Control of Industrial Robots

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July 10, 2023

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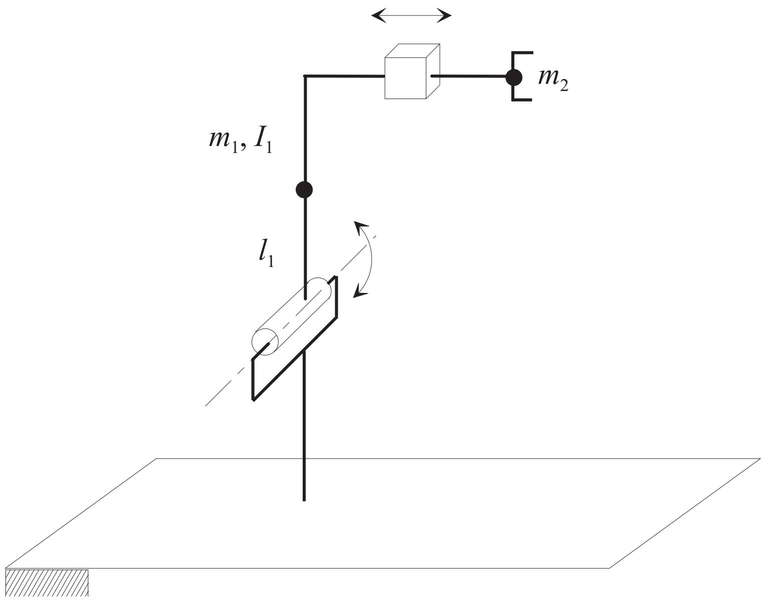
Warnings

- This file consists of **8** pages (including cover).
- During the exam you are not allowed to exit the room for any other reason than handing your work or withdrawing from the exam.
- You are not allowed to withdraw from the exam during the first 30 minutes.
- During the exam you are not allowed to consult books or any kind of notes.
- You are not allowed to use calculators with graphic display.
- Solutions and answers can be given **either in English or in Italian**.
- Solutions and answers must be given **exclusively in the reserved space**. Only in the case of corrections, or if the space is not sufficient, use the back of the front cover.
- The clarity and the order of the answers will be considered in the evaluation.
- At the end of the test you have to **hand this file only**. Every other sheet you may hand will not be taken into consideration.

EXERCISE 1

1. Consider the manipulator sketched in the picture, where the mass of the second link is assumed to be concentrated at the end-effector:



Find the expression of the inertia matrix $\mathbf{B}(\mathbf{q})$ of the manipulator.

2. Compute the matrix $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})$ of the Coriolis and centrifugal terms[1] for this manipulator.

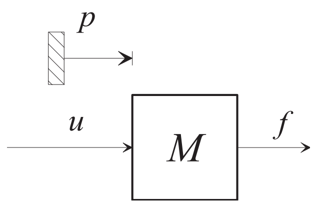
3. Ignoring the gravitational terms, write the complete dynamic model for this manipulator.

[1] The general expression of the Christoffel symbols is $c_{ijk} = \frac{1}{2}\left(\frac{\partial b_{ij}}{\partial q_k} + \frac{\partial b_{ik}}{\partial q_j} - \frac{\partial b_{jk}}{\partial q_i}\right)$

4. For this specific manipulator, wtite the expression of the kinetic energy. Is it possible that this kinetic energy is zero for joint velocities different from zero?

EXERCISE 2

1. Consider a single mass affected by an external force f and a control force u:



Write the expression of an impedance control law that makes the system react to the external force f like a mass-spring-damper system, with all parameters assignable.

2. Consider a manipulator where a system of forces is applied at the end-effector. Discuss the statics of the manipulator, i.e. find analytically the relation between this system of force and the joint torques at the equilibrium.

3. Write the expressions of a translational impedance and the expression of a rotational impedance.

4. Assume now that a force sensor at the end effector is unavailable. Discuss a method to estimate force and moments at the end effector, making reference to the concept of residual vector.

EXERCISE 3

1. Explain what is the purpose of the kinematic calibration of a robot manipulator and why it is needed.

2. In the kinematic calibration of a robot manipulator the following equation is used:

$$\Delta \mathbf{x} = \mathbf{\Phi} \Delta \zeta$$

   Explain the meaning of each symbol used in such equation, as well as the size of the vectors.

3. Consider now a robot mounting a camera. Explain what are the extrinsic and the intrinsic calibrations. What is the skew parameter in this context?

4. Explain the difference between an eye-to-hand and an eye-in-hand configuration for the camera. Which one suffers the most of occlusions and which one of changes of the field of view?