Introduction to Robotics
Tutorial

1. Consider the 1-DOF robot with a rotary joint driven using a DC motor and gearbox (with gear ratio r), with rotor inertia J_m, gearbox inertia J_g and damping B_m. The robot link can be considered to be a uniform rigid rod of length L and mass M.

   (a) Let V to be the voltage applied to the motor terminals and θ_l be the link position. Derive the differential equation governing the motion of the robot.

   (b) Assume that a force F_e acts at the tip of the robot in the direction perpendicular to the link. If $V = 0$, What are the apparent rotary inertia, damping and stiffness of the robot end-effector.

   (c) A force sensor with stiffness k_s is attached to the tip of the robot to measure the applied force. If the tip of the robot pushes against a rigid environment, design a explicit (direct) force controller such that a contact desired force F_d is maintained, such that $\theta_l \leq \theta_{max}$ at steady state. Assume that the link just touches the environment when $\theta_l = 0$.

   (d) Design an impedance controller to such that the apparent impedance of the link is that of a damper with a damping coefficient C_d, i.e, when an external force is applied to the link, the robot motion should satisfy $F_e = C_d\dot{\theta}_d$

2. Consider a planar 2R manipulator with identical link lengths. The links can be assumed to be uniform rigid rods of length L and mass M. Both joints are driven by identical motors with with rotor inertia J_m, gearbox inertia J_g and damping B_m and gear ratio r.

   (a) Derive the task space equations governing the motion of the robot.

   (b) Design a task space controller to move the robot to a desired end-effector position (x_d, y_d) along a straight line trajectory. You may choose any suitable velocity profile, but the robot should come to rest at the goal position.

   (c) If the robot end-effector is constrained to move along a elliptical slot, find the vector S_f such that environment force $F_e = S_f\beta$ where beta is a scalar.