Control of industrial robots

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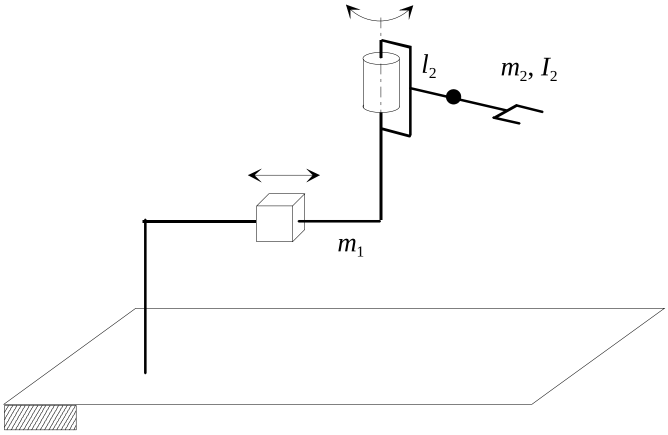
Warnings:

- This file consists of **8** pages (including cover). All the pages should be signed.
- 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.

Use this page ONLY in case of corrections or if the space reserved for some answers turned out to be insufficient

Exercise 1

Consider the manipulator sketched in the picture:



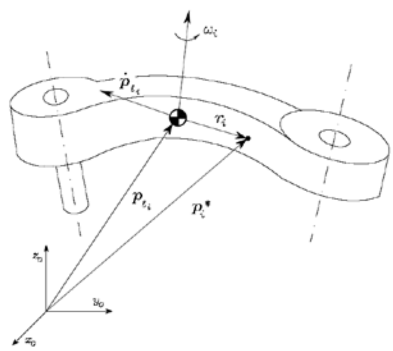
1.1 Find the expression of the inertia matrix of the manipulator[1].

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

1.2 Compute the expression of the Coriolis and centrifugal terms for this manipulator[2].

1.3 Check that matrix $\boldsymbol{N}(\boldsymbol{q},\dot{\boldsymbol{q}}) = \dot{\boldsymbol{B}}(\boldsymbol{q}) - 2\boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}})$ is skew-symmetric.

1.4 Consider a single link, as sketched in the picture. Without going through the derivation, write the expression of the kinetic energy of the link, specifying the meaning of all the symbols used.



[2] The 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

2.1 Using any motion programming language (for example COMAU PDL2) write the instruction to command a motion on a straight line towards a certain final position. Explain what options are usually available to command a motion other than along a straight line.

2.2 Write the parametric expression (in terms of a natural coordinate) of a segment in space, used for planning a linear path.

2.3 Prove that, in the general case, the absolute value of the time derivative of the natural coordinate s is the norm of the linear velocity of the end-effector.

2.4 Assume now that the length of the segment to cover is 0.5 *m* and that the maximum linear velocity of the end effector is 1.5 *m*/*s*. Compute the minimum positioning time, if a cubic dependence on time of the natural coordinate is used.

Exercise 3

Consider a kinematically redundant manipulator.

3.1 Explain what the "null-space motions" are, and write an expression for the null-space motions, explaining the meaning of each symbol used.

3.2 Consider a standard six degrees of freedom robot manipulator with rotational joints: specify a task for which this robot is redundant and the size of the null space of the Jacobian for such task.

3.3 Explain how the null-space motions can be used to satisfy secondary criteria, making at least two examples of such criteria.

3.4 Consider now a closed-loop kinematic control (i.e. an inverse kinematics scheme) for a redundant robot: sketch the block diagram of the controller.

Exercise 4

Consider the control of a manipulator with vision sensors.

4.1 Explain what we mean with “image-based” controller.

4.2 Sketch the block diagram of an image-based look-and-move controller. Briefly explain what is the advantage of using a look-and-move configuration.

4.3 Consider now a robot equipped with force sensors. For a single degree of freedom mechanism, sketch the block diagram of an implicit force controller in case of contact with a stiff environment. Briefly explain what is the advantage of using an implicit configuration.

4.4 Assuming that the dynamics of the position controller are correctly compensated, design the force controller in such a way to obtain a bandwidth of 10 rad/s.