Control of Industrial Robots

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February 6, 2020

NAME:

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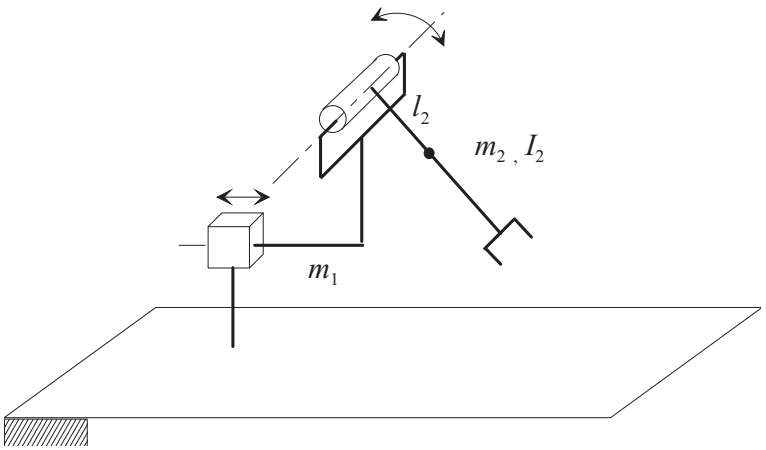
Warnings

- 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[1].

[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 matrix $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})$ of the Coriolis and centrifugal terms[2] for this manipulator.

3. Ignoring the gravitational terms, compute the dynamic model of this manipulator.

4. Write the dynamic model in a linear form with respect to a set of dynamic parameters.

[2]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. Sketch the block diagram of a position/speed control of a servomechanism, including a speed feed-forward action.

2. Consider now the speed control system. Write the expression of the loop transfer function $L_v(s)$, draw its amplitude Bode diagram and discuss how the speed controller can be tuned based on such Bode diagram.

3. Assume now the following values for the physical parameters of the servomechanism.

$$\begin{aligned} J_m &= 0.02 \ kgm^2 \\ D_m &\approx 0 \\ \rho &= 2 \end{aligned}$$

where ρ is the inertia ratio. Design a speed PI controller in such a way to obtain a crossover frequency $\omega_{cv} = 100$ rad/s.

4. Explain what is the difference between the repeatability and the accuracy of an industrial robot.

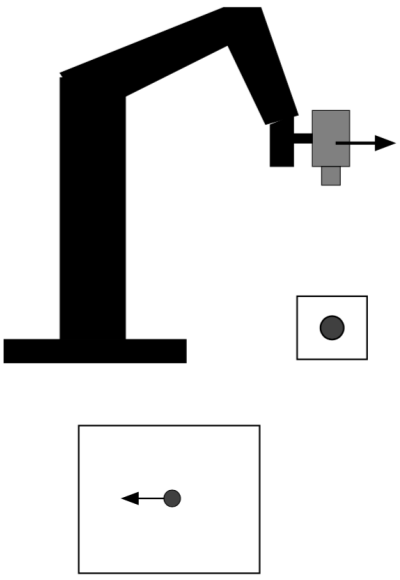
EXERCISE 3

Consider the control of a manipulator with vision sensors.

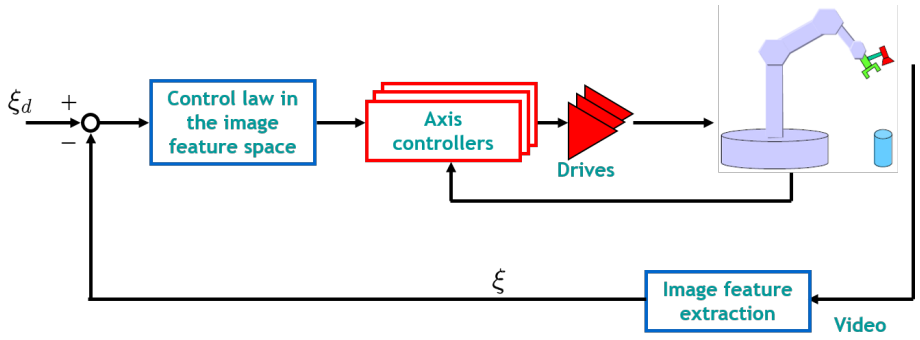
1. Discuss the *eye-to-hand* and the *eye-in-hand* configurations, explaining what these expressions refer to and listing pros and cons of the two solutions.

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. Consider the following control scheme. Explain what kind of vision control system it refers to. Write an expression for the block "Control law in the image feature space"



4. The interaction matrix has a null space. Explain what is the physical meaning of such null space, making an example of motions that fall into such null space.