Control of Industrial Robots

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UNIVERSITY ID NUMBER:

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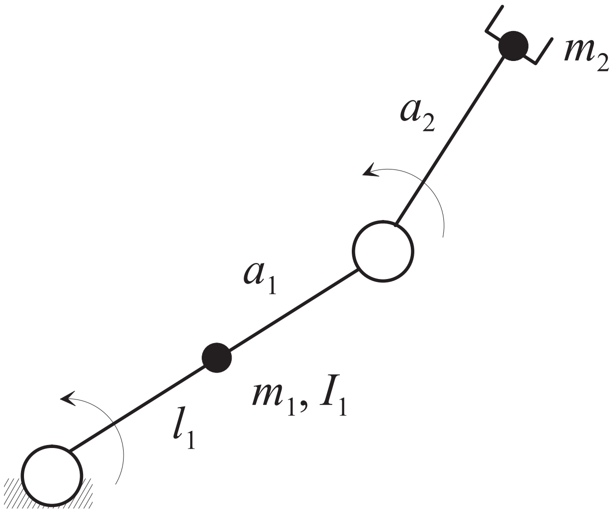
Warnings

- 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

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



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

2. Find the expression of the gravitational torques for this specific manipulator.

3. For a generic manipulator, write the expression of the dynamic model in terms of a set of dynamic parameters.

4. Using the expression of the dynamic model in terms of a set of dynamic parameters, explain the process to identify such parameters.

EXERCISE 2

1. Consider a kinematically redundant manipulator. Explain what the "null-space motions" are, and write an expression for the null-space motions, explaining the meaning of each symbol used.

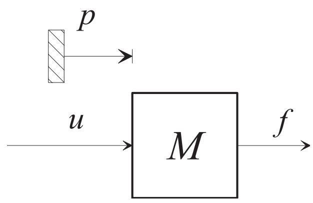
2. Making reference to the human arm, explain why it can be considered kinematically redundant. Explain also how the null-space motions can be revealed.

3. Define what is a repeatable, or cyclic, method for kinematic redundancy resolution. Explain what are the advantages in using a repeatable method.

4. Write the expression of the extended Jacobian method for redundancy resolution and explain why it is repeatable.

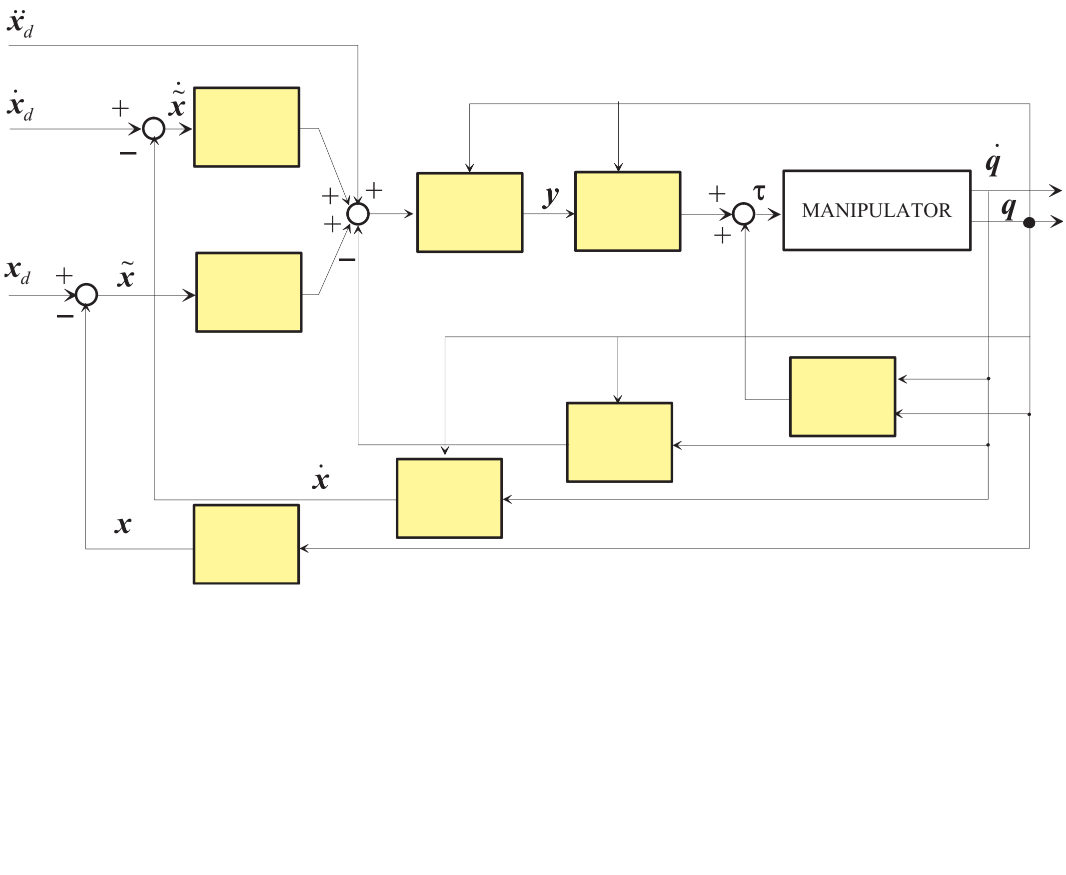
EXERCISE 3

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. In order to extend the previous result to the whole manipulator, the inverse dynamics in operational space is used. A block diagram of the method is sketched in the following picture:



Write the correct expression for each of the empty blocks of the diagram.

3. Explain what is the result that can be ideally obtained with the inverse dynamics in operational space for a manipulator in free motion.

4. Assume now that a system of forces is applied at the end-effector. Explain whether and how the result of the inverse dynamics in operational space previously described changes.