Control of Industrial Robots

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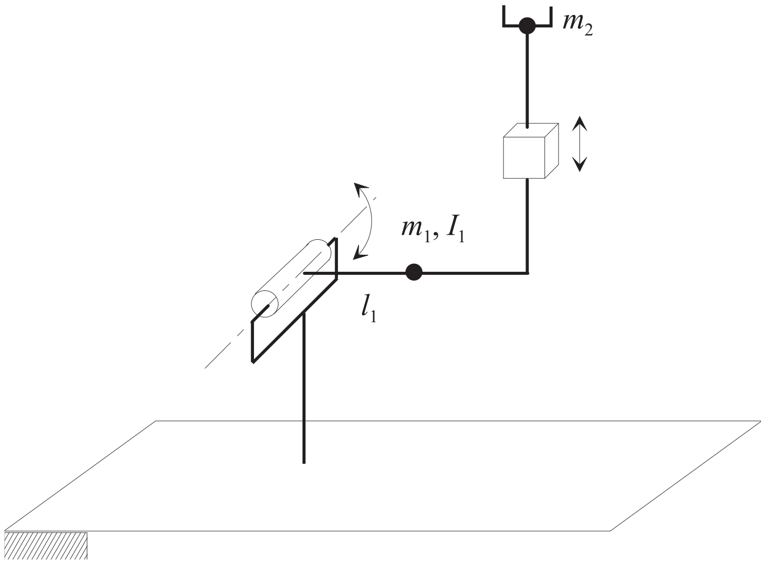
Warnings

- 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

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:

$$\begin{array}{ccccc} t_1 = 0 & t_2 = 2 & t_3 = 5 & t_4 = 8 & t_5 = 10 \\ q_1 = 20 & q_2 = 0 & q_3 = 20 & q_4 = 40 & q_5 = 50 \end{array}$$

   Assume that such points are interpolated by a single polynomial of suitable degree. Using the specific data of this exercise, write the equation in matrix form that allows to compute the coefficients of such polynomial.

2. Assume now that you want to use cubic polynomials in each interval. Assign suitable values to the speed at the intermediate points.

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

4. What are the maximum values (in terms of absolute values) of the speed and of the acceleration for the cubic profile determined at the previous step?

EXERCISE 3

Consider a kinematically redundant manipulator.

1. Write the general expression of the solutions of the inverse kinematics problem at velocity level, specifying what is the projection matrix and what is its role.

2. Express the solution in the form that includes a closed loop correction (kinematic control) and explain why this correction is used.

3. Explain what is a weighted pseudo inverse, what is the optimization problem a weighted pseudo inverse solves and why it might be used to solve the inverse kinematics for a redundant robot.

4. Discuss some criteria to select the joint velocities to be projected onto the null space of the Jacobian matrix.