Control of industrial robots

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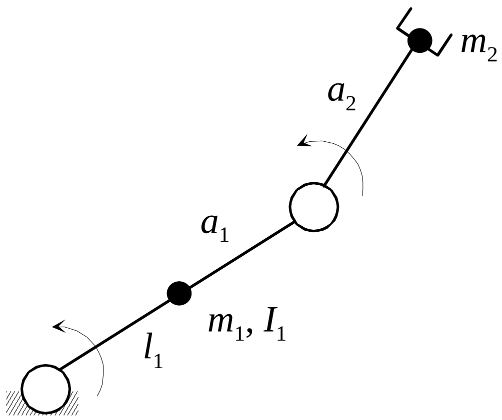
Warnings:

- 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 planar manipulator in the vertical plane 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 Find the expression of the gravitational torques for this specific manipulator

1.3 Assume now m_1 = 50 Kg, m_2 = 20 Kg, I_1 = 10 Kg m^2, $a_1 = a_2$ = 1 m, l_1 = 0.5 m.

Suppose that you want to use the expression of the inertia matrix computed in section 1.1 to tune a decentralized position/velocity controller. Find suitable values for the moments of inertia on the load side (J_{l1}, J_{l2}) for the design of the controllers for joints 1 and 2.

1.4 Assume now that the joints of the robot are affected by elasticity. Find the values of the stiffness constants K_{el1}, K_{el2}, such that, taking as values of the reduction ratios $n_1 = n_2 = 100$, the locked frequencies for both the joints are 100 rad/s.

Exercise 2

2.1 Explain what is meant with kinematic scaling of a trajectory and write the general expression of a trajectory in the form (parameterized) which is used in such scaling.

2.2 The parametric form of a cycloidal trajectory is given by:

$$\sigma(\tau) = \tau - \frac{1}{2\pi}\sin(2\pi\tau)$$

Find the expressions of the maximum velocity and maximum acceleration for such trajectory in terms of the positioning time *T* and the total displacement *h*.

2.3 Consider the design of a cycloidal trajectory from q_i = 10 to q_f = 40, with $\dot{q}_{\max} = 30$, $\ddot{q}_{\max} = 10$. Find the minimum positioning time.

2.4 Suppose now that for the same problem of the previous question, a harmonic trajectory is used. Do you expect a longer or a shorter minimum positioning time? Explain your answer.

Exercise 3

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

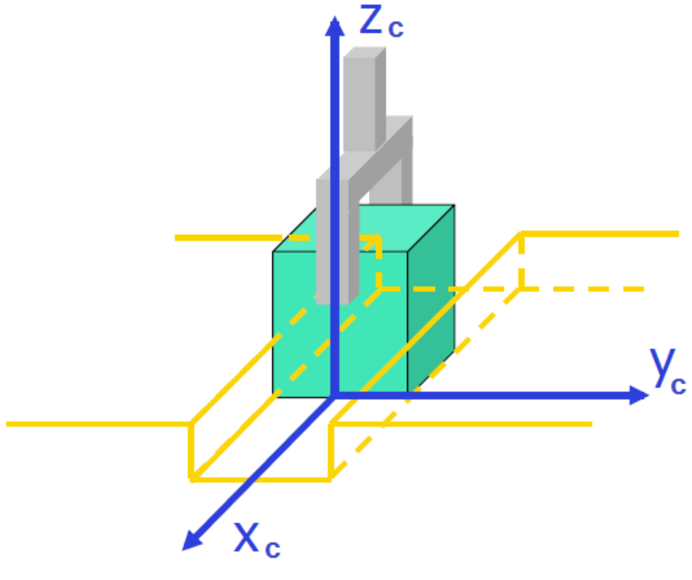
3.2 Write the expression of the "PD plus gravity compensation" control law in the operational space and sketch the related block diagram

3.3 Write the expression of the Lyapunov function used to prove the stability property of such control scheme, both for the joint space controller and for the operational space controller.

3.4 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.

Exercise 4

Consider an interaction task of a manipulator (sliding a cube along a guide), with a frictionless and rigid surface, as in this picture:



4.1 Based on the contact frame shown in the picture, express the natural and the artificial constraints for this problem.

4.2 Write the expression of the selection matrix for this problem, explaining the meaning of such matrix.

4.3 Suppose now that along the *z* direction an explicit force controller has to be designed. Find the expression of such controller, taking a bandwidth of 20 rad/s.

4.4 Sketch the block diagram of the controller of the previous question, when it is designed as an implicit force controller. What is the advantage in using an implicit controller?