Rahul_Goyal_main Usage and Description

ME 326 Winter 2018 - Laboratory Assignment #5

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Date Created: February 13, 2018

Date Modified: February 27, 2018

Description: This script simulates the motion of a slider-crank. Afterwards, it first animates the slider-crank by plotting the vectors tip-to-tail, animates the slider-crank again by using the simulation data. Additionally, it compares the velocity of link AB to the angular position of link OA.

Required Files:

- Simulator.slx - This file uses Simulink to double integrate a MATLAB Function Block which describes the accelerations of the simulation. It outputs the positions as xout, the velocities as vout, the accelerations as aout, and the times as tout with inputs of the MATLAB function and initial conditions.
- link_solver.m - This file contains a function that represents the accelerations of the simulation. It returns x with an input of u.

Called Functions

clear all; clc;

Given Values

The following assigns values given by the problem statement to variables.

```
% Given Values
tdot_2 = -3;                    % Angular velocity of link OA (rad/s)
l_ab = 350/1000;                % Length of link AB (m)
r_1 = 240/1000;                 % Length of vector R1 (m)
r_2 = 80/1000;                  % Length of vector R2 (m)
theta2_stop = -4*pi;            % Theta_2 final (rad)

% Set Values
t2_0 = deg2rad(0);              % Angular position initial of link OA (rad)
```

Initial Conditions

The following sets the initial conditions of the slider-crank. See the attached file for hand calculations.

```
% Position Initial Conditions
% Length initial of vector R2 (m) [Pythagorean Theorem]
r3_0 = hypot(r_1+r_2*cos(t2_0), r_2*sin(t2_0));
% Angular position initial of link OA (rad) [Law of Sines]
t3_0 = asin(sin(pi-t2_0)/r3_0 * r_2);
% COM[x] initial of link OA (m)
x2_0 = r_1 + r_2/2*cos(t2_0);
% COM[y] initial of link OA (m)
y2_0 = r_2/2*sin(t2_0);
% COM[x] initial of link AB (m)
```

```
x3_0 = r_1 + r_2*cos(t2_0) - l_ab/2*cos(t3_0);
% COM[y] initial of link AB (m)
y3_0 = r_2*sin(t2_0) - l_ab/2*sin(t3_0);

% Position Initial Conditions Matrix
x_0 = [r3_0, t3_0, x2_0, y2_0, x3_0, y3_0];

% Velocity Initial Conditions
A = [cos(t3_0), -r3_0*sin(t3_0);
     sin(t3_0), r3_0*cos(t3_0)];
b = [-r_2*tdot_2*sin(t2_0);
     r_2*tdot_2*cos(t2_0)];
x = A \ b;
% Velocity initial of vector R3 (m/s)
rdot3_0 = x(1);
% Angular velocity initial of link AB (rad/s)
tdot3_0 = x(2);
% Velocity_G[x] initial of link OA (m/s)
xdot2_0 = -tdot_2 * r_2/2*sin(t2_0);
% Velocity_G[y] initial of link OA (m/s)
ydot2_0 = tdot_2 * r_2/2*cos(t2_0);
% Velocity_G[x] initial of link AB (m/s)
xdot3_0 = -tdot3_0 * y3_0;
% Velocity_G[x] initial of link AB (m/s)
ydot3_0 = tdot3_0 * x3_0;

% Velocity Initial Conditions Matrix
v_0 = [rdot3_0, tdot3_0, xdot2_0, ydot2_0, xdot3_0, ydot3_0];
```

Simulate the Slider-Crank Using Simulink

The following calls the Simulink file Simulator.slx, which outputs the positions as xout, the velocities as vout, the accelerations as aout, and the times as tout with link_solver.m as the input for the MATLAB Fuction, tdot_2, t2_0, v_0, and x_0 as the inputs for the initial conditions, and theta2_stop as the input for the final conditions.

```
sim('Simulator.slx');
```

Tip-to-Tail Animation

The following animates the slider-crank by plotting the vectors tip-to-tail. Thus, the extension of link AB is not plotted. If a constant "pause" is used, this animation displays only kinematic position, and not kinematic velocity, because in reality the time step between each frame varies.

```
% Cartesian Coordinates of Vector R1
r1_x = [0, r_1];
r1_y = [0, 0];

for t = 1:length(tout)

    t_2 = t2_0 + tdot_2 * tout(t);  % Angular position of link OA (m)

    % Cartesian Coordinates of Vector R2, Link AB (tip-to-tail)
    r2_x = [r1_x(end), r1_x(end) + r_2*cos(t_2)];
    r2_y = [r1_y(end), r1_y(end) + r_2*sin(t_2)];
    r3_x = [r2_x(end), r1_x(1)];
    r3_y = [r2_y(end), r2_y(1)];

    % Plot the vector links
```

```
    plot(r1_x, r1_y, r2_x, r2_y, r3_x, r3_y, 'LineWidth', 2);

    % Keep the frame consistent
    axis equal;
    axis([-0.2, 0.4, -0.1, 0.1]);

    % Calculate the time step and pause accordingly
    if t ~= length(tout)            % Prevent index error
        % Calculate the time step (s)
        t_step = tout(t+1) - tout(t);
        pause(t_step);              % Assume negligible processing time
    end

end

% Plot labeling (last frame)
title('Tip-to-Tail Animation');
xlabel({'X Position (m)'
        ''
        % Figure label
        '\bfFigure 1: \rmTip-to-Tail Animation'});
ylabel('Y Position (m)');
legend('Vector R1', 'Vector R2', 'Vector R3');
```

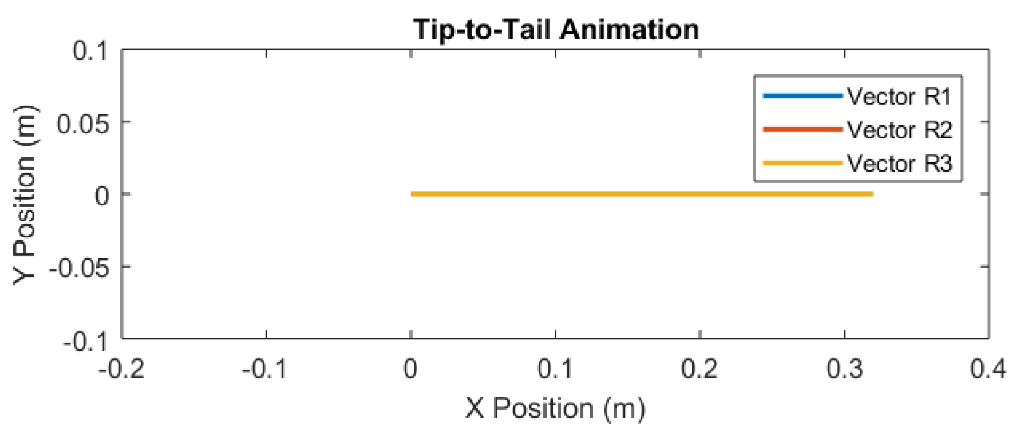


Figure 1: Tip-to-Tail Animation

Velocity of Vector R3 vs. Angular Position of Link OA

The following plots the velocity of vector R3 as a function of the angular position of link OA.

```
% Easy access to...
rdot_3s = vout(:, 1);           % Velocities of vector R3 (m/s)
t_2s = tdot_2*tout;             % Angular positions of link OA (rad)
```

```
% Plot
plot(t_2s, rdot_3s, 'LineWidth', 2);
title('Velocity of Vector R3 vs. Angular Position of Link OA');
xlabel({'Angular Position of Link OA (rad)'
        ''
        % Figure label
        '\bfFigure 2: \rmVeclocity of Vector R3 vs. Angular Position of Link OA'});
ylabel('Length of Vector R3 (m)');



% Find the time index of when the angular position of link OA is 140 degrees
t_140 = length(tout);
for t = 1:length(tout);
    % Best error (so far)
    best_error = abs(t_2s(t_140)-(deg2rad(140)-2*pi));
    % Current error
    curr_error = abs(t_2s(t)-(deg2rad(140)-2*pi));

    % If the current error is less than the best error (so far)...
    if curr_error < best_error
        t_140 = t;                  % Update the best error time index
    end
end



% Print results to console
fprintf("The velocity of link AB ");
fprintf("when the angular position of link OA is 140 degrees is: ");
fprintf("\n");
fprintf(num2str(rdot_3s(t_140)));
fprintf(" m/s.");
fprintf("\n");
[~, idx] = max(vout(:, 1));
fprintf("The maximum value of the velocity of link AB is: ");
fprintf("\n");
fprintf(num2str(rdot_3s(idx)));
fprintf(" m/s.");
fprintf("\n");
fprintf("The corresponding angular position of link OA is: ");
fprintf("\n");
fprintf(num2str(t_2s(idx)+2*pi));
fprintf(" radians.");
fprintf("\n");
```

```
The velocity of link AB when the angular position of link OA is 140 degrees is:
0.19633 m/s.
The maximum value of the velocity of link AB is:
0.24 m/s.
The corresponding angular position of link OA is:
-4.3786 radians.
```

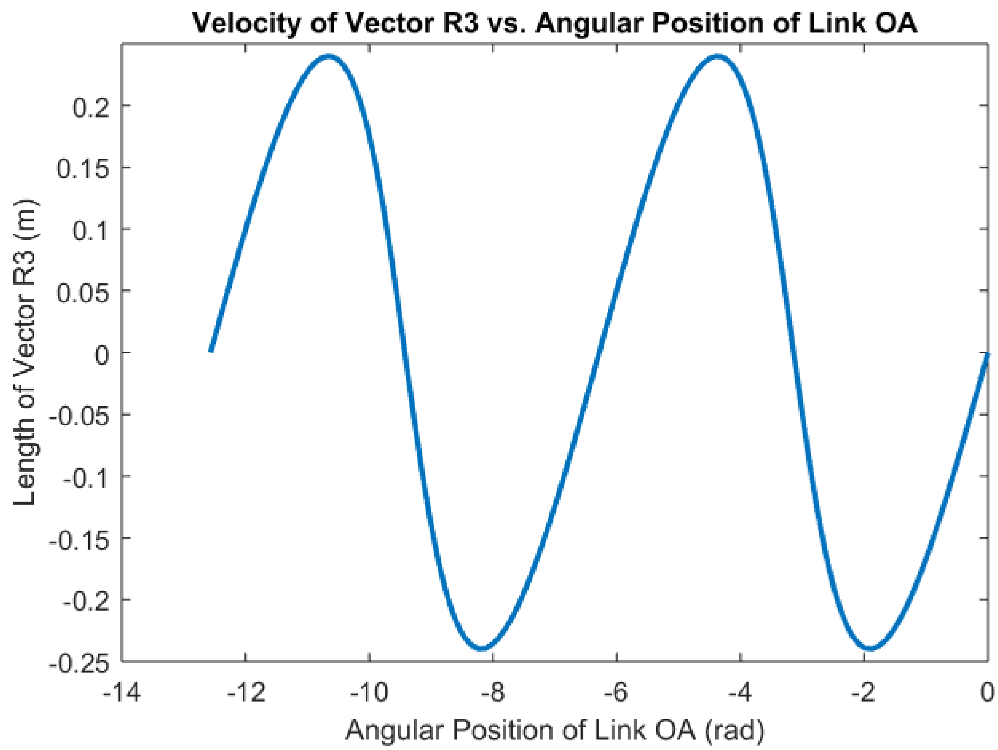


Figure 2: Veclocity of Vector R3 vs. Angular Position of Link OA

Simulation Animation

The following animates the slider-crank by using the simulation data.

```
% Cartesian Coordinates of COM of Vector R1
x_1 = (r1_x(end)-r1_y(1))/2;
y_1 = (r1_y(end)-r1_y(1))/2;

% Easy access to...
r_3 = xout(:, 1);                % Lengths of vector R3 (m)
t_3 = xout(:, 2);                % Angular positions of link AB (rad)
x_2 = xout(:, 3);                % COMs[x] of link OA (m)
y_2 = xout(:, 4);                % COMs[y] of link OA (m)
x_3 = xout(:, 5);                % COMs[x] of link AB (m)
y_3 = xout(:, 6);                % COMs[y] of link AB (m)

% Cartesian Coordinates of Point A
a_x = r1_x(end)+r_2*cos(t2_0+tdot_2*tout);
a_y = r1_y(end)+r_2*sin(t2_0+tdot_2*tout);
% Cartesian Coordinates of Point B
b_x = a_x - l_ab*cos(t_3);
b_y = a_y - l_ab*sin(t_3);

for t = 1:length(tout)

    t_2 = t2_0 + tdot_2*tout(t);    % Angular position of link OA (m)

    % Cartesian Coordinates of Vector R2
    r2_x = [r1_x(end), r1_x(end) + r_2*cos(t_2)];
    r2_y = [r1_y(end), r1_y(end) + r_2*sin(t_2)];
    % Cartesian Coordinates of Link AB
    lab_x = [r2_x(end), r2_x(end) - l_ab*cos(t_3(t))];
    lab_y = [r2_y(end), r2_y(end) - l_ab*sin(t_3(t))];
```

```
    % Plot the links, COMs, COM paths
    plot(r1_x, r1_y, ...              % Vector R1
         r2_x, r2_y, ...              % Vector R2
         lab_x, lab_y, ...            % Link AB
         x_2(1:t), y_2(1:t), ...      % Path of link OA COM
         x_3(1:t), y_3(1:t), ...      % Path of link AB COM
         a_x(1:t), a_y(1:t), ...      % Path of point A
         b_x(1:t), b_y(1:t), ...      % Path of point B
         'LineWidth', 2);             % Line Properties
    % COM of Vector R1
    viscircles([x_1, y_1], 0.0025, 'Color', 'k');
    % COM of Link OA
    viscircles([x_2(t), y_2(t)], 0.0025, 'Color', 'k');
    % COM of Link AB
    viscircles([x_3(t), y_3(t)], 0.0025, 'Color', 'k');

    % Keep the frame consistent
    axis equal;
    axis([-0.2, 0.8, -0.1, 0.1]);

    % Calculate the time step and pause accordingly
    if t ~= length(tout)              % Prevent index error
        % Calculate the time step (s)
        t_step = tout(t+1) - tout(t);
        pause(t_step);                % Assume negligible processing time
    end

% Plot labeling (last frame)
title('Simulation Animation');
xlabel({'X Position (m)'
        ''
        % Figure label
        '\bfFigure 3: \rmSimulation Animation'});
ylabel('Y Position (m)');
legend('Vector R1', 'Vector R2', 'Link AB', ...
       'Path of Link OA COM', 'Path of Link AB COM', ...
       'Path of Point A', 'Path of Point B');

end
```

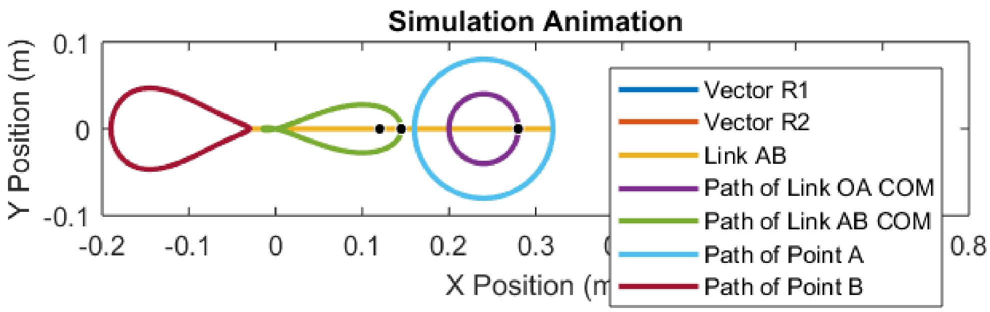


Figure 3: Simulation Animation

Published with MATLAB® R2017a

Contents

Called Functions

Given Values

The following assigns values given by the problem statement to variables.

```
l_ab = 350/1000;                % Length of link AB (m)
r_1 = 240/1000;                 % Length of vector R1 (m)
r_2 = 80/1000;                  % Length of vector R2 (m)
```

Solved Values

The following assigns values derived and/or solved from the given values to variables. See the attached file for hand calculations.

```
% Easy Access to...
t_2 = u(1);                     % Angular position of link OA (rad)
tdot_2 = u(2);                  % Angular velocity of link OA (rad/s)
r_3 = u(3);                     % Length of vector R3 (m)
t_3 = u(4);                     % Angular position of link AB (rad)
rdot_3 = u(9);                  % Velocity of vector R3 (m/s)
tdot_3 = u(10);                 % Angular velocity of link AB (rad/s)

A = [cos(t_3), -r_3*sin(t_3), 0, 0, 0, 0;
     sin(t_3), r_3*cos(t_3), 0, 0, 0, 0;
     0, 0, 1, 0, 0, 0;
     0, 0, 0, 1, 0, 0;
     -cos(t_3), (r_3-l_ab/2)*sin(t_3), 0, 0, 1, 0;
     -sin(t_3), -(r_3-l_ab/2)*cos(t_3), 0, 0, 0, 1];

b = [2*rdot_3*tdot_3*sin(t_3) + r_3*tdot_3^2*cos(t_3) - r_2*tdot_2^2*cos(t_2);
     -2*rdot_3*tdot_3*cos(t_3) + r_3*tdot_3^2*sin(t_3) - r_2*tdot_2^2*sin(t_2);
     -1/2*r_2*tdot_2^2*cos(t_2);
     -1/2*r_2*tdot_2^2*sin(t_2);
     -2*rdot_3*tdot_3*sin(t_3) - r_3*tdot_3^2*cos(t_3) + l_ab/2*tdot_3^2*cos(t_3);
     2*rdot_3*tdot_3*cos(t_3) - r_3*tdot_3^2*sin(t_3) + l_ab/2*tdot_3^2*sin(t_3)];
```

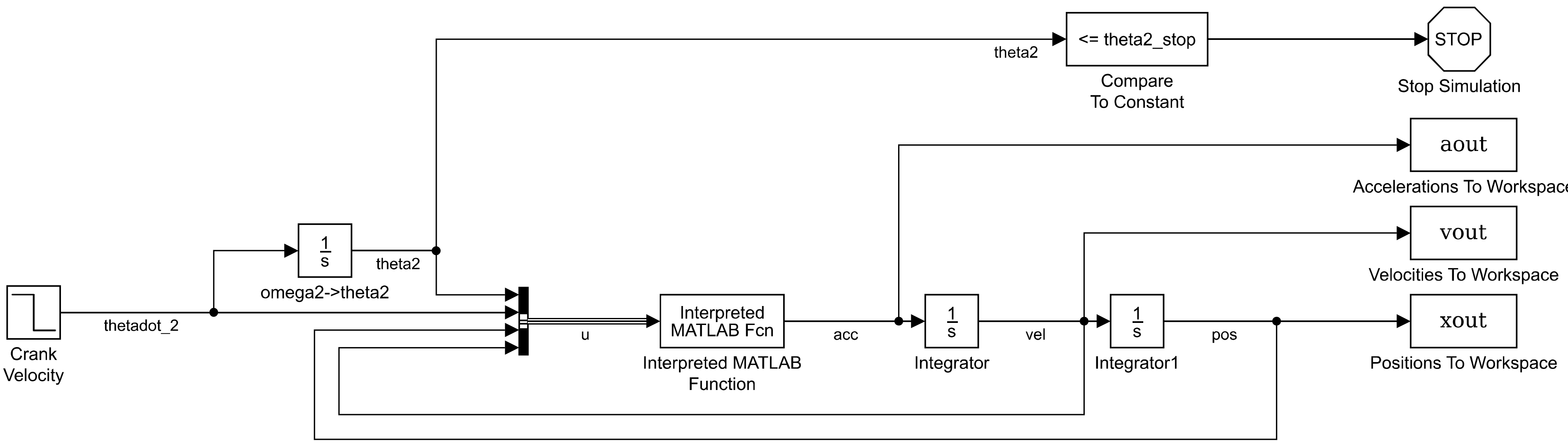
```
Not enough input arguments.

Error in link_solver (line 20)
t_2 = u(1);                     % Angular position of link OA (rad)
```

Solve for x

Solve for x using mldivide.

```
x = A \ b;
```

```
end
```



<= theta2_stop
Compare
To Constant
STOP
Stop Simulation
theta2
aout
Accelerations To Workspace
vout
Velocities To Workspace
xout
Positions To Workspace
1/s
omega2->theta2
theta2
Crank
Velocity
thetadot_2
u
Interpreted
MATLAB Fcn
Interpreted MATLAB
Function
acc
Integrator
vel
Integrator1
pos