EEL 4930/5934: Autonomous Robots
HH2: Hands-on Homework #2 (Spring 2023)

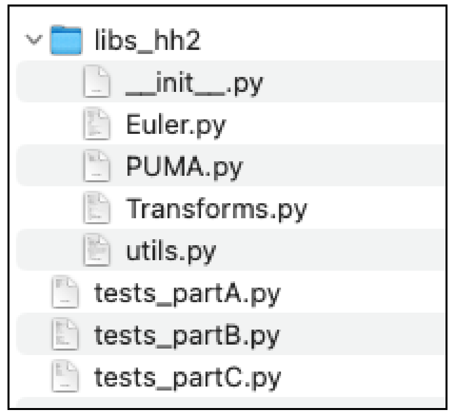
Tasks Overview:

A. Euler angles and axis of rotation
B. Transformation interpolation in quaternion space
   i. Find quaternion from rotation matrix
   ii. Find rotation matrix from quaternion
   iii. Quaternion SLERP interpolation
C. Forward kinematic functions for PUMA-560 manipulator

Grading Breakdown (Both Sections)
- Part A: 25% (15% + 10%)
- Part B: 50% (15% + 15% + 20%)
- Part C: 20% (5% + 10% + 10%)

Instructions
- Download the **HH2_Blank** folder from canvas
- Complete the functions asked for (see below)
- Test your code: `tests_partA/B/C.py`
- Generate the outputs and write in report (PDF)

References: Lecture 3-5 and Chapter 2-3 contents



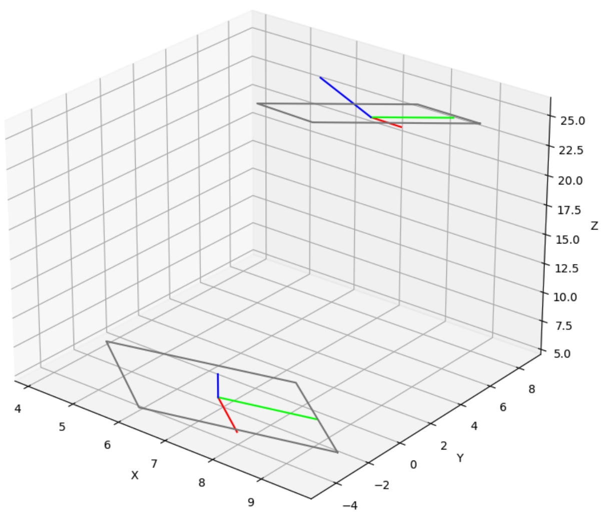
Submission: [Through Canvas only; Due: March 10, 2023 by 11.59pm]
- A single zip file with a folder (code) and PDF (report)
  - Your completed code: do not add any more python files, just complete the functions
  - A PDF report: the generated outputs only (things that are asked in **blue color**; see below)
- Assignments more than 10 MB file size will get negative penalty (-10% to -50%)

Part A: Euler Angles and Axis Of Rotation
Refer to the Chapter 2 (2.8) contents for Fixed-angle rotation and Euler-angle rotation formulations. In this part, we will complete the formulations of finding:
- Euler rotation matrix (`R_XYZ`) for a given order and angles
- Finding Euler angles and axis of rotation given `R_XYZ`
- Relevant library file: `Euler.py`
  - Complete the function: **`Euler_Angle`**`(alpha, beta, gamma, order='xyz')`
  - Complete the function: **`Euler_Angles_from_R`**`(matrix, order='xyz')`
  - Test your code by `tests_partA.py`
- In your report, show results for the case of `R_XYZ = Euler_Angle(60, 30, 60, 'yxz')`
  - Compute `R_XYZ`
  - Find the axis of rotation for `R_XYZ`

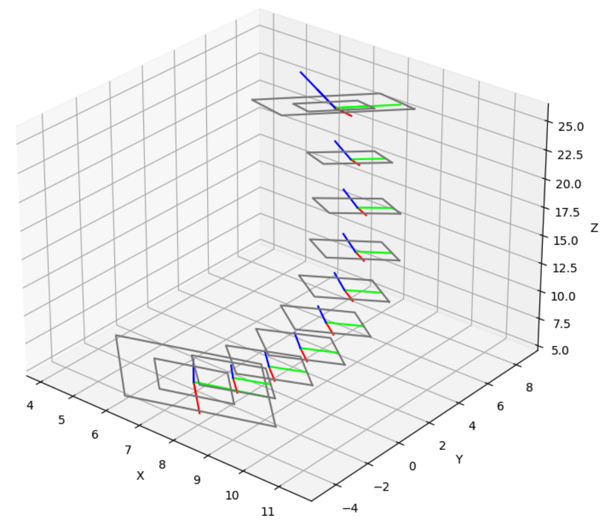
Part B: Transformation interpolation in quaternion space
Refer to Lecture-3 and Lecture-5 contents on quaternion notation for rotation and transformation interpolation. Given two transformations T1 and T2, we will interpolate intermediate transformations, which is important for smooth robot/joint motion)

Check the code in `tests_partB.py`

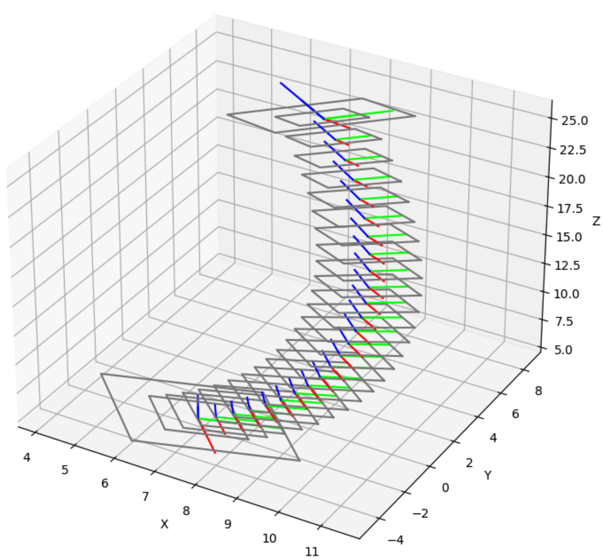
- Two poses are given with respect to the origin $T\{0\} \equiv \{\mathbf{I}_{3x3}, \mathbf{0}_{1x3}\}$
    - $T\{1\} \equiv \{R1 = 60^{\circ}$ rotation around Z_0 ; $t1 = [-5, -5, -5]^T\}$
    - $T\{2\} \equiv \{R2 = 45^{\circ}$ rotation around $k=[0, 1, 1]^T$; $t2 = [-15, -15, -15]^T\}$
- Suppose we want to move a robot/joint from T{1} to T{2}. We want to find 10/25/50 intermediate poses by quaternion interpolation - so that the output looks like the following:



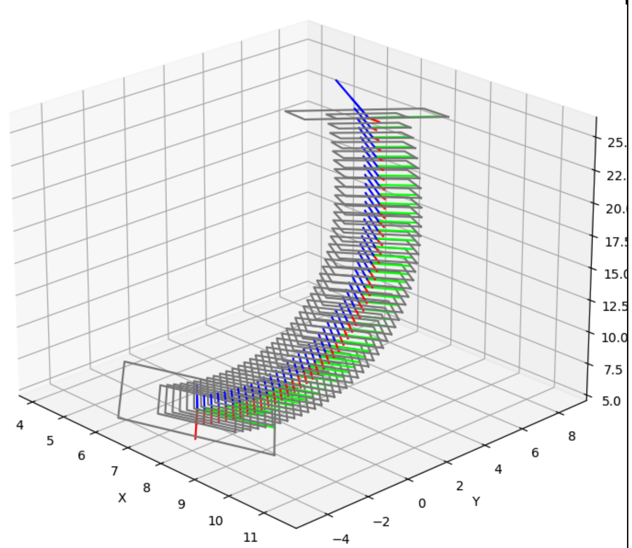
Two poses T1 and T2



Intermediate poses; `num_levels=10`



Intermediate poses; `num_levels=25`



Intermediate poses; `num_levels=50`

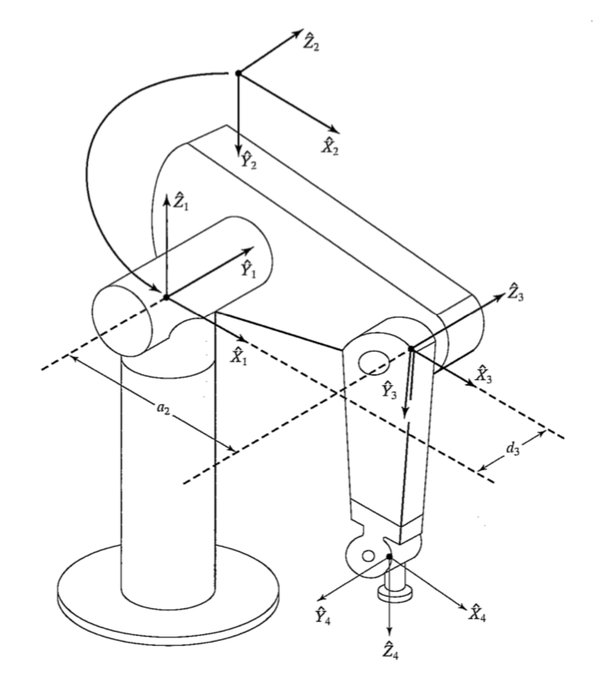
The drive code (`tests_partB.py`) is implemented for you! You need to do the following three functions defined in the `Transforms.py`; some other utility functions are implemented for your convenience).

- Complete the function: **`quaternion_from_R`**`(matrix)`
- Complete the function: **`R_from_quaternion`**`(quaternion)`
- Complete the function: **`quaternion_slerp`**`(quat0, quat1, levels=5)`

Test your code well, generate these four figures and show them in your report.

Part C: Forward kinematic functions for PUMA-560 manipulator

For PUMA-560 manipulator (see Chapter 3: 3.7), consider the following link parameters based on DH notation.



i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	$-\pi/2$	0	0	θ_2
3	0	a_2	d_3	θ_3
4	$-\pi/2$	a_3	d_4	θ_4
5	$\pi/2$	0	0	θ_5
6	$-\pi/2$	0	0	θ_6

See Fig. 3.18-3.21 in the book for clearer illustrations

Check `tests_partC.py`; for the given scenario and measurements,

Find the following and show the values in your report

- Find ${}^4T_6$
- Find ${}^0T_6$ and ${}^6T_0$
- Find ${}^0P = [5\ \ 5\ \ 5]^T$, then what is ${}^6P$?

To do this, you will need check the code outline in `PUMA.py` and

- Complete the function: **`get_Ti`**`(self, i=1, theta_i=0)`
- The remaining implementations are completed for your reference

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Remember, the assignment is due: <u>March 10, 2023 by 11.59pm</u>

*Your zipped submission folder (**HH2_ID.zip)** should contain the completed code folder and report PDF.*

When unzipped, the folder structure should look like the following: