MTRX5700: Experimental Robotics

Assignment 1

Note: This assignment contributes 5% towards your final mark. This assignment is due on Sunday, March 21st during **Week 3** before 11:59pm. Submit your report via the eLearning TurnItIn submission on the course's Canvas site. Late assignments will be subjected to the University's late submission policy unless accompanied by a valid special consideration form. Plagiarism will be dealt with in accordance with the University of Sydney plagiarism policy.

Total Marks: 100
This assignment should take an average student **8-15 hours** to complete with a passing grade.

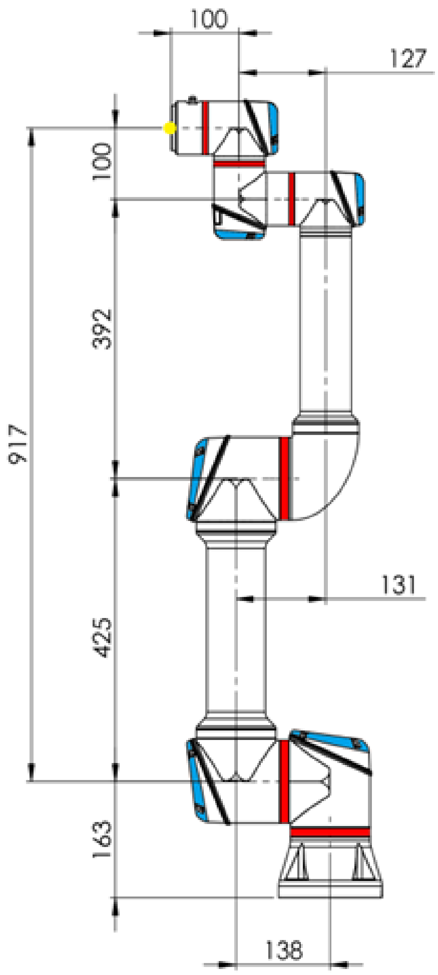
Page Limit: 16

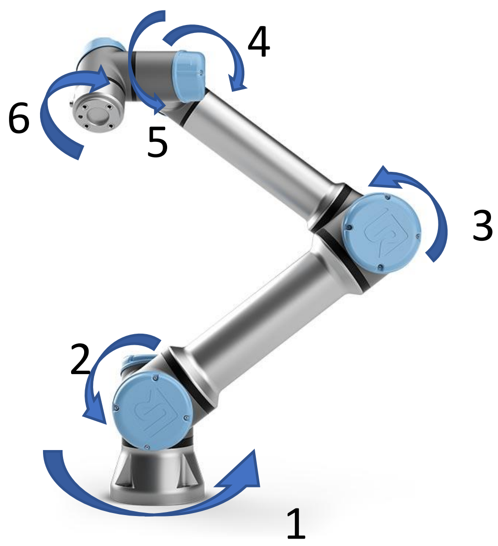
The front page of your report should include:

- Your SID only (do not include your name to comply with the University's new anonymous marking policy)

1. (30 points)
   You might have played with the robot arm UR5e in our lab. It is a six-axis arm with six rotational joints. A structural sketch of the robot can be found in Figure 1 (a) with joints marked in red and dimensions labelled accordingly. Those joints are also shown with arrows in Figure 1 (b). The angles of the six joints, from base to the final wrist, completely define the configuration of the robot, which is called state. Assuming that the robot state is $q[0, -\frac{3\pi}{4}, \frac{\pi}{2}, 0, 0, 0]$:
   a. Derive the forward kinematics with ***modified DH convention*** from the base to its end effector (the yellow point on the Figure 1(a)) in this configuration.
   b. Visualize your result with the coding language of your choice (Python recommended).
   c. Where is the end effector point in your base frame when the state is $q[0, -\frac{\pi}{2}, 0, -\frac{\pi}{2} 0, 0, 0]$ (this is called home position)? Check your answer with the simulator in question 2.

   Note: Remember to present how you establish your frames and show some intermediate steps.





(a) **(b)**

Figure 1 - UR5e joints and kinematic dimensions (mm). Joints are shown in red in (a) and they are marked with arrows in (b).

2. (30 + 5points)
   The robot arm UR5e described in Question 1 will be setup with several blocks in its workspace as shown in Figure 3. There are 5 blocks (yellow) randomly placed on the table and another random goal position is marked green in Fig. 2. Here are your tasks:
   a. Program UR5e to firstly ***read the message in ROS topic "/gazebo/model_states"*** to get the position of each block and your goal position, then pick the 5 blocks up from their initial positions and to build a tower by stacking the blocks on top of each other at the goal position. You may stack the blocks in any order you want.
   b. Avoid any possible collision between the arm and tower you built. Briefly explain how you achieve obstacle avoidance.
   c. (5 points) Bonus:
      (a) (off-line groups) Run your code on the hardware (under supervision).
      (b) (on-line groups) Add a pillar obstacle (radius: 0.04m, height: 0.5m) that randomly placed in the simulated environment and avoid it when planning motion.

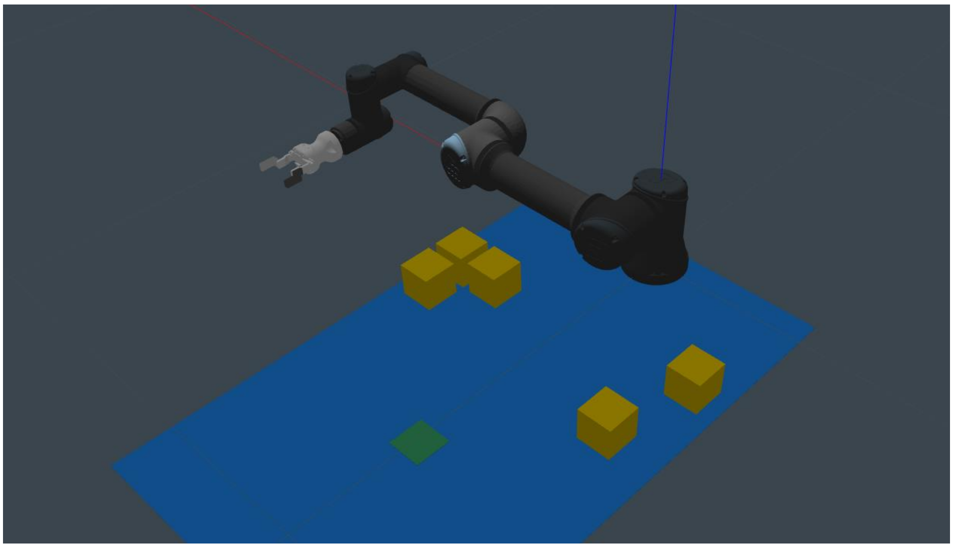
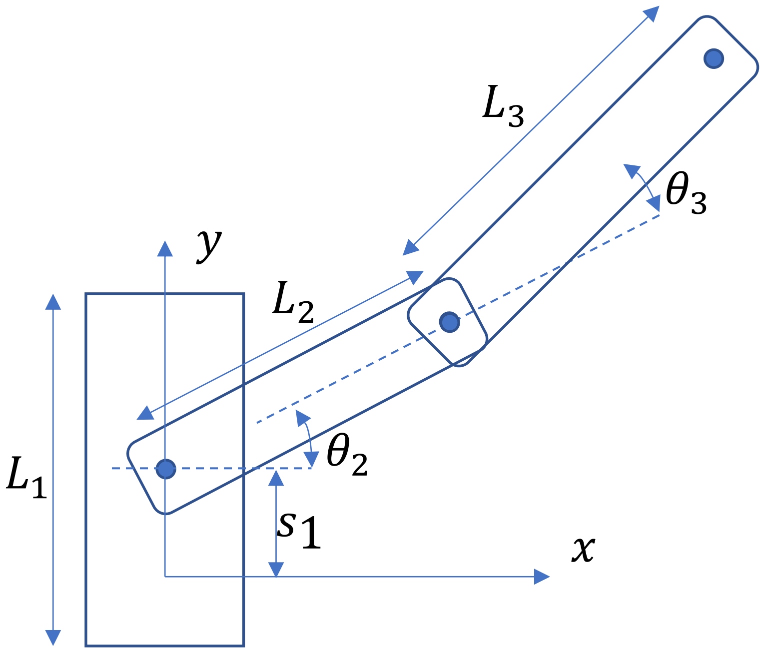


Figure 2 - Simulation environment with the robot, blocks (yellow), goal position (green)

Note:
Skeleton code (in python) to move the arm, and open and close the gripper is provided. You will need to fill in the missing details ***(in /assignment_1/scripts/build_tower)***. All the code that you write should be submitted. Please follow additional instructions and guidelines provided with the code.
Information on ROS, Gazebo and how to set the framework are provided along with the code. If you are new to ROS, please read them before answering.

3. (20 points)
The workspace of a planar manipulator describes the points in space that it can reach. For the planar robot shown below:



Where:

$$L_1 = 300mm$$

$$L_2 = 280mm$$

$$L_3 = 350mm$$

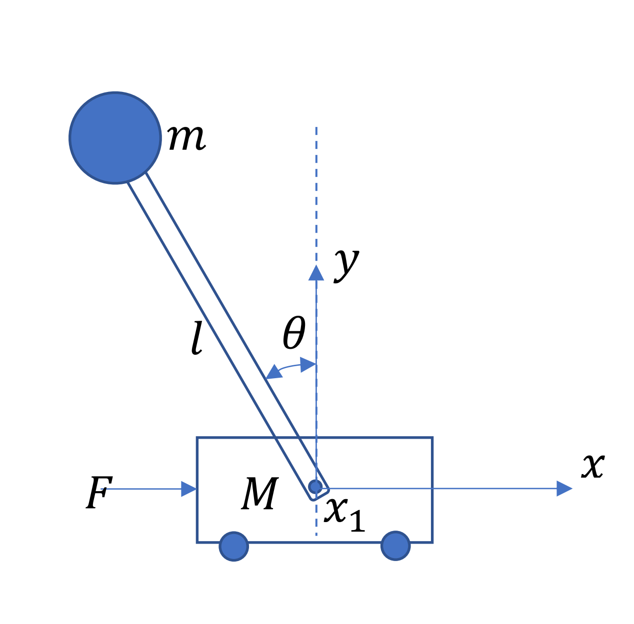
$$0 < s_1 < 150mm$$

$$-\frac{\pi}{3} < \theta_2 < \frac{\pi}{3}$$

$$-\frac{2\pi}{3} < \theta_3 < \frac{2\pi}{3}$$

a. Plot **both** the workspace and the configuration space of the 3-link planar arm in the following figure with the following specifications.
b. Where are the singularities for this robot? Briefly describe what happens at some of the singular points you found.
HINT: solve the forward kinematics for the manipulator for a series of values of the joint variables. Each solution corresponds to a point in the workspace).

4. (20 points) Consider a simpler planar robot shown here, which includes one linear cart and one rotational joint (inverted pendulum). Only the cart is actuated.



$M = 2.0\ kg$
$m = 1.0\ kg$
$l = 0.6\ m$

x_1 = translation of cart
θ = angle of inverted pendulum
F = force applied on cart

a. Derive the equations of motion that describe the system dynamics
   HINT: take either Newton's method or Euler-Lagrange method, show intermediate steps.
b. Recall what you learnt in physics and our lecture, with those dynamics equations you can further develop a simulator and controller for the system. Briefly discuss how can those things (simulator and controller) can help when you select actuators (motors for example) for this system?

Note: this system is called cart pole and is closely related to bipedal walking robot dynamics model.