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%% 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);

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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

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        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

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% 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

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%% 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;

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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

```

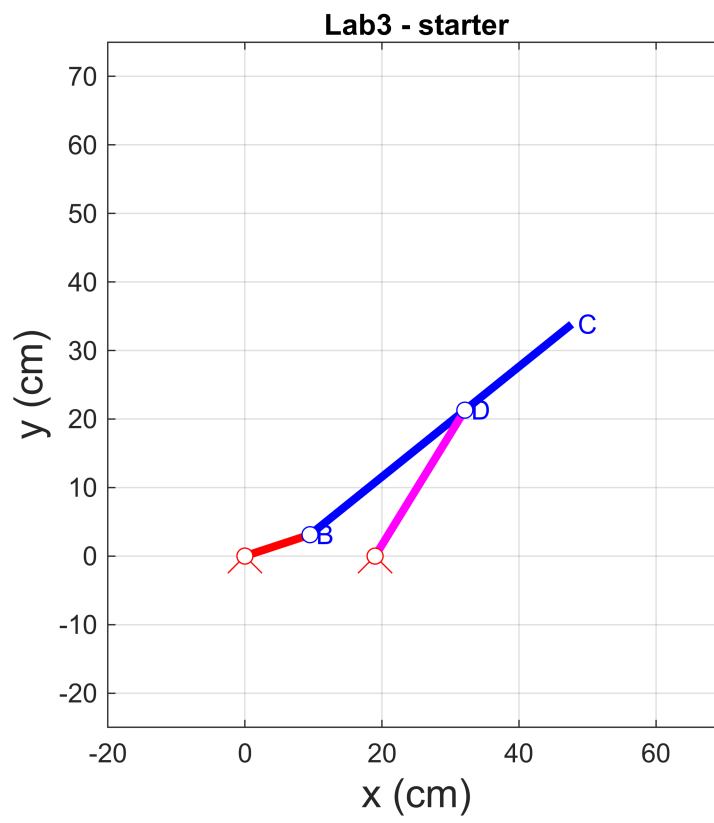
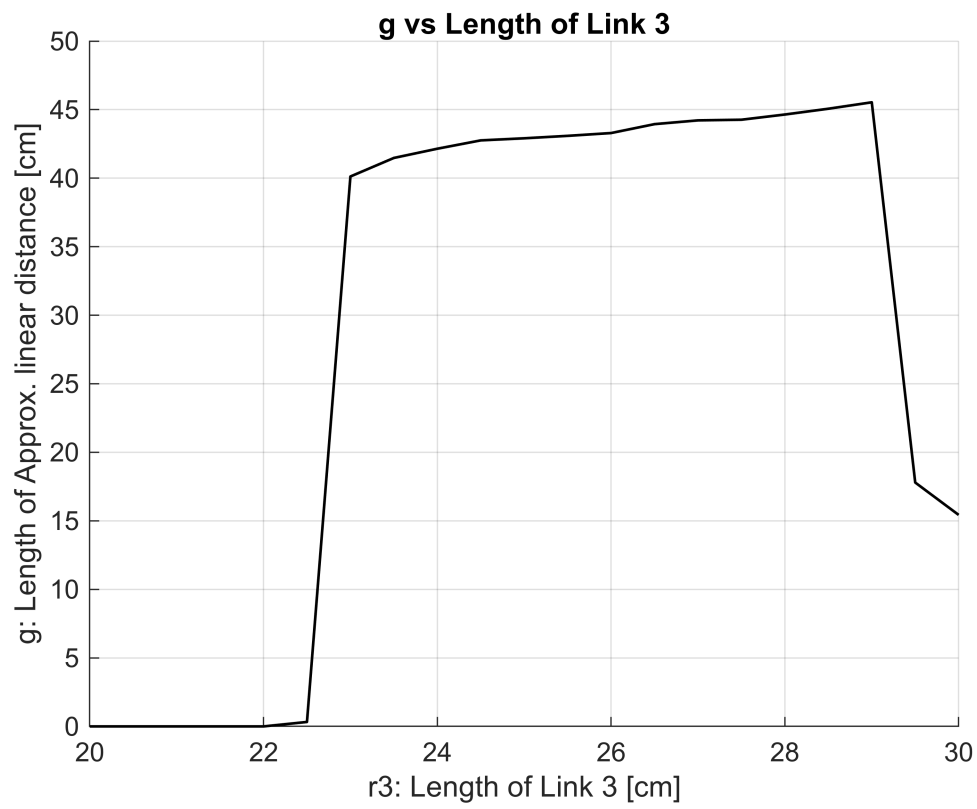
```

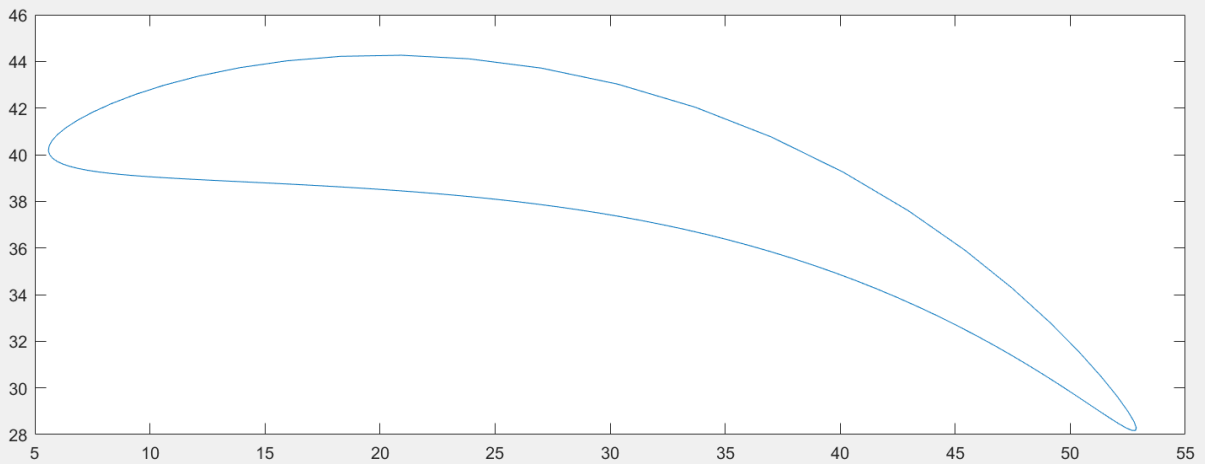
        plot(Bx(i), By(i), 'bo','MarkerFaceColor','w');    % draw a small
circle at B
        text(Bx(i)+0.9, By(i), 'B','color','b');          % label point B

        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(0.1);                                          % 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
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```
for i=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)
```

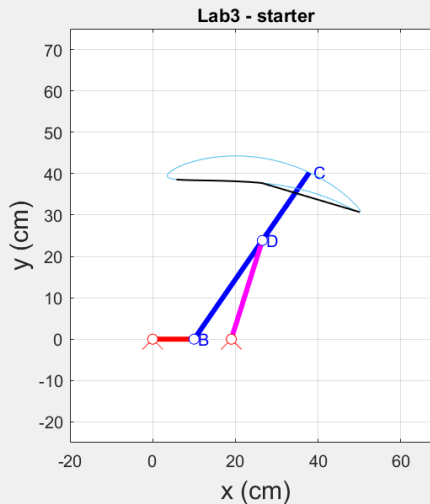
```
hold on
```



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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')

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%% part c - Input link angle?
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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;

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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

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min_angle = 43.6364
max_angle = 258.1818

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

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%% part d - Max and min speed and acceleration of the trace of point C through the
straight portion?

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% Hint: distance between C(i+1) and C(i-1) divided by 2 delta_t can give
% you an approximation of speed at point C(i)
% acceleration = change in speed/change in time

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

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

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