

Control of Industrial Robots

PROF. ROCCO

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NAME:

UNIVERSITY ID NUMBER:

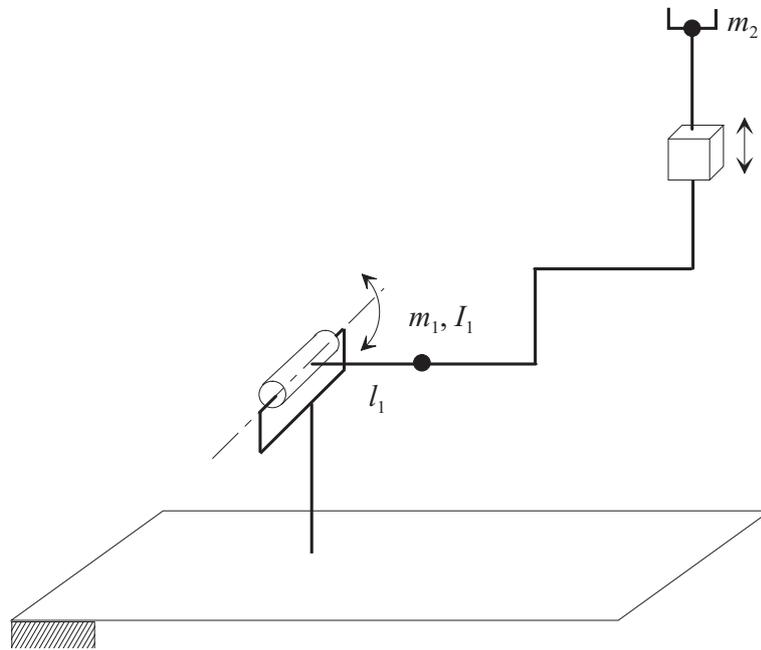
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Warnings

- 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 terms¹ for this manipulator.

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

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

3. Explain what are possible ways to define the joint velocities that generate the null-space motions.

4. Sketch the block diagram of a kinematic control for a redundant manipulator (closed loop inverse kinematics at velocity level). Why is closed loop used in this context?

3. Suppose now that along one of the force controlled directions an explicit force controller has to be designed. Determine the expression of such controller, taking a bandwidth of 30 rad/s.

4. Define what an implicit controller of the force is and explain why it might be more convenient to use than an explicit controller. Do you need to know precisely the stiffness constant of the environment to tune such controller?