Control of Industrial Robots

Prof. Rocco

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NAME:

UNIVERSITY ID NUMBER:

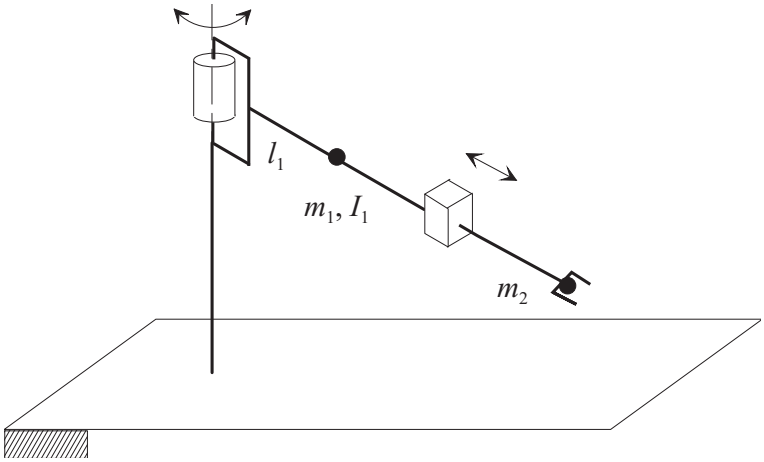
SIGNATURE: _____

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. Write the complete dynamic model for this manipulator.

4. Show that the model obtained in the previous step is linear with respect to a set of dynamic parameters.

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

EXERCISE 2

1. Explain what is the difference between the kinematic and the dynamic scaling of a trajectory

2. The parametric form of a cycloidal trajectory for kinematic scaling is given by:

$$\sigma(\tau) = \tau - \frac{1}{2\pi}\sin(2\pi\tau)$$

Find the expressions of the maximum velocity and maximum acceleration for such trajectory in terms of the positioning time T and the total displacement h.

3. Consider the design of a cycloidal trajectory from $q_i = 0$ to $q_f = 20$, with $\dot{q}_{\max} = 10$ and $\ddot{q}_{\max} = 20$. Find the minimum positioning time.

4. In the process of the dynamic scaling, the following relation is used, for each joint of the robot:

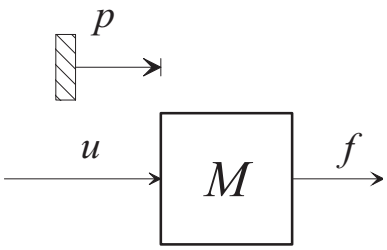
$$\tau_i(t) = \alpha_i(\sigma(t))\,\ddot{\sigma}(t) + \beta_i(\sigma(t))\,\dot{\sigma}^2(t) + \gamma_i(\sigma(t)), \qquad i = 1, \ldots, n, \qquad t \in [0, T]$$

Explain the meaning of symbol σ in this equation. Out of the three terms in the right hand side, which ones scale with time?

EXERCISE 3

1. Explain what is the difference between passive and active control of the interaction of a manipulator with the environment. What are the main devices used for passive control and for active control, respectively?

2. Consider now a simple mass as in this picture:



   Write the expression of an (explicit) impedance controller that can assign a prescribed impedance relation.

3. Still making reference to a single degree of freedom mechanism, sketch the block diagram of an admittance controller. What is the assumption that must be enforced on the motion control system in order to claim that the prescribed impedance is actually achieved?

4. Write the general expression of a rotational impedance.