Template of Manipulator Short project: Skull tumor surgery

Authors: Ana Siesto Pérez and Xavier Marti Llull

Team: G11-A

Shared Link with the teacher: https://drive.matlab.com/sharing/5ad6e326-a326-4433-8939-c068f5f932cd

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The Robotic environment (10%)

Think that later on the enviroment will move to any place in a Univers Reference Frame {U}

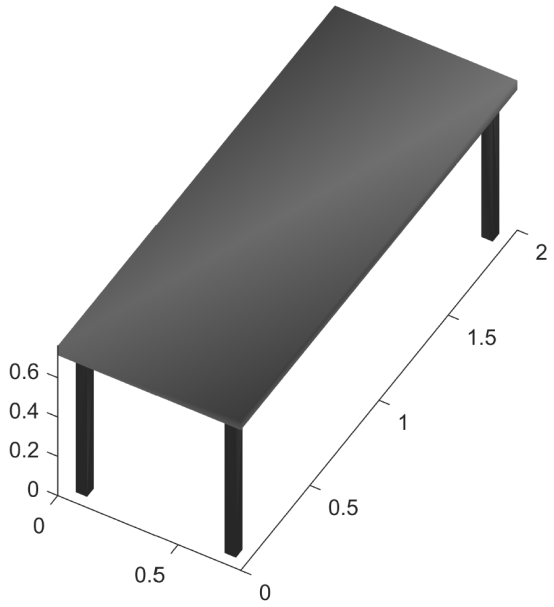
Use: 'c = uisetcolor' to chose your prefered colors

Operating table

It can be raised, lowered, and tilted in any direction, and an auxiliary table for the tools. Define: Vertices and Faces and use 'patch' functions to model it. See help patch to find and example.

Think that later on the enviroment will move to any place in a Univers Reference Frame {U}

Expected results



Cube of reference

```
% In this section of code we represent the cube that we will use as reference to create all the
clear
close all
clf
v_cubo = [0 0 0; 1 0 0; 1 1 0; 0 1 0; 0 0 1; 1 0 1; 1 1 1; 0 1 1]
```

```
v_cubo = 8×3
     0     0     0
     1     0     0
```

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

```
f = [1 2 6 5; 2 3 7 6; 3 4 8 7; 4 1 5 8; 1 2 3 4; 5 6 7 8]
```

```
f = 6×4
     1     2     6     5
     2     3     7     6
     3     4     8     7
     4     1     5     8
     1     2     3     4
     5     6     7     8
```

```
patch('Vertices', v_cubo, 'Faces', f, 'FaceVertexCData', hsv(6), 'FaceColor', 'black', 'FaceAlp
view(30, 45)
axis equal
```

Creating the top of the table

```
% We create all the parts by scaling propperly the initial cube and then we represent
% them separately
H = 2     % x
```

```
H = 2
```

```
W = 0.9   % y
```

```
W = 0.9000
```

```
D = 0.08  % z
```

```
D = 0.0800
```

```
v_tabla = [H 0 0;0 W 0;0 0 D]*v_cubo'
```

```
v_tabla = 3×8
         0    2.0000    2.0000         0         0    2.0000    2.0000         0
         0         0    0.9000    0.9000         0         0    0.9000    0.9000
         0         0         0         0    0.0800    0.0800    0.0800    0.0800
```

```
figure
patch('Vertices',v_tabla(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','FaceAl
grid on
xyzlabel
axis equal
view(3)
```

Creating the table's legs

```
H = 0.1  % x
```

```
H = 0.1000
```

```
W = 0.1  % y
```

```
W = 0.1000
```

```
D = 0.8  % z
```

```
D = 0.8000
```

```
v_pata = [H 0 0;0 W 0;0 0 D]*v_cubo'
```

```
v_pata = 3×8
         0    0.1000    0.1000         0         0    0.1000    0.1000         0
         0         0    0.1000    0.1000         0         0    0.1000    0.1000
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
```

```
figure
patch('Vertices',v_pata(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','FaceAlp
view(3)
xyzlabel
axis equal
```

Creating a representation of the human body

```
H = 1.6 % x
```

```
H = 1.6000
```

```
W = 0.6 % y
```

```
W = 0.6000
```

```
D = 0.2 % z
```

```
D = 0.2000
```

```
v_torso = [H 0 0;0 W 0;0 0 D]*v_cubo'
```

```
v_torso = 3×8
         0    1.6000    1.6000         0         0    1.6000    1.6000         0
         0         0    0.6000    0.6000         0         0    0.6000    0.6000
         0         0         0         0    0.2000    0.2000    0.2000    0.2000
```

```
figure
patch('Vertices',v_torso(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',[0.95,0.87,0.7
view(3)
xyzlabel
axis equal
```

Creating a representation of the human skull

```
H = 0.15 % x
```

```
H = 0.1500
```

```
W = 0.20 % y
```

```
W = 0.2000
```

```
D = 0.17 % z
```

```
D = 0.1700
```

```
v_craneo = [H 0 0;0 W 0;0 0 D]*v_cubo'
```

```
v_craneo = 3×8
         0    0.1500    0.1500         0         0    0.1500    0.1500         0
         0         0    0.2000    0.2000         0         0    0.2000    0.2000
         0         0         0         0    0.1700    0.1700    0.1700    0.1700
```

```
figure
patch('Vertices',v_craneo(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',[0.89,0.77,0.5
view(30,45)
xyzlabel
axis equal
```

Creating a tools table

```
H = 0.3   % x
```

```
H = 0.3000
```

```
W = 0.3   % y
```

```
W = 0.3000
```

```
D = 0.08  % z
```

```
D = 0.0800
```

```
v_tablaherramientas = [H 0 0;0 W 0;0 0 D]*v_cubo'
```

```
v_tablaherramientas = 3×8
         0    0.3000    0.3000         0         0    0.3000    0.3000         0
         0         0    0.3000    0.3000         0         0    0.3000    0.3000
         0         0         0         0    0.0800    0.0800    0.0800    0.0800
```

```
figure
patch('Vertices',v_tablaherramientas(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','bl
grid on
xyzlabel
axis equal
view(3)
```

Transformations

```
close all
% We move the top of the table to (-0.3, -0.5, 0.8) and then we rotate the
% z axis 60º. Then, we situate all the other elements in function of this and
% take advantage of T_table_0 to represent them with respect to the origin.
T_tabla_0 = transl(-0.3,-0.5,0.8)*trotz(pi/3) % IF YOU WANNA MOVE THE WHOLE SCENE CHANGE THIS I
```

```
T_tabla_0 = 4×4
    0.5000   -0.8660         0   -0.3000
    0.8660    0.5000         0   -0.5000
```

```
         0         0    1.0000    0.8000
         0         0         0    1.0000
```

```
T_pata1_tabla = transl(0.05,0.05,-0.8)
```

```
T_pata1_tabla = 4×4
    1.0000         0         0    0.0500
         0    1.0000         0    0.0500
         0         0    1.0000   -0.8000
         0         0         0    1.0000
```

```
T_pata1_0 = T_tabla_0*T_pata1_tabla
```

```
T_pata1_0 = 4×4
    0.5000   -0.8660         0   -0.3183
    0.8660    0.5000         0   -0.4317
         0         0    1.0000         0
         0         0         0    1.0000
```

```
T_pata2_tabla = transl(1.85,0.05,-0.8)
```

```
T_pata2_tabla = 4×4
    1.0000         0         0    1.8500
         0    1.0000         0    0.0500
         0         0    1.0000   -0.8000
         0         0         0    1.0000
```

```
T_pata2_0 = T_tabla_0*T_pata2_tabla
```

```
T_pata2_0 = 4×4
    0.5000   -0.8660         0    0.5817
    0.8660    0.5000         0    1.1271
         0         0    1.0000         0
         0         0         0    1.0000
```

```
T_pata3_tabla = transl(0.05,0.75,-0.8)
```

```
T_pata3_tabla = 4×4
    1.0000         0         0    0.0500
         0    1.0000         0    0.7500
         0         0    1.0000   -0.8000
         0         0         0    1.0000
```

```
T_pata3_0 = T_tabla_0*T_pata3_tabla
```

```
T_pata3_0 = 4×4
    0.5000   -0.8660         0   -0.9245
    0.8660    0.5000         0   -0.0817
         0         0    1.0000         0
         0         0         0    1.0000
```

```
T_pata4_tabla = transl(1.85,0.75,-0.8)
```

```
T_pata4_tabla = 4×4
    1.0000         0         0    1.8500
         0    1.0000         0    0.7500
         0         0    1.0000   -0.8000
         0         0         0    1.0000
```

```
T_pata4_0 = T_tabla_0*T_pata4_tabla
```

```
T_pata4_0 = 4×4
    0.5000   -0.8660         0   -0.0245
    0.8660    0.5000         0    1.4771
         0         0    1.0000         0
         0         0         0    1.0000
```

```
T_torso_tabla = transl(0.4,0.15,0.08)
```

```
T_torso_tabla = 4×4
    1.0000         0         0    0.4000
         0    1.0000         0    0.1500
         0         0    1.0000    0.0800
         0         0         0    1.0000
```

```
T_torso_0 = T_tabla_0*T_torso_tabla
```

```
T_torso_0 = 4×4
    0.5000   -0.8660         0   -0.2299
    0.8660    0.5000         0   -0.0786
         0         0    1.0000    0.8800
         0         0         0    1.0000
```

```
T_craneo_tabla = transl(2.1,0.35,0.08)
```

```
T_craneo_tabla = 4×4
    1.0000         0         0    2.1000
         0    1.0000         0    0.3500
         0         0    1.0000    0.0800
         0         0         0    1.0000
```

```
T_craneo_0 = T_tabla_0*T_craneo_tabla
```

```
T_craneo_0 = 4×4
    0.5000   -0.8660         0    0.4469
    0.8660    0.5000         0    1.4937
         0         0    1.0000    0.8800
         0         0         0    1.0000
```

```
T_tablaherramientas_tabla = transl(2.5,-0.5,0)
```

```
T_tablaherramientas_tabla = 4×4
    1.0000         0         0    2.5000
         0    1.0000         0   -0.5000
         0         0    1.0000         0
         0         0         0    1.0000
```

```
T_tablaherramientas_0 = T_tabla_0*T_tablaherramientas_tabla
```

```
T_tablaherramientas_0 = 4×4
    0.5000   -0.8660         0    1.3830
    0.8660    0.5000         0    1.4151
         0         0    1.0000    0.8000
         0         0         0    1.0000
```

```
T_pataherramientas_tablaherramientas = transl(0.1,0.1,-0.8)
```

```
T_pataherramientas_tablaherramientas = 4×4
    1.0000         0         0    0.1000
         0    1.0000         0    0.1000
         0         0    1.0000   -0.8000
         0         0         0    1.0000
```

```
T_pataherramientas_0 = T_tablaherramientas_0*T_pataherramientas_tablaherramientas
```

```
T_pataherramientas_0 = 4×4
    0.5000   -0.8660         0    1.3464
    0.8660    0.5000         0    1.5517
         0         0    1.0000         0
         0         0         0    1.0000
```

Operating vertices

```
% It's time to transform the vertexs of every part so they will be
% represented where corresponds. We also agroupate the different sets of
% vertices in a general vector so if we have to move the whole scene it
% will be more practical
v_tabla(4,:) = 1
```

```
v_tabla = 4×8
         0    2.0000    2.0000         0         0    2.0000    2.0000         0
         0         0    0.9000    0.9000         0         0    0.9000    0.9000
         0         0         0         0    0.0800    0.0800    0.0800    0.0800
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_tabla_0 = T_tabla_0*v_tabla
```

```
v_tabla_0 = 4×8
   -0.3000    0.7000   -0.0794   -1.0794   -0.3000    0.7000   -0.0794   -1.0794
   -0.5000    1.2321    1.6821   -0.0500   -0.5000    1.2321    1.6821   -0.0500
    0.8000    0.8000    0.8000    0.8000    0.8800    0.8800    0.8800    0.8800
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_pata(4,:) = 1
```

```
v_pata = 4×8
         0    0.1000    0.1000         0         0    0.1000    0.1000         0
         0         0    0.1000    0.1000         0         0    0.1000    0.1000
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_pata1_0 = T_pata1_0*v_pata
```

```
v_pata1_0 = 4×8
   -0.3183   -0.2683   -0.3549   -0.4049   -0.3183   -0.2683   -0.3549   -0.4049
   -0.4317   -0.3451   -0.2951   -0.3817   -0.4317   -0.3451   -0.2951   -0.3817
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_pata2_0 = T_pata2_0*v_pata
```

```
v_pata2_0 = 4×8
    0.5817    0.6317    0.5451    0.4951    0.5817    0.6317    0.5451    0.4951
    1.1271    1.2137    1.2637    1.1771    1.1271    1.2137    1.2637    1.1771
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_pata3_0 = T_pata3_0*v_pata
```

```
v_pata3_0 = 4×8
   -0.9245   -0.8745   -0.9611   -1.0111   -0.9245   -0.8745   -0.9611   -1.0111
   -0.0817    0.0049    0.0549   -0.0317   -0.0817    0.0049    0.0549   -0.0317
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
```

```
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_pata4_0 = T_pata4_0*v_pata
```

```
v_pata4_0 = 4×8
   -0.0245    0.0255   -0.0611   -0.1111   -0.0245    0.0255   -0.0611   -0.1111
    1.4771    1.5637    1.6137    1.5271    1.4771    1.5637    1.6137    1.5271
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_tablaherramientas(4,:) = 1
```

```
v_tablaherramientas = 4×8
         0    0.3000    0.3000         0         0    0.3000    0.3000         0
         0         0    0.3000    0.3000         0         0    0.3000    0.3000
         0         0         0         0    0.0800    0.0800    0.0800    0.0800
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_tablaherramientas_0 = T_tablaherramientas_0*v_tablaherramientas
```

```
v_tablaherramientas_0 = 4×8
    1.3830    1.5330    1.2732    1.1232    1.3830    1.5330    1.2732    1.1232
    1.4151    1.6749    1.8249    1.5651    1.4151    1.6749    1.8249    1.5651
    0.8000    0.8000    0.8000    0.8000    0.8800    0.8800    0.8800    0.8800
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_pataherramientas_0 = T_pataherramientas_0*v_pata
```

```
v_pataherramientas_0 = 4×8
    1.3464    1.3964    1.3098    1.2598    1.3464    1.3964    1.3098    1.2598
    1.5517    1.6383    1.6883    1.6017    1.5517    1.6383    1.6883    1.6017
         0         0         0         0    0.8000    0.8000    0.8000    0.8000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_torso(4,:) = 1
```

```
v_torso = 4×8
         0    1.6000    1.6000         0         0    1.6000    1.6000         0
         0         0    0.6000    0.6000         0         0    0.6000    0.6000
         0         0         0         0    0.2000    0.2000    0.2000    0.2000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_torso_0 = T_torso_0*v_torso
```

```
v_torso_0 = 4×8
   -0.2299    0.5701    0.0505   -0.7495   -0.2299    0.5701    0.0505   -0.7495
   -0.0786    1.3071    1.6071    0.2214   -0.0786    1.3071    1.6071    0.2214
    0.8800    0.8800    0.8800    0.8800    1.0800    1.0800    1.0800    1.0800
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_craneo(4,:) = 1
```

```
v_craneo = 4×8
         0    0.1500    0.1500         0         0    0.1500    0.1500         0
         0         0    0.2000    0.2000         0         0    0.2000    0.2000
         0         0         0         0    0.1700    0.1700    0.1700    0.1700
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
v_craneo_0 = T_craneo_0*v_craneo
```

```
v_craneo_0 = 4×8
```

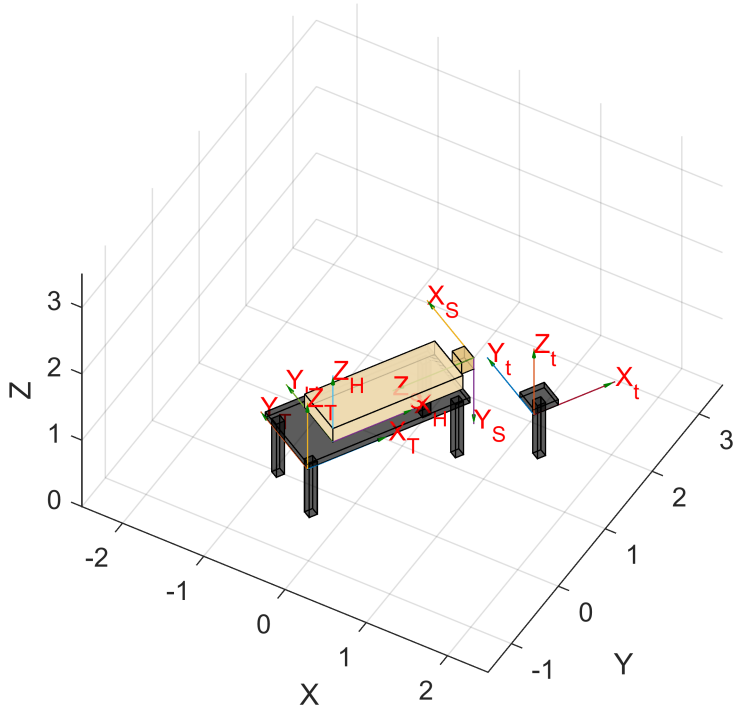
```
    0.4469    0.5219    0.3487    0.2737    0.4469    0.5219    0.3487    0.2737
    1.4937    1.6236    1.7236    1.5937    1.4937    1.6236    1.7236    1.5937
    0.8800    0.8800    0.8800    0.8800    1.0500    1.0500    1.0500    1.0500
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

Plotting parts

```
% Finally we plot the whole scene and the reference frames of the principal
% objects
figure
hold on
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_torso_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',[0.95,0.87,0.
patch('Vertices',v_craneo_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',[0.89,0.77,0
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])
```

Reference frames

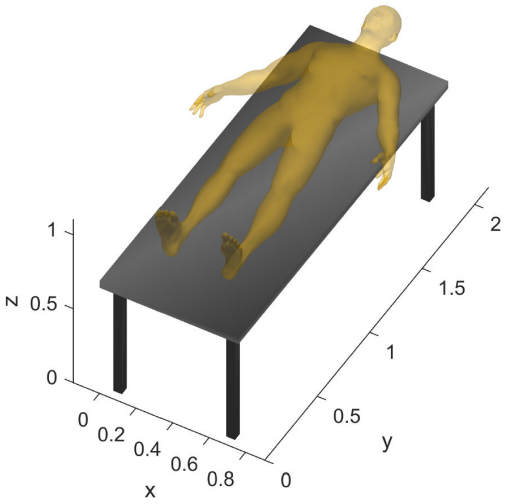
```
trplot(T_tabla_0,'frame','T' ,'color', 'red','arrow','width',0.4)
trplot(T_torso_0,'frame','H' ,'color', 'red','arrow','width',0.4)
trplot(T_tablaherramientas_0,'frame','t','color','red','arrow','width',0.4)
trplot(T_craneo_0*transl(0.15,0,0.17)*trotz(pi/2)*trotx(-pi/2),'frame','S','color','red','arrow
```



3D model of a human body

Situate the human model on the operating table.

Expected results




```
close all
% We load the human model to plot it together with the other elements
Human = load('F_V_HumanBody.mat')
```

```
Human = struct with fields:
```

```
    Fh: [48918×3 double]
    Vh: [24461×3 double]
```

```
v_humano = Human.Vh'
```

```
v_humano = 3×24461
   -0.1143   -0.1268   -0.1191   -0.1107   -0.1146   -0.1083   -0.1237   -0.1162 ···
    0.1432    0.1385    0.1450    0.1474    0.1484    0.1504    0.1452    0.1491
    1.3110    1.3149    1.3238    1.3206    1.3289    1.3286    1.3305    1.3344
```

```
v_humano(4,:) = 1
```

```
v_humano = 4×24461
   -0.1143   -0.1268   -0.1191   -0.1107   -0.1146   -0.1083   -0.1237   -0.1162 ···
    0.1432    0.1385    0.1450    0.1474    0.1484    0.1504    0.1452    0.1491
    1.3110    1.3149    1.3238    1.3206    1.3289    1.3286    1.3305    1.3344
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_humano_tabla = transl(0.45,0.45,0.205)*trotx(-pi/2)*troty(pi/2)
```

```
T_humano_tabla = 4×4
         0         0    1.0000    0.4500
   -1.0000         0         0    0.4500
         0   -1.0000         0    0.2050
         0         0         0    1.0000
```

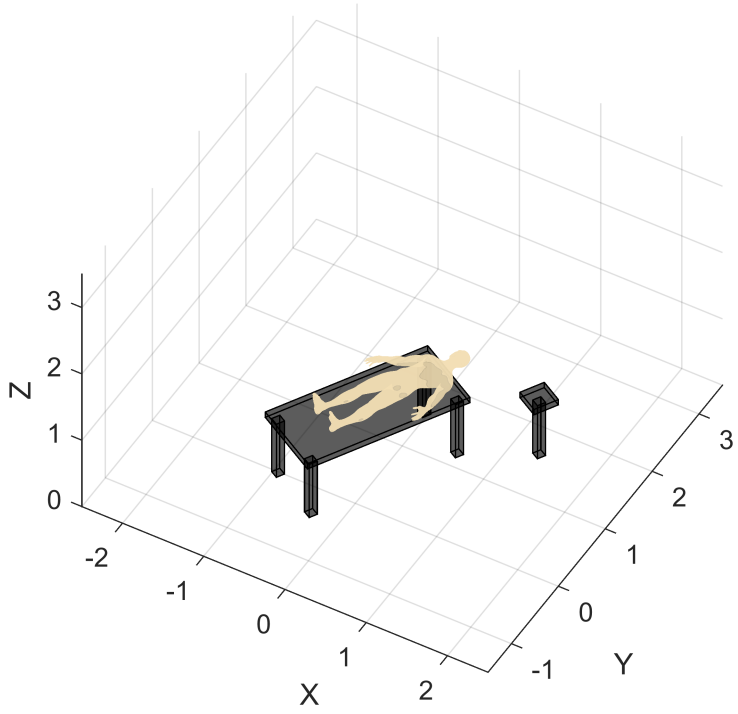
```
T_humano_0 = T_tabla_0*T_humano_tabla
```

```
T_humano_0 = 4×4
    0.8660         0    0.5000   -0.4647
   -0.5000         0    0.8660    0.1147
         0   -1.0000         0    1.0050
         0         0         0    1.0000
```

```
v_humano_0 = T_humano_0*v_humano
```

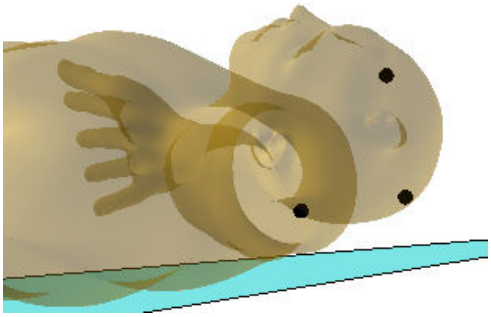
```
v_humano_0 = 4×24461
    0.0917    0.0829    0.0940    0.0997    0.1005    0.1058    0.0934    0.1019 ···
    1.3072    1.3168    1.3207    1.3138    1.3229    1.3195    1.3288    1.3285
    0.8618    0.8665    0.8600    0.8576    0.8566    0.8546    0.8598    0.8559
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
figure
hold on
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])
```



Fiducials

The Radiology Department before to take a Computer Tomography (CT) of the brain, fix three fiducials in the head of the patient for registering purpose, visit: https://en.wikipedia.org/wiki/Fiducial



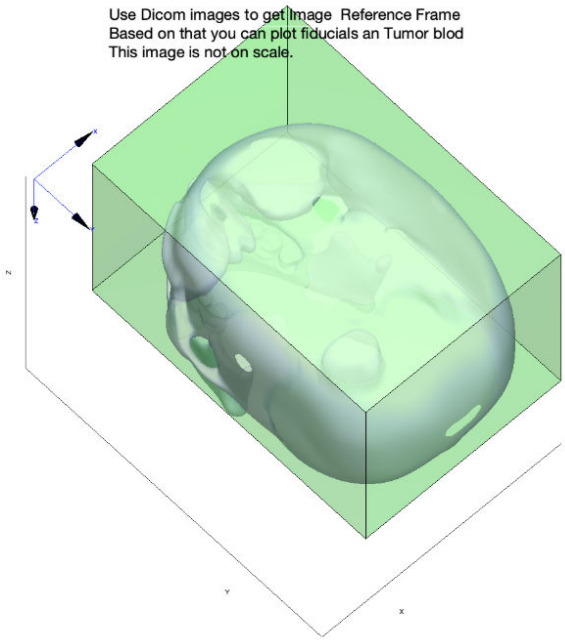
Dicom image vs Image Reference frame {I}

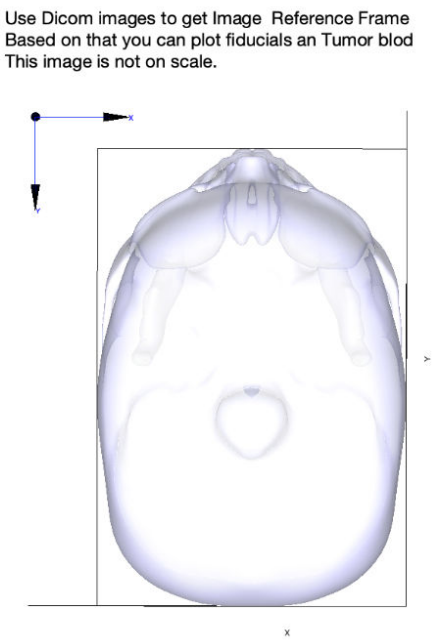
Get familiar with Dicom Images, Visit: https://www.imaios.com/en/Imaios-Dicom-Viewer#!

Use a container Box of the skull to infer the Image Reference Frame {I}

See: 6_Plot_Box_Cone.mlx and 7_Help_Image_RF_Containig_Box.fig to inspire yourselt

Expected results






```
close all
% We represent an scaled box with we can work with together with dicomm image's
% coordinates and load an skull to place it in, and then we rotate them to
% place them as they will be placed in the surgery
H = 2.55
```

```
H = 2.5500
```

```
W = 2.55
```

```
W = 2.5500
```

```
D = 1.568
```

```
D = 1.5680
```

```
v_contenedor = [H 0 0; 0 W 0; 0 0 D]*v_cubo'
```

```
v_contenedor = 3×8
         0    2.5500    2.5500         0         0    2.5500    2.5500         0
         0         0    2.5500    2.5500         0         0    2.5500    2.5500
         0         0         0         0    1.5680    1.5680    1.5680    1.5680
```

```
Skull = load("F_V_Skull.mat")
```

```
Skull = struct with fields:
    Fs: [80016×3 double]
    Vs: [40062×3 double]
```

```
H = 9.7
```

```
H = 9.7000
```

```
W = 9.7
```

```
W = 9.7000
```

```
D = 9.7
```

```
D = 9.7000
```

```
v_craneo = [H 0 0; 0 W 0; 0 0 D]*Skull.Vs'
```

```
v_craneo = 3×40062
   -0.1231   -0.0939   -0.0913   -0.1202   -0.0634   -0.0615   -0.0596   -0.0890 ···
   -1.1068   -1.1194   -1.1144   -1.1024   -1.1296   -1.1242   -1.1172   -1.1079
    0.0821    0.0799    0.1070    0.1085    0.0775    0.1049    0.1359    0.1378
```

```
v_craneo(4,:) = 1
```

```
v_craneo = 4×40062
   -0.1231   -0.0939   -0.0913   -0.1202   -0.0634   -0.0615   -0.0596   -0.0890 ···
   -1.1068   -1.1194   -1.1144   -1.1024   -1.1296   -1.1242   -1.1172   -1.1079
    0.0821    0.0799    0.1070    0.1085    0.0775    0.1049    0.1359    0.1378
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_craneo_contenedor = transl(1.25,1.3,-0.50)
```

```
T_craneo_contenedor = 4×4
    1.0000         0         0    1.2500
         0    1.0000         0    1.3000
         0         0    1.0000   -0.5000
         0         0         0    1.0000
```

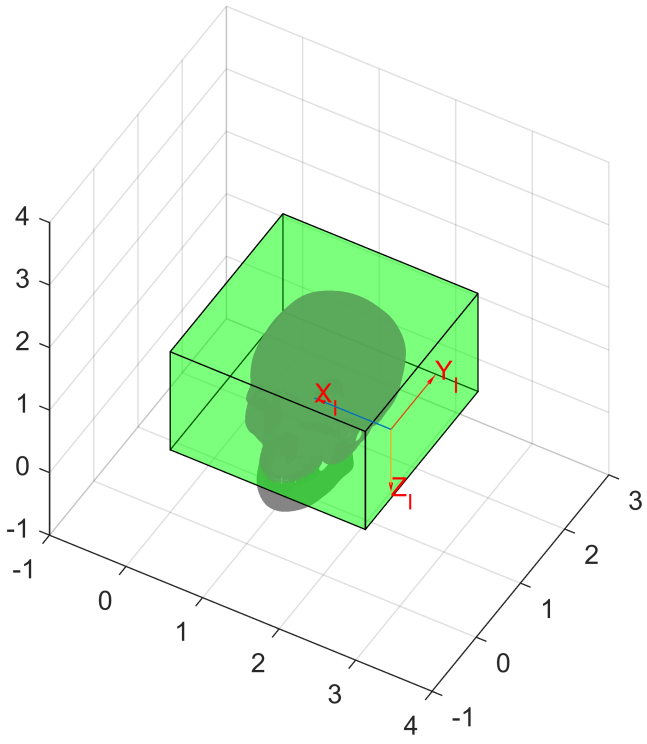
```
v_craneo_0 = T_craneo_contenedor*v_craneo
```

```
v_craneo_0 = 4×40062
    1.1269    1.1561    1.1587    1.1298    1.1866    1.1885    1.1904    1.1610 ···
    0.1932    0.1806    0.1856    0.1976    0.1704    0.1758    0.1828    0.1921
   -0.4179   -0.4201   -0.3930   -0.3915   -0.4225   -0.3951   -0.3641   -0.3622
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
figure
hold on
patch('Vertices', v_contenedor(1:3,:)', 'Faces', f, 'FaceVertexCData', hsv(6), 'FaceColor', [0
patch('Vertices',v_craneo_0(1:3,:)','Faces',Skull.Fs,'FaceVertexCData',hsv(6),'FaceColor',[0.5
view(30, 45)
grid on
axis equal
axis([-1.0 4.0 -1.0 3.0 -1.0 4.0])
T_contenedor_0 = transl(3,-0.2,2)*trotz(pi)*trotx(pi)
```

```
T_contenedor_0 = 4×4
   -1.0000         0         0    3.0000
         0    1.0000         0   -0.2000
         0         0   -1.0000    2.0000
         0         0         0    1.0000
```

```
trplot(T_contenedor_0,'frame','I' ,'color', 'r','arrow','width',0.4)
```

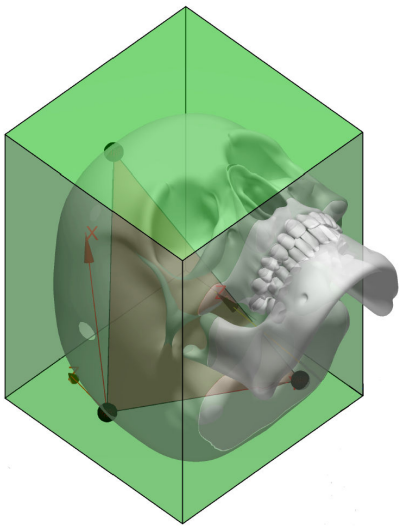


Fiducials wrt {I}

Use the Dicom images to place the fiducial relative to Image Reference Frame {I}.

See: 5_Skull_pose_estimation.mlx and use the skull to make the exercise.

Expected results



```
close all

v_contenedor(4,:) = 1
```

```
v_contenedor = 4×8
         0    2.5500    2.5500         0         0    2.5500    2.5500         0
         0         0    2.5500    2.5500         0         0    2.5500    2.5500
         0         0         0         0    1.5680    1.5680    1.5680    1.5680
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_contenedor_0 = trotx(-pi/2)
```

```
T_contenedor_0 = 4×4
     1     0     0     0
     0     0     1     0
     0    -1     0     0
     0     0     0     1
```

```
v_contenedor_0 = T_contenedor_0 * v_contenedor
```

```
v_contenedor_0 = 4×8
         0    2.5500    2.5500         0         0    2.5500    2.5500         0
         0         0         0         0    1.5680    1.5680    1.5680    1.5680
         0         0   -2.5500   -2.5500         0         0   -2.5500   -2.5500
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_craneo_contenedor = transl(1.25,1.35,-0.50)
```

```
T_craneo_contenedor = 4×4
    1.0000         0         0    1.2500
         0    1.0000         0    1.3500
         0         0    1.0000   -0.5000
         0         0         0    1.0000
```

```
T_craneo_0 = T_contenedor_0 * T_craneo_contenedor
```

```
T_craneo_0 = 4×4
    1.0000         0         0    1.2500
         0         0    1.0000   -0.5000
         0   -1.0000         0   -1.3500
         0         0         0    1.0000
```

```
v_craneo_0 = T_craneo_0*v_craneo
```

```
v_craneo_0 = 4×40062
    1.1269    1.1561    1.1587    1.1298    1.1866    1.1885    1.1904    1.1610 ···
   -0.4179   -0.4201   -0.3930   -0.3915   -0.4225   -0.3951   -0.3641   -0.3622
   -0.2432   -0.2306   -0.2356   -0.2476   -0.2204   -0.2258   -0.2328   -0.2421
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
% We move the fiducials to the coordinates that we have analyzed in the
% dicomm images
triangulo_fiducials = [2.55-1.22 1.568-0.252 -0.62; 2.55-0.7 1.568-1.12 -2.14; 2.55-1.86 1.568-
```

```
triangulo_fiducials = 3×3
    1.3300    1.3160   -0.6200
    1.8500    0.4480   -2.1400
    0.6900    0.9100   -2.1000
```

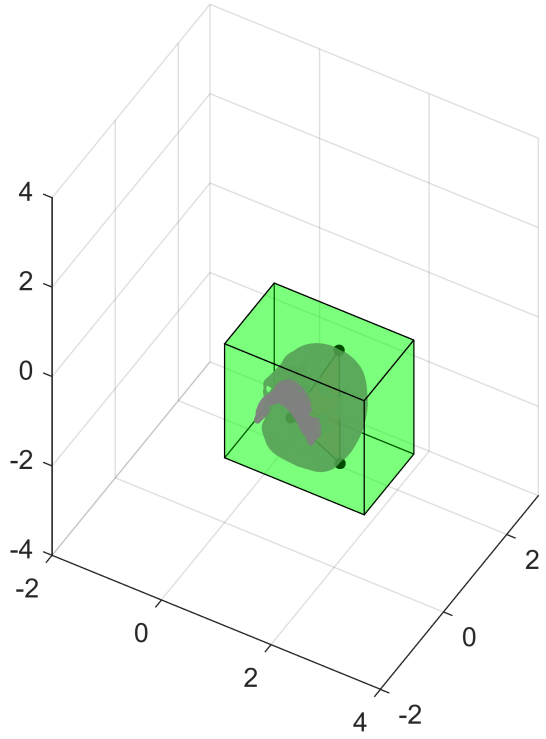
```
caras_triangulo_fiducials = [1 2 3]
```

```
caras_triangulo_fiducials = 1×3
     1     2     3
```

```
[X,Y,Z] = sphere;
r=0.08
```

```
r = 0.0800
```

```
figure
hold on
surf(X*r+2.55-1.22,Y*r+1.568-0.252,Z*r-0.62,'FaceColor',[1 0 0])
surf(X*r+2.55-0.70,Y*r+1.568-1.12,Z*r-2.14,'FaceColor',[1 0 0])
surf(X*r+2.55-1.86,Y*r+1.568-0.658,Z*r-2.10,'FaceColor',[1 0 0])
patch('Vertices', v_contenedor_0(1:3,:)', 'Faces', f, 'FaceVertexCData', hsv(6), 'FaceColor', |
patch('Vertices',v_craneo_0(1:3,:)','Faces',Skull.Fs,'FaceVertexCData',hsv(6),'FaceColor',[0.5
patch('Vertices',triangulo_fiducials,'Faces',caras_triangulo_fiducials,'FaceColor', [1 0 0], 'F
view(30, 45)
grid on
axis equal
axis([-2.0 4.0 -2.0 3.0 -4.0 4.0])
```

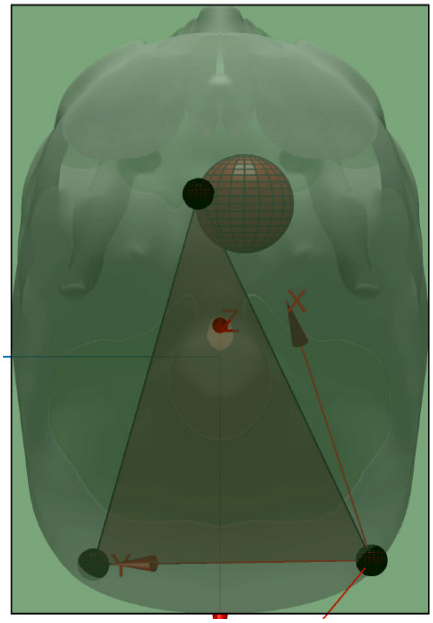


Tumor points wrt {I}

Use the Dicom images to get the points of the outer perimeter of the tumor relative to Image Reference Frame {I}.

You can simplify the tumor information by defining the center of mass and estimate an equivalent diameter.

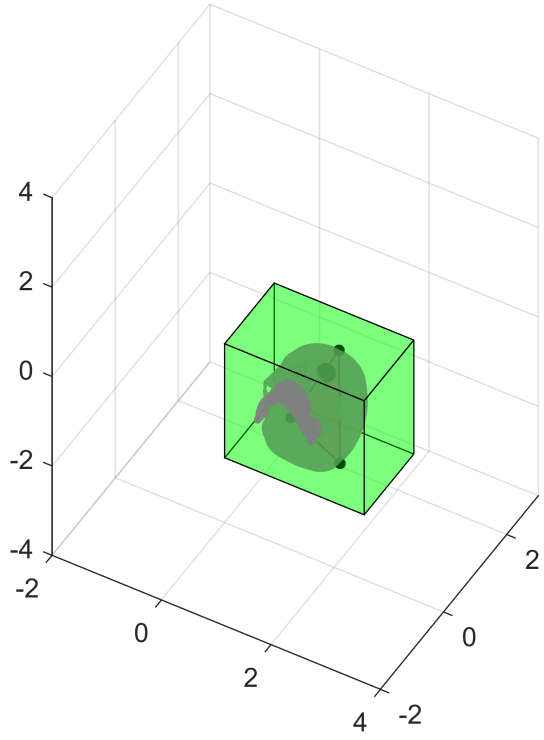
Expected results




```
close all
% We place the tumor in scale
r2 = 0.145
```

```
r2 = 0.1450
```

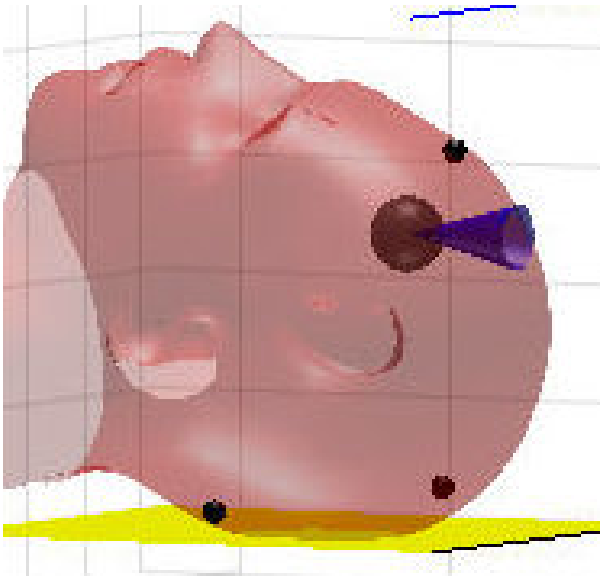
```
figure
hold on
surf(X*r+2.55-1.22,Y*r+1.568-0.252,Z*r-0.62,'FaceColor',[1 0 0])
surf(X*r+2.55-0.70,Y*r+1.568-1.12,Z*r-2.14,'FaceColor',[1 0 0])
surf(X*r+2.55-1.86,Y*r+1.568-0.658,Z*r-2.10,'FaceColor',[1 0 0])
surf(X*r2+2.55-1.32,Y*r2+1.568-0.49,Z*r2-0.97,'FaceColor',[1 0 0])
patch('Vertices', v_contenedor_0(1:3,:)', 'Faces', f, 'FaceVertexCData', hsv(6), 'FaceColor', |
patch('Vertices',v_craneo_0(1:3,:)','Faces',Skull.Fs,'FaceVertexCData',hsv(6),'FaceColor',[0.5
patch('Vertices',triangulo_fiducials,'Faces',caras_triangulo_fiducials,'FaceColor', [1 0 0], 'F
view(30, 45)
grid on
axis equal
axis([-2.0 4.0 -2.0 3.0 -4.0 4.0])
```



Fiducials and Tumor wrt Human Reference Frame

Place fiducial and tumor in the head of the human. You will have to re-do the containing box secction.

Expected results



```
close all
% We translate what we have done before to our concrete case, using an
% smaller scale. In addition, we plot a cone in parallel with the zy plane
% of the table that goes from the center of the tumor to outside the skull
```

```
H = 0.255
```

```
H = 0.2550
```

```
W = 0.255
```

```
W = 0.2550
```

```
D = 0.1568
```

```
D = 0.1568
```

```
v_contenedor = [H 0 0; 0 W 0; 0 0 D]*v_cubo'
```

```
v_contenedor = 3×8
         0    0.2550    0.2550         0         0    0.2550    0.2550         0
         0         0    0.2550    0.2550         0         0    0.2550    0.2550
         0         0         0         0    0.1568    0.1568    0.1568    0.1568
```

```
v_contenedor(4,:) = 1
```

```
v_contenedor = 4×8
         0    0.2550    0.2550         0         0    0.2550    0.2550         0
         0         0    0.2550    0.2550         0         0    0.2550    0.2550
         0         0         0         0    0.1568    0.1568    0.1568    0.1568
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_contenedor_tabla = transl(2.25,0.3225,0.33)*trotz(pi/2)*trotx(-pi/2)
```

```
T_contenedor_tabla = 4×4
         0         0   -1.0000    2.2500
    1.0000         0         0    0.3225
         0   -1.0000         0    0.3300
         0         0         0    1.0000
```

```
T_contenedor_0 = T_tabla_0*T_contenedor_tabla
```

```
T_contenedor_0 = 4×4
   -0.8660         0   -0.5000    0.5457
    0.5000         0   -0.8660    1.6098
         0   -1.0000         0    1.1300
         0         0         0    1.0000
```

```
v_contenedor_0 = T_contenedor_0 * v_contenedor
```

```
v_contenedor_0 = 4×8
    0.5457    0.3249    0.3249    0.5457    0.4673    0.2465    0.2465    0.4673
    1.6098    1.7373    1.7373    1.6098    1.4740    1.6015    1.6015    1.4740
    1.1300    1.1300    0.8750    0.8750    1.1300    1.1300    0.8750    0.8750
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_fiducial1_contenedor = transl(0.07,0.214,0.112)
```

```
T_fiducial1_contenedor = 4×4
    1.0000         0         0    0.0700
         0    1.0000         0    0.2140
         0         0    1.0000    0.1120
         0         0         0    1.0000
```

```
T_fiducial1_0 = T_contenedor_0 * T_fiducial1_contenedor
```

```
T_fiducial1_0 = 4×4
   -0.8660         0   -0.5000    0.4291
    0.5000         0   -0.8660    1.5478
         0   -1.0000         0    0.9160
         0         0         0    1.0000
```

```
T_fiducial2_contenedor = transl(0.186,0.210,0.0658)
```

```
T_fiducial2_contenedor = 4×4
    1.0000         0         0    0.1860
         0    1.0000         0    0.2100
         0         0    1.0000    0.0658
         0         0         0    1.0000
```

```
T_fiducial2_0 = T_contenedor_0 * T_fiducial2_contenedor
```

```
T_fiducial2_0 = 4×4
   -0.8660         0   -0.5000    0.3517
    0.5000         0   -0.8660    1.6458
         0   -1.0000         0    0.9200
         0         0         0    1.0000
```

```
T_fiducial3_contenedor = transl(0.122,0.064,0.0252)
```

```
T_fiducial3_contenedor = 4×4
    1.0000         0         0    0.1220
         0    1.0000         0    0.0640
         0         0    1.0000    0.0252
         0         0         0    1.0000
```

```
T_fiducial3_0 = T_contenedor_0 * T_fiducial3_contenedor
```

```
T_fiducial3_0 = 4×4
   -0.8660         0   -0.5000    0.4275
    0.5000         0   -0.8660    1.6490
         0   -1.0000         0    1.0660
         0         0         0    1.0000
```

```
T_tumor_contenedor = transl(0.132,0.099,0.050)
```

```
T_tumor_contenedor = 4×4
    1.0000         0         0    0.1320
         0    1.0000         0    0.0990
         0         0    1.0000    0.0500
         0         0         0    1.0000
```

```
T_tumor_0 = T_contenedor_0 * T_tumor_contenedor
```

```
T_tumor_0 = 4×4
   -0.8660         0   -0.5000    0.4064
    0.5000         0   -0.8660    1.6325
         0   -1.0000         0    1.0310
         0         0         0    1.0000
```

```
Cono = load('F_V_Cone.mat')
```

```
Cono = struct with fields:
    fvc: [1×1 struct]
```

```
H = 0.01
```

```
H = 0.0100
```

```
W = 0.01
```

```
W = 0.0100
```

```
D = 0.0495
```

```
D = 0.0495
```

```
v_cono = [H 0 0; 0 W 0; 0 0 D]*Cono.fvc.vertices'
```

```
v_cono = 3×42
    0.0100         0    0.0095         0    0.0081         0    0.0059         0 ···
         0         0    0.0031         0    0.0059         0    0.0081         0
         0    0.0495         0    0.0495         0    0.0495         0    0.0495
```

```
v_cono(4,:) = 1
```

```
v_cono = 4×42
    0.0100         0    0.0095         0    0.0081         0    0.0059         0 ···
         0         0    0.0031         0    0.0059         0    0.0081         0
         0    0.0495         0    0.0495         0    0.0495         0    0.0495
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_cono_contenedor = transl(0.132,0.099,0.0)
```

```
T_cono_contenedor = 4×4
    1.0000         0         0    0.1320
         0    1.0000         0    0.0990
         0         0    1.0000         0
         0         0         0    1.0000
```

```
T_cono_0 = T_contenedor_0 * T_cono_contenedor
```

```
T_cono_0 = 4×4
   -0.8660         0   -0.5000    0.4314
    0.5000         0   -0.8660    1.6758
         0   -1.0000         0    1.0310
         0         0         0    1.0000
```

```
v_cono_0 = v_cono
```

```
v_cono_0 = 4×42
    0.4227    0.4066    0.4232    0.4066    0.4244    0.4066    0.4263    0.4066 ···
    1.6808    1.6329    1.6806    1.6329    1.6799    1.6329    1.6787    1.6329
    1.0310    1.0310    1.0279    1.0310    1.0251    1.0310    1.0229    1.0310
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
r = 0.008
```

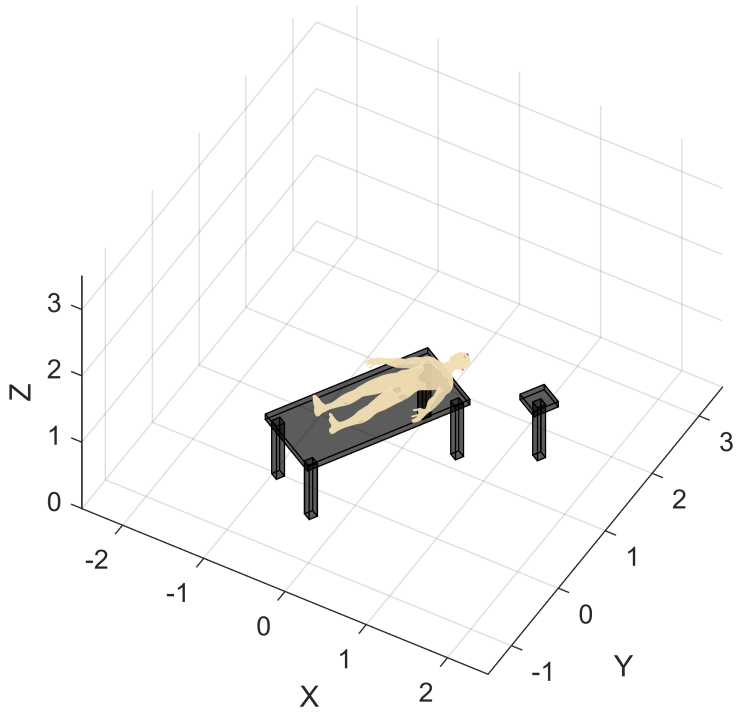
```
r = 0.0080
```

```
r2 = 0.0145
```

```
r2 = 0.0145
```

```
figure
hold on
```

```
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_cono_0(1:3,:)','Faces',Cono.fvc.faces,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+T_fiducial1_0(1,4),Y*r+T_fiducial1_0(2,4),Z*r+T_fiducial1_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial2_0(1,4),Y*r+T_fiducial2_0(2,4),Z*r+T_fiducial2_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial3_0(1,4),Y*r+T_fiducial3_0(2,4),Z*r+T_fiducial3_0(3,4),'FaceColor',[1 0 0],
surf(X*r2+T_tumor_0(1,4),Y*r2+T_tumor_0(2,4),Z*r2+T_tumor_0(3,4),'FaceColor',[1 0 0], 'EdgeColo
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])
```



First approach (10%)

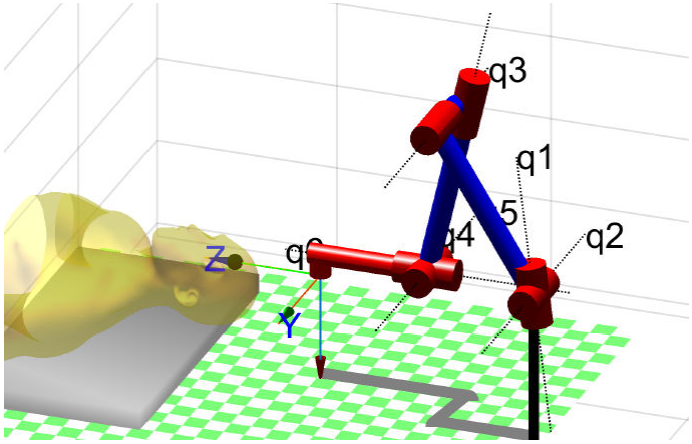
Asume that the ZX plane of the Robot is aligned with the plane of symmetry of the human body.

Robot manipulator

Consider the best position of manipulator to be nearby the operating table to warranty that the head is in the reachable work space. Use a Puma 560. Use p560.teach to play.

Use: p560.base & p560.tool to locate the Puma and add the tools.

Expected results




```
% Now we place a puma560 with respect to the table in a place that the head
% is reachable to do the surgery
mdl_puma560
% (l1-l2)^2 <= (x^2+y^2) <= (l1+l2)^2
T_p560_tabla = transl(3,0.45,0.08)*trotz(pi)
```

```
T_p560_tabla = 4×4
   -1.0000         0         0    3.0000
         0   -1.0000         0    0.4500
         0         0    1.0000    0.0800
         0         0         0    1.0000
```

```
T_p560_0 = T_tabla_0*T_p560_tabla
```

```
T_p560_0 = 4×4
   -0.5000    0.8660         0    0.8103
   -0.8660   -0.5000         0    2.3231
         0         0    1.0000    0.8800
         0         0         0    1.0000
```

```
p560.base = T_p560_0
```

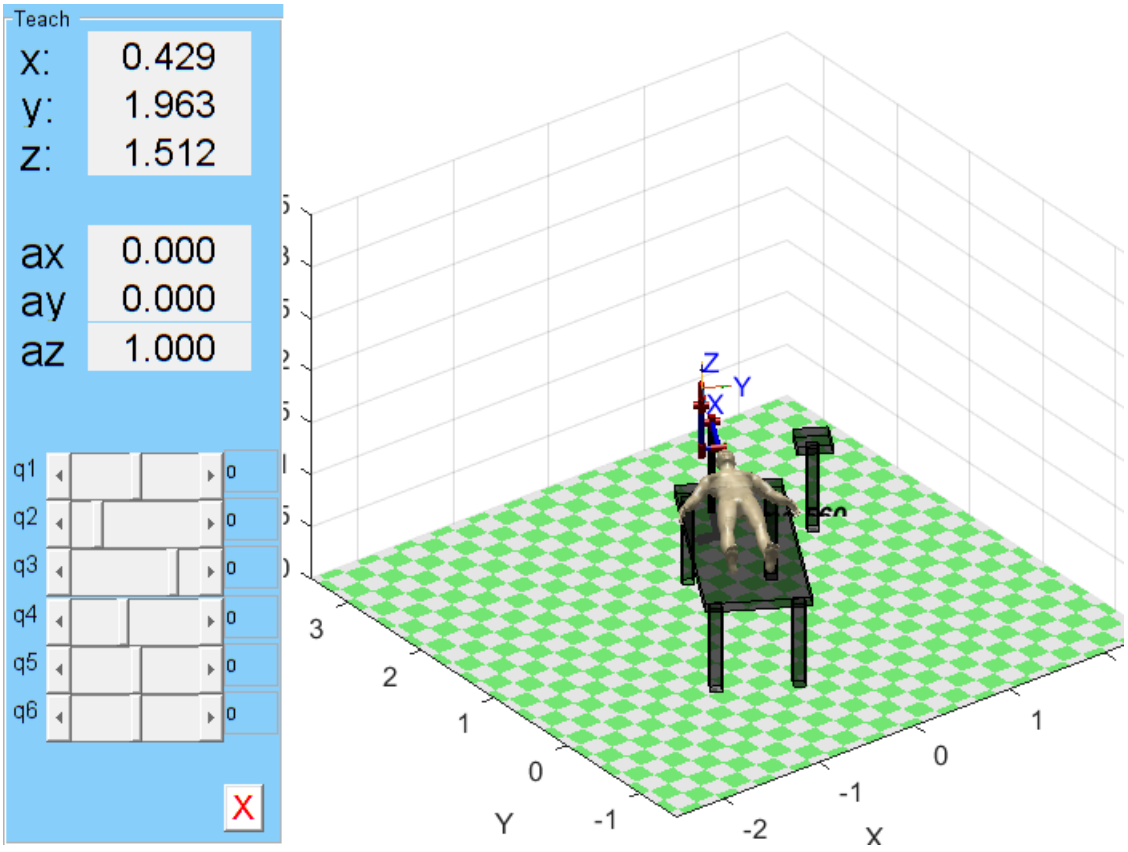
```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
```

```
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
```

```
p560.tool=transl(0.05,0,0.2)
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0.05, 0, 0.2), RPY/xyz = (0, 0, 0) deg
```

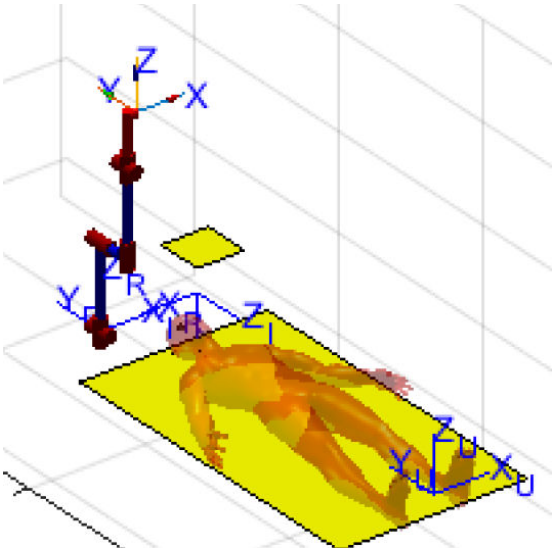
```
p560.plot(qr, 'workspace', [-2.5 2.5 -1.5 3.5 0.0 3.5], 'scale', 0.5);
p560.teach('approach')
```



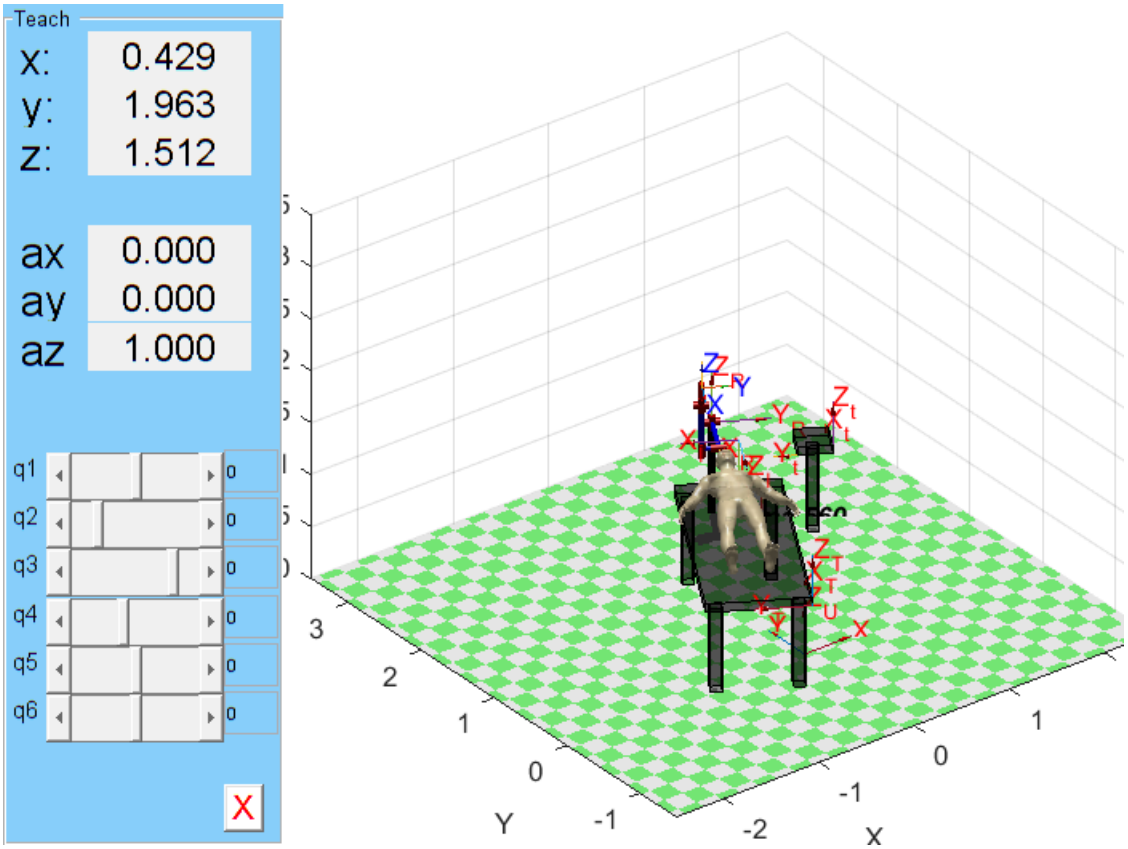
Reference Frames

Display all necessary reference frame. Use best scale to see it.

- {U} Univers [0 0 0]
- {R} Robot
- {I} Image
- {Tb} Table_body
- {Tt} Table tool
- {EE} End Efector
- others
- ...




```
trplot(T_contenedor_0,'frame','I' ,'color', 'r','arrow','width',0.4,'length',0.5)
trplot(transl(0,0,0),'frame','U','color','r','arrow','width',0.4,'length',0.5)
trplot(T_p560_0,'frame', 'R', 'color', 'r','arrow','width',0.4,'length',0.5)
trplot(T_tabla_0,'frame', 'T', 'color', 'r', 'arrow','width',0.4,'length',0.5)
trplot(T_tablaherramientas_0,'frame','t','color','r','arrow','width',0.4,'length',0.5)
```



Surgery (55%)

Biospy

Prepare a script that perform a biopsy. Zoom in the scene and record a video with the best view.

Use a tool that has the following Transformation: transl(0.05 0 0.25)

Let us see the 'trail' option of plot to visualize the trajectory.

```
close all

figure
hold on
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+T_fiducial1_0(1,4),Y*r+T_fiducial1_0(2,4),Z*r+T_fiducial1_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial2_0(1,4),Y*r+T_fiducial2_0(2,4),Z*r+T_fiducial2_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial3_0(1,4),Y*r+T_fiducial3_0(2,4),Z*r+T_fiducial3_0(3,4),'FaceColor',[1 0 0],
```

```
surf(X*r2+T_tumor_0(1,4),Y*r2+T_tumor_0(2,4),Z*r2+T_tumor_0(3,4),'FaceColor',[1 0 0], 'EdgeColo
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])

% We set the appropriate tool to do the biopsy and then we set the frames
% that will divide our trajectories
p560.tool = transl(0.05,0,0.25)
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0.05, 0, 0.25), RPY/xyz = (0, 0, 0) deg
```

```
T1 = T_contenedor_0*(T_tumor_contenedor*transl(0.0,0.0,-0.3)*trotz(pi/2)) % From robot initial
```

```
T1 = 4×4
         0    0.8660   -0.5000    0.5564
         0   -0.5000   -0.8660    1.8923
   -1.0000         0         0    1.0310
         0         0         0    1.0000
```

```
T2 = T_contenedor_0*(T_tumor_contenedor*trotz(pi/2)) % From T1 final point to tumor
```

```
T2 = 4×4
         0    0.8660   -0.5000    0.4064
         0   -0.5000   -0.8660    1.6325
   -1.0000         0         0    1.0310
         0         0         0    1.0000
```

```
T0 = p560.fkine(qr)
```

```
T0 =
   -0.5000    0.8660         0    0.6452
   -0.8660   -0.5000         0     2.337
         0         0         1     1.994
         0         0         0         1
```

```
q_0 = p560.ikine6s(T0,'run');
q_1 = p560.ikine6s(T1,'run');
t_0 = linspace(0.0,3.0,30)
```

```
t_0 = 1×30
         0    0.1034    0.2069    0.3103    0.4138    0.5172    0.6207    0.7241 ···
```

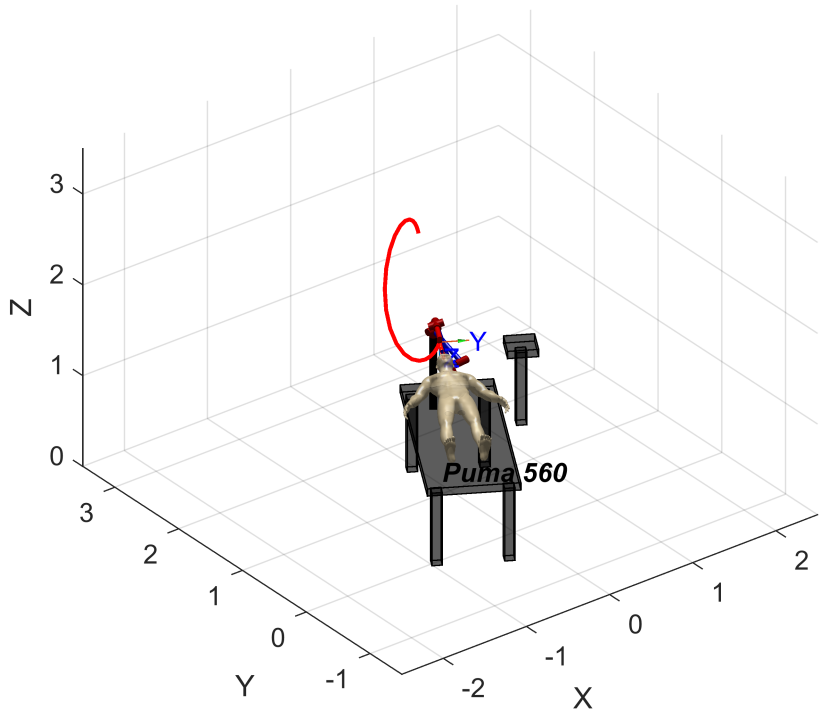
```
Q_0 = jtraj(q_0,q_1,t_0); % For the first trajectory we follow an eliptic path
t_1 = linspace(0.0,5.0,50);
S = tpoly(0,1,t_1);
S(1) = 0
```

```
S = 50×1
         0
    0.0001
    0.0006
    0.0021
    0.0048
    0.0091
    0.0152
    0.0233
    0.0336
    0.0461
      ⋮
```

```
S(50) = 1
```

```
S = 50×1
         0
    0.0001
    0.0006
    0.0021
    0.0048
    0.0091
    0.0152
    0.0233
    0.0336
    0.0461
      ⋮
```

```
T_1_2 = ctraj(T1,T2,S); % For the second trajectory we follow an straight path with non constar
Q_1 = p560.ikine(T_1_2);
T_2_1 = ctraj(T2,T1,S); % We will perform a third trajectory that consists in returning to T1
Q_2 = p560.ikine(T_2_1);
QT = [Q_0;Q_1;Q_2];
p560.plot(QT,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
```



Trepanation

Prepare a script that perform trepanation. Zoom in the scene and record a video with the best view.

Use a tool that has the following Transformation: transl(0 0 0.2)

Let us see the 'trail' option of plot to visualize the trajectory. Place a 45º cone on top of the trepanation to better understand. See: 6_Plot_Box_Cone.mlx. You will have to scale it. Play with transparency.

```
close all

% We plot a cone in top of the skull forming 45 degrees with its
% longitudinal axis
Cono = load('F_V_Cone.mat')
```

```
Cono = struct with fields:
    fvc: [1×1 struct]
```

```
H = 0.2
```

```
H = 0.2000
```

```
W = 0.2
```

```
W = 0.2000
```

```
D = 0.2
```

```
D = 0.2000
```

```
v_cono = [H 0 0; 0 W 0; 0 0 D]*Cono.fvc.vertices'
```

```
v_cono = 3×42
    0.2000         0    0.1902         0    0.1618         0    0.1176         0 ···
         0         0    0.0618         0    0.1176         0    0.1618         0
         0    0.2000         0    0.2000         0    0.2000         0    0.2000
```

```
v_cono(4,:) = 1
```

```
v_cono = 4×42
    0.2000         0    0.1902         0    0.1618         0    0.1176         0 ···
         0         0    0.0618         0    0.1176         0    0.1618         0
         0    0.2000         0    0.2000         0    0.2000         0    0.2000
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
T_cono_contenedor = transl(0.132,0.099,-0.2)
```

```
T_cono_contenedor = 4×4
    1.0000         0         0    0.1320
         0    1.0000         0    0.0990
         0         0    1.0000   -0.2000
         0         0         0    1.0000
```

```
T_cono_0 = T_contenedor_0 * T_cono_contenedor
```

```
T_cono_0 = 4×4
   -0.8660         0   -0.5000    0.5314
    0.5000         0   -0.8660    1.8490
         0   -1.0000         0    1.0310
         0         0         0    1.0000
```

```
v_cono_0 = T_cono_0 * v_cono
```

```
v_cono_0 = 4×42
    0.3582    0.4314    0.3667    0.4314    0.3913    0.4314    0.4296    0.4314 ···
    1.9490    1.6758    1.9441    1.6758    1.9299    1.6758    1.9078    1.6758
    1.0310    1.0310    0.9692    1.0310    0.9134    1.0310    0.8692    1.0310
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

```
figure
hold on
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_cono_0(1:3,:)','Faces',Cono.fvc.faces,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+T_fiducial1_0(1,4),Y*r+T_fiducial1_0(2,4),Z*r+T_fiducial1_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial2_0(1,4),Y*r+T_fiducial2_0(2,4),Z*r+T_fiducial2_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial3_0(1,4),Y*r+T_fiducial3_0(2,4),Z*r+T_fiducial3_0(3,4),'FaceColor',[1 0 0],
surf(X*r2+T_tumor_0(1,4),Y*r2+T_tumor_0(2,4),Z*r2+T_tumor_0(3,4),'FaceColor',[1 0 0], 'EdgeColo
```

```
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])

% We set the appropriate tool to do the trepanation and then we set the frames
% that will divide our trajectories
p560.tool = transl(0.0,0,0.2)
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0, 0, 0.2), RPY/xyz = (0, 0, 0) deg
```

```
T1 = T_contenedor_0*(T_tumor_contenedor*transl(0.0,-0.00725,-0.05)*trotz(pi/2)*troty(pi/4)) % F
```

```
T1 = 4×4
    0.3536    0.8660   -0.3536    0.4314
    0.6124   -0.5000   -0.6124    1.6758
   -0.7071         0   -0.7071    1.0383
         0         0         0    1.0000
```

```
T0 = p560.fkine(qr)
```

```
T0 =
   -0.5000    0.8660         0    0.6702
   -0.8660   -0.5000         0     2.381
         0         0         1     1.944
         0         0         0         1
```

```
q_0 = p560.ikine6s(T0,'run');
q_1 = p560.ikine6s(T1,'run');
t_0 = linspace(0.0,3.0,30)
```

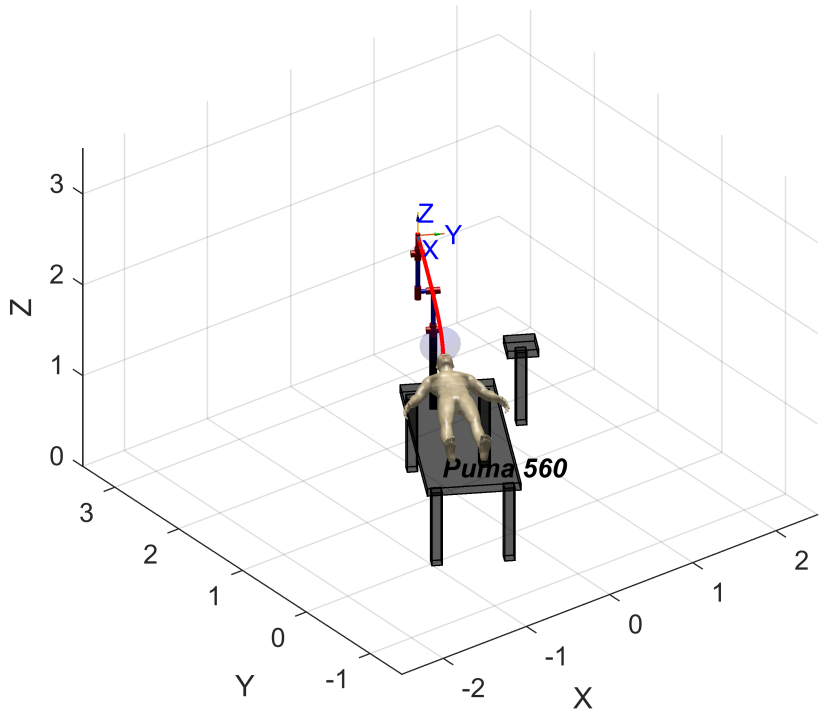
```
t_0 = 1×30
         0    0.1034    0.2069    0.3103    0.4138    0.5172    0.6207    0.7241 ···
```

```
% We do the trepanation always perforing the skull with 45 degrees wrt the
% longitudinal axis of the human
for i=1:50
Trepanation_Pose(:,:,i)= T_contenedor_0*(T_tumor_contenedor*transl(0.0,0.0,-0.05)*trotz((2*pi*
end
```

```
Q_0 = jtraj(q_0,q_1,t_0); % For the first trajectory we follow an eliptic path
Q_1 = p560.ikine6s(Trepanation_Pose, 'run'); % For the trepanation we follow constant velocity
Q_2 = jtraj(q_1,q_0,t_0) % We return to initial position
```

```
Q_2 = 30×6
    0.2417    1.1693   -2.9213    2.8538    0.6389   -2.7357
    0.2416    1.1695   -2.9208    2.8539    0.6387   -2.7334
    0.2410    1.1705   -2.9174    2.8546    0.6370   -2.7183
    0.2394    1.1731   -2.9086    2.8565    0.6329   -2.6803
    0.2366    1.1778   -2.8928    2.8599    0.6254   -2.6116
    0.2323    1.1849   -2.8688    2.8650    0.6140   -2.5070
    0.2264    1.1948   -2.8358    2.8720    0.5984   -2.3633
    0.2189    1.2073   -2.7935    2.8810    0.5784   -2.1795
    0.2097    1.2226   -2.7422    2.8920    0.5542   -1.9561
    0.1989    1.2404   -2.6823    2.9047    0.5258   -1.6952
     ⋮
```

```
QT = [Q_0;Q_1;Q_2];
p560.plot(QT,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
```



Tumor burning

Prepare a script that perform tumor burning with the laser. Zoom in the scene and record a video with the best view.

You ought to think in an algorithm, that in order, fill up the tumor's equivalent sphere with small burning spheres of 4m diameter.

Use a tool that has the following Transformation: transl(0 0 0.2)

```
close all

figure
hold on

% We plot the tumor subdivided in little spheres with radius = 4mm
esferas = zeros(33, 3)
```

```
esferas = 33×3
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     ⋮
```

```
i = 1
```

```
i = 1
```

```
rpeq = 0.004;
rgran = 0.0145;
[x, y, z] = sphere;
w = linspace(-rgran + rpeq, rgran - rpeq, 4);
light('Position',[2 3 1])

for ix = w
   for iy = w
      for iz = w
          if (ix)^2 + (iy)^2 + (iz)^2 < rgran^2

              esferas(i,:) = [ix iy iz];
              surf(x * rpeq + ix + T_tumor_0(1,4), y * rpeq + iy + T_tumor_0(2,4), z * rpeq + i
                  'FaceColor',[1 0 0], 'EdgeColor','none', 'FaceLighting', 'gouraud');
              i = i + 1

          end
      end
   end
end
```

```
i = 2
i = 3
i = 4
i = 5
i = 6
i = 7
i = 8
i = 9
i = 10
```

```
i = 11
i = 12
i = 13
i = 14
i = 15
i = 16
i = 17
i = 18
i = 19
i = 20
i = 21
i = 22
i = 23
i = 24
i = 25
i = 26
i = 27
i = 28
i = 29
i = 30
i = 31
i = 32
i = 33
```

```
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+T_fiducial1_0(1,4),Y*r+T_fiducial1_0(2,4),Z*r+T_fiducial1_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial2_0(1,4),Y*r+T_fiducial2_0(2,4),Z*r+T_fiducial2_0(3,4),'FaceColor',[1 0 0],
surf(X*r+T_fiducial3_0(1,4),Y*r+T_fiducial3_0(2,4),Z*r+T_fiducial3_0(3,4),'FaceColor',[1 0 0],
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])

% We set the appropriate tool to do the burning and then we set the frames
% that will divide our trajectories
p560.tool = transl(0.0,0,0.2)
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
```

```
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0, 0, 0.2), RPY/xyz = (0, 0, 0) deg
```

```
T1 = T_contenedor_0*(T_tumor_contenedor*transl(0.0,0.0,-0.3)*trotz(pi/2)) % From robot initial
```

```
T1 = 4×4
         0    0.8660   -0.5000    0.5564
         0   -0.5000   -0.8660    1.8923
   -1.0000         0         0    1.0310
         0         0         0    1.0000
```

```
T0 = p560.fkine(qr)
```

```
T0 =
   -0.5000    0.8660         0    0.6702
   -0.8660   -0.5000         0     2.381
         0         0         1     1.944
         0         0         0         1
```

```
q_0 = p560.ikine6s(T0,'run');
q_1 = p560.ikine6s(T1,'run');
t_0 = linspace(0.0,3.0,30)
```

```
t_0 = 1×30
         0    0.1034    0.2069    0.3103    0.4138    0.5172    0.6207    0.7241 ···
```

```
Q_0 = jtraj(q_0,q_1,t_0); % For the first trajectory we follow an eliptic path

T_ini = T_contenedor_0*(T_tumor_contenedor*transl(0.0,0.0,-0.075)*trotz(pi/2))
```

```
T_ini = 4×4
         0    0.8660   -0.5000    0.4439
         0   -0.5000   -0.8660    1.6975
   -1.0000         0         0    1.0310
         0         0         0    1.0000
```

```
t_1 = linspace(0.0,5.0,50);
S = tpoly(0,1,t_1);
S(1) = 0
```

```
S = 50×1
         0
    0.0001
    0.0006
    0.0021
    0.0048
    0.0091
    0.0152
    0.0233
    0.0336
    0.0461
      ⋮
```

```
S(50) = 1
```

```
S = 50×1
         0
    0.0001
    0.0006
    0.0021
    0.0048
    0.0091
    0.0152
    0.0233
    0.0336
    0.0461
     ⋮
```

```
T_1_ini = ctraj(T1,T_ini,S); % For the second trajectory we follow an straight path with non co
Q_1 = p560.ikine(T_1_ini);
p560.plot([Q_0;Q_1],'zoom',2,'trail',{'r', 'LineWidth', 1.5});

q_ini = p560.ikine6s(T_ini)
```

```
q_ini = 1×6
    2.8432    1.9319    0.3109    2.6827    0.7258    0.3540
```

```
t_2 = linspace(0.0,0.5,5);

% Between each point to burn we create a trajectory, so we point one sphere
% and then we move the tool rotating it to point another
for i=1:33

    dy = sqrt((0.0-esferas(i,1))^2 + (-0.075-esferas(i,2))^2)
    dx = sqrt((0.0-esferas(i,3))^2 + (-0.075-esferas(i,2))^2)
    ax = asin(esferas(i,1)/dy)
    ay = asin(esferas(i,3)/dx)
    T_i = T_contenedor_0*(T_tumor_contenedor*transl(0.0,0.0,-0.075)*trotz(pi/2)*trotx(-ax)*trot
    q_i = p560.ikine6s(T_i, 'lun');
    Q_i = jtraj(q_ini,q_i,t_2);
    p560.plot(Q_i,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
    surf(x * rpeq + esferas(i,1) + T_tumor_0(1,4), y * rpeq + esferas(i,2) + T_tumor_0(2,4), z
                'FaceColor','#006400', 'EdgeColor','none', 'FaceLighting', 'gouraud');
    q_ini = q_i
end
```

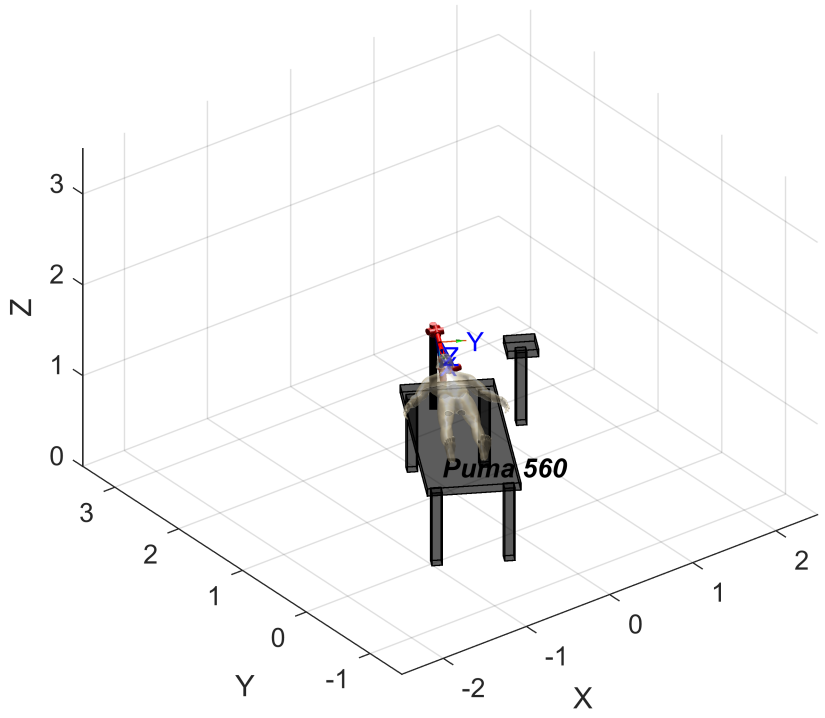
```
dy = 0.0723
dx = 0.0716
ax = -0.1458
ay = -0.0489
q_ini = 1×6
    2.8999    1.9244    0.2940    2.9726    0.6052    0.1347
dy = 0.0723
dx = 0.0716
ax = -0.1458
ay = 0.0489
q_ini = 1×6
    2.8999    1.9517    0.3103    3.0001    0.7454    0.1090
dy = 0.0792
```

```
dx = 0.0786
ax = -0.1330
ay = -0.0446
q_ini = 1×6
    2.8948    1.9246    0.2962    2.9435    0.6144    0.1575
dy = 0.0792
dx = 0.0786
ax = -0.1330
ay = 0.0446
q_ini = 1×6
    2.8948    1.9494    0.3111    2.9729    0.7417    0.1300
dy = 0.0646
dx = 0.0646
ax = -0.0542
ay = -0.0542
q_ini = 1×6
    2.8641    1.9183    0.2997    2.7555    0.6275    0.3056
dy = 0.0646
dx = 0.0646
ax = -0.0542
ay = 0.0542
q_ini = 1×6
    2.8641    1.9486    0.3179    2.8209    0.7774    0.2447
dy = 0.0716
dx = 0.0723
ax = -0.0489
ay = -0.1458
q_ini = 1×6
    2.8629    1.8981    0.2774    2.6572    0.5051    0.3976
dy = 0.0716
dx = 0.0716
ax = -0.0489
ay = -0.0489
q_ini = 1×6
    2.8621    1.9194    0.3010    2.7476    0.6371    0.3110
dy = 0.0716
dx = 0.0716
ax = -0.0489
ay = 0.0489
q_ini = 1×6
    2.8621    1.9469    0.3174    2.8081    0.7720    0.2548
dy = 0.0716
dx = 0.0723
ax = -0.0489
ay = 0.1458
q_ini = 1×6
    2.8629    1.9793    0.3260    2.8510    0.9051    0.2166
dy = 0.0786
dx = 0.0792
ax = -0.0446
ay = -0.1330
q_ini = 1×6
    2.8611    1.9005    0.2811    2.6607    0.5247    0.3923
dy = 0.0786
dx = 0.0786
ax = -0.0446
ay = -0.0446
q_ini = 1×6
    2.8604    1.9204    0.3021    2.7413    0.6449    0.3153
dy = 0.0786
dx = 0.0786
ax = -0.0446
ay = 0.0446
q_ini = 1×6
```

```
    2.8604    1.9454    0.3170    2.7975    0.7676    0.2631
dy = 0.0786
dx = 0.0792
ax = -0.0446
ay = 0.1330
q_ini = 1×6
    2.8611    1.9746    0.3255    2.8385    0.8889    0.2265
dy = 0.0856
dx = 0.0856
ax = -0.0409
ay = -0.0409
q_ini = 1×6
    2.8589    1.9213    0.3029    2.7361    0.6515    0.3188
dy = 0.0856
dx = 0.0856
ax = -0.0409
ay = 0.0409
q_ini = 1×6
    2.8589    1.9442    0.3166    2.7885    0.7639    0.2702
dy = 0.0646
dx = 0.0646
ax = 0.0542
ay = -0.0542
q_ini = 1×6
    2.8231    1.9186    0.2992    2.5290    0.6846    0.4774
dy = 0.0646
dx = 0.0646
ax = 0.0542
ay = 0.0542
q_ini = 1×6
    2.8231    1.9490    0.3173    2.6232    0.8241    0.3908
dy = 0.0716
dx = 0.0723
ax = 0.0489
ay = -0.1458
q_ini = 1×6
    2.8263    1.8985    0.2770    2.4267    0.5676    0.5765
dy = 0.0716
dx = 0.0716
ax = 0.0489
ay = -0.0489
q_ini = 1×6
    2.8250    1.9198    0.3005    2.5446    0.6881    0.4648
dy = 0.0716
dx = 0.0716
ax = 0.0489
ay = 0.0489
q_ini = 1×6
    2.8250    1.9472    0.3169    2.6286    0.8145    0.3876
dy = 0.0716
dx = 0.0723
ax = 0.0489
ay = 0.1458
q_ini = 1×6
    2.8263    1.9796    0.3255    2.6904    0.9411    0.3333
dy = 0.0786
dx = 0.0792
ax = 0.0446
ay = -0.1330
q_ini = 1×6
    2.8277    1.9008    0.2807    2.4542    0.5801    0.5521
dy = 0.0786
dx = 0.0786
ax = 0.0446
```

```
ay = -0.0446
q_ini = 1×6
    2.8266    1.9208    0.3016    2.5574    0.6911    0.4545
dy = 0.0786
dx = 0.0786
ax = 0.0446
ay = 0.0446
q_ini = 1×6
    2.8266    1.9457    0.3165    2.6330    0.8067    0.3849
dy = 0.0786
dx = 0.0792
ax = 0.0446
ay = 0.1330
q_ini = 1×6
    2.8277    1.9749    0.3250    2.6901    0.9225    0.3345
dy = 0.0856
dx = 0.0856
ax = 0.0409
ay = -0.0409
q_ini = 1×6
    2.8279    1.9216    0.3025    2.5680    0.6936    0.4459
dy = 0.0856
dx = 0.0856
ax = 0.0409
ay = 0.0409
q_ini = 1×6
    2.8279    1.9445    0.3162    2.6368    0.8001    0.3826
dy = 0.0723
dx = 0.0716
ax = 0.1458
ay = -0.0489
q_ini = 1×6
    2.7902    1.9254    0.2925    2.3705    0.7527    0.5903
dy = 0.0723
dx = 0.0716
ax = 0.1458
ay = 0.0489
q_ini = 1×6
    2.7902    1.9527    0.3089    2.4681    0.8692    0.5022
dy = 0.0792
dx = 0.0786
ax = 0.1330
ay = -0.0446
q_ini = 1×6
    2.7946    1.9255    0.2949    2.3970    0.7487    0.5707
dy = 0.0792
dx = 0.0786
ax = 0.1330
ay = 0.0446
q_ini = 1×6
    2.7946    1.9503    0.3098    2.4846    0.8560    0.4913
dy = 0.0750
dx = 0.0750
ax = 0
ay = 0
q_ini = 1×6
    2.8432    1.9319    0.3109    2.6827    0.7258    0.3540
```

```
T_ini_1 = ctraj(T_ini, T1, S); % Finally we return to T1 with a cartesian trajectory
Q_2 = p560.ikine(T_ini_1);
p560.plot(Q_2,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
```



Second approach: (25%)

Modify your code to repeat the exercise if the table with the patient is given as happend in the Rosa video.

To know the head relative pose with respect to the Puma Robot ...

See: '4_Sckeching_Key_ideas_students.mlx' , '5_Skull_pose estimation.mlx' for inspiration and Second_approach_SPM.pdf

Robot Frame wrt Universe {U}

```
close all

% We locate the robot near the table
mdl_puma560
T_p560_tabla = transl(3,0.45,0.08)*trotz(pi)
```

```
T_p560_tabla = 4×4
   -1.0000         0         0    3.0000
         0   -1.0000         0    0.4500
         0         0    1.0000    0.0800
         0         0         0    1.0000
```

```
T_p560_0 = T_tabla_0*T_p560_tabla
```

```
T_p560_0 = 4×4
   -0.5000    0.8660         0    0.8103
```

```
   -0.8660   -0.5000         0    2.3231
         0         0    1.0000    0.8800
         0         0         0    1.0000
```

```
p560.base = T_p560_0
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
```

Fiducials wrt Universe {U}

```
% We get our fiducials coordinates with respect to universe
F1 = T_fiducial1_0(1:3,4)
```

```
F1 = 3×1
    0.4291
    1.5478
    0.9160
```

```
F2 = T_fiducial2_0(1:3,4)
```

```
F2 = 3×1
    0.3517
    1.6458
    0.9200
```

```
F3 = T_fiducial3_0(1:3,4)
```

```
F3 = 3×1
    0.4275
    1.6490
    1.0660
```

Fiducials wrt Robot {R}

```
% We put the fiducial coordinates with respect to the robot
Fi_R=inv(T_p560_0)*[F1 F2 F3;ones(1,3)]
```

```
Fi_R = 4×3
    0.8620    0.8158    0.7752
    0.0575   -0.0585    0.0055
    0.0360    0.0400    0.1860
    1.0000    1.0000    1.0000
```

Fiducials {F} reference frame wrt Robot {R} reference frame

```
% We construct the transformation to go from {R} to {F}, F1 is taken as
% Pa_BORG where a is {R}
Yf = (Fi_R(1:3,2)-Fi_R(1:3,1))/norm(Fi_R(1:3,2)-Fi_R(1:3,1));
b=(Fi_R(1:3,3)-Fi_R(1:3,1))/norm(Fi_R(1:3,3)-Fi_R(1:3,1));
Zf = cross(Yf,b)/norm(cross(Yf,b));
Xf = cross(Yf,Zf)/norm(cross(Yf,Zf));
T_F_p560 = [[Xf;0] [Yf;0] [Zf;0] [Fi_R(:,1)]]
```

```
T_F_p560 = 4×4
    0.3464   -0.3698   -0.8621    0.8620
   -0.1698   -0.9286    0.3301    0.0575
   -0.9226    0.0320   -0.3844    0.0360
         0         0         0    1.0000
```

```
det(T_F_p560)
```

```
ans = 1.0000
```

Fiducials {F} reference frame wrt Universe {U} reference frame

```
% We put {F} with respect to {U}
T_F_0 = T_p560_0 * T_F_p560
```

```
T_F_0 = 4×4
   -0.3202   -0.6192    0.7169    0.4291
   -0.2151    0.7845    0.5816    1.5478
   -0.9226    0.0320   -0.3844    0.9160
         0         0         0    1.0000
```

```

% We check that Pu_FORG is coincident with the coordinate of fiducial1 in
% {U}
RPY = tr2rpy(T_F_p560,'zyx')
```

```
RPY = 1×3
    3.0585    1.1748   -0.4557
```

```
T_F1_0 = T_p560_0*transl(Fi_R(1:3,1))*trotz(RPY(3))*troty(RPY(2))*trotx(RPY(1))
```

```
T_F1_0 = 4×4
   -0.3202   -0.6192    0.7169    0.4291
   -0.2151    0.7845    0.5816    1.5478
   -0.9226    0.0320   -0.3844    0.9160
         0         0         0    1.0000
```

```
T_F_0
```

```
T_F_0 = 4×4
   -0.3202   -0.6192    0.7169    0.4291
   -0.2151    0.7845    0.5816    1.5478
   -0.9226    0.0320   -0.3844    0.9160
         0         0         0    1.0000
```

Fiducials wrt {I}

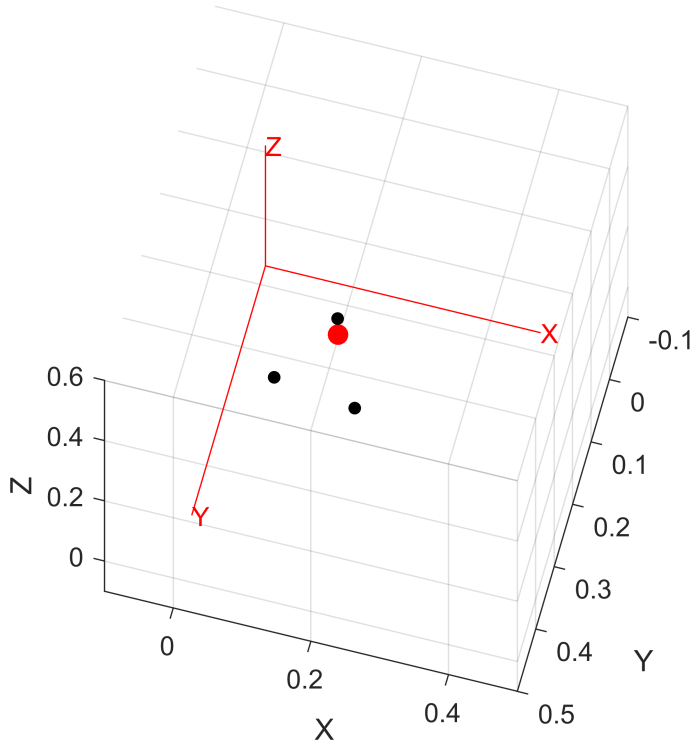
```
% We put fiducials with respect to image frame and then we plot them
pitch =1.4; % Pitch among slices
F1D = [0.07 0.214 0.08*pitch]';
F2D = [0.186 0.210 0.047*pitch]';
F3D = [0.122 0.064 0.018*pitch]';
Tumor=[0.132 0.099 0.03571*pitch]';

figure
trplot(eye(3),'Frame','I','color', 'r','length',0.4)
hold on
axis([-0.1 0.5 -0.1 0.5 -0.1 0.6])
view (-15,-65) % For better understanding

[X,Y,Z] = sphere;
r = 0.008
```

```
r = 0.0080
```

```
r2 = 0.0145
```

```
r2 = 0.0145
```

```
X2 = X * r;
Y2 = Y * r;
Z2 = Z * r;
surf(X2+F1D(1),Y2+F1D(2),Z2+F1D(3),'FaceColor',[0 1 0])
surf(X2+F2D(1),Y2+F2D(2),Z2+F2D(3),'FaceColor',[0 1 0])
surf(X2+F3D(1),Y2+F3D(2),Z2+F3D(3),'FaceColor',[0 1 0])
surf(X*r2+Tumor(1),Y*r2+Tumor(2),Z*r2+Tumor(3),'FaceColor',[1 0 0], 'EdgeColor','none')
```



T_F_I - Frame Description

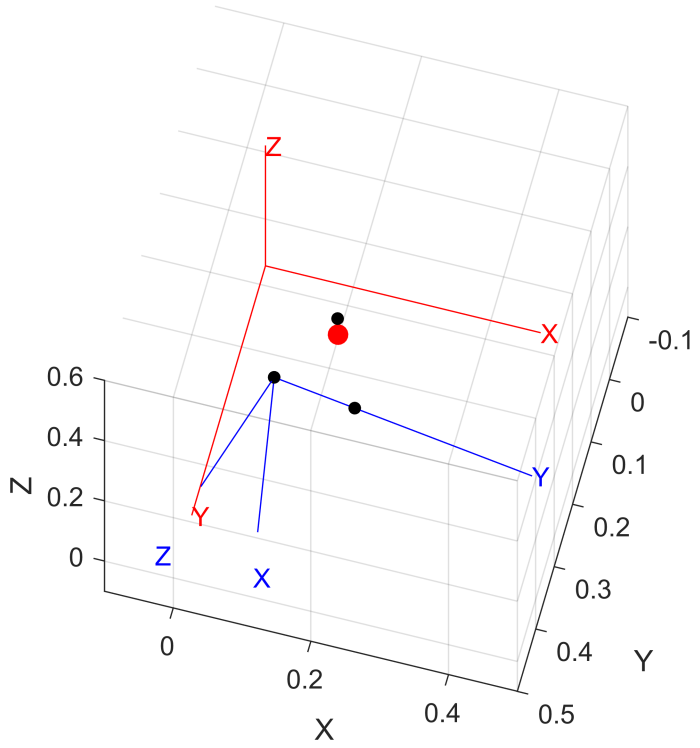
```
% We construct the transformation to go from {F} to {I}, F1 is taken as
% Pa_BORG where a is {F}
YfD = (F2D-F1D)/norm(F2D-F1D);
bD = (F3D-F1D)/norm(F3D-F1D);
ZfD = cross(YfD,bD)/norm(cross(YfD,bD));
XfD = cross(YfD,ZfD)/norm(cross(YfD,ZfD));

T_F_I = [[XfD;0] [YfD;0] [ZfD;0] [F1D;1]]
```

```
T_F_I = 4×4
    0.1698    0.9286   -0.3301    0.0700
    0.9226   -0.0320    0.3844    0.2140
    0.3464   -0.3698   -0.8621    0.1120
         0         0         0    1.0000
```

```
det(T_F_I)
```

```
ans = 1.0000
```

```
trplot(T_F_I,'Frame','F','color', 'b','length',0.4)
```




```
% We again check if Pu_FORG is coincident with the coordinate of fiducial1 in
% {U}
RPY=tr2rpy(T_F_I,'zyx')
```

```
RPY = 1×3
   -2.7364   -0.3537    1.3888
```

```
T_F_02=transl(F1D)*trotz(RPY(3))*troty(RPY(2))*trotx(RPY(1))
```

```
T_F_02 = 4×4
    0.1698    0.9286   -0.3301    0.0700
    0.9226   -0.0320    0.3844    0.2140
    0.3464   -0.3698   -0.8621    0.1120
         0         0         0    1.0000
```

```
T_F_I
```

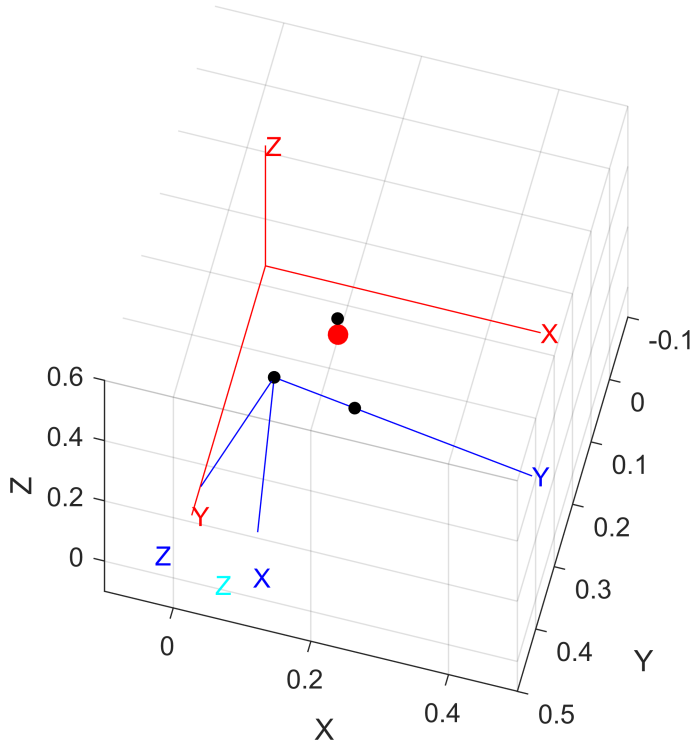
```
T_F_I = 4×4
    0.1698    0.9286   -0.3301    0.0700
    0.9226   -0.0320    0.3844    0.2140
    0.3464   -0.3698   -0.8621    0.1120
         0         0         0    1.0000
```

Image {I} reference frame wrt Univers {U} reference frame

```
% We put {I} with respect to {U}
T_I_0 = T_F_0*inv(T_F_I)
```

```
T_I_0 = 4×4
   -0.8660    0.0000   -0.5000    0.5457
    0.5000    0.0000   -0.8660    1.6098
   -0.0000   -1.0000   -0.0000    1.1300
         0         0         0    1.0000
```

```
trplot(T_I_0,'Frame','I','color', 'cyan','length',0.7)
```



T_I_R System equation

```
% We construct the transformation to go from {I} to {R}
T_I_p560 = inv(T_p560_0)*T_F_0*inv(T_F_I)
```

```
T_I_p560 = 4×4
   -0.0000   -0.0000    1.0000    0.7500
   -1.0000    0.0000   -0.0000    0.1275
   -0.0000   -1.0000   -0.0000    0.2500
         0         0         0    1.0000
```

```
% We check that with the given fiducials coordinates in image reference
% frame we can also obtain them in robot reference frame
Fi_R2=T_I_p560*[[F1D F2D F3D];ones(1,3)]
```

```
Fi_R2 = 4×3
    0.8620    0.8158    0.7752
    0.0575   -0.0585    0.0055
    0.0360    0.0400    0.1860
    1.0000    1.0000    1.0000
```

```
Fi_R
```

```
Fi_R = 4×3
    0.8620    0.8158    0.7752
    0.0575   -0.0585    0.0055
    0.0360    0.0400    0.1860
    1.0000    1.0000    1.0000
```

Fiducials in Universe Frame

```
% We check that with the given fiducials coordinates in image reference
% frame we can also obtain them in universe reference frame
Fi_0=T_p560_0*T_I_p560*[[F1D F2D F3D];ones(1,3)]
```

```
Fi_0 = 4×3
    0.4291    0.3517    0.4275
    1.5478    1.6458    1.6490
    0.9160    0.9200    1.0660
    1.0000    1.0000    1.0000
```

```
Tumor_0=T_p560_0*T_I_p560*[Tumor;1]
```

```
Tumor_0 = 4×1
    0.4064
    1.6325
    1.0310
    1.0000
```

Surgery (55%)

Biospy

Prepare a script that perform a biopsy. Zoom in the scene and record a video with the best view.

Take into account:

- Use a tool that has the following Transformation: transl(0.05 0 0.25)
- Use 'trail' option of plot to visualize the trajectory.
- The speed of biopsy function that you design ought to be a parameter to satisfy the surgeons.

Answer these questions:

- Display in a figure the displacement, velocity and aceleration of the tool in End Efector Reference frame.

Done at the bottom of this section

- How much enter the tool in the patient brain.

Taking into account that between images 112 and 78 there are 34 images, and between images there is a distance of 1.4mm, from the top of the skull to the center of the tumor there are 34 * 1.4mm = 47.6mm, what is equal to how much the tool enters in the patient brain.

- What is the speed of the tool in World Reference Frame.

Done at the bottom of this section

```
% Now Biopsy, Trepanation and Burning will be done as before but using the
% information extracted from the position of the fiducials
close all

figure
hold on
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+Fi_0(1,1),Y*r+Fi_0(2,1),Z*r+Fi_0(3,1),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r+Fi_0(1,2),Y*r+Fi_0(2,2),Z*r+Fi_0(3,2),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r+Fi_0(1,3),Y*r+Fi_0(2,3),Z*r+Fi_0(3,3),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r2+Tumor_0(1,1),Y*r2+Tumor_0(2,1),Z*r2+Tumor_0(3,1),'FaceColor',[1 0 0], 'EdgeColor','no
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])

% We set the appropriate tool to do the biopsy and then we set the frames
% that will divide our trajectories
p560.tool = transl(0.05,0,0.25)
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0.05, 0, 0.25), RPY/xyz = (0, 0, 0) deg
```

```
T1 = [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*transl(0.0,0.0,-0.3)*trotz(pi/2) % From robot ini
```

```
T1 = 4×4
```

```
    0.0000    0.8660   -0.5000    0.5564
    0.0000   -0.5000   -0.8660    1.8923
   -1.0000    0.0000   -0.0000    1.0310
         0         0         0    1.0000
```

```
T2 = [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*trotz(pi/2) % From T1 final point to tumor
```

```
T2 = 4×4
    0.0000    0.8660   -0.5000    0.4064
    0.0000   -0.5000   -0.8660    1.6325
   -1.0000    0.0000   -0.0000    1.0310
         0         0         0    1.0000
```

```
T0 = p560.fkine(qr)
```

```
T0 =
   -0.5000    0.8660         0    0.6452
   -0.8660   -0.5000         0     2.337
         0         0         1     1.994
         0         0         0         1
```

```
q_0 = p560.ikine6s(T0,'run');
q_1 = p560.ikine6s(T1,'run');
t_0 = linspace(0.0,3.0,30);
Q_0 = jtraj(q_0,q_1,t_0); % For the first trajectory we follow an eliptic path
t_1 = linspace(0.0,5.0,50);
S = tpoly(0,1,t_1);
S(1) = 0;
S(50) = 1;
T_1_2 = ctraj(T1,T2,S); % For the second trajectory we follow an straight path with non constar
Q_1 = p560.ikine(T_1_2);
T_2_1 = ctraj(T2,T1,S); % We will perform a third trajectory that consists in returning to T1
Q_2 = p560.ikine(T_2_1);
QT = [Q_0;Q_1;Q_2];
p560.plot(QT,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
```

Displacement, velocity and aceleration of the tool in End Efector Reference frame

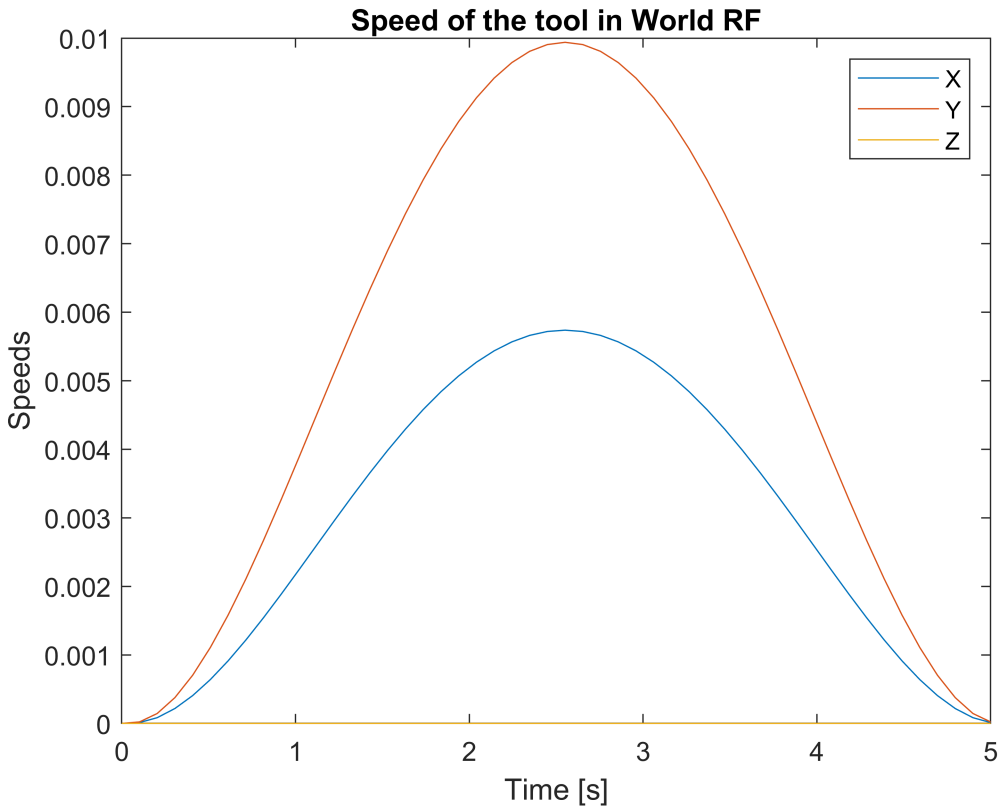
(Part of getting into the skull, the part of returning back would be the same but in reverse direction)

```
close all

t = t_1;
T_EEini_0 = T1;
T_EEact_0 = T_1_2;

% We convert world positions to end effector position with respect to
% initial end effector position
for i=1:50
    T_EEact_EEini(:,:,i) = inv(T_EEini_0)*T_EEact_0(:,:,i);
end
figure
traj_points_xyz=transl(T_EEact_EEini);
```

```
velocity=diff(traj_points_xyz(:,:));
accel=diff(velocity);

% We plot the displacement, velocity and aceleration of the tool in End
% Effector Reference Frame
subplot(3,1,1)
plot(t,traj_points_xyz(:,:))
title('Displacement of the tool in EE RF')
ylabel('Positions')
xlabel('Time [s]')
legend('X','Y','Z')
subplot(3,1,2)
plot(t,[0 0 0; velocity])
title('Velocity of the tool in EE RF')
ylabel('Velocities')
xlabel('Time [s]')
legend('X','Y','Z')
subplot(3,1,3)
plot(t,[0 0 0; accel; 0 0 0])
title('Acceleration of the tool in EE RF')
ylabel('Accelerations')
xlabel('Time [s]')
legend('X','Y','Z')
```

Speed of the tool in World Reference Frame

```
% Now we plot the speed of the tool in World Reference Frame
close all

t = t_1;
traj_points_xyz=transl(T_1_2);
velocity=abs(diff(traj_points_xyz(:,:)));

figure
subplot(1,1,1)
plot(t,[0 0 0; velocity])
title('Speed of the tool in World RF')
ylabel('Speeds');
xlabel('Time [s]');
legend('X','Y','Z');
```



Trepanation

Prepare a script that perform trepanation. Zoom in the scene and record a video with the best view.

Take into account:

- Use a tool that has the following Transformation: transl(0 0 0.2)
- Use 'trail' option of plot to visualize the trajectory.
- Place a 45º cone on top of the trepanation to better understand.
- See: 6_Plot_Box_Cone_fiducials.mlx. You will have to scale it. Play with transparency.

Answer these questions:

- Display in a figure the lineal displacement, velocity and aceleration of the tool in End Efector Reference frame.
- Display in a figure the manipulabitlity of the trepanation function either for translation and rotation.
- Find an alternate robot location for improving your manipulabitity.

All done at the bottom of this section

```
close all

% We plot a cone in top of the skull forming 45 degrees with its
% longitudinal axis
Cono = load('F_V_Cone.mat')
```

```
Cono = struct with fields:
    fvc: [1×1 struct]
```

```
H = 0.2
```

```
H = 0.2000
```

```
W = 0.2
```

```
W = 0.2000
```

```
D = 0.2
```

```
D = 0.2000
```

```
v_cono = [H 0 0; 0 W 0; 0 0 D]*Cono.fvc.vertices';
v_cono(4,:) = 1;
T_cono_I = transl(0.132,0.099,-0.2)
```

```
T_cono_I = 4×4
    1.0000         0         0    0.1320
         0    1.0000         0    0.0990
         0         0    1.0000   -0.2000
         0         0         0    1.0000
```

```
T_cono_0 = T_I_0 * T_cono_I
```

```
T_cono_0 = 4×4
   -0.8660    0.0000   -0.5000    0.5314
    0.5000    0.0000   -0.8660    1.8490
   -0.0000   -1.0000   -0.0000    1.0310
         0         0         0    1.0000
```

```
v_cono_0 = T_cono_0 * v_cono;

figure
hold on
patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_cono_0(1:3,:)','Faces',Cono.fvc.faces,'FaceVertexCData',hsv(6),'FaceColor',
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','b
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+Fi_0(1,1),Y*r+Fi_0(2,1),Z*r+Fi_0(3,1),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r+Fi_0(1,2),Y*r+Fi_0(2,2),Z*r+Fi_0(3,2),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r+Fi_0(1,3),Y*r+Fi_0(2,3),Z*r+Fi_0(3,3),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r2+Tumor_0(1,1),Y*r2+Tumor_0(2,1),Z*r2+Tumor_0(3,1),'FaceColor',[1 0 0], 'EdgeColor','no
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])
```

```
% We set the appropriate tool to do the trepanation and then we set the frames
% that will divide our trajectories
p560.tool = transl(0.0,0,0.2)
```

```
p560 =

Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0, 0, 0.2), RPY/xyz = (0, 0, 0) deg
```

```
T1 = [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*transl(0.0,-0.00725,-0.05)*trotz(pi/2)*troty(pi/4
```

```
T1 = 4×4
    0.3536    0.8660   -0.3536    0.4314
    0.6124   -0.5000   -0.6124    1.6758
   -0.7071    0.0000   -0.7071    1.0383
         0         0         0    1.0000
```

```
T0 = p560.fkine(qr)
```

```
T0 =
   -0.5000    0.8660         0    0.6702
   -0.8660   -0.5000         0     2.381
         0         0         1     1.944
         0         0         0         1
```

```
q_0 = p560.ikine6s(T0,'run');
q_1 = p560.ikine6s(T1,'run');
t_0 = linspace(0.0,3.0,30);
% We do the trepanation always perforing the skull with 45 degrees wrt the
% longitudinal axis of the human
for i=1:50
Trepanation_Pose(:,:,i)= [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*transl(0.0,0.0,-0.05)*trotz(
end
Q_0 = jtraj(q_0,q_1,t_0); % For the first trajectory we follow an eliptic path
Q_1 = p560.ikine6s(Trepanation_Pose, 'run'); % For the trepanation we follow constant velocity
Q_2 = jtraj(q_1,q_0,t_0) % We return to initial position
```

```
Q_2 = 30×6
    0.2417    1.1693   -2.9214    2.8538    0.6389   -2.7357
    0.2416    1.1695   -2.9208    2.8539    0.6386   -2.7334
    0.2410    1.1705   -2.9174    2.8546    0.6370   -2.7183
    0.2395    1.1731   -2.9086    2.8565    0.6329   -2.6803
```

```
    0.2366    1.1778   -2.8929    2.8599    0.6254   -2.6116
    0.2323    1.1850   -2.8688    2.8650    0.6140   -2.5070
    0.2264    1.1948   -2.8358    2.8720    0.5984   -2.3633
    0.2189    1.2073   -2.7936    2.8810    0.5784   -2.1795
    0.2097    1.2226   -2.7422    2.8920    0.5541   -1.9561
    0.1989    1.2404   -2.6823    2.9047    0.5258   -1.6952
     ⋮
```

```
QT = [Q_0;Q_1;Q_2];
p560.plot(QT,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
```

Displacement, velocity and aceleration of the tool in End Efector Reference frame

(Part of perforing the skull)

```
close all
ts = 0.1
```

```
ts = 0.1000
```

```
tf = 5
```

```
tf = 5
```

```
t = (0:ts:tf-ts)
```

```
t = 1×50
         0    0.1000    0.2000    0.3000    0.4000    0.5000    0.6000    0.7000 ···
```

```
T_EEini_0 = T1
```

```
T_EEini_0 = 4×4
    0.3536    0.8660   -0.3536    0.4314
    0.6124   -0.5000   -0.6124    1.6758
   -0.7071    0.0000   -0.7071    1.0383
         0         0         0    1.0000
```

```
T_EEact_0 = Trepanation_Pose
```

```
T_EEact_0 =
T_EEact_0(:,:,1) =

    0.4303    0.8592   -0.2768    0.4252
    0.5681   -0.4961   -0.6567    1.6794
   -0.7015    0.1253   -0.7015    1.0301
         0         0         0    1.0000


T_EEact_0(:,:,2) =

    0.5058    0.8388   -0.2013    0.4253
    0.5244   -0.4843   -0.7003    1.6793
   -0.6849    0.2487   -0.6849    1.0292
         0         0         0    1.0000


T_EEact_0(:,:,3) =

    0.5790    0.8052   -0.1281    0.4256
```

```
    0.4822   -0.4649   -0.7425    1.6792
   -0.6575    0.3681   -0.6575    1.0283
         0         0         0    1.0000


T_EEact_0(:,:,4) =

    0.6486    0.7589   -0.0585    0.4259
    0.4420   -0.4382   -0.7827    1.6790
   -0.6196    0.4818   -0.6196    1.0275
         0         0         0    1.0000


T_EEact_0(:,:,5) =

    0.7135    0.7006    0.0064    0.4263
    0.4046   -0.4045   -0.8202    1.6787
   -0.5721    0.5878   -0.5721    1.0267
         0         0         0    1.0000


T_EEact_0(:,:,6) =

    0.7728    0.6313    0.0656    0.4268
    0.3703   -0.3645   -0.8544    1.6785
   -0.5155    0.6845   -0.5155    1.0260
         0         0         0    1.0000


T_EEact_0(:,:,7) =

    0.8254    0.5520    0.1183    0.4274
    0.3400   -0.3187   -0.8848    1.6781
   -0.4507    0.7705   -0.4507    1.0254
         0         0         0    1.0000


T_EEact_0(:,:,8) =

    0.8706    0.4640    0.1635    0.4280
    0.3139   -0.2679   -0.9109    1.6778
   -0.3789    0.8443   -0.3789    1.0249
         0         0         0    1.0000


T_EEact_0(:,:,9) =

    0.9076    0.3687    0.2005    0.4287
    0.2925   -0.2129   -0.9323    1.6774
   -0.3011    0.9048   -0.3011    1.0244
         0         0         0    1.0000


T_EEact_0(:,:,10) =

    0.9360    0.2676    0.2288    0.4295
    0.2761   -0.1545   -0.9486    1.6769
   -0.2185    0.9511   -0.2185    1.0241
         0         0         0    1.0000


T_EEact_0(:,:,11) =

    0.9551    0.1623    0.2480    0.4302
```

```
    0.2651   -0.0937   -0.9597    1.6765
   -0.1325    0.9823   -0.1325    1.0239
         0         0         0    1.0000


T_EEact_0(:,:,12) =

    0.9647    0.0544    0.2576    0.4310
    0.2595   -0.0314   -0.9652    1.6760
   -0.0444    0.9980   -0.0444    1.0238
         0         0         0    1.0000


T_EEact_0(:,:,13) =

    0.9647   -0.0544    0.2576    0.4318
    0.2595    0.0314   -0.9652    1.6756
    0.0444    0.9980    0.0444    1.0238
         0         0         0    1.0000


T_EEact_0(:,:,14) =

    0.9551   -0.1623    0.2480    0.4326
    0.2651    0.0937   -0.9597    1.6751
    0.1325    0.9823    0.1325    1.0239
         0         0         0    1.0000


T_EEact_0(:,:,15) =

    0.9360   -0.2676    0.2288    0.4333
    0.2761    0.1545   -0.9486    1.6747
    0.2185    0.9511    0.2185    1.0241
         0         0         0    1.0000


T_EEact_0(:,:,16) =

    0.9076   -0.3687    0.2005    0.4341
    0.2925    0.2129   -0.9323    1.6743
    0.3011    0.9048    0.3011    1.0244
         0         0         0    1.0000


T_EEact_0(:,:,17) =

    0.8706   -0.4640    0.1635    0.4348
    0.3139    0.2679   -0.9109    1.6739
    0.3789    0.8443    0.3789    1.0249
         0         0         0    1.0000


T_EEact_0(:,:,18) =

    0.8254   -0.5520    0.1183    0.4354
    0.3400    0.3187   -0.8848    1.6735
    0.4507    0.7705    0.4507    1.0254
         0         0         0    1.0000


T_EEact_0(:,:,19) =

    0.7728   -0.6313    0.0656    0.4360
```

```
    0.3703    0.3645   -0.8544    1.6732
    0.5155    0.6845    0.5155    1.0260
         0         0         0    1.0000


T_EEact_0(:,:,20) =

    0.7135   -0.7006    0.0064    0.4365
    0.4046    0.4045   -0.8202    1.6729
    0.5721    0.5878    0.5721    1.0267
         0         0         0    1.0000


T_EEact_0(:,:,21) =

    0.6486   -0.7589   -0.0585    0.4369
    0.4420    0.4382   -0.7827    1.6726
    0.6196    0.4818    0.6196    1.0275
         0         0         0    1.0000


T_EEact_0(:,:,22) =

    0.5790   -0.8052   -0.1281    0.4372
    0.4822    0.4649   -0.7425    1.6724
    0.6575    0.3681    0.6575    1.0283
         0         0         0    1.0000


T_EEact_0(:,:,23) =

    0.5058   -0.8388   -0.2013    0.4375
    0.5244    0.4843   -0.7003    1.6723
    0.6849    0.2487    0.6849    1.0292
         0         0         0    1.0000


T_EEact_0(:,:,24) =

    0.4303   -0.8592   -0.2768    0.4376
    0.5681    0.4961   -0.6567    1.6722
    0.7015    0.1253    0.7015    1.0301
         0         0         0    1.0000


T_EEact_0(:,:,25) =

    0.3536   -0.8660   -0.3536    0.4377
    0.6124    0.5000   -0.6124    1.6722
    0.7071   -0.0000    0.7071    1.0310
         0         0         0    1.0000


T_EEact_0(:,:,26) =

    0.2768   -0.8592   -0.4303    0.4376
    0.6567    0.4961   -0.5681    1.6722
    0.7015   -0.1253    0.7015    1.0319
         0         0         0    1.0000


T_EEact_0(:,:,27) =

    0.2013   -0.8388   -0.5058    0.4375
```

```
    0.7003    0.4843   -0.5244    1.6723
    0.6849   -0.2487    0.6849    1.0328
         0         0         0    1.0000


T_EEact_0(:,:,28) =

    0.1281   -0.8052   -0.5790    0.4372
    0.7425    0.4649   -0.4822    1.6724
    0.6575   -0.3681    0.6575    1.0337
         0         0         0    1.0000


T_EEact_0(:,:,29) =

    0.0585   -0.7589   -0.6486    0.4369
    0.7827    0.4382   -0.4420    1.6726
    0.6196   -0.4818    0.6196    1.0345
         0         0         0    1.0000


T_EEact_0(:,:,30) =

   -0.0064   -0.7006   -0.7135    0.4365
    0.8202    0.4045   -0.4046    1.6729
    0.5721   -0.5878    0.5721    1.0353
         0         0         0    1.0000


T_EEact_0(:,:,31) =

   -0.0656   -0.6313   -0.7728    0.4360
    0.8544    0.3645   -0.3703    1.6732
    0.5155   -0.6845    0.5155    1.0360
         0         0         0    1.0000


T_EEact_0(:,:,32) =

   -0.1183   -0.5520   -0.8254    0.4354
    0.8848    0.3187   -0.3400    1.6735
    0.4507   -0.7705    0.4507    1.0366
         0         0         0    1.0000


T_EEact_0(:,:,33) =

   -0.1635   -0.4640   -0.8706    0.4348
    0.9109    0.2679   -0.3139    1.6739
    0.3789   -0.8443    0.3789    1.0371
         0         0         0    1.0000


T_EEact_0(:,:,34) =

   -0.2005   -0.3687   -0.9076    0.4341
    0.9323    0.2129   -0.2925    1.6743
    0.3011   -0.9048    0.3011    1.0376
         0         0         0    1.0000


T_EEact_0(:,:,35) =

   -0.2288   -0.2676   -0.9360    0.4333
```

```
    0.9486    0.1545   -0.2761    1.6747
    0.2185   -0.9511    0.2185    1.0379
         0         0         0    1.0000


T_EEact_0(:,:,36) =

   -0.2480   -0.1623   -0.9551    0.4326
    0.9597    0.0937   -0.2651    1.6751
    0.1325   -0.9823    0.1325    1.0381
         0         0         0    1.0000


T_EEact_0(:,:,37) =

   -0.2576   -0.0544   -0.9647    0.4318
    0.9652    0.0314   -0.2595    1.6756
    0.0444   -0.9980    0.0444    1.0382
         0         0         0    1.0000


T_EEact_0(:,:,38) =

   -0.2576    0.0544   -0.9647    0.4310
    0.9652   -0.0314   -0.2595    1.6760
   -0.0444   -0.9980   -0.0444    1.0382
         0         0         0    1.0000


T_EEact_0(:,:,39) =

   -0.2480    0.1623   -0.9551    0.4302
    0.9597   -0.0937   -0.2651    1.6765
   -0.1325   -0.9823   -0.1325    1.0381
         0         0         0    1.0000


T_EEact_0(:,:,40) =

   -0.2288    0.2676   -0.9360    0.4295
    0.9486   -0.1545   -0.2761    1.6769
   -0.2185   -0.9511   -0.2185    1.0379
         0         0         0    1.0000


T_EEact_0(:,:,41) =

   -0.2005    0.3687   -0.9076    0.4287
    0.9323   -0.2129   -0.2925    1.6774
   -0.3011   -0.9048   -0.3011    1.0376
         0         0         0    1.0000


T_EEact_0(:,:,42) =

   -0.1635    0.4640   -0.8706    0.4280
    0.9109   -0.2679   -0.3139    1.6778
   -0.3789   -0.8443   -0.3789    1.0371
         0         0         0    1.0000


T_EEact_0(:,:,43) =

   -0.1183    0.5520   -0.8254    0.4274
```

```
    0.8848   -0.3187   -0.3400    1.6781
   -0.4507   -0.7705   -0.4507    1.0366
         0         0         0    1.0000


T_EEact_0(:,:,44) =

   -0.0656    0.6313   -0.7728    0.4268
    0.8544   -0.3645   -0.3703    1.6785
   -0.5155   -0.6845   -0.5155    1.0360
         0         0         0    1.0000


T_EEact_0(:,:,45) =

   -0.0064    0.7006   -0.7135    0.4263
    0.8202   -0.4045   -0.4046    1.6787
   -0.5721   -0.5878   -0.5721    1.0353
         0         0         0    1.0000


T_EEact_0(:,:,46) =

    0.0585    0.7589   -0.6486    0.4259
    0.7827   -0.4382   -0.4420    1.6790
   -0.6196   -0.4818   -0.6196    1.0345
         0         0         0    1.0000


T_EEact_0(:,:,47) =

    0.1281    0.8052   -0.5790    0.4256
    0.7425   -0.4649   -0.4822    1.6792
   -0.6575   -0.3681   -0.6575    1.0337
         0         0         0    1.0000


T_EEact_0(:,:,48) =

    0.2013    0.8388   -0.5058    0.4253
    0.7003   -0.4843   -0.5244    1.6793
   -0.6849   -0.2487   -0.6849    1.0328
         0         0         0    1.0000


T_EEact_0(:,:,49) =

    0.2768    0.8592   -0.4303    0.4252
    0.6567   -0.4961   -0.5681    1.6794
   -0.7015   -0.1253   -0.7015    1.0319
         0         0         0    1.0000


T_EEact_0(:,:,50) =

    0.3536    0.8660   -0.3536    0.4251
    0.6124   -0.5000   -0.6124    1.6794
   -0.7071    0.0000   -0.7071    1.0310
         0         0         0    1.0000
```

```
T_EEact_EEini = []
```

```
T_EEact_EEini =

     []
```

```
for i=1:50
    T_EEact_EEini(:,:,i) = inv(T_EEini_0)*T_EEact_0(:,:,i);
end
figure
traj_points_xyz=transl(T_EEact_EEini)
```

```
traj_points_xyz = 50×3
    0.0058   -0.0072    0.0058
    0.0064   -0.0070    0.0064
    0.0070   -0.0067    0.0070
    0.0076   -0.0064    0.0076
    0.0081   -0.0059    0.0081
    0.0086   -0.0053    0.0086
    0.0091   -0.0046    0.0091
    0.0095   -0.0039    0.0095
    0.0098   -0.0031    0.0098
    0.0100   -0.0022    0.0100
      ⋮
```

```
velocity=diff(traj_points_xyz(:,:))
```

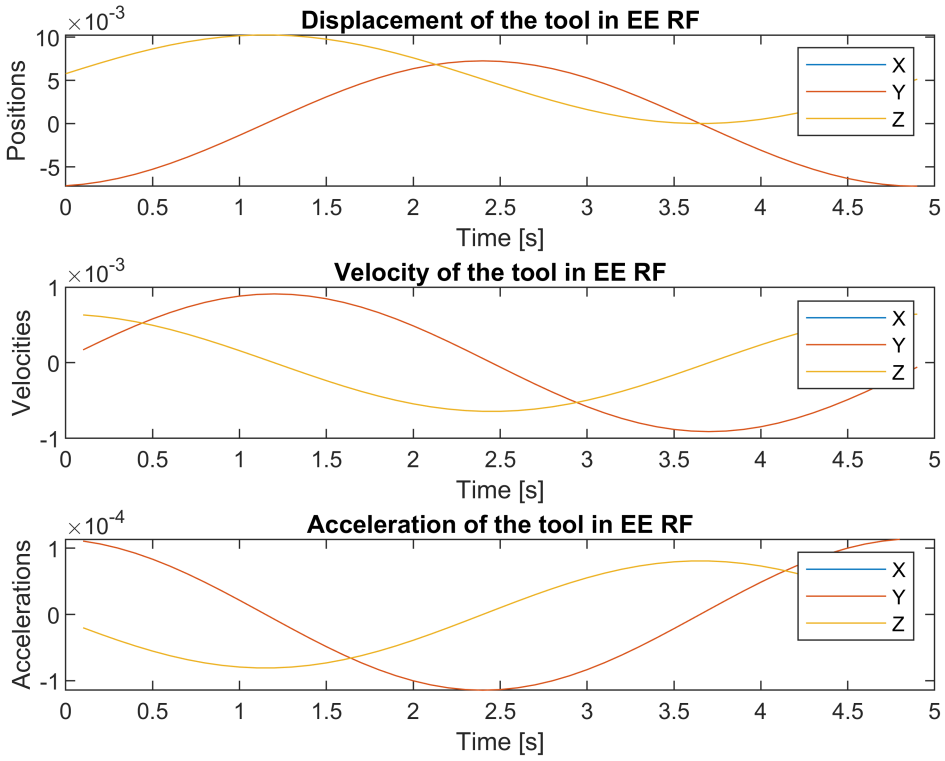
```
velocity = 49×3
1.0e-03 *
    0.6324    0.1706    0.6324
    0.6123    0.2813    0.6123
    0.5825    0.3877    0.5825
    0.5436    0.4879    0.5436
    0.4961    0.5804    0.4961
    0.4407    0.6637    0.4407
    0.3784    0.7366    0.3784
    0.3102    0.7978    0.3102
    0.2370    0.8465    0.2370
    0.1601    0.8819    0.1601
      ⋮
```

```
accel=diff(velocity)
```

```
accel = 48×3
1.0e-03 *
   -0.0201    0.1107   -0.0201
   -0.0298    0.1063   -0.0298
   -0.0389    0.1002   -0.0389
   -0.0475    0.0925   -0.0475
   -0.0553    0.0833   -0.0553
   -0.0623    0.0729   -0.0623
   -0.0683    0.0613   -0.0683
   -0.0732    0.0487   -0.0732
   -0.0769    0.0353   -0.0769
   -0.0794    0.0214   -0.0794
      ⋮
```

```


subplot(3,1,1)
plot(t,traj_points_xyz(:,:))
```

```
title('Displacement of the tool in EE RF')
ylabel('Positions')
xlabel('Time [s]')
legend('X','Y','Z')
subplot(3,1,2)
plot(t(2:50),velocity)
title('Velocity of the tool in EE RF')
ylabel('Velocities')
xlabel('Time [s]')
legend('X','Y','Z')
subplot(3,1,3)
plot(t(2:49),accel)
title('Acceleration of the tool in EE RF')
ylabel('Accelerations')
xlabel('Time [s]')
legend('X','Y','Z')
```



Manipulability

```
% Although qn configuration has a better manipulability than the others, we
% have seen that qr was the one that worked better for our case, so we have
% chosen qn
m1 = p560.maniplty(qr)
```

```
m1 = 0
```

```
m2=p560.maniplty(qn)
```

```
m2 = 0.0786
```

```
m3=p560.maniplty(qs)
```

```
m3 = 9.7886e-11
```

```
m4=p560.maniplty(qz)
```

```
m4 = 0
```

Tumor burning

Prepare a script that perform tumor burning with the laser. Zoom in the scene and record a video with the best view.

You ought to think in an algorithm, that in order, fill up the tumor's equivalent sphere with small burning spheres of 4mm diameter.

Use a tool that has the following Transformation: transl(0 0 0.2)

Answer these questions:

- Display in a figure the lineal displacement, velocity and aceleration of the tool in End Efector Reference frame.

Done at the bottom of this section

- How long it takes your burning function to burn the tumor

Our burning function takes 16.5 seconds to burn the tumor as we define a trajectory that lasts 0.5 seconds between each tumor point and we have 33 tumor points. If we also consider the trajectory of going from robot initial pose to in front of the skull, the trajectory of going from in front of the skull to the small hole made and the trajectory of returning back from there, all together lasts 3 + 5 + 16.5 + 5 = 29.5 seconds

```
close all

figure
hold on

% We plot the tumor subdivided in little spheres with radius = 4mm
esferas = zeros(33, 3)
```

```
esferas = 33×3
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
     0     0     0
```

⋮

```
i = 1
```

```
i = 1
```

```
rpeq = 0.004;
rgran = 0.0145;
[x, y, z] = sphere;
w = linspace(-rgran + rpeq, rgran - rpeq, 4);
light('Position',[2 3 1])

for ix = w
   for iy = w
      for iz = w
          if (ix)^2 + (iy)^2 + (iz)^2 < rgran^2

              esferas(i,:) = [ix iy iz];
              surf(x * rpeq + ix + Tumor_0(1,1), y * rpeq + iy + Tumor_0(2,1), z * rpeq + iz +
                  'FaceColor',[1 0 0], 'EdgeColor','none', 'FaceLighting', 'gouraud');
              i = i + 1;

          end
      end
   end
end

patch('Vertices',v_tabla_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata1_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata2_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata3_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_pata4_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','black','Face
patch('Vertices',v_tablaherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor',
patch('Vertices',v_pataherramientas_0(1:3,:)','Faces',f,'FaceVertexCData',hsv(6),'FaceColor','
patch('Vertices',v_humano_0(1:3,:)','Faces',Human.Fh,'FaceVertexCData',hsv(6),'FaceColor',[0.95
surf(X*r+Fi_0(1,1),Y*r+Fi_0(2,1),Z*r+Fi_0(3,1),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r+Fi_0(1,2),Y*r+Fi_0(2,2),Z*r+Fi_0(3,2),'FaceColor',[1 0 0], 'EdgeColor','none')
surf(X*r+Fi_0(1,3),Y*r+Fi_0(2,3),Z*r+Fi_0(3,3),'FaceColor',[1 0 0], 'EdgeColor','none')
view(30,45)
grid on
xyzlabel
axis equal
axis([-2.5 2.5 -1.5 3.5 0.0 3.5])

% We set the appropriate tool to do the burning and then we set the frames
% that will divide our trajectories
p560.tool = transl(0.0,0,0.2)
```

```
p560 =
```

```
Puma 560 [Unimation]:: 6 axis, RRRRRR, stdDH, slowRNE
 - viscous friction; params of 8/95;
+---+-----------+-----------+-----------+-----------+-----------+
| j |     theta |         d |         a |     alpha |    offset |
+---+-----------+-----------+-----------+-----------+-----------+
|  1|         q1|          0|          0|     1.5708|          0|
|  2|         q2|          0|     0.4318|          0|          0|
|  3|         q3|    0.15005|     0.0203|    -1.5708|          0|
|  4|         q4|     0.4318|          0|     1.5708|          0|
|  5|         q5|          0|          0|    -1.5708|          0|
|  6|         q6|          0|          0|          0|          0|
+---+-----------+-----------+-----------+-----------+-----------+
base:    t = (0.81, 2.32, 0.88), RPY/xyz = (-120, 0, 0) deg
tool:    t = (0, 0, 0.2), RPY/xyz = (0, 0, 0) deg
```

```
T1 = [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*transl(0.0,0.0,-0.3)*trotz(pi/2) % From robot ini
```

```
T1 = 4×4
    0.0000    0.8660   -0.5000    0.5564
    0.0000   -0.5000   -0.8660    1.8923
   -1.0000    0.0000   -0.0000    1.0310
         0         0         0    1.0000
```

```
T0 = p560.fkine(qr)
```

```
T0 =
   -0.5000    0.8660         0    0.6702
   -0.8660   -0.5000         0     2.381
         0         0         1     1.944
         0         0         0         1
```

```
q_0 = p560.ikine6s(T0,'run');
q_1 = p560.ikine6s(T1,'run');
t_0 = linspace(0.0,3.0,30);
Q_0 = jtraj(q_0,q_1,t_0); % For the first trajectory we follow an eliptic path

T_ini = [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*transl(0.0,0.0,-0.075)*trotz(pi/2)
```

```
T_ini = 4×4
    0.0000    0.8660   -0.5000    0.4439
    0.0000   -0.5000   -0.8660    1.6975
   -1.0000    0.0000   -0.0000    1.0310
         0         0         0    1.0000
```

```
t_1 = linspace(0.0,5.0,50);
S = tpoly(0,1,t_1);
S(1) = 0;
S(50) = 1;
T_1_ini = ctraj(T1,T_ini,S); % For the second trajectory we follow an straight path with non co
Q_1 = p560.ikine(T_1_ini);
p560.plot([Q_0;Q_1],'zoom',2,'trail',{'r', 'LineWidth', 1.5});

q_ini = p560.ikine6s(T_ini);
t_2 = linspace(0.0,0.5,5);
```

```
% Between each point to burn we create a trajectory, so we point one sphere
% and then we move the tool rotating it to point another
for i=1:33

    dy = sqrt((0.0-esferas(i,1))^2 + (-0.075-esferas(i,2))^2);
    dx = sqrt((0.0-esferas(i,3))^2 + (-0.075-esferas(i,2))^2);
    ax = asin(esferas(i,1)/dy);
    ay = asin(esferas(i,3)/dx);
    T_i = [T_I_0(1:3,1:3) Tumor_0(1:3,:); 0 0 0 1]*transl(0.0,0.0,-0.075)*trotz(pi/2)*trotx(-ax
    Burning_Pose(:,:,i)=T_i;
    q_i = p560.ikine6s(T_i, 'lun');
    Q_i = jtraj(q_ini,q_i,t_2);
    p560.plot(Q_i,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
    surf(x * rpeq + esferas(i,1) + Tumor_0(1,1), y * rpeq + esferas(i,2) + Tumor_0(2,1), z * rp
                'FaceColor','#006400', 'EdgeColor','none', 'FaceLighting', 'gouraud');
    q_ini = q_i;
end

T_ini_1 = ctraj(T_ini, T1, S); % Finally we return to T1 with a cartesian trajectory
Q_2 = p560.ikine(T_ini_1);
p560.plot(Q_2,'zoom',2,'trail',{'r', 'LineWidth', 1.5});
```

Displacement, velocity and aceleration of the tool in End Efector Reference frame

(Part of going to the entry of the skull, then the tool only rotates with respect to x and y axis of end effector reference frame to burn the tumor)

```
close all

t = t_1;
T_EEini_0 = T1
```

```
T_EEini_0 = 4×4
    0.0000    0.8660   -0.5000    0.5564
    0.0000   -0.5000   -0.8660    1.8923
   -1.0000    0.0000   -0.0000    1.0310
         0         0         0    1.0000
```

```
T_EEact_0 = T_1_ini;
T_EEact_EEini = [];
for i=1:50
    T_EEact_EEini(:,:,i) = inv(T_EEini_0)*T_EEact_0(:,:,i);
end
figure
traj_points_xyz=transl(T_EEact_EEini);
velocity=diff(traj_points_xyz(:,:));
accel=diff(velocity);

subplot(3,1,1)
plot(t,traj_points_xyz(:,:))
title('Displacement of the tool in EE RF')
```

```
ylabel('Positions')
xlabel('Time [s]')
legend('X','Y','Z')
subplot(3,1,2)
plot(t,[0 0 0; velocity])
title('Velocity of the tool in EE RF')
ylabel('Velocities')
xlabel('Time [s]')
legend('X','Y','Z')
subplot(3,1,3)
plot(t,[0 0 0; accel; 0 0 0])
title('Acceleration of the tool in EE RF')
ylabel('Accelerations')
xlabel('Time [s]')
legend('X','Y','Z')
```