Homework 5, Exercise 5.25

```
% David Lim
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% 02/18/25

clear
% Add path to MR functions
addpath /Users/davidlim/Documents/ModernRobotics/packages/MATLAB/mr;

% Define fixed parameters
W1 = 0.109;
W2 = 0.082;
L1 = 0.425;
L2 = 0.392;
H1 = 0.089;
H2 = 0.095;

% Define variable parameters
theta1 = pi/2;
theta2 = theta1;
theta3 = theta1;
theta4 = theta1;
theta5 = theta1;
theta6 = theta1;

% Define screw axes in {s} frame
S1 = [0 0 1 0 0 0]';
S2 = [0 1 0 -H1 0 0]';
S3 = [0 1 0 -H1 0 L1]';
S4 = [0 1 0 -H1 0 L1+L2]';
S5 = [0 0 -1 -W1 L1+L2 0]';
S6 = [0 1 0 H2-H1 0 L1+L2]';
```

(a) Compute space Jacobian

```
Js1 = S1;
Js2 = Adjoint(MatrixExp6(VecTose3(S1*theta1)))*S2;
Js3 = Adjoint(MatrixExp6(VecTose3(S1*theta1))*...
    MatrixExp6(VecTose3(S2*theta2)))*S3;
Js4 = Adjoint(MatrixExp6(VecTose3(S1*theta1))*...
    MatrixExp6(VecTose3(S2*theta2))*...
    MatrixExp6(VecTose3(S3*theta3)))*S4;
Js5 = Adjoint(MatrixExp6(VecTose3(S1*theta1))*...
    MatrixExp6(VecTose3(S2*theta2))*...
    MatrixExp6(VecTose3(S3*theta3))*...
    MatrixExp6(VecTose3(S4*theta4)))*S5;
Js6 = Adjoint(MatrixExp6(VecTose3(S1*theta1))*...
    MatrixExp6(VecTose3(S2*theta2))*...
    MatrixExp6(VecTose3(S3*theta3))*...
    MatrixExp6(VecTose3(S4*theta4))*...
    MatrixExp6(VecTose3(S5*theta5)))*S6;
```

```
Js = [Js1 Js2 Js3 Js4 Js5 Js6];
Jw = Js(1:3,:);
Jv = Js(4:6,:);

disp(round(Js,12))
disp(' ')
disp(round(Jw,12))
disp(' ')
disp(round(Jv,12))
disp(' ')
```

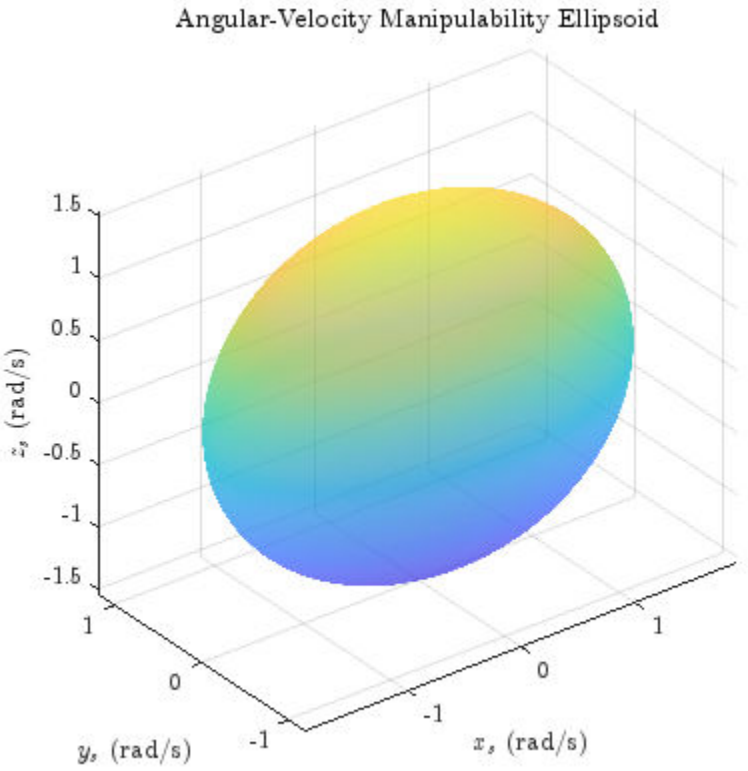
```
         0   -1.0000   -1.0000   -1.0000         0         0
         0         0         0         0    1.0000         0
    1.0000         0         0         0         0    1.0000
         0         0         0         0    0.3360   -0.2970
         0   -0.0890    0.3360    0.3360         0    0.1090
         0         0         0   -0.3920   -0.1090         0

     0    -1    -1    -1     0     0
     0     0     0     0     1     0
     1     0     0     0     0     1

         0         0         0         0    0.3360   -0.2970
         0   -0.0890    0.3360    0.3360         0    0.1090
         0         0         0   -0.3920   -0.1090         0
```

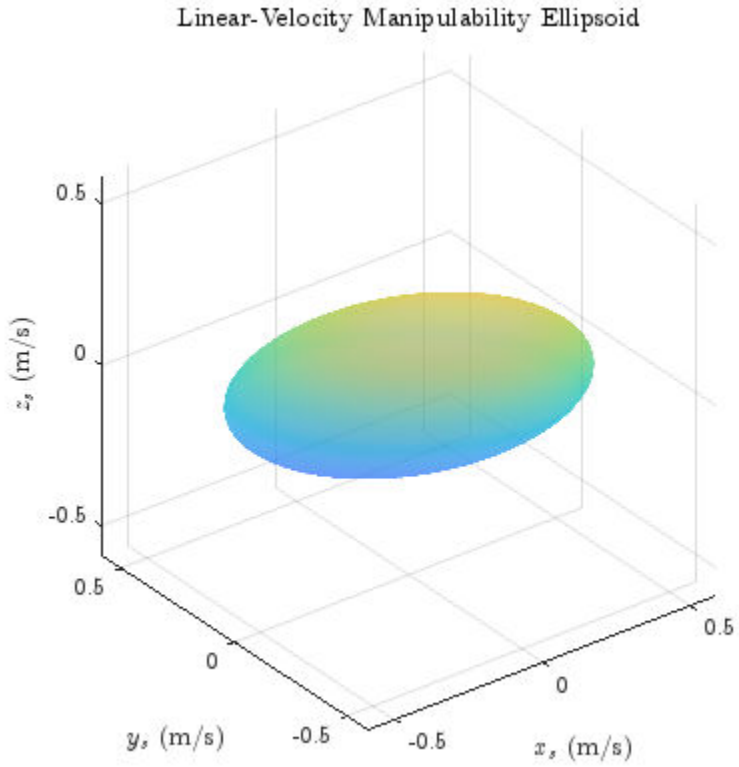
(b) Compute velocity manipulability ellipsoids

```
Aw = Jw*Jw';
Av = Jv*Jv';

[Vw,Dw] = eig(Aw);
[Vv,Dv] = eig(Av);

disp(Vw)
disp(' ')
disp(sqrt(Dw))
disp(' ')
disp(Vv)
disp(' ')
disp(sqrt(Dv))
disp(' ')

syms qx qy qz real

figure(1)
fimplicit3([qx; qy; qz]'*Aw^-1*[qx; qy;
qz]==1,'EdgeColor','none','FaceAlpha',0.5)
xlabel('$$x_s$$ (rad/s)','Interpreter','latex')
ylabel('$$y_s$$ (rad/s)','Interpreter','latex')
zlabel('$$z_s$$ (rad/s)','Interpreter','latex')
```

```
title('Angular-Velocity Manipulability Ellipsoid','Interpreter','latex')
set(gca,'FontSize',12,'TickLabelInterpreter','latex')
axis equal

figure(2)
fimplicit3([qx; qy; qz]'*Av^-1*[qx; qy;
qz]==1,'EdgeColor','none','FaceAlpha',0.5)
xlabel('$$x_s$$ (m/s)','Interpreter','latex')
ylabel('$$y_s$$ (m/s)','Interpreter','latex')
zlabel('$$z_s$$ (m/s)','Interpreter','latex')
title('Linear-Velocity Manipulability Ellipsoid','Interpreter','latex')
set(gca,'FontSize',12,'TickLabelInterpreter','latex')
axis equal
```

```
     0     0     1
     1     0     0
     0     1     0

    1.0000         0         0
         0    1.4142         0
         0         0    1.7321

    0.3106    0.9500   -0.0314
    0.5696   -0.1596    0.8062
    0.7609   -0.2683   -0.5907

    0.2280         0         0
         0    0.4657         0
         0         0    0.5860
```

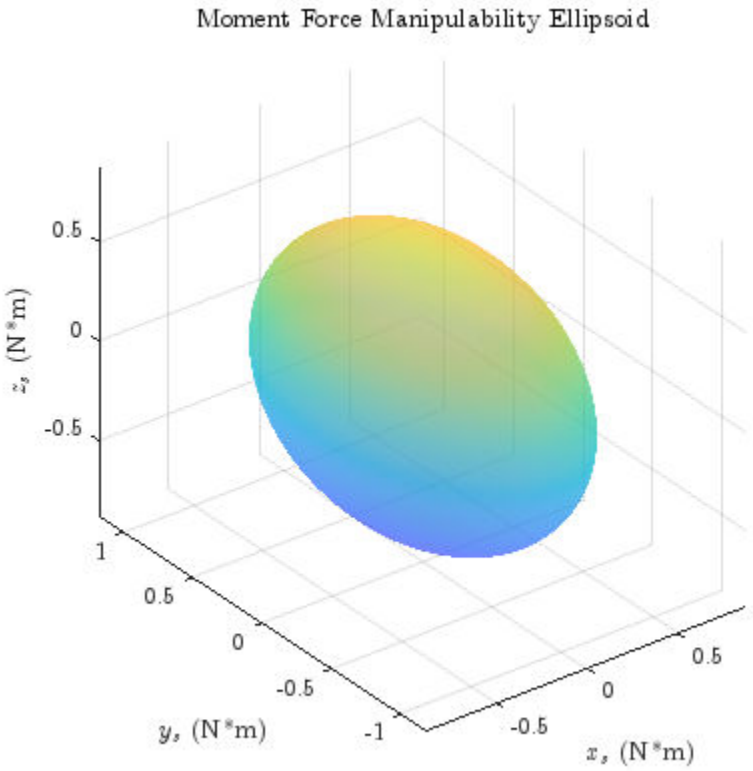

Angular-Velocity Manipulability Ellipsoid
1.5
1
0.5
0
-0.5
-1
-1.5
z_s (rad/s)
1
0
-1
y_s (rad/s)
1
0
-1
x_s (rad/s)

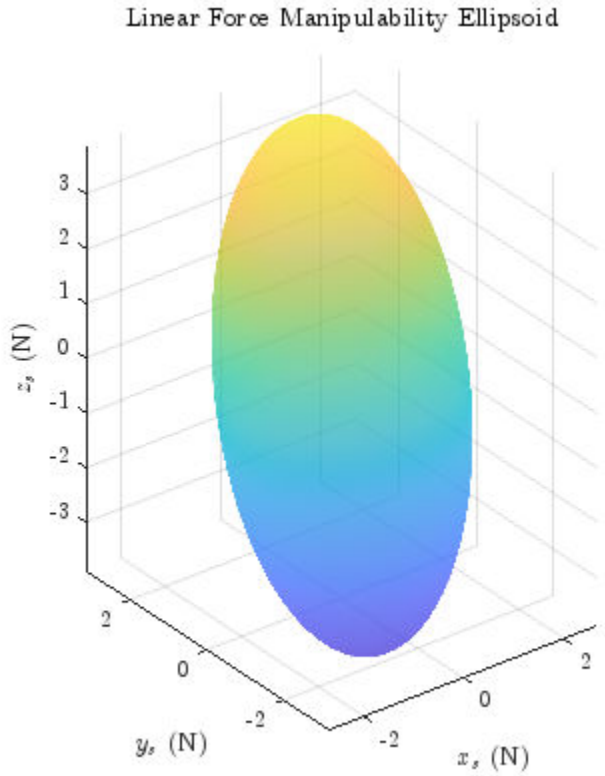

Linear-Velocity Manipulability Ellipsoid
0.5
0
-0.5
z_s (m/s)
0.5
0
-0.5
y_s (m/s)
0.5
0
-0.5
x_s (m/s)

(c) Compute force ellipsoids

```
Bw = Aw^-1;
Bv = Av^-1;

[Vw,Dw] = eig(Bw);
[Vv,Dv] = eig(Bv);

disp(Vw)
disp(' ')
disp(sqrt(Dw))
disp(' ')
disp(Vv)
disp(' ')
disp(sqrt(Dv))
disp(' ')

figure(3)
fimplicit3([qx; qy; qz]'*Bw^-1*[qx; qy;
qz]==1,'EdgeColor','none','FaceAlpha',0.5)
xlabel('$$x_s$$ (N*m)','Interpreter','latex')
ylabel('$$y_s$$ (N*m)','Interpreter','latex')
zlabel('$$z_s$$ (N*m)','Interpreter','latex')
title('Moment Force Manipulability Ellipsoid','Interpreter','latex')
set(gca,'FontSize',12,'TickLabelInterpreter','latex')
axis equal

figure(4)
fimplicit3([qx; qy; qz]'*Bv^-1*[qx; qy;
qz]==1,'EdgeColor','none','FaceAlpha',0.5)
xlabel('$$x_s$$ (N)','Interpreter','latex')
ylabel('$$y_s$$ (N)','Interpreter','latex')
zlabel('$$z_s$$ (N)','Interpreter','latex')
title('Linear Force Manipulability Ellipsoid','Interpreter','latex')
set(gca,'FontSize',12,'TickLabelInterpreter','latex')
axis equal
```

```
    1.0000         0   -0.0000
         0         0    1.0000
         0    1.0000         0

    0.5774         0         0
         0    0.7071         0
         0         0    1.0000

   -0.0314    0.9500    0.3106
    0.8062   -0.1596    0.5696
   -0.5907   -0.2683    0.7609

    1.7066         0         0
         0    2.1473         0
         0         0    4.3854
```


Moment Force Manipulability Ellipsoid
0.5
0
-0.5
z, (N*m)
1
0.5
0
-0.5
-1
y, (N*m)
0.5
0
-0.5
x, (N*m)


Linear Force Manipulability Ellipsoid
3
2
1
0
-1
-2
-3
z, (N)
2
0
-2
y, (N)
2
0
-2
x, (N)

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