Control of industrial robots

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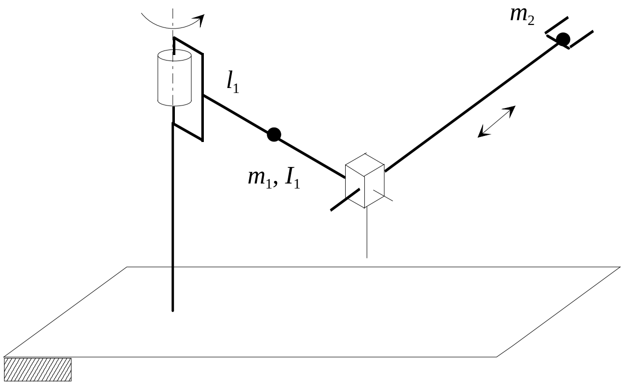
Warnings:

- 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, 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 $\boldsymbol{B}(\boldsymbol{q})$ of the manipulator.

1.2 Compute the matrix $\boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}})$ of the Coriolis and centrifugal terms [1] for this manipulator.

1.3 Show 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 Compute the expression of the derivative of the kinetic energy $\boldsymbol{T}(\boldsymbol{q},\dot{\boldsymbol{q}}) = \frac{1}{2}\dot{\boldsymbol{q}}^T \boldsymbol{B}(\boldsymbol{q})\dot{\boldsymbol{q}}$ (notice that no gravitational load acts on the manipulator).

[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 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 of a segment in space, used for planning a linear path.

2.3 Suppose that you want to use a cubic dependence on time of the natural coordinate $s(t)$. Write a parametric expression for such cubic dependence (the one used in kinematic scaling of trajectories).

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 2 m/s. Compute the minimum positioning time, if a cubic dependence on time of the natural coordinate is used.

Exercise 3

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

Assume the following values for the physical parameters:

$J_m = 0.02\ Kg\ m^2$

$D_m \cong 0$

$J_l = 3\ Kg\ m^2$

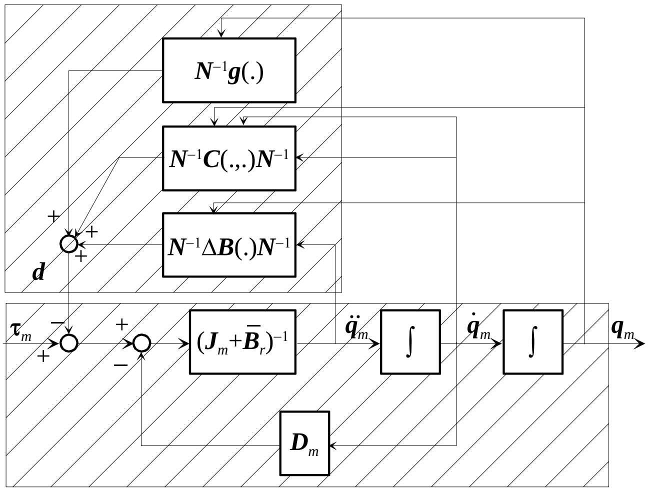
$n = 10$

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 Suppose now that the servomechanism is actually one of the joints of a robot manipulator. Explain how to assign a value to the parameter J_l (moment of inertia at the load side) .

3.4 Consider now the block diagram sketched in the picture: explain what it represents, what are the two areas in the dashed boxes, and what is the relation of such block diagram with the independent joint control of robot manipulators.



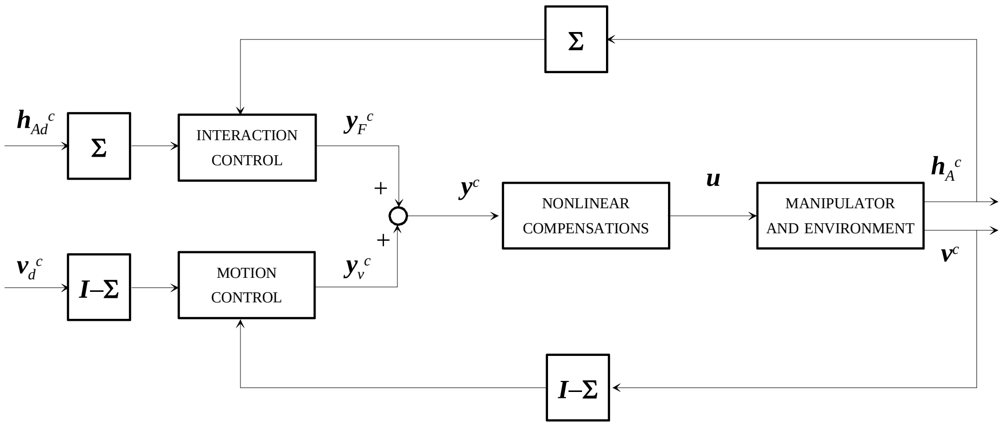
Exercise 4

Consider an interaction task of a manipulator, with a frictionless and rigid surface, as in this picture:

4.1 Assume a point contact and draw a contact frame directly on the picture. Based on this frame and neglecting angular velocities and moments, 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 Consider the block diagram shown in the picture. Explain what control scheme is represented in the block diagram and what happens if there is some friction at the contact.



4.4 Suppose now that along the force controlled direction an explicit force controller has to be designed. Determine the expression of such controller, taking a bandwidth of 30 rad/s.