+0.9, Cy(i,1), 'C','color','b');         % label point C

                xlabel('x (cm)', 'fontsize', 15);   % axis label
                ylabel('y (cm)', 'fontsize', 15);   % axil label
                title('Lab3 - starter');            % add a title to the figure
                axis equal;                         % make sure the figure is not
stretched
                grid on;
                axis( [xmin xmax ymin ymax] );      % figure axis limits
            end
            %pause(0.1);                            % wait to proceed to next
configuration, seconds
        end
         %pause(.01); %pause after drawing the current and previous paths, seconds



    % compute slope on point c path
    for i=1:1:length(Cx)
        if i==1
        s(i)=(Cy(2)-Cy(end))/(Cx(2)-Cx(end));
        elseif i==length(Cx)
        s(i)=(Cy(1)-Cy(end-1))/(Cx(1)-Cx(end-1));
        else
        s(i)=(Cy(i+1)-Cy(i-1))/(Cx(i+1)-Cx(i-1));
        end
    end
    % get the very left and right points on point c path
    index_left=find(Cx==max(Cx));
    index_right=find(Cx==min(Cx));
```

```
    k = find(abs(s) < a(k)); % find the poins with slope smaller than a
    k_bottom=k(k<index_right & k>index_left);% select the points at the bottom of
the path

    % compute length of straight portion

    g=0;
    if isempty(k_bottom)
        g=0
    else
        k_start=k_bottom(1);
        k_end=k_bottom(end);
        for j=k_start:1:k_end-1
            g_=((Cx(j+1)-Cx(j))^2+(Cy(j+1)-Cy(j))^2)^0.5;
            g=g+g_;
        end
    end

    G_2 = [G_2; g];

end
```




```
% Plotting the length g against tolerance a

figure;
hold on;
grid on;
plot(a, G_2',"Color",'black', 'LineWidth',1);
title('g vs Slope tolerance a');
xlabel('a: Tolerance of slope');
ylabel('g: Length of Approx. linear distance [cm]');
hold off;
```


g vs Slope tolerance a
0.7
0.6
0.5
0.4
0.3
0.2
0.1
g: Length of Approx. linear distance [cm]
0.05
0.1
0.15
a: Tolerance of slope