

ME 449 Assignment 2  
Due 1:00 PM, Thursday October 22, 2020

Starting from the `IKinBody` in the MR code library, write a new function, `IKinBodyIterates`. This function prints out a report for each iteration of the Newton-Raphson process, for iterates 0 (the initial guess) to the final answer. Each iteration reports the iteration number  $i$ , the joint vector  $\theta^i$ , the end-effector configuration  $T_{sb}(\theta^i)$ , the error twist  $\mathcal{V}_b$ , and the angular and linear error magnitudes,  $\|\omega_b\|$  and  $\|v_b\|$  (something like the table at the end of Chapter 6.2.2). For a four-joint robot, a typical iterate might look like:

```
Iteration 3:

joint vector:
0.221, 0.375, 2.233, 1.414

SE(3) end-effector config:
1.000  0.000  0.000  3.275
0.000  1.000  0.000  4.162
0.000  0.000  1.000 -5.732
0      0      0      1

error twist V_b:
0.232, 0.171, 0.211, 0.345, 1.367, -0.222

angular error magnitude ||omega_b||:  0.357

linear error magnitude ||v_b||:  1.427
```

The function should also save the joint vector of each iteration as a row in a matrix. For a four-joint robot with three iterates (including the initial guess), the matrix would be

$$\begin{bmatrix} \theta_1^0 & \theta_2^0 & \theta_3^0 & \theta_4^0 \\ \theta_1^1 & \theta_2^1 & \theta_3^1 & \theta_4^1 \\ \theta_1^2 & \theta_2^2 & \theta_3^2 & \theta_4^2 \end{bmatrix}.$$

When your function completes, it should save the matrix as a .csv file, where each row of the text file consists of the comma separated joint values for that iterate. You can learn more about generating .csv files [here](#).

Test your new function for the UR5 robot of Example 4.5 of Chapter 4.1.2 (Figure 4.6). The home configuration of the end-effector  $M$  is given in the book, as well as the numerical values of the constants  $L_1, L_2, H_1, H_2, W_1, W_2$ . The screw axes  $\mathcal{B}_i$  in the end-effector frame are

```
joint 1: (0, 1, 0, W1 + W2, 0, L1 + L2)
joint 2: (0, 0, 1, H2, -L1 - L2, 0)
joint 3: (0, 0, 1, H2, -L2, 0)
joint 4: (0, 0, 1, H2, 0, 0)
joint 5: (0, -1, 0, -W2, 0, 0)
joint 6: (0, 0, 1, 0, 0, 0)
```

The desired end-effector configuration is

$$T_{sd} = \begin{bmatrix} 0 & 1 & 0 & -0.5 \\ 0 & 0 & -1 & 0.1 \\ -1 & 0 & 0 & 0.1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where linear distances are in meters. Use  $\epsilon_\omega = 0.001$  rad ( $0.057^\circ$ ) and  $\epsilon_v = 0.0001$  (0.1 mm). Choose an initial guess  $\theta^0$  so that the numerical inverse kinematics converges after 3–5 Newton-Raphson steps. For example, you could use the sliders in the CoppeliaSim UR5 interactive scene (Scene 1) to find an initial guess. (Check out [http://hades.mech.northwestern.edu/index.php/CoppeliaSim\\_Introduction](http://hades.mech.northwestern.edu/index.php/CoppeliaSim_Introduction) for more information.) You can type the final joint angles found by your function into the UR5 interactive scene to confirm that your function works properly and the joint angles of the solution achieve the desired end-effector configuration.

Once you have done this, assemble your documents for submission. You will submit one pdf file (FamilyName\_GivenName\_asst2.pdf) and one zip file (FamilyName\_GivenName\_asst2.zip).

- The pdf file should contain:

1. Any information that will help the grader understand your entire submission (this should be very brief).
2. A log showing how your code is called and its output, i.e., the Newton-Raphson iterates that are printed to the screen when you call `IKinBodyIterates` with your initial guess.
3. A CoppeliaSim screenshot showing the UR5 at the solution configuration, made using the UR5 interactive scene. This screenshot should clearly show the UR5's end-effector configuration as well as the  $SE(3)$  configuration reported by the scene's interface, confirming that your code calculated a good solution.

- The zip file should contain:

1. Your commented code in a directory called “code.”
2. A text file called “iterates.csv,” created by your `IKinBodyIterates` function and used to generate the video below.
3. A CoppeliaSim video animating the Newton-Raphson iterations. Use the CoppeliaSim csv animation scene for the UR5 (Scene 2). The video should show CoppeliaSim “playing” your .csv file. (Go to [http://hades.mech.northwestern.edu/index.php/CoppeliaSim\\_Introduction](http://hades.mech.northwestern.edu/index.php/CoppeliaSim_Introduction) to learn about making videos with CoppeliaSim.) The video is just a sequence of configurations of the robot, equal to the number of iterates in your .csv file. You should uncheck the “Interpolate” checkbox in the CoppeliaSim UR5 animation scene to make this video. Your video should be a “reasonable” size (e.g., a few MB, less than 10 MB) and use a standard codec (e.g., some variant of .mp4) that common video viewers, in Mac OS, Windows, or Linux, can view. Your video should be taken from a virtual camera angle that makes it easy to see the end-effector configuration.