Control of industrial robots

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Name: ....

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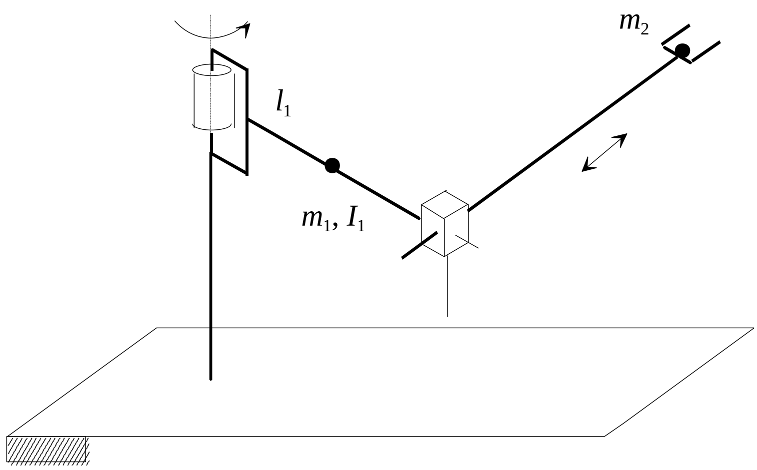
Warnings:

- 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, where the mass of the second link is assumed to be concentrated at the end-effector:



1.1 Find the expression of the inertia matrix of the manipulator.

1.2 Compute the Christoffel symbols[1] for this manipulator.

1.3 Write the dynamic model of this manipulator.

1.4 Show that this model is linear with respect to a suitable 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

2.1 Write the expression of a "PD plus gravity compensation" control law in joint space.

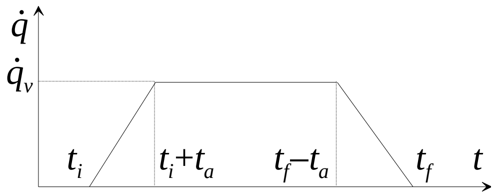
2.2 Write the expression of the Lyapunov function used to prove the stability property of such control scheme and specify what kind of stability can be guaranteed by this method.

2.3 The stability proof for this control scheme is based on a property of the dynamic model of the robot manipulator. Specify what is this property.

2.4 Write the expression of the "PD plus gravity compensation" control law in the operational space.

Exercise 3

Consider a trajectory characterized by the trapezoidal velocity profile sketched in the picture:



3.1 Set $t_i = 0$, $t_f = 4$, $\dot{q}_v = 3$, and find the acceleration time t_a in such a way that the distance covered is $h = 9$.

3.2 Assume now that the maximum allowable acceleration is the one determined at the previous step of this exercise for the initial acceleration phase. Assume however that the maximum speed be limited $\dot{q}_{\max} = 1$. Find the minimum positioning time in such situation.

3.3 Sketch a velocity profile similar to the one reported in the picture, but with jerk limitation.

3.4 Assume now that some intermediate points are given and the whole trajectory has to be covered connecting trajectories with trapezoidal velocity profile. Describe a method that can be used to avoid that motion is stopped at each intermediate point.

Exercise 4

Consider the control of a robot with visual measurements.

4.1 Explain what a perspective projection is and how it works.

4.2 Explain the difference between internal and external calibrations.

4.3 Explain the difference between the “eye-in-hand” and the “eye-to-hand” configurations and comment on advantages and disadvantages of the two strategies.

4.4 Sketch the control scheme of an “Image-based visual servoing” method. What does “image-based” means?