```
%MATLAB CODE ASSIGNMENT 4 ENPM662
%ANSWER 2 (a) 2 (b) 2 (c)

%%2(a) generic jacobian form written by hand
clc
clear all
%writing the code for A matrices
%%declaring the variables and symbols for the matrix multiplication
syms theta1 theta2 theta3 l1 l2 l3 l4 %%declaring all the unknown
 values as symbols

%%declaring the values of the a variables for translation along Xn
a2=0;
a3=0;
a4=0;
a5=0;
%%declaring the values of the alpha variables for rotation about Xn
alpha1=-90;
alpha2=90;
alpha3=0;
alpha4=90;
alpha5=0;
%%declaring the value of theta for frame 3 to 4 transformation
theta5=90;

%%The general form of the matrices are obtained by multiplying the
%%following

%%first A matrix A_1
Rz_theta1=[cosd(theta1) -sind(theta1) 0 0;sind(theta1) cosd(theta1) 0
 0;0 0 1 0;0 0 0 1];
Rx_alpha1=[1 0 0 0;0 cosd(alpha1) -sind(alpha1) 0;0 sind(alpha1)
 cosd(alpha1) 0;0 0 0 1];
Tz_d1=[1 0 0 0;0 1 0 0;0 0 1 (0);0 0 0 1];
Tx_a1=[1 0 0 l1;0 1 0 0;0 0 1 0;0 0 0 1];

A_1=Rz_theta1*Tz_d1*Tx_a1*Rx_alpha1

%%second A matrix A_2
Rz_theta2=[cosd(theta2+90) -sind(theta2+90) 0 0;sind(theta2+90)
 cosd(theta2+90) 0 0;0 0 1 0;0 0 0 1];
Rx_alpha2=[1 0 0 0;0 cosd(alpha2) -sind(alpha2) 0;0 sind(alpha2)
 cosd(alpha2) 0;0 0 0 1];
Tz_d2=[1 0 0 0;0 1 0 0;0 0 1 (0);0 0 0 1];
Tx_a2=[1 0 0 a2;0 1 0 0;0 0 1 0;0 0 0 1];

A_2=Rz_theta2*Tz_d2*Tx_a2*Rx_alpha2

%%third A matrix A_3
Rz_theta3=[cosd(0) -sind(0) 0 0;sind(0) cosd(0) 0 0;0 0 1 0;0 0 0 1];
Rx_alpha3=[1 0 0 0;0 cosd(alpha3) -sind(alpha3) 0;0 sind(alpha3)
 cosd(alpha3) 0;0 0 0 1];
```

```
Tz_d3=[1 0 0 0;0 1 0 0;0 0 1 (l2);0 0 0 1];
Tx_a3=[1 0 0 a3;0 1 0 0;0 0 1 0;0 0 0 1];

A_3=Rz_theta3*Tz_d3*Tx_a3*Rx_alpha3

%%fourth A matrix A_4
Rz_theta4=[cosd(theta3+90) -sind(theta3+90) 0 0;sind(theta3+90)
 cosd(theta3+90) 0 0;0 0 1 0;0 0 0 1];
Rx_alpha4=[1 0 0 0;0 cosd(alpha4) -sind(alpha4) 0;0 sind(alpha4)
 cosd(alpha4) 0;0 0 0 1];
Tz_d4=[1 0 0 0;0 1 0 0;0 0 1 (l3);0 0 0 1];
Tx_a4=[1 0 0 a4;0 1 0 0;0 0 1 0;0 0 0 1];

A_4=Rz_theta4*Tz_d4*Tx_a4*Rx_alpha4

%%fifth A matriX A_5
Rz_theta5=[cosd(theta5) -sind(theta5) 0 0;sind(theta5) cosd(theta5) 0
 0;0 0 1 0;0 0 0 1];
Rx_alpha5=[1 0 0 0;0 cosd(alpha5) -sind(alpha5) 0;0 sind(alpha5)
 cosd(alpha5) 0;0 0 0 1];
Tz_d5=[1 0 0 0;0 1 0 0;0 0 1 (l4);0 0 0 1];
Tx_a5=[1 0 0 a5;0 1 0 0;0 0 1 0;0 0 0 1];

A_5=Rz_theta5*Tz_d5*Tx_a5*Rx_alpha5

%%FINDING HOMOGENEOUS, ROTATION MATRICES AND ORIGINS FOR JACOBIAN
 CALCULATION
%%JOINT 1
H_1_0=A_1 %%Homogeneous Matrix for Joint 1
R_1_0=H_1_0(1:3,1:3) %%Rotation matrix for Joint 1
O_1_0=H_1_0(1:3,4); %%Origin for matrix 1
%%JOINT 2
H_2_0=A_1*A_2*A_3 %%Homogeneous Matrix for Joint 2
R_2_0=H_2_0(1:3,1:3) %%Rotation matrix for Joint 2
O_2_0=H_2_0(1:3,4); %%Origin for matrix 2
%%JOINT 3
H_3_0=A_1*A_2*A_3*A_4 %%Homogeneous Matrix for Joint 3
R_3_0=H_3_0(1:3,1:3)  %%Rotation matrix for Joint 3
O_3_0=H_3_0(1:3,4); %%Origin for matrix 3
%%JOINT 4
H_4_0=A_1*A_2*A_3*A_4*A_5  %%Homogeneous Matrix for Joint 4
R_4_0=H_4_0(1:3,1:3) %%Rotation matrix for Joint 4
O_4_0=H_4_0(1:3,4); %%Origin for matrix 4

fprintf("Answer B: ")
fprintf("The o matrices are given here :  ")
O_1_0=H_1_0(1:3,4)
O_2_0=H_2_0(1:3,4)
O_3_0=H_3_0(1:3,4)
O_4_0=H_4_0(1:3,4)
fprintf("The z matrices are given below : ")
z1=R_1_0*[0 0 1]' %%z1 matrix for jacobian calculation
z2=R_2_0*[0 0 1]' %%z2 matrix for jacobian calculation
z3=R_3_0*[0 0 1]' %%z3 matrix for jacobian calculation
```

```
fprintf("Answer C: ")
%%substituting the values of l given in the question
l1=3;
l2=2;
l3=1;
%%substituting the values  of theta given in the question
theta1=0;
theta2=45;
theta3=30;
l4=0.5;
%%substituting the values of a
a2=0;
a3=0;
a4=0;
a5=0;
%%substituting the values of alpha
alpha1=-90;
alpha2=90;
alpha3=0;
alpha4=90;
alpha5=0;
%%substituting the values of theta
theta5=90;

%%The general form of the matrices are obtained by multiplying the
%%following

%%first A matrix
Rz_theta1=[cosd(theta1) -sind(theta1) 0 0;sind(theta1) cosd(theta1) 0
 0;0 0 1 0;0 0 0 1];
Rx_alpha1=[1 0 0 0;0 cosd(alpha1) -sind(alpha1) 0;0 sind(alpha1)
 cosd(alpha1) 0;0 0 0 1];
Tz_d1=[1 0 0 0;0 1 0 0;0 0 1 (0);0 0 0 1];
Tx_a1=[1 0 0 l1;0 1 0 0;0 0 1 0;0 0 0 1];

%%second A matrix
Rz_theta2=[cosd(theta2+90) -sind(theta2+90) 0 0;sind(theta2+90)
 cosd(theta2+90) 0 0;0 0 1 0;0 0 0 1];
Rx_alpha2=[1 0 0 0;0 cosd(alpha2) -sind(alpha2) 0;0 sind(alpha2)
 cosd(alpha2) 0;0 0 0 1];
Tz_d2=[1 0 0 0;0 1 0 0;0 0 1 (0);0 0 0 1];
Tx_a2=[1 0 0 a2;0 1 0 0;0 0 1 0;0 0 0 1];

%%third A matrix
Rz_theta3=[cosd(0) -sind(0) 0 0;sind(0) cosd(0) 0 0;0 0 1 0;0 0 0 1];
Rx_alpha3=[1 0 0 0;0 cosd(alpha3) -sind(alpha3) 0;0 sind(alpha3)
 cosd(alpha3) 0;0 0 0 1];
Tz_d3=[1 0 0 0;0 1 0 0;0 0 1 (l2);0 0 0 1];
Tx_a3=[1 0 0 a3;0 1 0 0;0 0 1 0;0 0 0 1];

%%fourth A matrix
Rz_theta4=[cosd(theta3+90) -sind(theta3+90) 0 0;sind(theta3+90)
 cosd(theta3+90) 0 0;0 0 1 0;0 0 0 1];
```

```
Rx_alpha4=[1 0 0 0;0 cosd(alpha4) -sind(alpha4) 0;0 sind(alpha4)
 cosd(alpha4) 0;0 0 0 1];
Tz_d4=[1 0 0 0;0 1 0 0;0 0 1 (l3);0 0 0 1];
Tx_a4=[1 0 0 a4;0 1 0 0;0 0 1 0;0 0 0 1];

%%fifth A matrix
Rz_theta5=[cosd(theta5) -sind(theta5) 0 0;sind(theta5) cosd(theta5) 0
 0;0 0 1 0;0 0 0 1];
Rx_alpha5=[1 0 0 0;0 cosd(alpha5) -sind(alpha5) 0;0 sind(alpha5)
 cosd(alpha5) 0;0 0 0 1];
Tz_d5=[1 0 0 0;0 1 0 0;0 0 1 (l4);0 0 0 1];
Tx_a5=[1 0 0 a5;0 1 0 0;0 0 1 0;0 0 0 1];

%%Matrix multiplicaion
A_1=Rz_theta1*Tz_d1*Tx_a1*Rx_alpha1
A_2=Rz_theta2*Tz_d2*Tx_a2*Rx_alpha2
A_3=Rz_theta3*Tz_d3*Tx_a3*Rx_alpha3
A_4=Rz_theta4*Tz_d4*Tx_a4*Rx_alpha4
A_5=Rz_theta5*Tz_d5*Tx_a5*Rx_alpha5
%%Multipltying to get the T matrix we get

%%REVOLUTE MATRICES FOR JACOBIAN CALCULATION
%%JOINT 1
O_0_0=[0 0 0]'
H_1_0=A_1
R_1_0=H_1_0(1:3,1:3)
O_1_0=H_1_0(1:3,4)
%%JOINT 2
H_2_0=A_1*A_2*A_3
R_2_0=H_2_0(1:3,1:3)
O_2_0=H_2_0(1:3,4)
%%JOINT 3
H_3_0=A_1*A_2*A_3*A_4
R_3_0=H_3_0(1:3,1:3)
O_3_0=H_3_0(1:3,4)
%%JOINT 4
H_4_0=A_1*A_2*A_3*A_4*A_5
R_4_0=H_4_0(1:3,1:3)
O_4_0=H_4_0(1:3,4)

z0=eye(3)*[0 0 1]'
z1=R_1_0*[0 0 1]'
z2=R_2_0*[0 0 1]'
z3=R_3_0*[0 0 1]'

%%taking cross products of the vectors and calculating the Jacobian
 Matrix
q_dot=[3,4,5,0.5]'%given in the question
Jacobian=[cross(z0,O_4_0-O_0_0) cross(z1,O_4_0-O_1_0) cross(z2,O_4_0-
O_2_0) z3;z0 z1 z2 [0 0 0]']
velocity_vectors=Jacobian*q_dot
```

A_1 =

```
[ cos((pi*theta1)/180),  0, -sin((pi*theta1)/180),
 l1*cos((pi*theta1)/180)]
[ sin((pi*theta1)/180),  0,  cos((pi*theta1)/180),
 l1*sin((pi*theta1)/180)]
[                    0, -1,                     0,
    0]
[                    0,  0,                     0,
    1]


A_2 =

[ cos((pi*(theta2 + 90))/180), 0,  sin((pi*(theta2 + 90))/180), 0]
[ sin((pi*(theta2 + 90))/180), 0, -cos((pi*(theta2 + 90))/180), 0]
[                           0, 1,                            0, 0]
[                           0, 0,                            0, 1]


A_3 =

[ 1, 0, 0,  0]
[ 0, 1, 0,  0]
[ 0, 0, 1, l2]
[ 0, 0, 0,  1]


A_4 =

[ cos((pi*(theta3 + 90))/180), 0,  sin((pi*(theta3 + 90))/180),  0]
[ sin((pi*(theta3 + 90))/180), 0, -cos((pi*(theta3 + 90))/180),  0]
[                           0, 1,                            0, l3]
[                           0, 0,                            0,  1]


A_5 =

[ 0, -1, 0,  0]
[ 1,  0, 0,  0]
[ 0,  0, 1, l4]
[ 0,  0, 0,  1]


H_1_0 =

[ cos((pi*theta1)/180),  0, -sin((pi*theta1)/180),
 l1*cos((pi*theta1)/180)]
[ sin((pi*theta1)/180),  0,  cos((pi*theta1)/180),
 l1*sin((pi*theta1)/180)]
[                    0, -1,                     0,
    0]
[                    0,  0,                     0,
    1]
```

```
R_1_0 =

[ cos((pi*theta1)/180),  0, -sin((pi*theta1)/180)]
[ sin((pi*theta1)/180),  0,  cos((pi*theta1)/180)]
[                    0, -1,                     0]


H_2_0 =

[ cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180), -
sin((pi*theta1)/180), cos((pi*theta1)/180)*sin((pi*(theta2
 + 90))/180), l1*cos((pi*theta1)/180) +
 l2*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)]
[ sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180),
 cos((pi*theta1)/180), sin((pi*theta1)/180)*sin((pi*(theta2
 + 90))/180), l1*sin((pi*theta1)/180) +
 l2*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)]
[                      -sin((pi*(theta2 + 90))/180),
  0,                      cos((pi*(theta2 + 90))/180),
                                l2*cos((pi*(theta2 + 90))/180)]
[                                                 0,
  0,                                                 0,
                                                             1]


R_2_0 =

[ cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180), -
sin((pi*theta1)/180), cos((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180)]
[ sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180),
 cos((pi*theta1)/180), sin((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180)]
[                      -sin((pi*(theta2 + 90))/180),
  0,                      cos((pi*(theta2 + 90))/180)]


H_3_0 =

[ cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180) - sin((pi*theta1)/180)*sin((pi*(theta3
 + 90))/180), cos((pi*theta1)/180)*sin((pi*(theta2
 + 90))/180), sin((pi*theta1)/180)*cos((pi*(theta3 +
 90))/180) + cos((pi*theta1)/180)*cos((pi*(theta2 +
 90))/180)*sin((pi*(theta3 + 90))/180), l1*cos((pi*theta1)/180)
 + l2*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180) +
 l3*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)]
[ cos((pi*theta1)/180)*sin((pi*(theta3 + 90))/180) +
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180), sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3
 + 90))/180) - cos((pi*theta1)/180)*cos((pi*(theta3 + 90))/180),
```

```
 l1*sin((pi*theta1)/180) + l2*sin((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180) + l3*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)]
[
      -cos((pi*(theta3 + 90))/180)*sin((pi*(theta2 + 90))/180),
                  cos((pi*(theta2 + 90))/180),
                                                  -sin((pi*(theta2 +
 90))/180)*sin((pi*(theta3 + 90))/180),
                                      l2*cos((pi*(theta2 + 90))/180) +
 l3*cos((pi*(theta2 + 90))/180)]
[
                                                          0,
                                      0,

                           0,

                    1]


R_3_0 =

[ cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180) - sin((pi*theta1)/180)*sin((pi*(theta3 +
 90))/180), cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
 sin((pi*theta1)/180)*cos((pi*(theta3 + 90))/180) +
 cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3 +
 90))/180)]
[ cos((pi*theta1)/180)*sin((pi*(theta3 + 90))/180) +
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180), sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3 +
 90))/180) - cos((pi*theta1)/180)*cos((pi*(theta3 + 90))/180)]
[
      -cos((pi*(theta3 + 90))/180)*sin((pi*(theta2 + 90))/180),
                  cos((pi*(theta2 + 90))/180),
                                                  -sin((pi*(theta2 +
 90))/180)*sin((pi*(theta3 + 90))/180)]


H_4_0 =

[ cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
  sin((pi*theta1)/180)*sin((pi*(theta3 + 90))/180) -
 cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180), sin((pi*theta1)/180)*cos((pi*(theta3 +
 90))/180) + cos((pi*theta1)/180)*cos((pi*(theta2 +
 90))/180)*sin((pi*(theta3 + 90))/180), l1*cos((pi*theta1)/180)
 + l4*(sin((pi*theta1)/180)*cos((pi*(theta3 + 90))/180) +
 cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3 +
 90))/180)) + l2*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180) +
 l3*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)]
[ sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
 - cos((pi*theta1)/180)*sin((pi*(theta3 + 90))/180) -
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180), sin((pi*theta1)/180)*cos((pi*(theta2
```

```
 + 90))/180)*sin((pi*(theta3 + 90))/180) -
 cos((pi*theta1)/180)*cos((pi*(theta3 + 90))/180),
 l1*sin((pi*theta1)/180) - l4*(cos((pi*theta1)/180)*cos((pi*(theta3
 + 90))/180) - sin((pi*theta1)/180)*cos((pi*(theta2
 + 90))/180)*sin((pi*(theta3 + 90))/180)) +
 l2*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180) +
 l3*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)]
[                       cos((pi*(theta2 + 90))/180),

 cos((pi*(theta3 + 90))/180)*sin((pi*(theta2 + 90))/180),
                                                                  -
sin((pi*(theta2 + 90))/180)*sin((pi*(theta3 + 90))/180),


 l2*cos((pi*(theta2 + 90))/180) + l3*cos((pi*(theta2 + 90))/180) -
 l4*sin((pi*(theta2 + 90))/180)*sin((pi*(theta3 + 90))/180)]
[                                                    0,

                                            0,

                                 0,



                     1]


R_4_0 =

[ cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
  sin((pi*theta1)/180)*sin((pi*(theta3 + 90))/180) -
 cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180), sin((pi*theta1)/180)*cos((pi*(theta3 + 90))/180) +
 cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3 +
 90))/180)]
[ sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180),
 - cos((pi*theta1)/180)*sin((pi*(theta3 + 90))/180) -
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*cos((pi*(theta3
 + 90))/180), sin((pi*theta1)/180)*cos((pi*(theta2
 + 90))/180)*sin((pi*(theta3 + 90))/180) -
 cos((pi*theta1)/180)*cos((pi*(theta3 + 90))/180)]
[                       cos((pi*(theta2 + 90))/180),

 cos((pi*(theta3 + 90))/180)*sin((pi*(theta2 + 90))/180),
                                                                  -
sin((pi*(theta2 + 90))/180)*sin((pi*(theta3 + 90))/180)]

Answer B: The o matrices are given here :
O_1_0 =

 l1*cos((pi*theta1)/180)
 l1*sin((pi*theta1)/180)
                       0
```

```
O_2_0 =

 l1*cos((pi*theta1)/180) + l2*cos((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180)
 l1*sin((pi*theta1)/180) + l2*sin((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180)
                                                     l2*cos((pi*(theta2 +
 90))/180)


O_3_0 =

 l1*cos((pi*theta1)/180) + l2*cos((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180) + l3*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)
 l1*sin((pi*theta1)/180) + l2*sin((pi*theta1)/180)*sin((pi*(theta2 +
 90))/180) + l3*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)

 l2*cos((pi*(theta2 + 90))/180) + l3*cos((pi*(theta2 + 90))/180)


O_4_0 =

 l1*cos((pi*theta1)/180) + l4*(sin((pi*theta1)/180)*cos((pi*(theta3
 + 90))/180) + cos((pi*theta1)/180)*cos((pi*(theta2
 + 90))/180)*sin((pi*(theta3 + 90))/180)) +
 l2*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180) +
 l3*cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)
 l1*sin((pi*theta1)/180) - l4*(cos((pi*theta1)/180)*cos((pi*(theta3
 + 90))/180) - sin((pi*theta1)/180)*cos((pi*(theta2
 + 90))/180)*sin((pi*(theta3 + 90))/180)) +
 l2*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180) +
 l3*sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)


    l2*cos((pi*(theta2 + 90))/180) + l3*cos((pi*(theta2 + 90))/180) -
 l4*sin((pi*(theta2 + 90))/180)*sin((pi*(theta3 + 90))/180)

The z matrices are given below :
z1 =

 -sin((pi*theta1)/180)
  cos((pi*theta1)/180)
                     0


z2 =

 cos((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)
 sin((pi*theta1)/180)*sin((pi*(theta2 + 90))/180)
                      cos((pi*(theta2 + 90))/180)


z3 =
```

```
 sin((pi*theta1)/180)*cos((pi*(theta3 + 90))/180) +
 cos((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3 +
 90))/180)
 sin((pi*theta1)/180)*cos((pi*(theta2 + 90))/180)*sin((pi*(theta3 +
 90))/180) - cos((pi*theta1)/180)*cos((pi*(theta3 + 90))/180)

  -sin((pi*(theta2 + 90))/180)*sin((pi*(theta3 + 90))/180)

Answer C:
A_1 =

     1     0     0     3
     0     0     1     0
     0    -1     0     0
     0     0     0     1


A_2 =

   -0.7071         0    0.7071         0
    0.7071         0    0.7071         0
         0    1.0000         0         0
         0         0         0    1.0000


A_3 =

     1     0     0     0
     0     1     0     0
     0     0     1     2
     0     0     0     1


A_4 =

   -0.5000         0    0.8660         0
    0.8660         0    0.5000         0
         0    1.0000         0    1.0000
         0         0         0    1.0000


A_5 =

         0   -1.0000         0         0
    1.0000         0         0         0
         0         0    1.0000    0.5000
         0         0         0    1.0000


O_0_0 =

     0
     0
```

```
     0


H_1_0 =

     1     0     0     3
     0     0     1     0
     0    -1     0     0
     0     0     0     1


R_1_0 =

     1     0     0
     0     0     1
     0    -1     0


O_1_0 =

     3
     0
     0


H_2_0 =

   -0.7071         0    0.7071    4.4142
         0    1.0000         0         0
   -0.7071         0   -0.7071   -1.4142
         0         0         0    1.0000


R_2_0 =

   -0.7071         0    0.7071
         0    1.0000         0
   -0.7071         0   -0.7071


O_2_0 =

    4.4142
         0
   -1.4142


H_3_0 =

    0.3536    0.7071   -0.6124    5.1213
    0.8660         0    0.5000         0
    0.3536   -0.7071   -0.6124   -2.1213
         0         0         0    1.0000
```

```
R_3_0 =

    0.3536    0.7071   -0.6124
    0.8660         0    0.5000
    0.3536   -0.7071   -0.6124


O_3_0 =

    5.1213
         0
   -2.1213


H_4_0 =

    0.7071   -0.3536   -0.6124    4.8151
         0   -0.8660    0.5000    0.2500
   -0.7071   -0.3536   -0.6124   -2.4275
         0         0         0    1.0000


R_4_0 =

    0.7071   -0.3536   -0.6124
         0   -0.8660    0.5000
   -0.7071   -0.3536   -0.6124


O_4_0 =

    4.8151
    0.2500
   -2.4275


z0 =

     0
     0
     1


z1 =

     0
     1
     0


z2 =

    0.7071
```

```
         0
   -0.7071


z3 =

   -0.6124
    0.5000
   -0.6124


q_dot =

    3.0000
    4.0000
    5.0000
    0.5000


Jacobian =

   -0.2500   -2.4275    0.1768   -0.6124
    4.8151         0    0.4330    0.5000
         0   -1.8151    0.1768   -0.6124
         0         0    0.7071         0
         0    1.0000         0         0
    1.0000         0   -0.7071         0


velocity_vectors =

   -9.8823
   16.8605
   -6.6828
    3.5355
    4.0000
   -0.5355
```

Published with MATLAB® R2018a