Control of industrial robots

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Name:

University ID number:

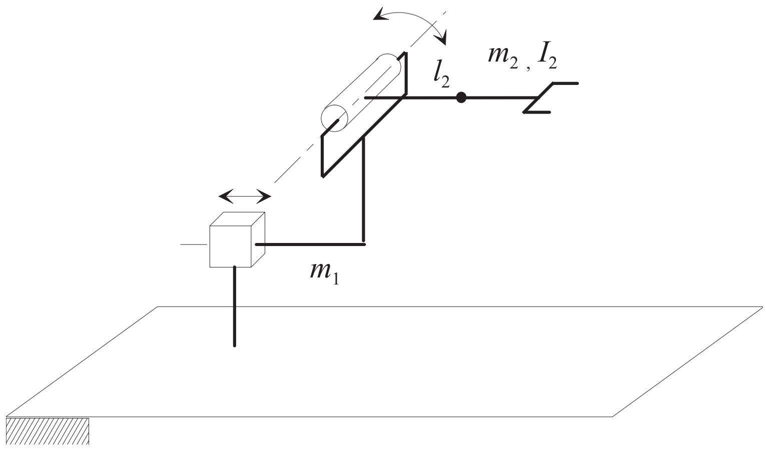
Signature:..

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:



Find the expression of the inertia matrix $\mathbf{B}(\mathbf{q})$ of the manipulator[1]

[1]The cross product between vector $a = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$ and $b = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}$ is $c = a \times b = \begin{bmatrix} a_2 b_3 - a_3 b_2 \\ a_3 b_1 - a_1 b_3 \\ a_1 b_2 - a_2 b_1 \end{bmatrix}$

2. Ignoring the Coriolis and centrifugal terms, write the dynamic model of the manipulator.

3. Show that the dynamic model is linear with respect to a certain set of dynamic parameters.

4. Write the expression of a “PD + gravity compensation” control law in the joint space for this specific manipulator.

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 $q_i = 10$ to $q_f = 30$, with $\dot{q}_{\max} = 20$ and $\ddot{q}_{\max} = 10$. Find the minimum positioning time.

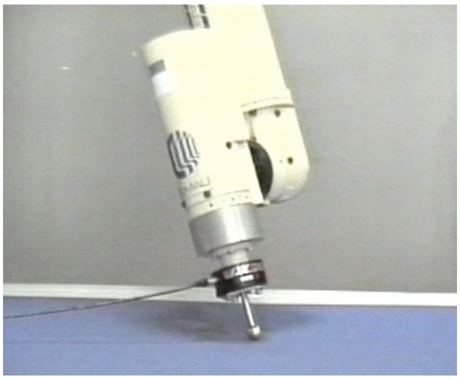
4. In the process of the dynamic scaling, the following relation is used, for each joint of the robot:

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

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. Consider an interaction task of a manipulator, with a frictionless and rigid surface, as in this picture:



   Assume a point contact and draw a contact frame directly on the picture. Based on this frame and neglecting angular velocities and moments, express the natural and the artificial constraints for this problem, and specify the selection matrix.

2. Explain what an implicit force controller is and why it might be convenient with respect to an explicit solution.

3. Suppose now that along the force controlled direction an explicit force controller has to be designed. Sketch the block diagram of such controller and design it taking a bandwidth of 30 rad/s.

4. Repeat the process in case an implicit force controller, for the same bandwidth, has to be designed.