Control of Industrial Robots

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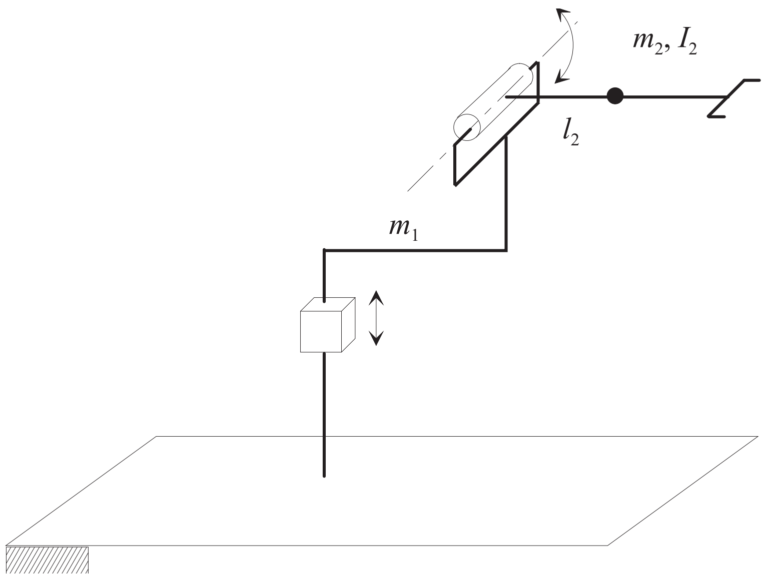
Warnings

- 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 manipulator sketched in the picture:



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

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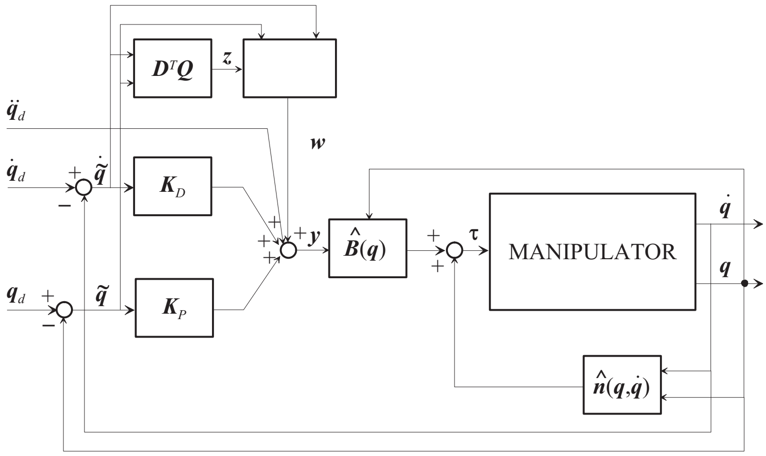
[1]The cross product between vector $a = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$ and $b = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}$ is $c = a \times b = \begin{bmatrix} a_2 b_3 - a_3 b_2 \\ a_3 b_1 - a_1 b_3 \\ a_1 b_2 - a_2 b_1 \end{bmatrix}$

2. Compute the gravitational terms for this robot.

3. Write the expression of an inverse dynamics controller in joint space for this specific manipulator that ignores centrifugal and Coriolis terms.

4. If you want to make the control system robust against a partial knowledge of the dynamic model of the robot (for example lack of knowledge of the centrifugal and Coriolis terms) you can use a particular control law. Making reference to the following sketch, briefly comment this control law and explain the nature of the additional term computed in the empty block of the sketch.



EXERCISE 2

1. Suppose that a trajectory for a scalar variable has to be defined, which achieves the values reported in the following table, at the given instants:

$$\begin{array}{ccccc} t_1 = 0 & t_2 = 1 & t_3 = 5 & t_4 = 7 & t_5 = 10 \\ q_1 = 10 & q_2 = 0 & q_3 = 30 & q_4 = 40 & q_5 = 55 \end{array}$$

Assign suitable values to the speed at the intermediate points.

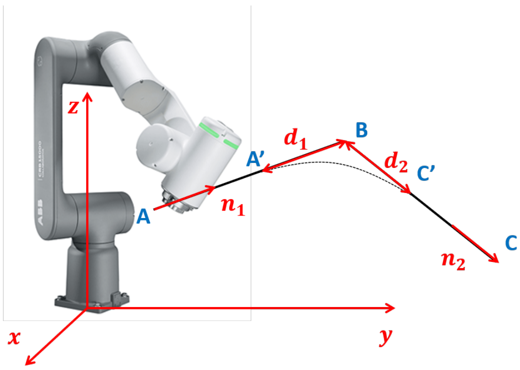
2. Using the values of speed previously evaluated, compute the expression of the cubic polynomial for the first interval (from t_1 to t_2).

3. In the spline method, the following equation has to be solved:

$$\mathbf{A}\mathbf{v} = \mathbf{c}$$

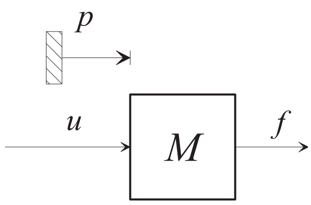
Explain what is the meaning of $\mathbf{v}$, what is the size of matrix $\mathbf{A}$ and whether matrix $\mathbf{A}$ has any particular shape.

4. Consider now the concatenation of linear paths. Making reference to the following picture, and without going through the mathematics, explain what are the assumptions that are enforced to compute the blending:



EXERCISE 3

1. Consider a simple mass as in this picture:



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

2. 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?

3. The admittance controller can be used to implement one of the possible collaborative modes between the robot and the human. Explain what is this mode and cite also the other collaborative modes allowed by the safety standards.

4. Consider now a robot that is compliant with the power and force limiting safety standards. Making reference to the following picture, derive the expression of the maximum value of the relative velocity between robot and human requested by such standard.