ME 547 Winter 2024

Lab 1 Instructions: Forward Kinematics and Vision *(6 pts)*

The lab consists of two parts. In part 1, you will use the Fanuc robot (Fanuc section) and the other section is based on the QArm robot (QArm section). Note that, you need to perform the pre-lab exercises and in-lab experiments for both sections. After the lab, each group needs to submit a group lab report (see the General Lab Report Guidelines).

Objectives:

- For the Fanuc robot, you will
  - Derive the forward kinematics equations for the Fanuc robot.
  - Use forward kinematics to calculate the coordinates required to complete a shape-drawing task.
- For the QArm robot, you will
  - Apply the coordinate transformations between the robot and an overhead camera to convert the position of an object from the camera frame to the robot frame.
  - Perform a basic pick-and-place operation

Pre-Lab (2 pts):

Submit your pre-lab results on Learn at least one day prior to your in-person scheduled lab session.

Fanuc Pre-Lab

Error! Reference source not found. shows an isometric view of the Fanuc manipulator. In this f igure, frames 0, 1 and 6 are assigned.

- Derive the forward kinematics of the Fanuc robot including:
  - Assignment of the frames 2, 3, 4 and 5
  - DH table (in mm and °) (using Modified DH convention as in the course slides)
  - Transformation matrices
  - Equations for the position of the end effector (x, y, z) given the robot joint angles $\{\theta_1, \theta_2, \theta_3, \theta_4, \theta_5\}$.
- Refer to Figure 2 for dimensions (We are using the 4SH tool in this lab).
- You can verify your derivation with the following examples given in the format: $\begin{bmatrix}\theta_1\\\theta_2\\\theta_3\\\theta_4\\\theta_5\end{bmatrix} \rightarrow \begin{bmatrix}x\\y\\z\end{bmatrix}$ (the angles and the positions are in degrees and millimeters, respectively.)

$$\begin{bmatrix}0\\-45\\-90\\135\\0\end{bmatrix} \rightarrow \begin{bmatrix}467.40\\0\\-21.71\end{bmatrix}, \begin{bmatrix}30\\-90\\-135\\135\\0\end{bmatrix} \rightarrow \begin{bmatrix}245.56\\141.78\\54.44\end{bmatrix}, \begin{bmatrix}-45\\-30\\-45\\90\\0\end{bmatrix} \rightarrow \begin{bmatrix}411.04\\-411.04\\34.57\end{bmatrix}, \begin{bmatrix}-25\\-70\\-70\\110\\0\end{bmatrix} \rightarrow \begin{bmatrix}410.49\\-191.41\\271.00\end{bmatrix}$$

- Calculate the end effector position (x, y, z) by using the joint angles (in degrees) shown in Figure 3.

Note that the θ's used here are θ_i's in the DH angles. i.e., the joint state for the configuration shown in Figure 1 is $\begin{bmatrix}\theta_1\\\theta_2\\\theta_3\\\theta_4\\\theta_5\end{bmatrix} = \begin{bmatrix}0\\-90\\-86.1\\86.1\\0\end{bmatrix}$.

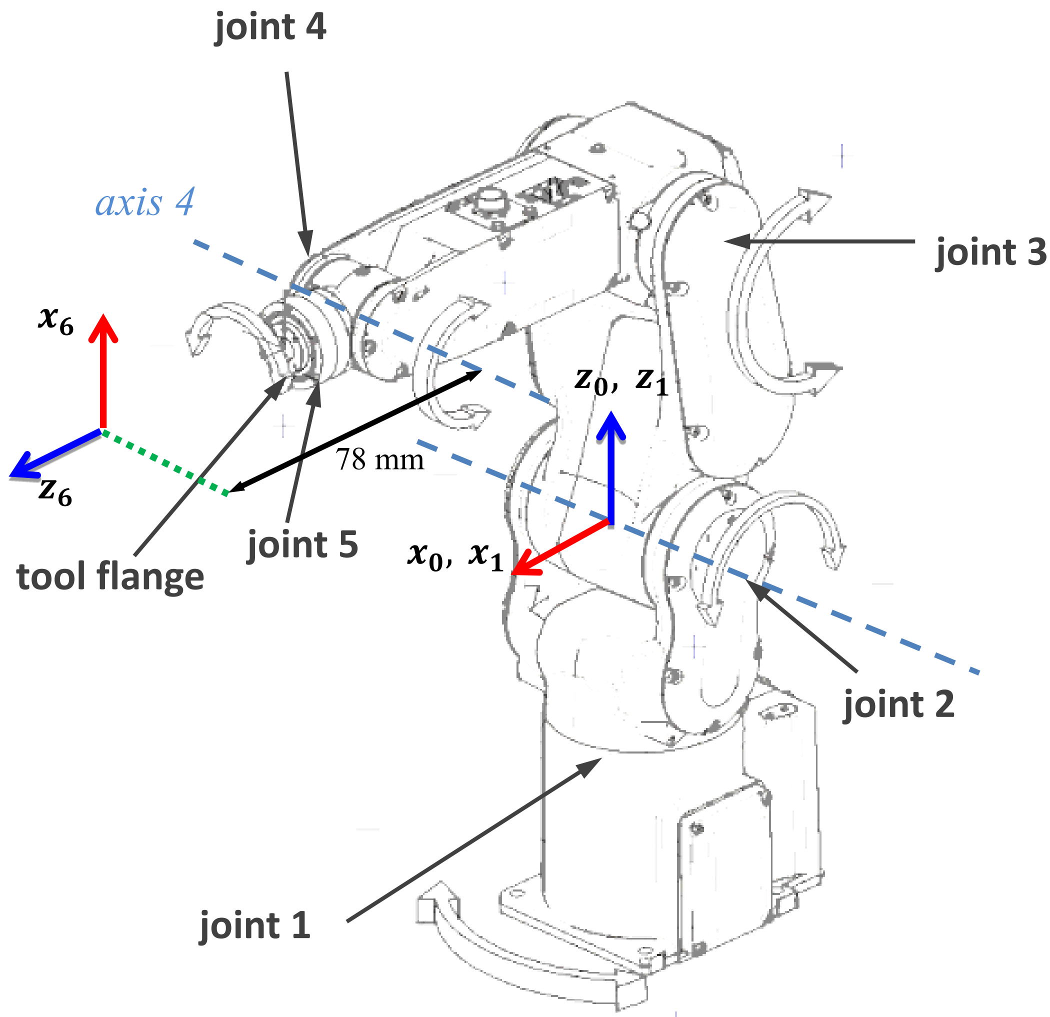

Figure 1 – Isometric view of the manipulator with assignment of frames 0, 1 and 6.

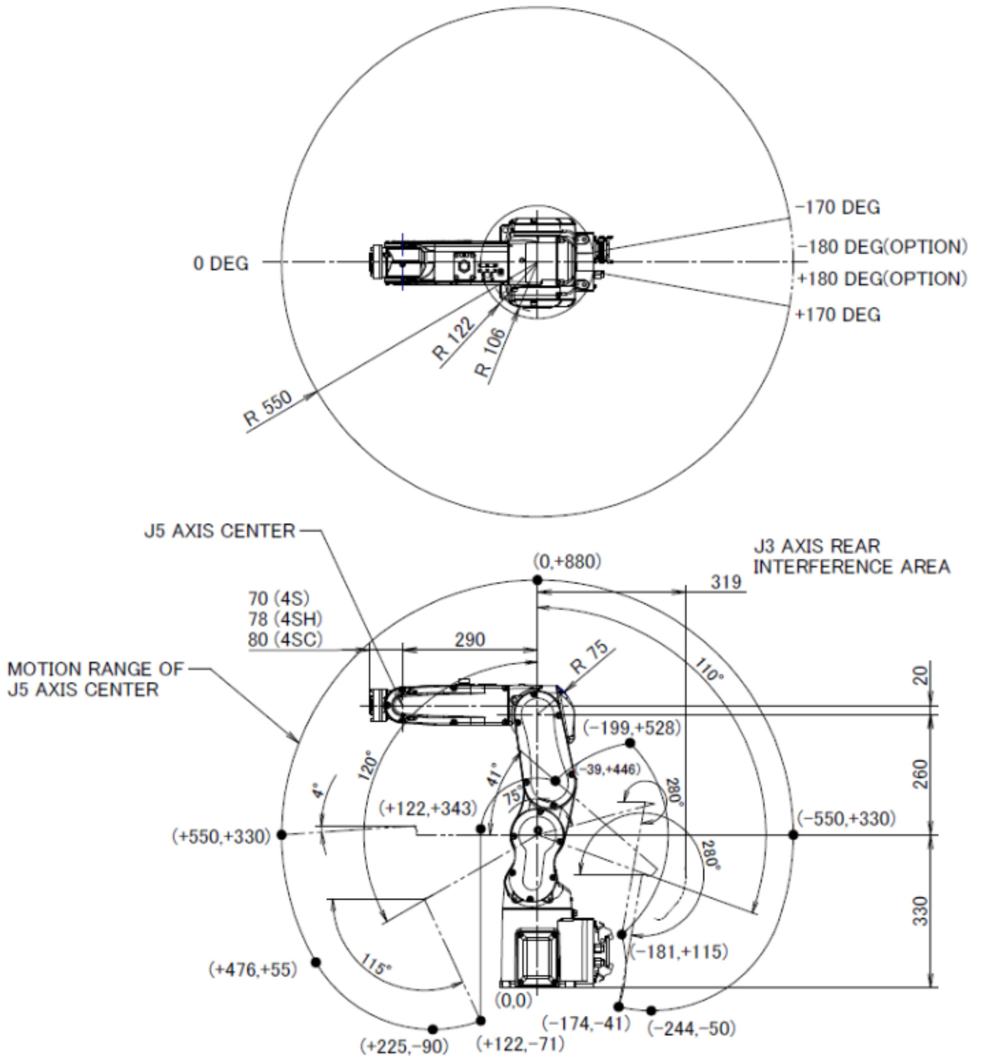

Figure 2: Manipulator's dimensions (in mm).

<u>QArm Pre-Lab</u>

- Derive the camera transformation matrices below based on Figure 2 to convert the position of an object in pixel coordinates to the position of the object in real-world coordinates with respect to the inertial/reference frame located at the base of the robot. All parameters needed for this task are given below.
  - $T_S^C = \begin{bmatrix} \quad & \quad & \quad \\ & & \\ & & \end{bmatrix}$, $\quad T_C^A = \begin{bmatrix} \quad & \quad & \quad \\ & & \\ & & \end{bmatrix}$.

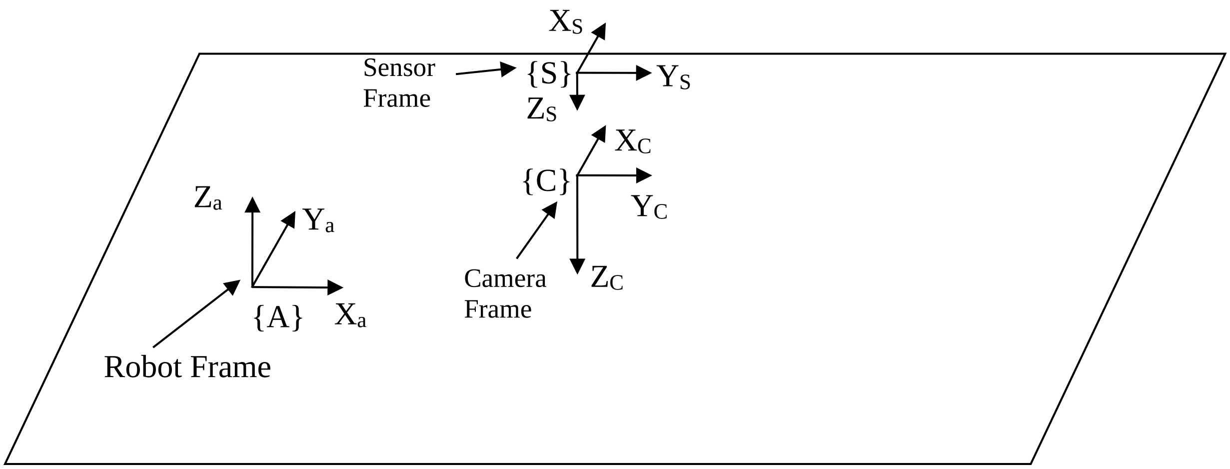

Figure 3: Camera and robot frames.

AC(x,y,z)=(515mm, 90mm, 990mm).

CS(x,y,z)=(0mm, 0mm, -4.3mm).

- Given an object position expressed in the sensor frame $p^S = (x, y, z)$, find its position in the camera frame (p^C) and the robot frame (p^A) based on the transformation matrices you derived.

In-Lab Experiments

The following parts will be performed during your scheduled lab session with TAs.

Fanuc Experiment (2 pts) :

Procedure:

- In the provided Visual Basic (.vb) template, modify the forwKin() function according to the forward kinematics equations you derived. This function uses the five joint angles as inputs and then computes the corresponding end effector's Cartesian coordinates.
    - Before running your code, ask the TA to check your forwKin() function
    - The position calculated by forwKin() and a predefined orientation are passed into the moveLin() function. The function then produces linear trajectories.
- Build and run the code (You may ask the TA to help running the code).

- After the code is compiled, the robot will move its end effector to draw the shape given in Figure 3.
- Do not forget to take pictures/videos during the lab to complete your report.

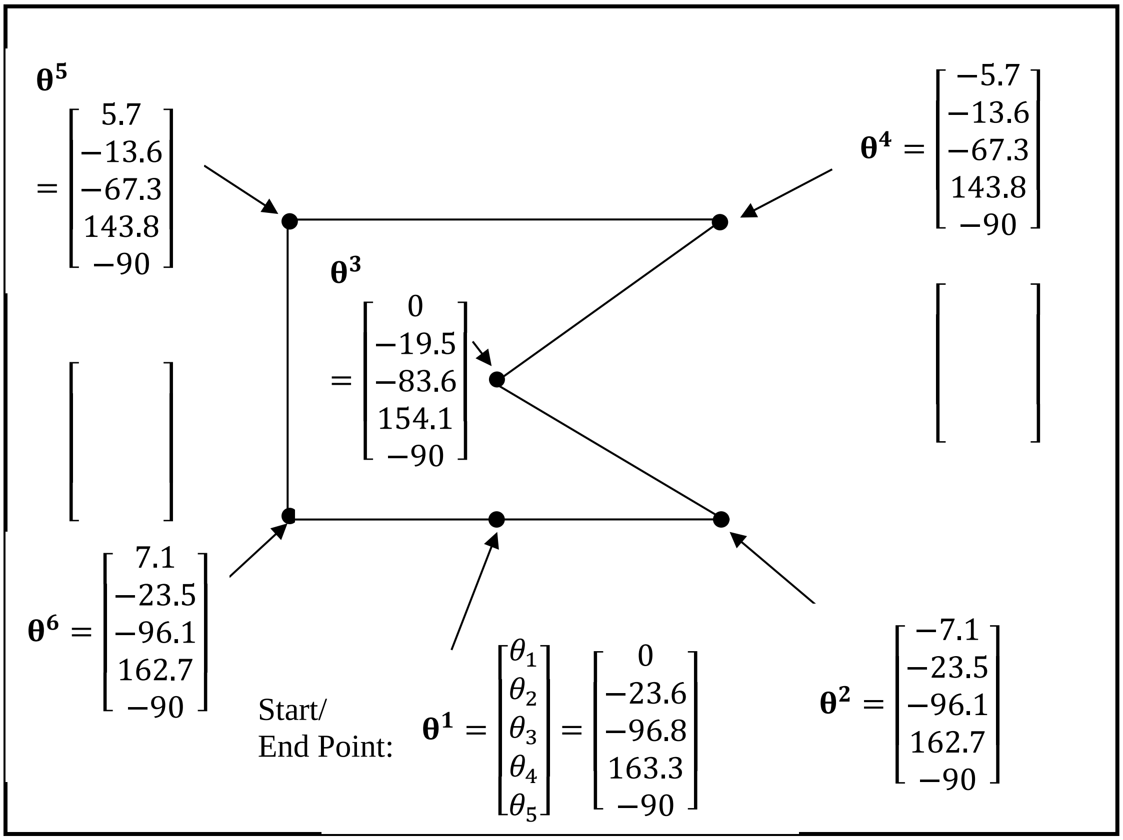

Figure 4: The shape of the polygon that will be drawn by the robot arm. Angles in degrees.

<u>QArm Experiment (2 pts) :</u>

<u>Procedure:</u>

- In this part, you will use the overhead camera to capture an object in the workspace. Then calculate the object's location with respect to the robot. This location will guide the robot to perform a pick-and-place operation.
- Use the **Camera** application to capture an image of the object. The image resolution is 640x480 and the field of view should be similar to Figure 5.

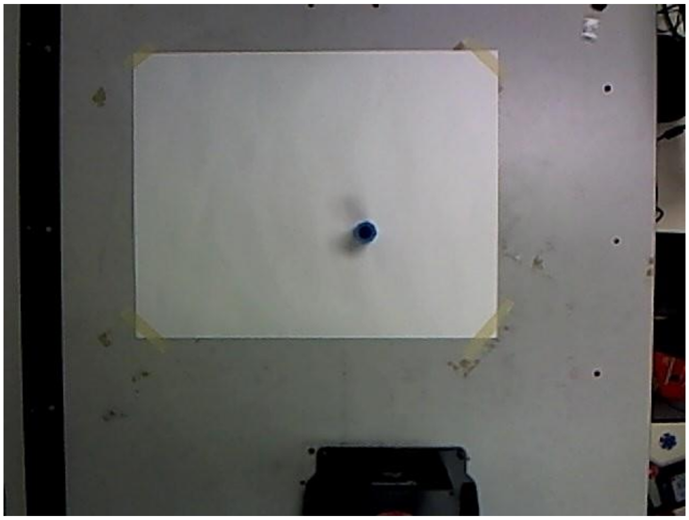

Figure 5: A sample image from the overhead camera.

- Open the image with **Paint**, **GIMP**, or other graphic editing programs.
- Flip the picture horizontally and vertically.
- Find the distances of the object center in both x and y directions from the center of the image. These distances are in pixels and they should follow the sign convention in Figure 6.

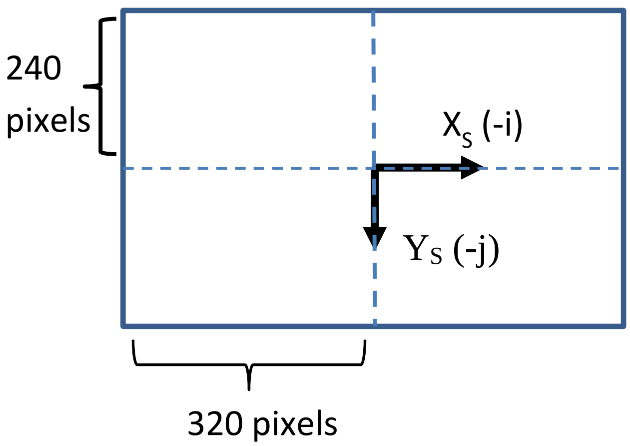

Figure 6: Sign convention for pixel location.

- Now that the pixel location (i, j) in the image is available, you can find (u, v) which is the position of the object in the sensor plane by using the equations below.
  - $(x^I, y^I) = (ip_x, jp_y)$
  - $f_i = 4.3mm,\ p_x = p_y = 0.0081mm$
  - $\begin{cases} x^I = \frac{f_i u}{f_i - w} \\ y^I = \frac{f_i v}{f_i - w} \end{cases}$
  - Note that you need to refer to Figure 3 to find w.

- By using the transformation matrices from your pre-lab, you should find the position of the object in the sensor frame (p^S), the camera frame (p^C), and the robot frame (p^A).
- In the provided Simulink template, change variable PosX and PosY according to p^A.
    - Before running the code, ask the TA to check your results
- Build and run the code.
- After the code is complied, the robot will pick up the object and then put it down.
- Do not forget to take pictures/videos during the lab to complete your report.

Lab Report

- After the lab, each group is required to complete a short lab report.
- In your report, include the followings:
    - Analysis and results from the pre-lab
    - Any calculations performed during the lab
        - i.e., finding the object location from the image
        - Also include the image from the overhead camera to support your calculations
    - Pictures showing that the robot completed all of the required tasks
    - Short discussion on your observations on the accuracy of the performed task