ME 449 Assignment 3
Due 1:00 PM, Thursday November 5, 2020

The UR5 is a popular 6-dof industrial robot arm. The robot has geared motors at each joint, but in this project, we ignore the effects of gearing, such as friction and the increased apparent inertia of the rotor.

The relevant kinematic and inertial parameters of the UR5 are:

$$M_{01} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.089159 \\ 0 & 0 & 0 & 1 \end{bmatrix}, M_{12} = \begin{bmatrix} 0 & 0 & 1 & 0.28 \\ 0 & 1 & 0 & 0.13585 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, M_{23} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -0.1197 \\ 0 & 0 & 1 & 0.395 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$$M_{34} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0.14225 \\ 0 & 0 & 0 & 1 \end{bmatrix}, M_{45} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0.093 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, M_{56} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.09465 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$$M_{67} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0.0823 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, G_1 = \texttt{diag}([0.010267495893, 0.010267495893, 0.00666, 3.7, 3.7, 3.7]),$$

$$G_2 = \texttt{diag}([0.22689067591, 0.22689067591, 0.0151074, 8.393, 8.393, 8.393]),$$
$$G_3 = \texttt{diag}([0.049443313556, 0.049443313556, 0.004095, 2.275, 2.275, 2.275]),$$
$$G_4 = \texttt{diag}([0.111172755531, 0.111172755531, 0.21942, 1.219, 1.219, 1.219]),$$
$$G_5 = \texttt{diag}([0.111172755531, 0.111172755531, 0.21942, 1.219, 1.219, 1.219]),$$
$$G_6 = \texttt{diag}([0.0171364731454, 0.0171364731454, 0.033822, 0.1879, 0.1879, 0.1879]),$$

$$\texttt{Slist} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & -1 & 0 \\ 0 & -0.089159 & -0.089159 & -0.089159 & -0.10915 & 0.005491 \\ 0 & 0 & 0 & 0 & 0.81725 & 0 \\ 0 & 0 & 0.425 & 0.81725 & 0 & 0.81725 \end{bmatrix}.$$

For your convenience, these parameters are given in Python, Mathematica, and MATLAB at `http://hades.mech.northwestern.edu/index.php/Modern_Robotics#Supplemental_Information`.

Your job is to write code, building on the MR code library, that simulates the motion of the UR5 for a specified amount of time (in seconds), from a specified initial configuration (at zero velocity), when zero torques are applied to the joints. In other words, the robot simply falls in gravity. Gravity is $g = 9.81$ m/s^2 in the $-\hat{z}_s$-direction, i.e., gravity acts downward. The motion should be simulated with at least 100 integration steps per second, and first-order Euler integration is sufficient. Your program should calculate and record the robot joint angles at each step. This data should be saved as a .csv file, where each row has six numbers separated by commas. This .csv file is suitable for animation with the V-REP UR5 csv animation scene.

You will perform two simulations and make videos of each, clearly showing the smooth motion of the robot:

1. The robot falling from the zero (home) configuration for 3 seconds.

2. The robot falling from a configuration where all joints are at their zero position, except for joints 1 and 2, which are both at -1 radian. This simulation should last 5 seconds.

Important: Since the simulated robot has no friction and zero motor torques, no energy is added or subtracted during the simulated motion. Therefore, the total energy of the robot (kinetic plus potential) must remain constant during the simulation. If you see the robot swinging higher and higher, or noticeably losing energy, something is wrong with your simulation.

Also important: You are welcome to talk to classmates about concepts at the development phase, but you are not allowed to share or look at each others' code. You cannot ask to look at someone else's code, and they cannot ask to look at yours. Sophisticated AI-based software easily detects shared and altered code with common origins, so do not do it.

What to turn in: You should turn in a single pdf file and a single zip file, one named FamilyName_GivenName_asst3.pdf and one named FamilyName_GivenName_asst3.zip. The pdf file should contain any information needed to understand your code solution.

The zip file should contain your commented code in a directory called "code," two csv files generated by your code following the instructions above, and two videos generated from the csv files, clearly showing the robot's motion. Other standard instructions for submitting are given on the class website.