MIT - Mechanical Engineering Department

2.12 Introduction to Robotics - Fall 2016 - HW5

Released: November 2, 2016 Due: November 9, 2016

Notes:

- Turn in individual problems in **separate pages** and put your name on **each page**.
- Show the process to get to the answer and not just the solution.
- Clearly highlight solutions, i.e., draw a rectangle around them.

Problem 1

Generating a Desired Force in a Static Manipulator

A planar robot with three revolute joints is shown below. Let θ_i and l_i be the angle of joint i and the length of link i, respectively, and (x_e, y_e, ϕ_e) be the end-effecter position and orientation viewed from the base coordinate frame, as shown in the figure. Linear forces F_x and F_y and moment N_z act on the end-effecter. Answer the following questions:

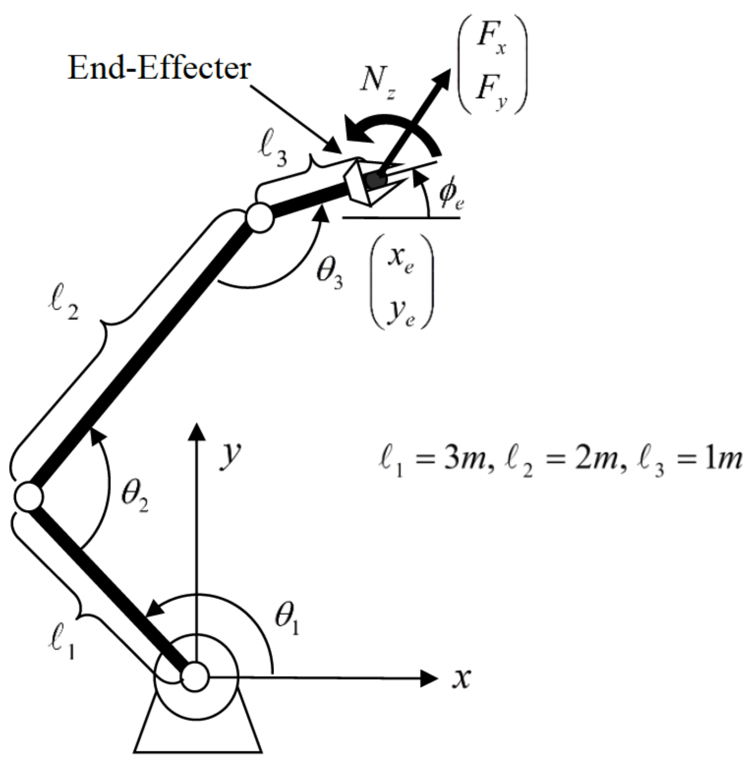


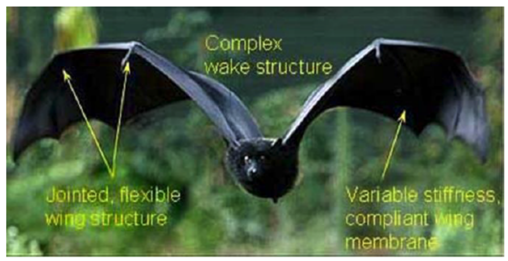
Figure 1: 3 Link Manipulator Generating a Force and Moment.

1. At arm configuration of $(\theta_1 = 135^o, \theta_2 = 45^o, \theta_3 = 225^o)$ obtain the 3×3 Jacobian matrix relating the end-effector position and orientation to joint displacements.
2. We want to generate an endpoint force of $(F_x = 10\text{N}, F_y = -2\text{N}, N_z = 0.2\text{Nm})$. Obtain the equivalent joint torques needed for generating the endpoint force. Ignore friction and gravity.

Problem 2

Principle of Virtual Work - Bat Robot

Consider the cool (and potentially useful for Halloween) bat robot below. This robot has biologically inspired with elastic joints that are activated with artificial muscle actutators. Figure 2 shows the cross-sectional view of the wing structure. Each wing consists of two rigid bodies, Link 1 (line AB) and Link 2 (line BE), connected at Joint 2 (Point B). A coil spring of spring constant k is inserted between Points C and D, generating a contracting force $F_s = k(h - h_0)$, as shown in the figure. Parameter h_0 is the unstrung length of the spring, and h is the distance between C and D, both of which are at distance b from Joint 2. An artificial muscle actuator is attached to one end of Link 1 (Point A), which rotates around Joint 1. Using the joint angles θ_1 and θ_2, link lengths l_0, l_1 and l_2 shown in the figure, answer the following questions. Ignore friction and use the *Energy Method*.



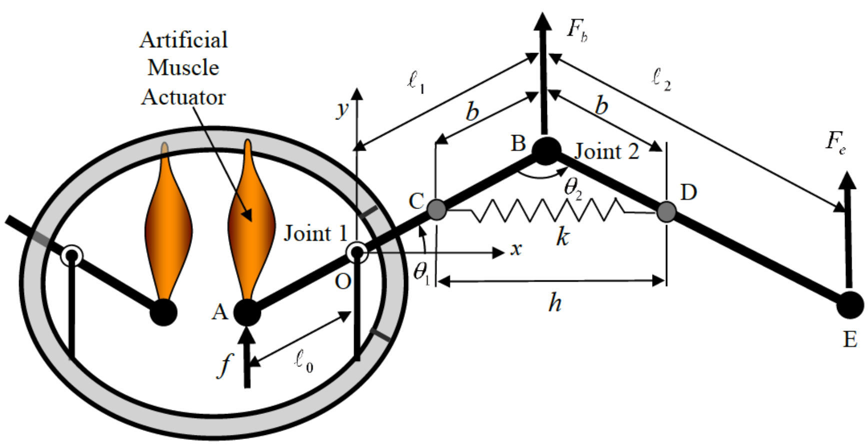


Figure 2: Bat Robot Schematic.

1. What are a complete and independent set of generalized coordinates that locate the single wing system described above?

2. Obtain the length of the coil spring h as a function of joint angle θ_2 . Also obtain the differential relationship between virtual displacements δh and $\delta\theta_2$.

3. When the bat robot glides, aerodynamic lift acts along the wing. For the sake of simplicity the lift is approximated to two forces F_b and F_e acting at Points B and E, respectively. Using the Principle of Virtual Work, obtain the linear actuator force f needed for bearing the forces F_b and F_e . Assume no friction and no gravity.

4. Obtain the joint angle θ_2 when the system with given forces F_b , F_e, and the actuator force f is in equilibrium. For simplicity set the parameter $h_0 = 0$ to zero and assume $\theta_1 = 0$.

Problem 3

Hybrid position/force Control Constraints

Shown below is an office robot drying ink with blotting paper attached to a semicircular roller of radius R. The roller should not slide but roll on the paper in order to avoid smearing the wet signature. Assuming that the process is quasi-static and frictionless, we want to perform the task using hybrid position/force control. Obtain natural and artificial constraints in terms of velocities and forces at the robot endpoint E. Describe the constraints with respect to the coordinate system $\{O - xyz\}$ that is fixed to space but is at Point E at the instant shown. Note that Point E is in the middle of the top surface of the semicircular roller and that the x and y axes are parallel to the sheet of paper. Is the rolling-contact requirement a natural constraint or an artificial constraint? [The key is to differentiate constraints that physics dictates, i.e. natural constraints, from the type of trajectories that you want the robot to follow in order to accomplish a given task, i.e. artificial constraints.]

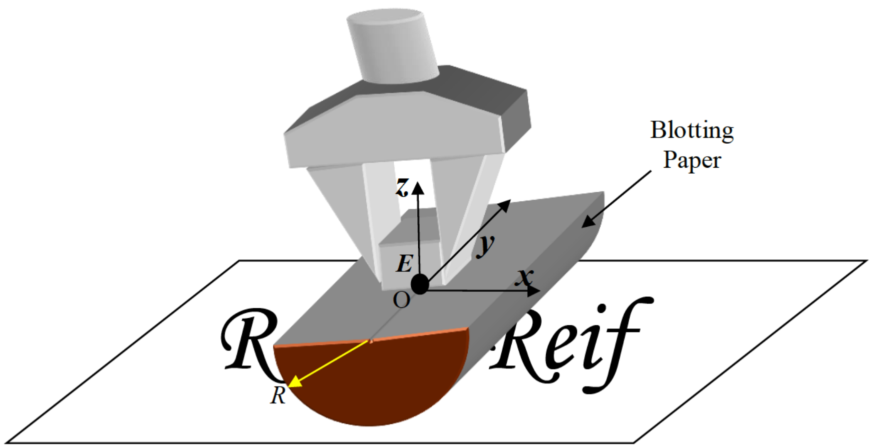


Figure 3: Office robot of President Rafael Reif drying ink with blotting paper.