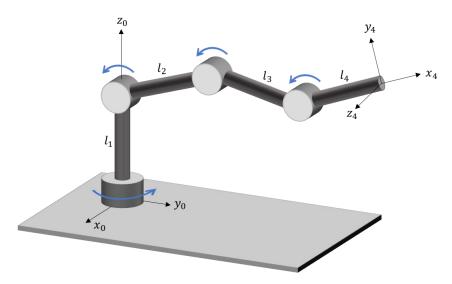
Homework Exercise 2

Submission is in pairs only.

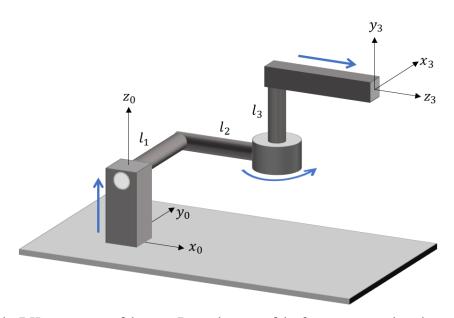
Submission deadline: 5/5/2021, 23:59

Question 1



- A. Find the DH parameters of the arm. Draw the axes of the frames you used on the arm.
- B. Find the direct kinematics function of the arm $T_4^0(q)$.

Question 2



A. Find the DH parameters of the arm. Draw the axes of the frames you used on the arm.

Question 3

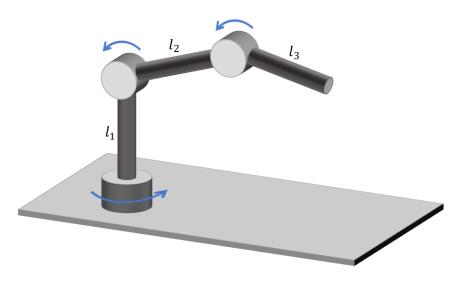
Prove the following matrix properties (see Lecture 4 for definitions and notations):

- 1. For a rotation matrix $R \in SO(3)$ and vectors a, b, show that $R(a \times b) = (Ra) \times (Rb)$
- 2. For a rotation matrix $R \in SO(3)$, a skew-symmetric matrix $S \in SS(3)$, and a vector a, we have that $RS(a)R^T = S(Ra)$.

Hint: multiplying by an arbitrary vector b and use (1) to show the equality holds.

Question 4

Consider the anthropomorphic arm which we have discussed in class.



The robot manufacturer states that $l_1 = l_2 = l_3 = 2[m]$.

For our purposes we need a very accurate arm and thus we wish to find accurate values of l_1 , l_2 , l_3 . We measure the end-effector's position for several given angles θ_1 , θ_2 , θ_3 (assume the angle measurements are accurate).

Attached to this exercise is the table of measurements. Write a program, preferably in Python, which uses these measurements to calibrate l_1 , l_2 , l_3 .

- 1. Write down an optimization function to estimate l_1, l_2, l_3 from the data (see the lectures).
- 2. Plot the value of the objective function throughout the optimization steps and find the values of l_1, l_2, l_3 that minimize it.
- 3. Relate the optimization function to a physical error measurement. What is the error before and after the optimization?

Technical tips:

- To solve this optimization problem, you will need to use an optimization library. <u>SciPy's fmin</u> is recommended.
- To easily load the data, you can use <u>pandas' read_csv</u>.
- To iterate over the measurements, you can use <u>pandas' iterrows</u>.