Control of industrial robots

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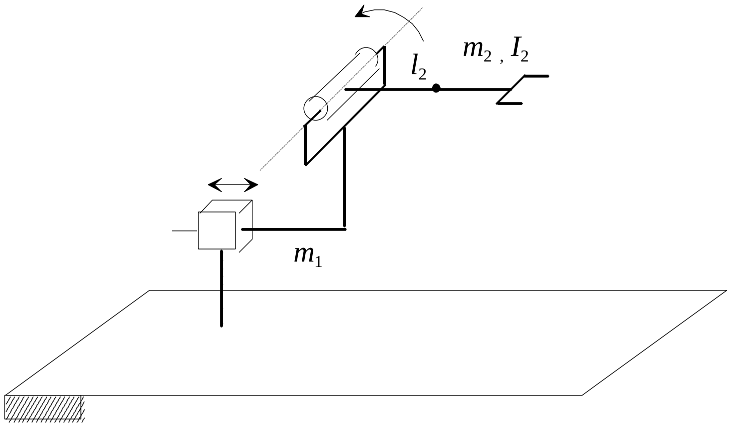
Warnings:

- 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 Write the expression of the gravitational terms for this manipulator.

1.3 Write the expression of a "PD + gravity compensation" control law in the joint space for this specific manipulator.

1.4 Writhe the expression of a "PD + gravity compensation" control law in the operational space for the generic manipulator.

Exercise 2

Consider a kinematically redundant manipulator.

2.1 Explain what the “null-space motions” are.

2.2 Write an expression for the null-space motions, explaining the meaning of each symbol used.

2.3 Consider now motion planning of the end-effector position. Select as an initial point $\boldsymbol{p}_i$ = [1, 0, 1] and as a final point $\boldsymbol{p}_f$ = [3, 2, 2]. Write the expression of a segment connecting the initial and the final points, parameterized with the natural coordinate.

2.4 Assume that the maximum linear velocity and the maximum linear acceleration of the end-effector are given by $v_{max} = 2$ m/s and $a_{max} = 3$ m/s^2, respectively. Assuming a trapezoidal velocity profile, find the minimum travelling time for the trajectory.

Exercise 3

Consider the decentralized control of a manipulator.

3.1 Explain what is meant with "independent joint control".

3.2 What is the property of industrial robots upon which such method heavily relies? Why?

3.3 Assume now that the joints are affected by flexibility: sketch the root locus of the speed control and explain what is the graphical method to tune the speed controller based on such locus.

3.4 Assume now the following values for the physical parameters of one of the joints :

J_l = 9 Kg m^2, ρ = 2, n = 30, K_{el} = 400.

Tune a PI speed controller for this servomechanism.

Exercise 4

4.1 Explain the difference between an impedance control and a force control.

4.2 Sketch the block diagram of an implicit impedance control scheme for a single d.o.f. system.

4.3 Sketch the block diagram of an implicit force control scheme for a single d.o.f. system, in contact with an environment.

4.4 Assume that the contact established with the environment is practically rigid and that the system of item 4.3 is position controlled with a PID, whose gains are K_P = 60, K_I = 10, K_D = 50. Find the expression of the force controller, tuned to achieve a bandwidth of 30 rad/s.