Control of Industrial Robots

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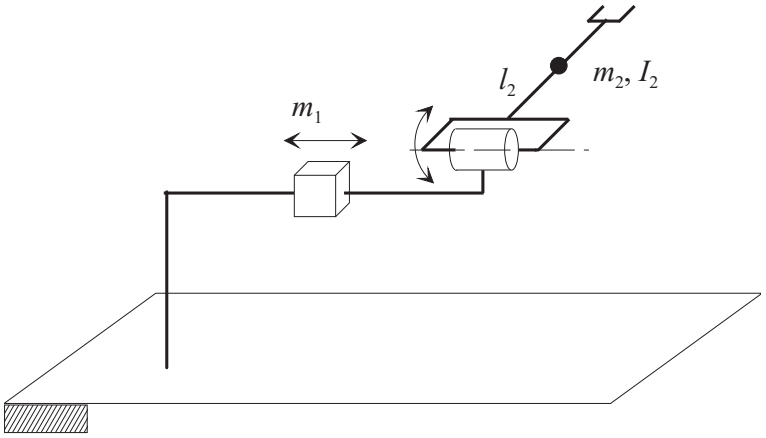
Warnings

- 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:



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

2. Write the complete dynamic model for this manipulator.

3. Consider the adoption of an inverse dynamics controller for this manipulator. Write the expressions of the two control variables.

4. Assume that the inverse dynamics controller assigns the same dynamics in closed loop to both joints of the manipulator. Compute the gains of the controller in such a way that both eigenvalues are equal to -10.

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:

$$\begin{array}{ccccc} t_1 = 0 & t_2 = 2 & t_3 = 5 & t_4 = 8 & t_5 = 10 \\ q_1 = 10 & q_2 = 0 & q_3 = 30 & q_4 = 40 & q_5 = 50 \end{array}$$

   Assign suitable values to the speed at the intermediate points.

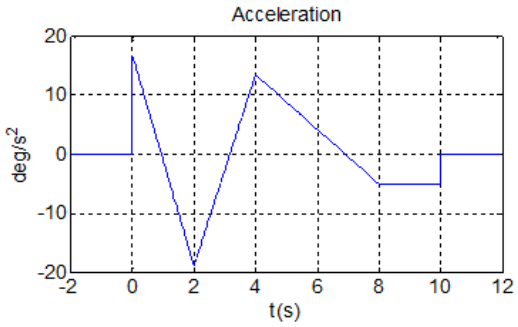
2. Using the values of speed previously evaluated, compute the expression of the cubic polynomial for the first interval (from t_1 to t_2).

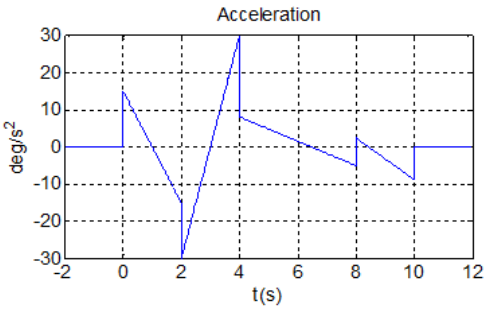
3. In the spline method, the following equation has to be solved:

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

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:

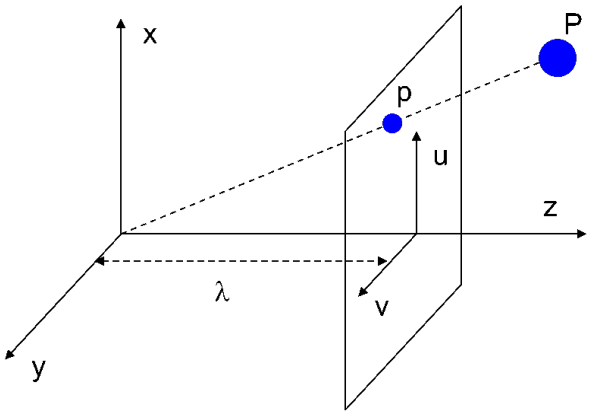




EXERCISE 3

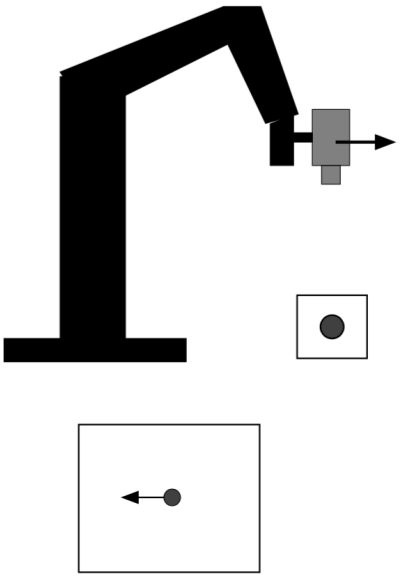
Consider the control of a manipulator with vision sensors.

1. Explain what is the "perspective projection" method and, making reference to the following picture, write the related formulas.



2. Making reference to the following picture, explain what is the interaction matrix in the context of visual control, specifying precisely:

   - the variables that are related by the interaction matrix
   - the size of the interaction matrix
   - the variables upon which the interaction matrix depends



3. Explain what is the image Jacobian and what is its relation with the interaction matrix.

4. Sketch the block diagram of an image-based look-and-move control scheme, specifying the control law in the image space in terms of the image Jacobian.