Control of industrial robots

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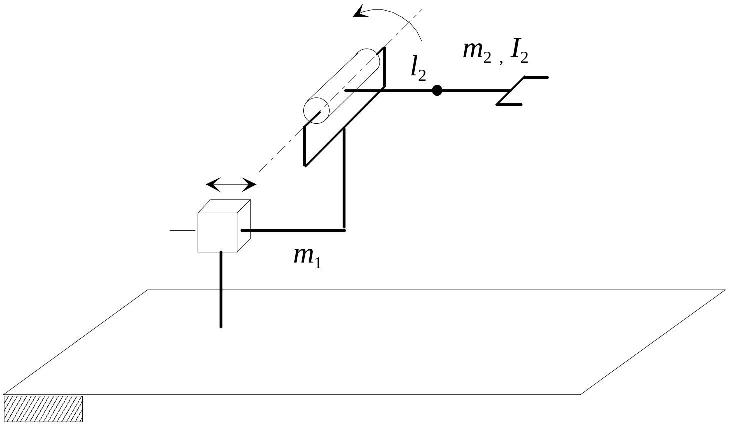
Warnings:

- 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 Neglecting the Coriolis and centrifugal terms, write the expression of an inverse dynamics control law in the joint space for this specific manipulator.

1.4 Explain why the inertia matrix of a manipulator is always a positive definite matrix.

Exercise 2

Consider a kinematically redundant manipulator.

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

2.2 Define what is a repeatable, or cyclic, method for kinematic redundancy resolution.

2.3 Write the expression of the extended Jacobian method for redundancy resolution and explain why it is repeatable.

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

If the end-effector task is expressed in terms of position only, what is the minimum number of joints for the manipulator to be redundant with respect to this task?

Exercise 3

Consider a P/PI control system for a rigid servomechanism.

Assume the following values for the physical parameters:

$J_m = 0.02\ Kg\ m^2$

$D_m \cong 0$

$J_l = 3\ Kg\ m^2$

$n = 10$

3.1 Design a speed PI controller in such a way to obtain a crossover frequency $\omega_{cv} \cong 300$ rad/s

3.2 Design a P position controller in such a way to obtain a crossover frequency $\omega_{cp} \cong 30$ rad/s.

3.3 Find the minimum value of the stiffness constant K_{el} such that the design of the controller made in 3.1 is adequate.

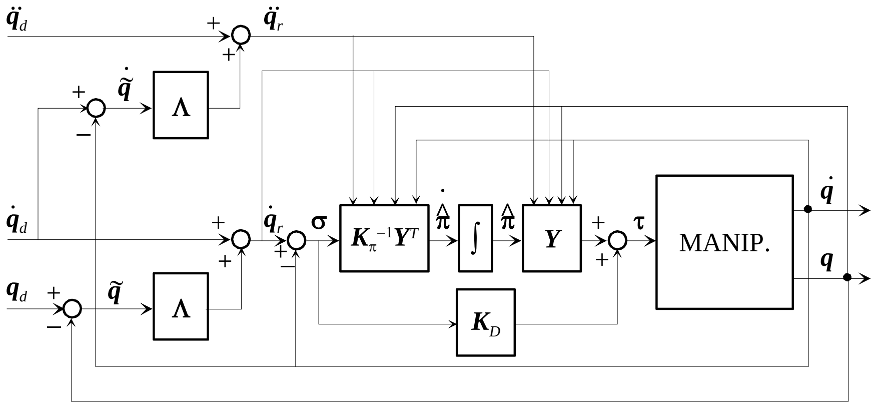
3.4 Explain what are the advantages and disadvantages of closing the position loop either on the motor coordinate or on the load coordinate.

Exercise 4

4.1 Explain what do we mean with “adaptive” control.

4.2 The adaptive controller is based on an important property of the dynamic model of the manipulator: explain what is this property and in what other problem in robotics it is used.

4.3 Consider this sketch of an adaptive controller:



Explain what is the meaning of symbol ***Y*** and what is the adaptation rule of the parameters of the model.

4.4 Suppose that the robot carries at the end effector a payload of unknown mass: explain if the adaptive controller can be an effective control solution for this case.