ENME480 Lab 4: Inverse Kinematics

Objectives

The objective of this lab is to derive and implement a solution to the inverse kinematics problem for the UR3 robot. In this lab we will:

- Derive elbow-up inverse kinematic equations for the UR3
- Write a Python function that moves the UR3 to a point in space specified by the user

Task Description

The joints and links of the UR3 robot are annotated in Figure 1. The goal is to find the rotation angles of the 6 joints ($\theta_1, \dots, \theta_6$), so that the end-effector (end of Link 10) can reach to a given position ($x_{grip}, y_{grip}, z_{grip}$) and orientation $\{\theta_{yaw}, \theta_{pitch}, \theta_{roll}\}$ input by the user.

There are many possible solutions to the inverse kinematics problem. To make the derivation manageable, we will only implement one of the *elbow-up* solution in this lab. θ_{pitch} and θ_{roll} of the end-effector are fixed by letting the vacuum gripper aluminum plate (Link 9) always be parallel to the x-y plane of world frame coordinates (i.e., desk plane), and θ_5 is always equal to -90°. Thus, the user will input the desired position and yaw angle of the end-effector in world frame coordinates (xWgrip, yWgrip, zWgrip, yawWgrip), and the output of the program should be the joint angles θ_1 to θ_6.

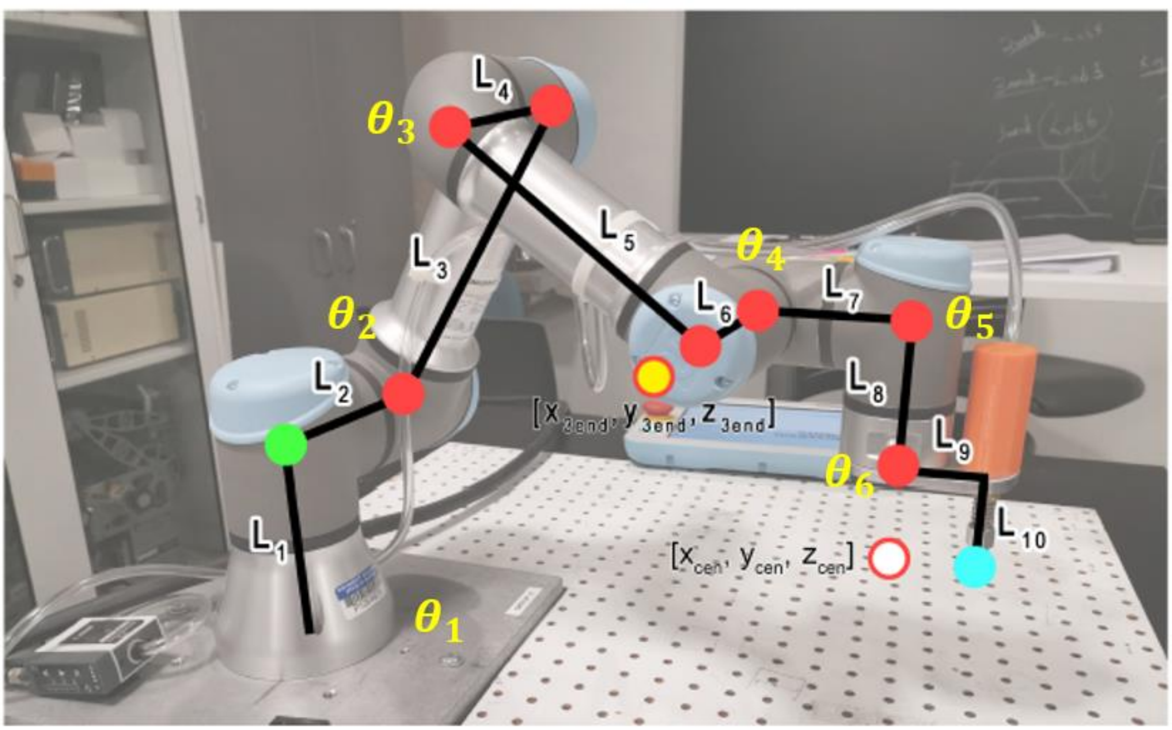

Figure 1. Joints and links of UR3

Solution Steps

In this section, a suggested solution approach is described.

1. Establish the world coordinate frame (frame w) centered at the corner of the UR3's base shown in Figure 2. We will solve the inverse kinematics problem in the base frame (frame 0), so we will convert the coordinates $(x_{w-grip}, y_{w-grip}, z_{w-grip})$ entered by the user to base frame coordinates $(x_{grip}, y_{grip}, z_{grip})$. The origin of the base frame is at (-0.15, 0.15, 0.01) in the world frame. Set $\theta_5 = -90^{\circ}$ in unit of radian.

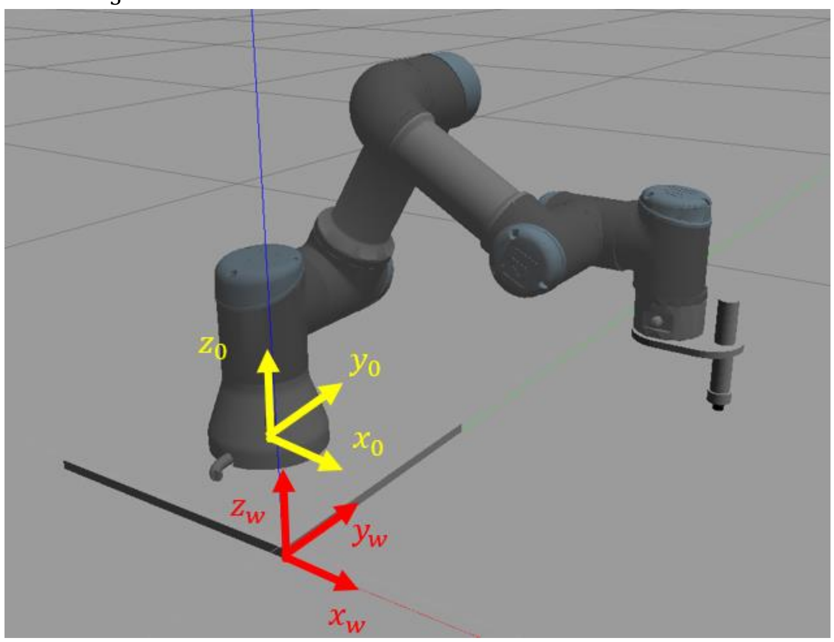

Figure 2. World frame and UR3 base frame

2. We will define a "wrist center" as z_{cen} which equals the same desired z value of the vacuum gripper, and x_{cen}, y_{cen} are the coordinates of θ_6's z axis (see Figure 1). Link 9 (gripper plate) has a length of 0.0535 meters from the center line of the gripper to the center line of Joint 6. Given the desired position of the gripper $(x_{grip}, y_{grip}, z_{grip})$ in the base frame and the yaw angle, find wrist's center point $(x_{cen}, y_{cen}, z_{cen})$.
3. Given the wrist's center point $(x_{cen}, y_{cen}, z_{cen})$, find the waist angle θ_1. Figure 3 shows the top-down view of the robot, which is helpful for formulating the relations.
4. Solve for the value of θ_6, given θ_1 and the desired yaw angle (should be converted to radian from the input degree value). $\theta_6 = 0$ when Link 9 is parallel to Link 4 and Link 6.
5. We will define another virtual point. A projected end point $(x_{3end}, y_{3end}, z_{3end})$ is a point off the UR3 but lies along the Link 6 axis, as shown in Figure 1 and Figure 3. For example, if $\theta_1 = 0$ then $y_{3end} = 0$. If $\theta_1 = 90^{\circ}$ then $x_{3end} = 0$. Use the top-down view (Figure 3) to find x_{3end} and y_{3end} from x_{cen}, y_{cen}. Figure 4 is a side view that is a projection of the robot onto a plane perpendicular to the x-y plane of world frame and rotated by θ_1 about the base frame. From this figure we can see that z_{3end} is z_{cen} offset by a constant. The end of the gripper is 0.052m from the center of the gripper plate in the z-axis direction.

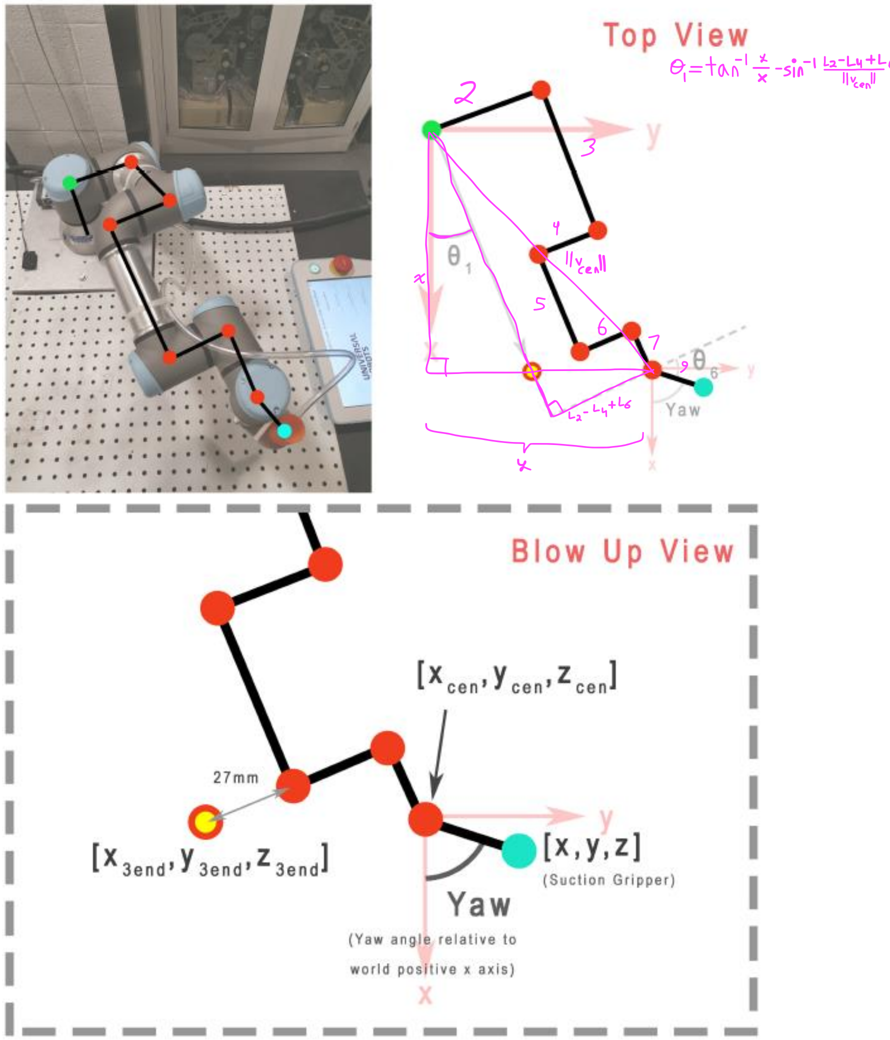

Figure 3. Top view of UR3

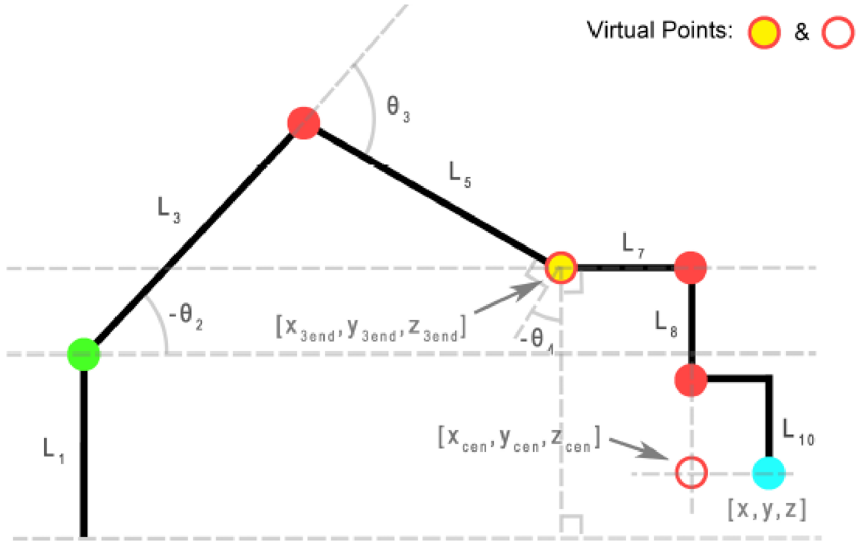

Figure 4. Side view of UR3

6. Find θ_2, θ_3 and θ_4 from the end point $(x_{3end}, y_{3end}, z_{3end})$. In Figure 4, a parallel to the base construction line through Joint 2 and a parallel to the base construction line through Joint 4 are helpful in finding the needed partial angles. θ_2 and θ_3 can be found from the geometry, while θ_4 is determined due to the requirement that Link 7 and Link 9 must be parallel to the x-y plane of the world frame.

Now that your code solves for all the joint variables (θ_1 to θ_6), send these six values to the Lab 3 function *lab_fk()*. You can then copy your Lab 3 solution into these functions to move the UR3 in Gazebo accordingly.

You will need the dimensions of the links to calculate the inverse kinematics solution, which are shown in Figure 5 below.

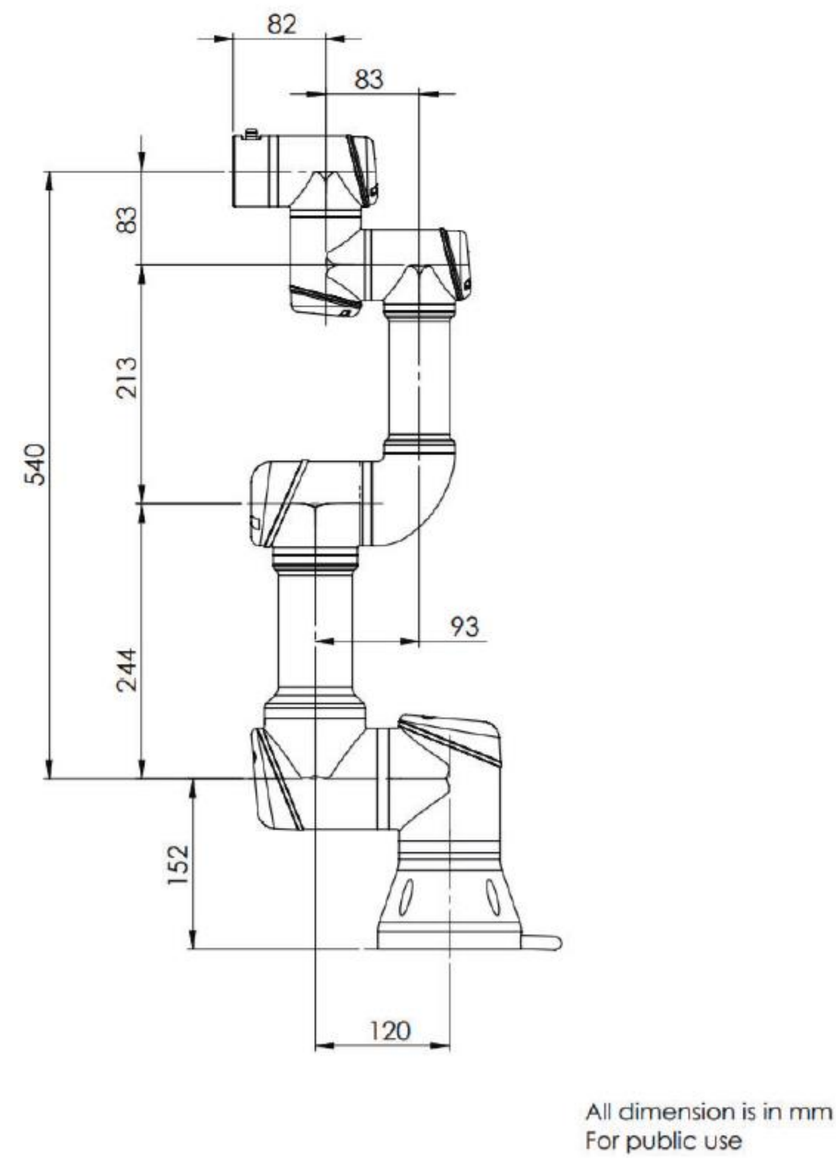

Figure 5. UR3 dimensions

Procedure

Here is the procedure to run and test your program.

1. You may use the previous workspace to complete this lab. To start, download the script zip file and unzip the 'lab4' folder into the 'src' folder of the workspace.
2. For the lab assignment, all the work required to complete is inside the 'lab4_func.py' file. Code in the script to find the inverse kinematic solution.
3. Compile the workspace, and enter in the first terminal
   ```
   $ source devel/setup.bash
   $ roslaunch lab4 lab4.launch
   ```
   By running this launch file, Gazebo will start and the UR3 robot will show up. Then in the second terminal, enter
   ```
   $ source devel/setup.bash
   $ rosrun lab4 lab4_main.py <x> <y> <z> <yaw (degree)>
   ```
   where <x>, <y>, <z>, <yaw (degree)> are numerical values. The robot will then move to the input position, and the gripper plate will rotate with the given yaw angle.
4. After the robot moves to the desired position, in the third terminal, enter
   ```
   $ source devel/setup.bash
   $ rostopic echo /gripper/position -n 1
   ```
   This will output the gripper position in the world frame coordinates. If the derivation is correct, the output values should be close to the input position <x>, <y> and <z>, but there will be small differences. You will propose some analysis on these differences in the lab report. You can manually verify whether the desired yaw angle is satisfied by viewing the robot from the top.

Submission

This is an group assignment.

<u>Due date: Oct 31, 11:59 PM (two weeks from the studio)</u>

Please start early and contact TAs as soon as possible if there are any issues.

Submission to ELMS

- 'lab4_main.py' and 'lab4_func.py' scripts
- Report document (in pdf)

Report

- Include a clearly written derivation of the inverse kinematics solution for each joint variable ($\theta_1, \ldots, \theta_6$). Include clear diagrams and explanations in your derivation.
- Include the following table where you will fill in the results according to the given 5 test inputs (results round to 4 decimal places)

Test Point Inputs (x, y, z, yaw)	**IK solution ($\boldsymbol{\theta_1, \ldots, \theta_6}$)**	**Output from /gripper/position**
(0.2, 0.3, 0.3, 45)		
(0.1, 0.4, 0.1, 90)		
(0.2, 0.2, 0.2, 0)		
(0.2, -0.2, 0.1, 0)		
(0.2, 0.3, 0.4, 30)		

- Include the screenshots of Gazebo for the first two test points
- Include a brief discussion of sources of error

Report

Grading

Total: 100 points

Refer Rubric on ELMS

References

UIUC ECE470 course Lab 4

Modern Robotics, Chapter 6

Robot Modeling and Control, Chapter 5