DEPARTMENT OF MECHANICAL ENGINEERING
RICE UNIVERSITY

MECH/ELEC/COMP 498/598: INTRODUCTION TO ROBOTICS

Lab #2
Inverse Kinematics: Robo Picasso

Due Friday, March 13th at 11:59pm

Assignment Description
This assignment will most likely be very time-consuming, meaning you should start working on it well in advance of the deadline. **For this assignment, undergraduate students may work in groups of 2.** You will be required to hand in **individual** paper submissions, and a group electronic submission. The lab consists of solving the inverse kinematics problem for a 6-DOF robot. There is a simulation element that is provided to help you troubleshoot more effectively, but this simulation will not be heavily used until Lab 3, at which point you will simulate full drawing capabilities.

This code uses Python classes. if you are not familiar with object-oriented programming and how classes work, please take some time to familiarize yourself with it before jumping into the lab.

You will be provided with a partially complete Fanuc class, and additional complete classes to make the visualization work. You are expected to fill code in under the areas marked with TODO comments. Otherwise, these complete classes make up parts of the Fanuc, allow for drawing, and allow easy calling and data storage. You may modify the provided classes if you'd like, but you do not need to in order to complete the assignment.

Note: Lab 3 is a continuation from Lab 2. Therefore, much of the helper classes are mostly unused in this Lab and will be used more heavily when you begin simulating your robot through motion in Lab 3.

Submission Instructions
Your submission for this assignment will have an electronic and a paper component. The paper submission can be turned in to the box outside of the MAHI Lab, to the MECH dropbox in the Mechanical Engineering Building, or in class.

For the electronic submission, just as the previous lab, you will upload your code via the gradescope auto-grader for the Lab2 submission. You must zip all of your code into one .zip file for submission. You may submit as many times as you want before the deadline. The auto-grader is written such that it will tell you where it's failing, to give you a debugging tool. The result from the auto-grader IS your score for the electronic portion of the lab. If it says 91/91, that is what you will get (9 points are your written portion).

1. [10 points] **Written Assignment:** Using the attached specification sheet for dimensions of the fANUC S-500 robot, create a sketch of the position of the robot when all joint angles are zero with

the frames labeled, and fill out a D-H parameter table. This will be included in the written portion of your submission, and there should be one from **each** member of your team.

Here are some notes on creating your DH parameters. As is done for the PUMA 560 robot in the textbook, frame {0} should be coincident with frame {1} for ease of constructing the forward and inverse kinematics. In this lab we will use the terminology "base" frame for the origin of our graphical representation which occurs at the actual base of the robot. Meanwhile, frame {0} will be referred to as the "station" frame. Use a station frame (frame {0}) with $\hat{\mathbf{z}}_0$ pointing up and $\hat{\mathbf{x}}_0$ pointing horizontally forward in front of the robot. The end effector frame, frame {6}, will have $\hat{\mathbf{z}}_6$ pointing along the end effector's axis of rotation and its x axis point in the same direction as $\hat{\mathbf{z}}_0$ when in the zero configuration.

Note: The side-view drawing is the zero position, but if you follow D-H convention, you will be required to include an offset in one of the joint angles (probably joint 2). Also, there is a missing dimension in the vertical direction between the joint 3 and joint 4 axes, which should correspond to a_3. Consider this distance to be 180 mm. Finally, assume the joint ranges given are to be centered about the robot's zero position.

2. [30 points] Using the DH table you created in problem 2, complete the unfinished areas of the class initialization function `__init__()`. Then initialize each of the joint classes via `_setup_joints()`. This will include:

    a. setting the dh parameters for the joint using the spec sheet. Keep all lengths in mm.
        i. a
        ii. alpha
        iii. d
        iv. (theta will be fed in each time you calculate your forward kinematics)

    b. Setting the joint limits (max and min, in radians) (Note: the function `math.radians(input_angle)` will turn the *input_angle* from degrees into radians.)

    c. The color (up to you, just for fun)

    The auto-grader will evaluate each of your dh parameters for each joint as well as your min and max.

3. [15 points] Next, fill in the function `calculate_fk(joint_angles)`. This function takes in a 6 element vector of joint angles. It should check that the joint angles are within the allowed boundaries, then set the dh transform using the `set_joint_angle()` function in each joint. You will then be able to grab each joint's homogenous transformation matrix as well as the position of the end effector using the provided property `ee_frame`. (If you've not seen Python properties before, give it a quick google before continuing) The auto-grader will verify many different possible fk solutions, starting from simple solutions to more complex ones to ensure all cases are covered.

    Lastly for this problem, use the function `draw_fanuc(joint_angles)` to draw the FANUC at different positions. A script at the bottom of the Fanuc class is runnable to give you the basics for how to visualize the robot. This is for troubleshooting Lab2. (It will be used MUCH more heavily in the simulation in Lab3)

4. [45 points] Fill in the function *`calcukate_ik(ee_frame, prev_joint_angles)`*. This takes in the location of the end-effector and a 6-element vector of the previous FANUC joint angles. It should return a Boolean of whether or not a solution exists and, if it does, the 6 joint angles that make that solution closest to the previous joint angles. (You will have multiple solutions much of the time, be sure to pick the closest option to avoid large jumps in joint angle)
   You should check to see if a solution exists by checking if the *`ee_frame`* is within the workspace and that the resulting joint angles are within the boundaries of the joints you set when you setup your Fanuc.

   Note: Don't forget about the draw_fanuc() method to draw your robot as a debugging tool. Also, if your result for your FK don't match your IK, you're gonna have a bad time.

S-500™

FANUC Robotics

Basic Description

Six-axis, modular construction, electric servo-driven robot designed for a variety of manufacturing and system processes. The FANUC S-500 robot is engineered for precision, high-speed operation, user-friendly setup and maximum reliability supported by our extensive service and parts network.

S-500, the Solution for:

- Dispensing
- Material handling
- Material removal
- Machine load/unload
- Welding
- Waterjet cutting
- Parts transfer

Benefits

- Large work envelope and payload allow robot operation in a wide range of manufacturing processes
- Can operate in environments ranging from harsh to traditional factory floor
- No robot modifications for upright, inverted and wall mounting
- Absolute serial encoder positioning
- Slender arm design improves robot repeatability

Features

- 6 axes of motion
- 15kg (33 lbs) load capacity
- ± 0.25mm (± 0.010”) repeatability
- Axes speed up to 320° per second

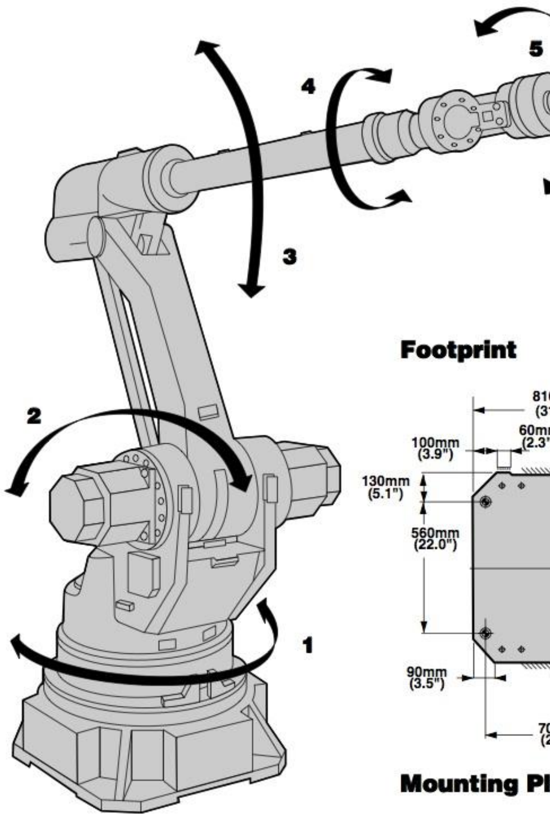
Reliability Features

- Grease fittings on all lubrication points for quick and easy maintenance
- RV speed reducers provide smooth motion at all speeds
- Sealed bearings and drives provide protection and improve reliability
- Interfaces with most types of servo-driven or indexing positioners
- Hollow joint construction encloses all cable routing to eliminate snagging
- Brushless AC servo motors minimize motor maintenance
- Maximum speed and torque drive motors

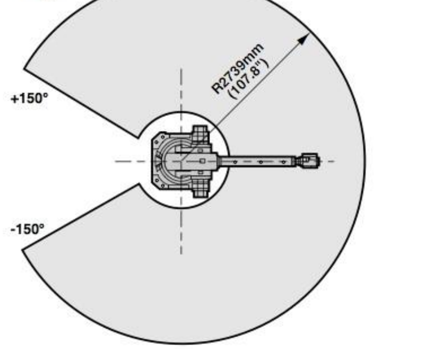
Options

- Axis 6 speed up to 600° per second
- 3.5” floppy disk drive for off-line storage
- Program/data printer
- RS-232-C communication port
- Integrated auxiliary axes

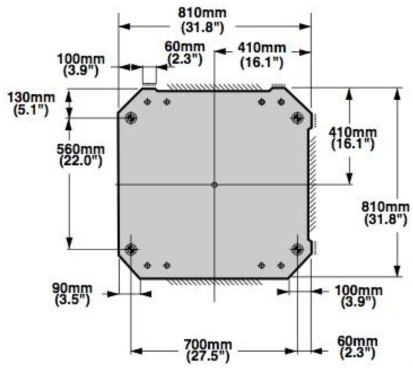
S-500 Dimensions



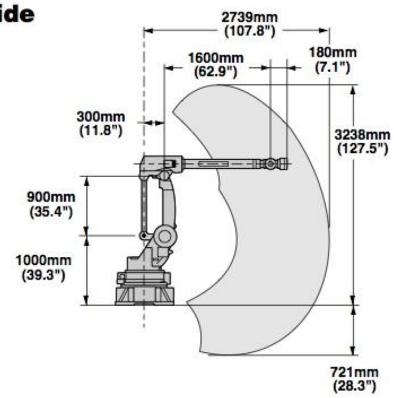
Top



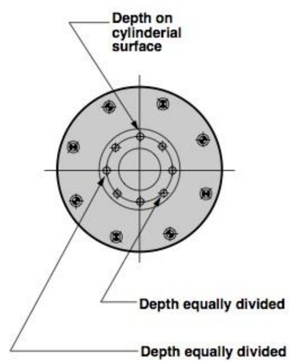
Footprint



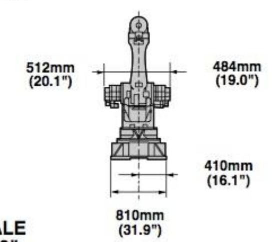
Side



Mounting Plate



Front



SCALE
1/100"

S-500 Specifications

Items		Range	Speed
Motion range and speed	Axis 1	300˚	90˚/sec.
	Axis 2	160˚	90˚/sec.
	Axis 3	160˚	320˚/sec.
	Axis 4	480˚	320˚/sec.
	Axis 5	240˚	320˚/sec.
	Axis 6	900˚	320˚/sec.
Moments	Axis 1	2.0 kgf • cm	
	Axis 2	3.0 kgf • cm	
	Axis 3	3.0 kgf • cm	
Load inertia	Axis 1	2.2 kgf • cm • sec^2	
	Axis 2	6.2 kgf • cm • sec^2	
	Axis 3	6.2 kgf • cm • sec^2	
Repeatability		±0.25mm(±0.010")	
Max. load capacity		15kg (33 lbs)	
Mounting method		Floor/ceiling/angle	
Mechanical brakes		All axes	
Mechanical weight		900 kg (1985 lbs)	

FANUC
Robotics

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Literature Request
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