SSY156 Lab 1

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Exercise 1

DH table

i	θ	d	a	α
1	$q1$	$L1$	0	$-\frac{\pi}{2}$
2	$q2 - \frac{\pi}{2}$	0	$L2$	0
3	$q3 + al$	0	$L7$	0
4	$q4 - al + \frac{\pi}{2}$	0	$L8$	0

where the parameter is:
$L1 = 0.29;$
$L2 = 0.27;$
$L3 = 0.07;$
$L4 = 0.302;$
$L5 = 0.072;$
$L6 = 0.1;$
$L7 = sqrt(L4^2 + L3^2);$
$L8 = (L5 + L6);$
$al = atan(L4/L3);$

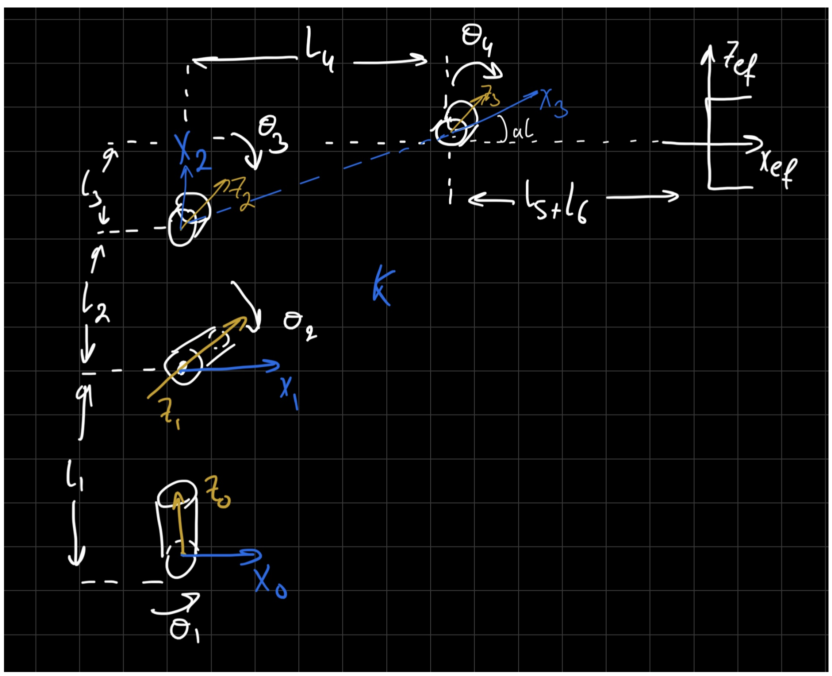


Figure 1: robot frame 1

Question 3

From the DH table, we can derive the necessary coordinate frames (CF) crucial for effective robot control. Figures 2 and 3 depict two distinct robot positions along with their corresponding validated coordinate frames determined from the DH table. The accuracy of these coordinate frames is confirmed through visual validation using pictures taken in the lab PM.

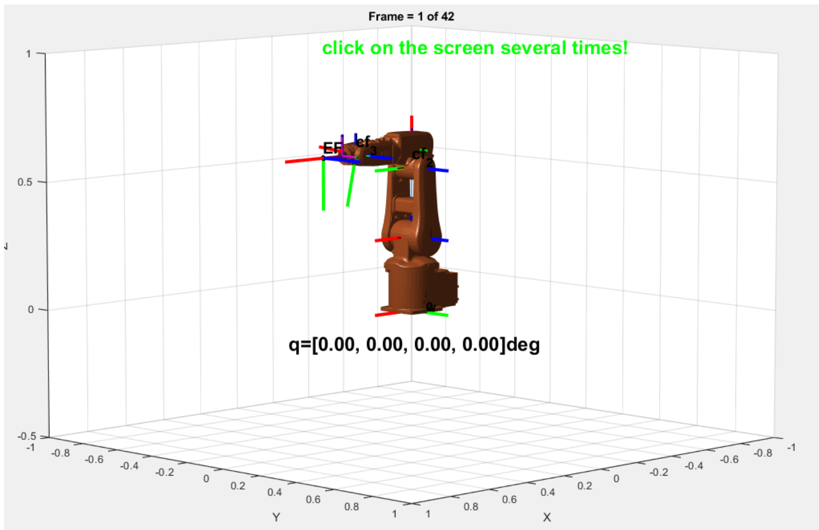


Figure 2: robot frame 1

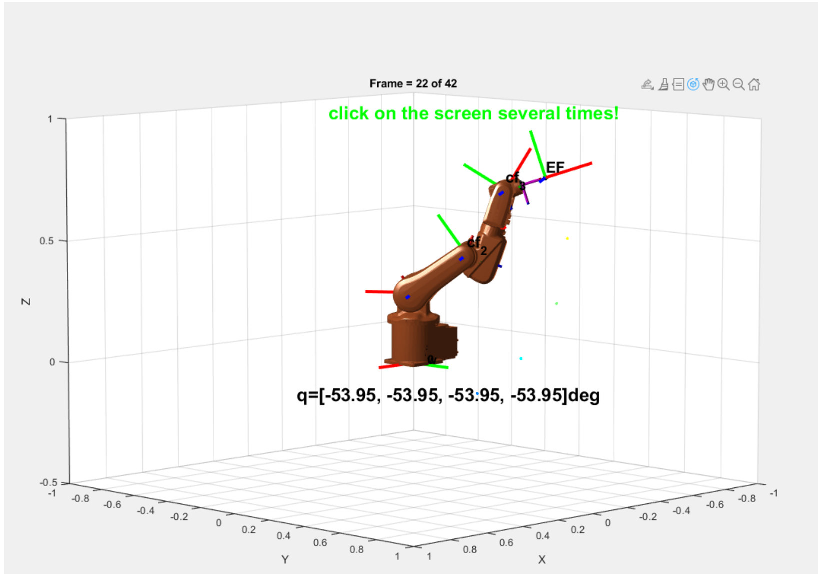
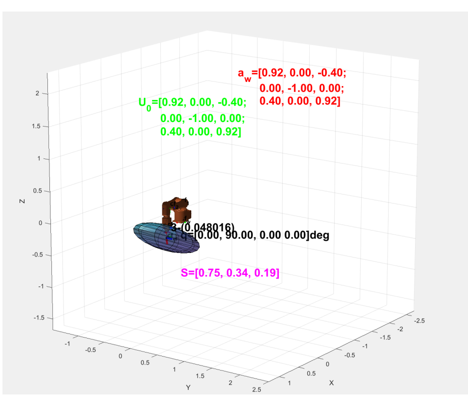


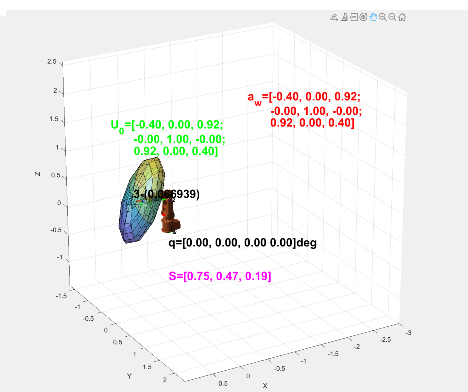
Figure 3: robot frame 1

Question 5

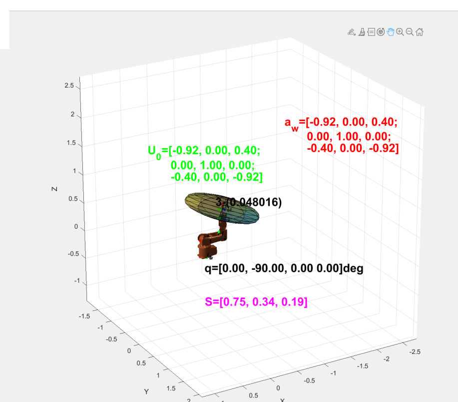
The graphs I got match the ones they showed us in the lab. They help us see how well the robot moves. Looking at fixed positions helps find tricky robot poses, and comparing different movements shows how fast the robot can go. The changing shape of the graphs with different robot positions tells us how the robot's joints affect its movements.Overall, this simulation shows I understand how well the ABB IRB1204 robot can move and react.



(a) Robot Frame 1 - $\pi/2$ Manipulation



(b) Robot Frame 2 - 0 Manipulation



(c) Another Robot Frame 1 - $-\pi/2$ Manipulation

Figure 5: Different Robot Frames with Manipulations

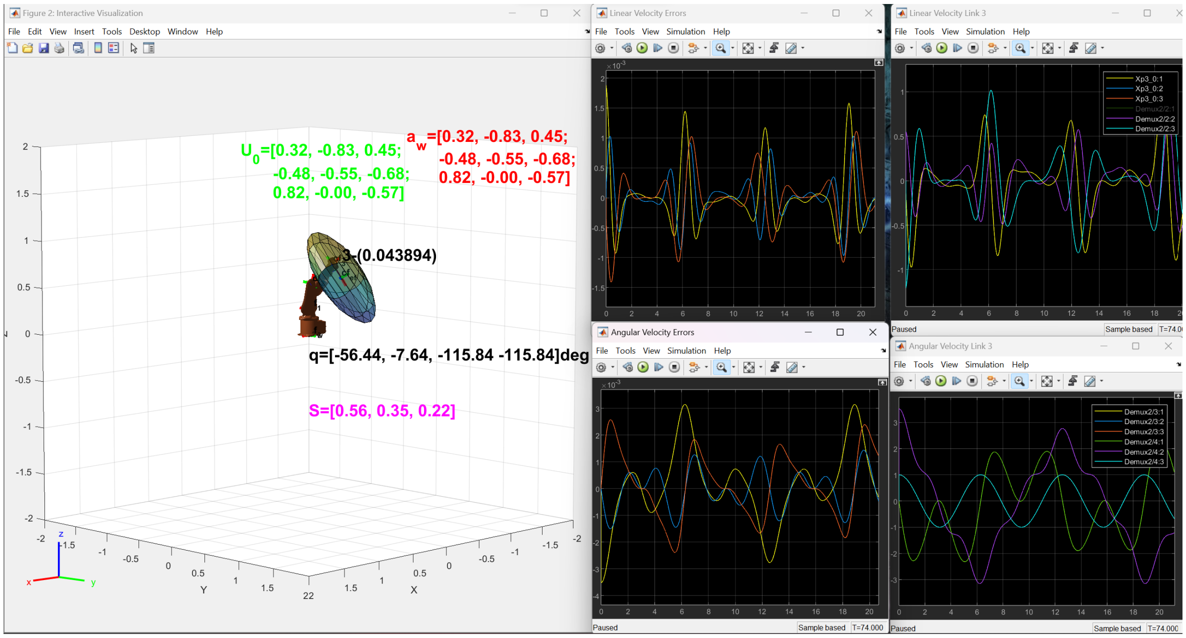


Figure 4: robot frame 1

Question 6

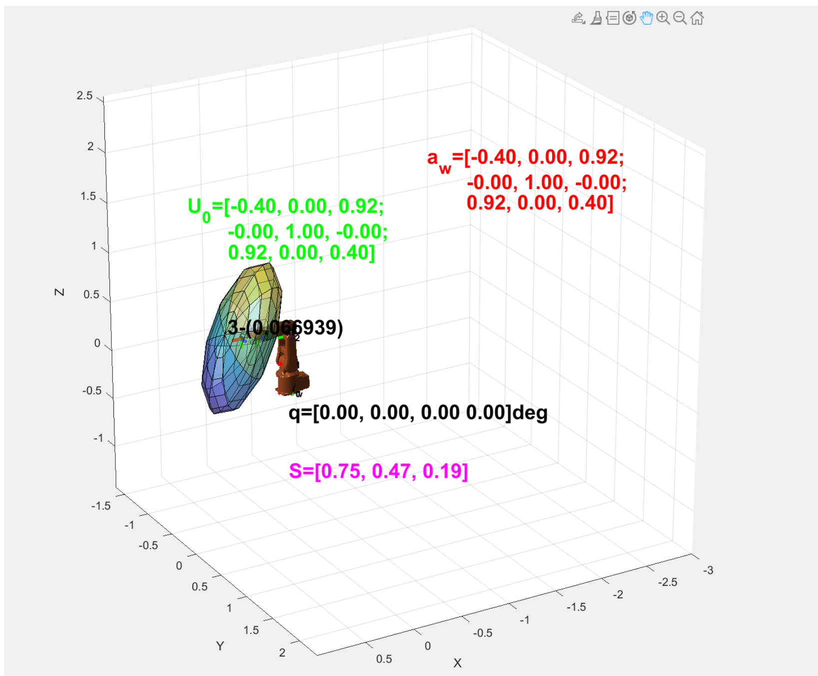
The manipulability ellipsoid undergoes changes in shape as joint configurations vary, influenced by the robot's kinematics. Factors such as joint angles, singularities, redundancy, and joint limits contribute to the alterations in the ellipsoid's appearance. Singular points and the utilization of redundant degrees of freedom, for instance, can modify the ellipsoid's shape, providing insights into the robot's adaptability in different directions. This visual representation aids in understanding the flexibility and constraints of the robot in diverse joint setups.

The manipulability index is calculated as $\sqrt{\det(J_{\text{ef}_v} \cdot J'_{\text{ef}_v})}$, signifying that manipulability relies on the Jacobian, which, in turn, is dependent on joint angles.

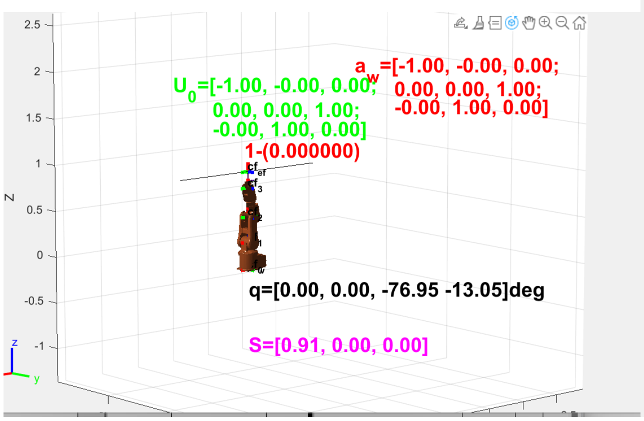
Question 7

The following figures show:

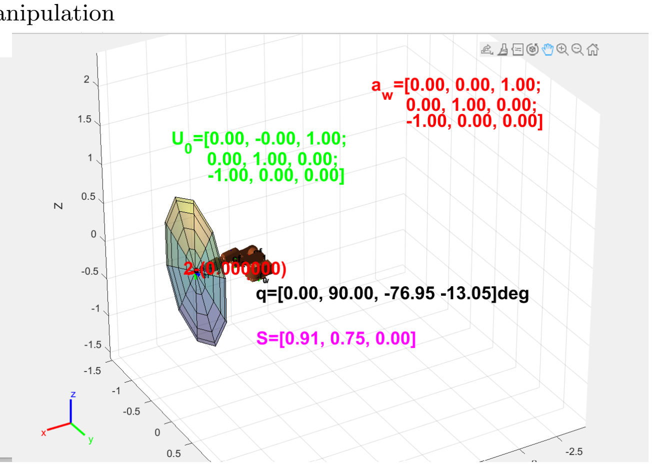
- Figure 6c shows the robot is in a singular configuration, and the DOFs=2. This means that the robot has 2 degrees of freedom, and therefore the ellipsoid is like a circle because there is no "Z" axis to move on.
- Figure 6b The robot is in a singular configuration, and the DOFs=1. This means that the robot has 1 degree of freedom, and therefore the ellipsoid is like a line because there is no "Z" and "Y" axes to move on.



(a) Robot Frame 1 - $\pi/2$ Manipulation



(b) Robot Frame 2 - 0 Manipulation



(c) Another Robot Frame 1 - $-\pi/2$ Manipulation

Figure 6: Different Robot Frames with Manipulations

Kinematic Model KUKA Robot

Exercise 8

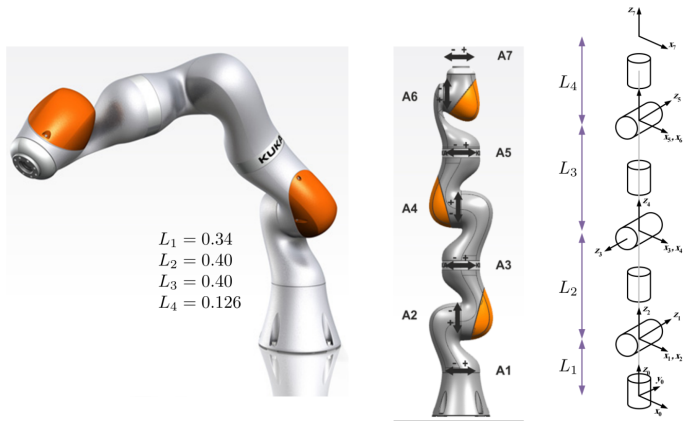


Figure 7: KUKA Robot DH cf's

DH table:

i	θ_i	d_i	a_i	α_i
1	$q1$	$L1$	0	$-\frac{\pi}{2}$
2	$q2$	0	0	$\frac{\pi}{2}$
3	$q3$	$L2$	0	$\frac{\pi}{2}$
4	$q4$	0	0	$-\frac{\pi}{2}$
5	$q5$	$L3$	0	$-\frac{\pi}{2}$
6	$q6$	0	0	$\frac{\pi}{2}$
7	$q7$	$L4$	0	0

Exercise 10

Referring to the DH table for the KUKA robot with 7 degrees of freedom, we can determine the essential coordinate frames (CF) vital for efficient robot control. Figures 8 and 9 showcase two distinct robot positions, each accompanied by their validated coordinate frames derived from the DH table. The accuracy of these coordinate frames is affirmed through visual validation, employing images captured in the lab PM.

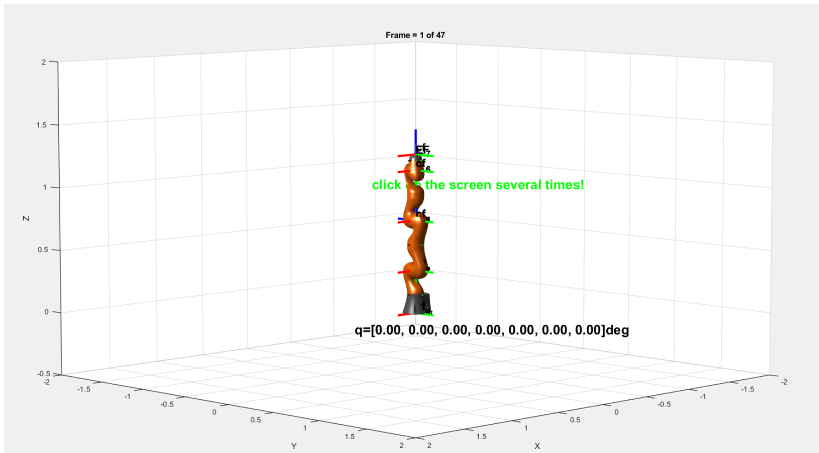


Figure 8: robot frame 1

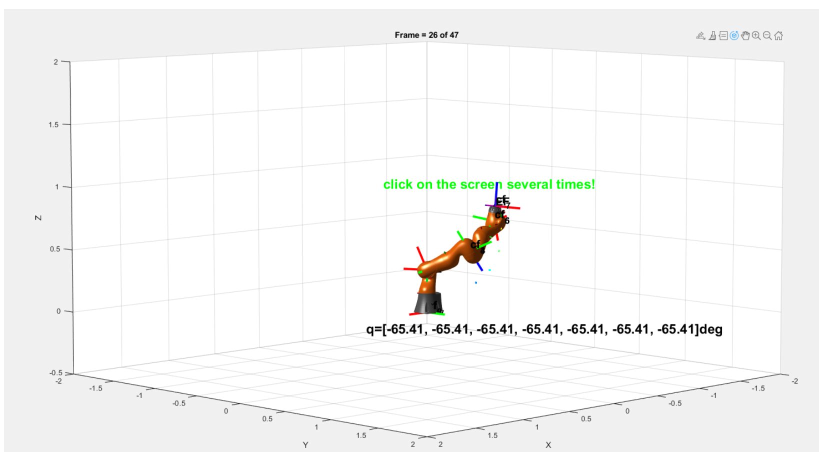


Figure 9: robot frame 26

Exercise 12

The graphs in Figure 10 display the linear and angular velocity, along with the error. It's evident that the error, both in linear and angular aspects, is very small. The plot illustrates the robot arm in motion, alongside the manipulability ellipsoid (M-ellipsoid), indicating the proximity of the robot to a singularity configuration. At this particular moment, the figure illustrates that the robot can move freely in all degrees of freedom, and the manipulability ellipsoid describes the extent to which the robot can move in each direction.

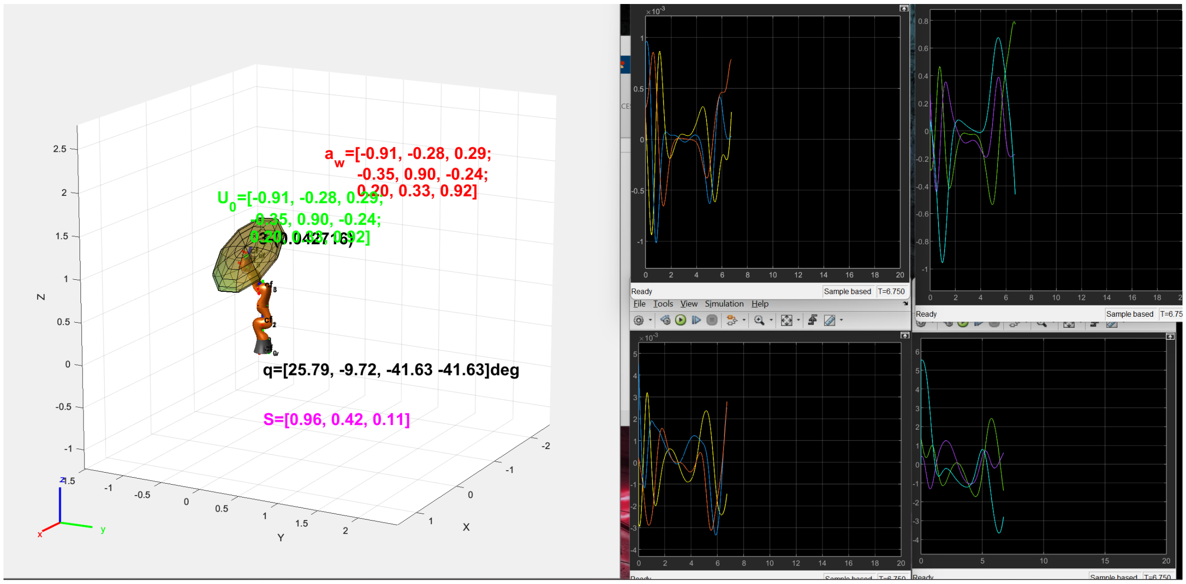


Figure 10: robot frame 26

Exercise 13

```
jef\_w = jef\_0(4:6,:);
[U,S,V] = svd(jef\_w,0);

dU = det(U);
nU = norm(U);
IU = U*U';
su = size(U);
ss = size(S);
ru = rank(U,0.01);
w = sqrt(det(jef\_w*jef\_w'));
EAxis\_W = R0\_W*U;
S = S(1:3,1:3);
S(4,4) = 1;
```

Listing 1: MATLAB code with LaTeX formatting

To derive the manipulability ellipsoid for angular velocity, one can calculate the principal axes, which indicate the extent and direction of the robot's movement. The angular velocity's principal axes, denoted as $EAxis\_W$, can be obtained through the matrix multiplication $EAxis\_W = R0\_W \cdot U$.

The matrix U can be computed using the singular value decomposition (SVD) of the angular velocity Jacobian, jef_w. The SVD is expressed as

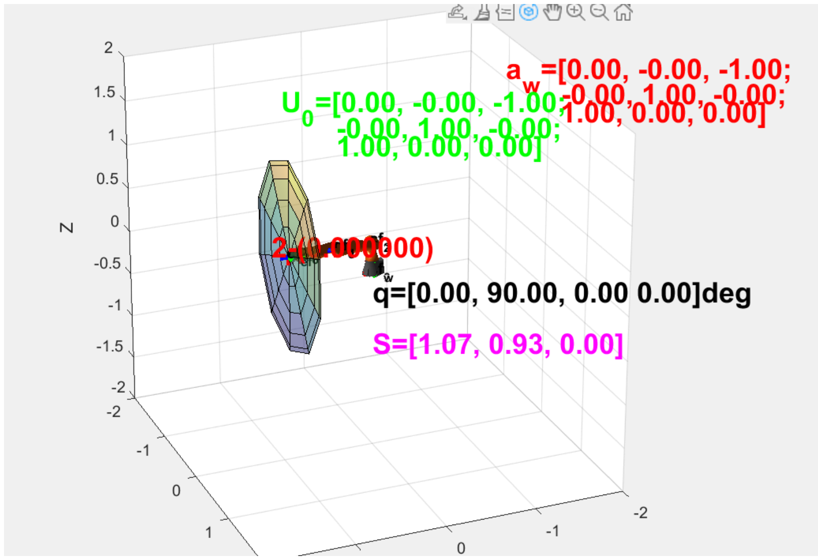
$$[U, S, V] = \text{svd}(jef\_w, 0)$$

, where U represents the left singular vectors.

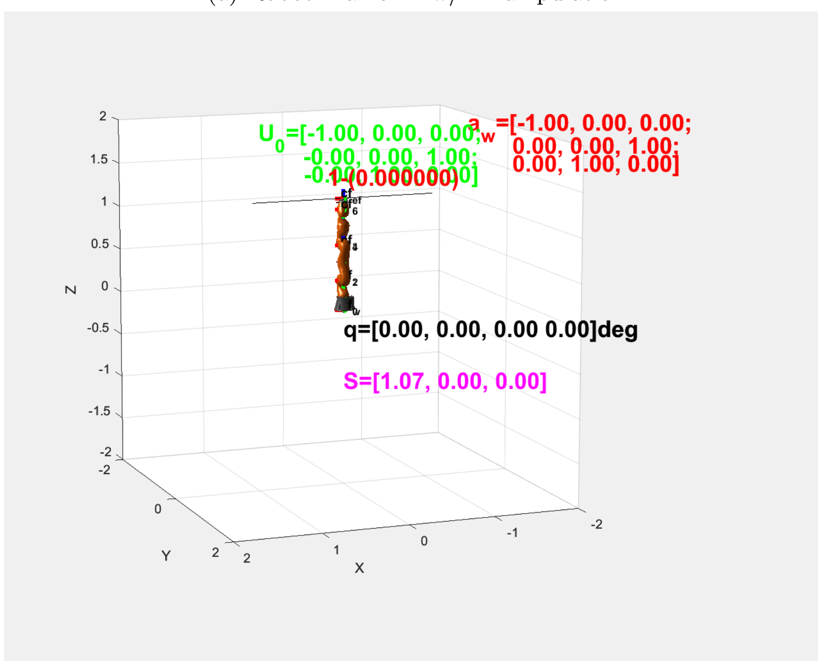
To isolate the angular velocity portion from the Jacobian, one can utilize the expression $jef\_w = jef\_0(4:6, :)$, where jef_0 contains the complete Jacobian and jef_w corresponds to the angular velocity part.

Changing the angles can lead to singularity in the robot. In Figure 10, we can clearly see that the manipulability ellipsoid becomes infinite in some cases, as illustrated in Figure 11a. This indicates a loss of 2 degrees of freedom, while in other figures, it loses only 1 degree of freedom. The manipulability ellipsoid describes how far the robot is from singularity, and if the manipulability index becomes 0, it signifies that the robot is in singularity. The figures demonstrate when the index is 0 and provide insights into the number of degrees of freedom the robot has at that moment.

The angular that gives less degree of freedom is provided in the following figures.



(a) Robot Frame 1 - $\pi/2$ Manipulation



(b) Robot Frame 2 - 0 Manipulation

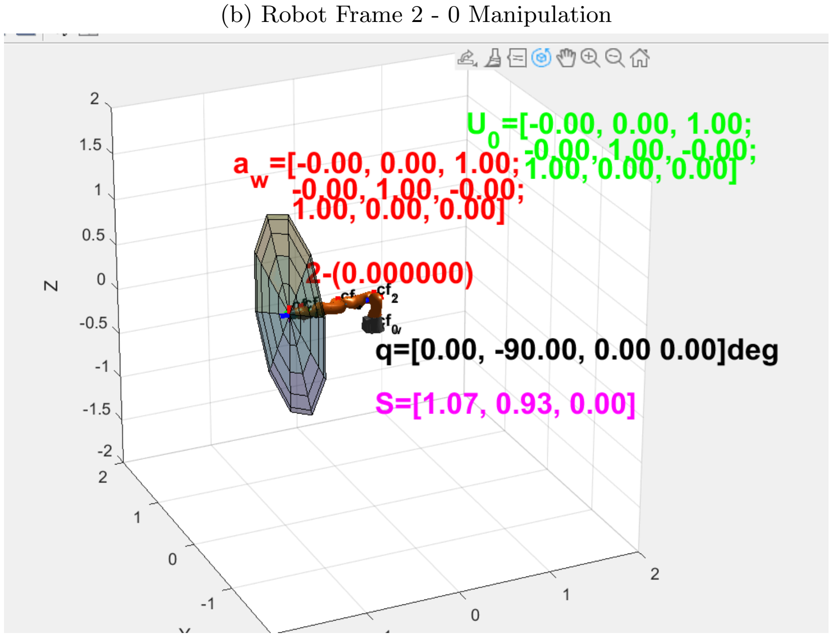


Figure 12 illustrates the ellipsoid corresponding to linear velocity, while Figure 13 depicts the ellipsoid associated with angular velocity, both aligned in the same angular configuration. The disparity lies in the additional degree of freedom (DOF) present in the angular ellipsoid compared to the linear velocity, stemming from the independent control over the end effector's orientation. The linear velocity ellipsoid delineates the possible linear movements of the end effector in various directions, whereas the independent control over orientation allows for rotational adjustments at different end effector positions, thereby introducing an extra degree of freedom.

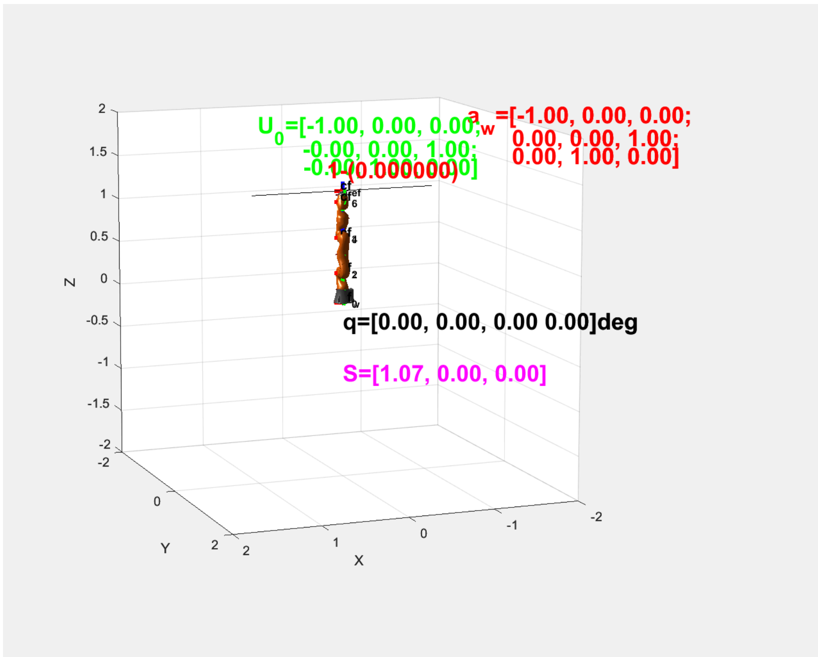


Figure 12: Another Robot Frame 1 - $-\pi/2$ Manipulation

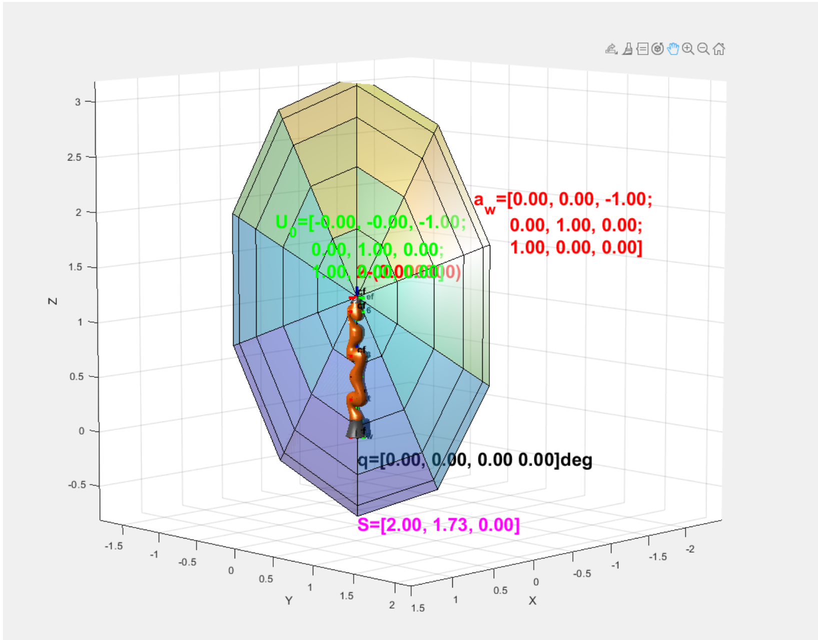


Figure 13: Another Robot Frame 1 - $-\pi/2$ Manipulation