Control of Industrial Robots

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UNIVERSITY ID NUMBER:

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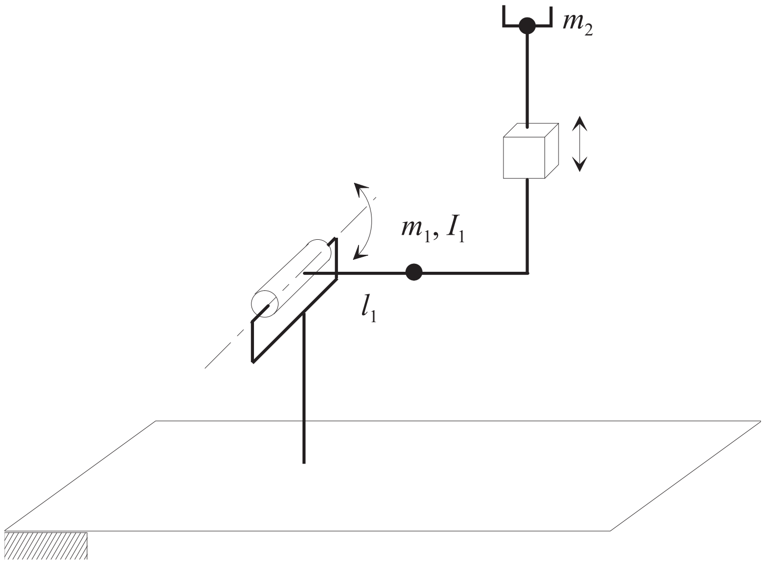
Warnings

- 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

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. Check that the expression $\dot{\mathbf{q}}^T \mathbf{N}(\mathbf{q}, \dot{\mathbf{q}})\dot{\mathbf{q}} = 0$, where $\mathbf{N}(\mathbf{q}, \dot{\mathbf{q}}) = \dot{\mathbf{B}}(\mathbf{q}) - 2\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})$, is true in this case.

4. Disregarding the gravitational terms, write the dynamic model of this manipulator in a form that 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. 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:

$$
\begin{array}{ccccc}
t_1 = 0 & t_2 = 2 & t_3 = 5 & t_4 = 8 & t_5 = 10 \\
q_1 = 0 & q_2 = -5 & q_3 = 10 & q_4 = 40 & q_5 = 60
\end{array}
$$

   Assign suitable values to the speed at the intermediate points.

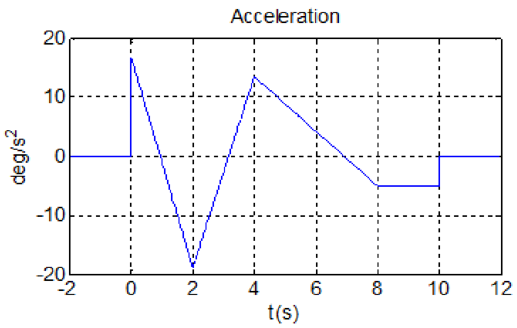
2. Using the values of speed previously evaluated, compute the expression of the cubic polynomial for the first interval (from t_1 to t_2).

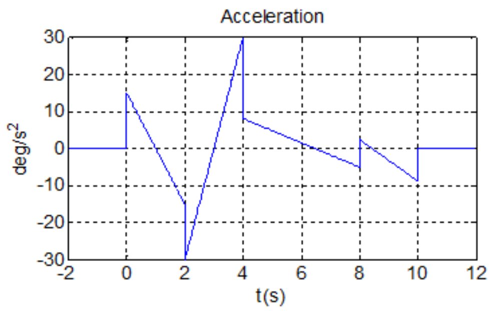
3. In the spline method, the following equation has to be solved:

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

Explain what is the meaning of the symbols used in this equation, what are their sizes, and whether matrix $\mathbf{A}$ has any particular shape.

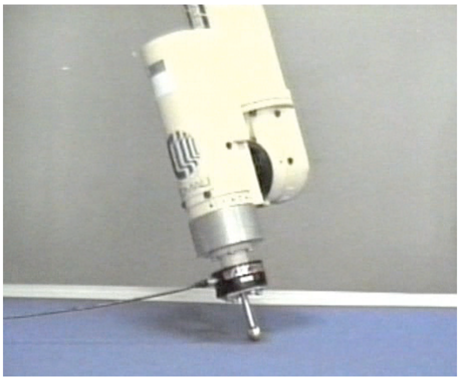
4. Explain which one of the acceleration profiles shown in the following pictures has been obtained with the spline method:





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. For the same control problem of the previous question, sketch the block diagram of an implicit force controller.