M.E. 530.646 Lab 3:
Forward Kinematics

Ryan Keating
Johns Hopkins University

Download the ROS package for this assignment from Blackboard and put it in `src` directory of your catkin workspace.

To complete this assignment, you will write code in both `lab3_main.cpp` and `lab3.cpp`. You will implement a number of different functions in `lab3.cpp` (which already includes their declarations), and you will use `lab3_main.cpp` to test them and complete the rest of the assignment. You will need to use the Eigen library, and so examples of how to use the necessary functions are included in `lab3_main.cpp`. For this assignment, you will be using 3D models of the UR5 robot. To start rviz with the models imported, enter the following command in the terminal:

```
roslaunch ur5 ur5_rviz.launch
```

Provided Functions

In addition to the functions provided in the previous lab, all of the functions that you wrote for previous labs can be used in `lab3_main.cpp` and `lab3.cpp`.

plotfwd This function accepts a 6x1 vector of joint angles and moves the full UR5 model to the corresponding position. It also prints out the 4x4 matrix that defines the transformation from the base of the robot to the frame of its end-effector. This function is intended to help you debug the function `plotframes` you will implement in question 6.

Assignment

Be sure to comment all of your code!

1. Write a function `dhf` that accepts the Denavit-Hartenberg parameters a, d, α, and θ and returns the corresponding 4x4 transformation.

2. Using the schematic for the *Universal Robot UR5*, determine the set of Denavit-Hartenberg parameters for the robot. **Use units of meters and radians.**
   Use a fixed base frame, frame 0, defined such that $\hat{Z}_0$ points up. Number the frames sequentially. The gripper frame, frame 6, will be defined such that $\hat{Z}_6$ points along the gripper's axis of rotation.
   Create a hand-drawn sketch, in the style of Figure 1(left), that shows how you chose to assign frames to the links of the UR5. Include a table of the D-H parameters with your sketch.

3. Replace the 0s in `UR5::alpha[]`, `UR5::a[]`, and `UR5::d[]` in `lab3.cpp` with the Denavit-Hartenberg parameters for the UR5 found in the previous question.

4. Create another sketch of the robot when all joint angles, θ_i, are zero.

5. Write a function `fwd` that accepts an array of doubles containing the six joint angles for the UR5 robot. It returns the transformation from the robot base frame, `base_link`, to the frame of the end-effector,

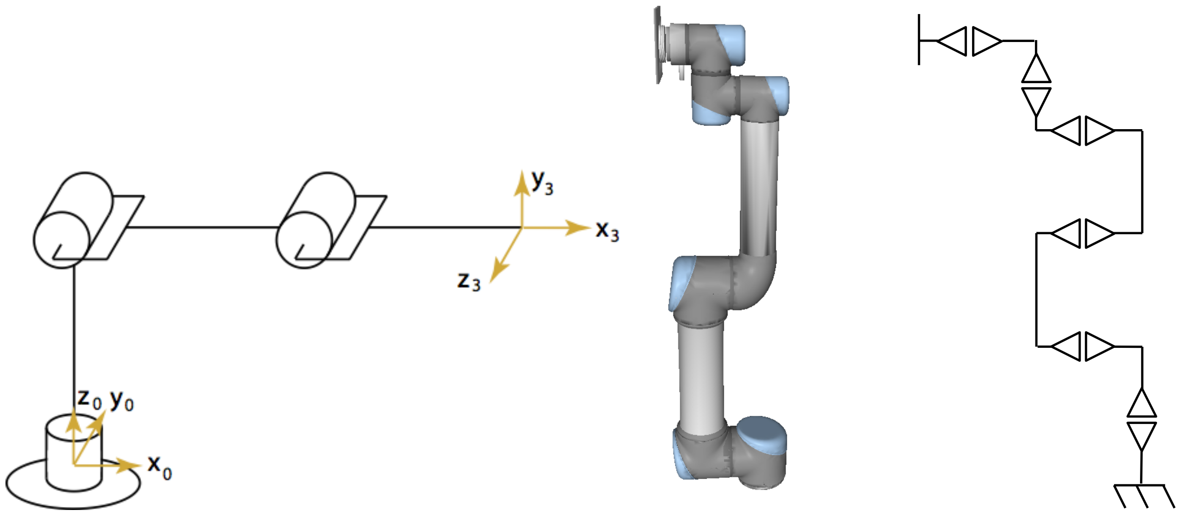

Figure 1: Left: Schematic of a Simple Robot Manipulator [1]. Right: Shematic of UR5 [2].

`ee_link`.
Your function should use both the function **`dhf`** *and the D-H parameters you found in question 2.*

6. Write a function `plotframes` that accepts an array of doubles containing the six joint angles for the UR5 robot. The function should assign coordinate frames (according to D-H convention) to each link of the robot by defining the transformations between their coordinate frames and the `base_link`

   Hint: Use the plotf function from lab 1.

7. For three different robot configurations, complete the following:

   (a) Use `plotfwd` and `plotframes` to move both the full UR5 model and its individual links to the desired position. Print out the rviz window.

   (b) Label the printout with both the vector of joint positions and the transformation from the base of the robot to its end-effector.

Submission Guidelines

As with both previous labs, you will push your code to your git repository to submit the assignment. In addition to the code, please include a pdf titled `Lab3.pdf`. This document should include the answers to questions posed in the lab and also annotated screenshots that show you experimented with the functions you implemented.

References

[1] J. P. Fiene. Forward kinematics. `http://www.medesign.seas.upenn.edu/index.php/Courses.MEAM520-12A-A03`. Accessed 2014-07-14.

[2] K. R. Petersen and M. Bing. Multiple-view vision-based robot calibration. Master's thesis, Syddansk Universitet, 2012.

This lab was adapted from a previous version of the course with permission of Dr. Louis Whitcomb.