Control of industrial robots

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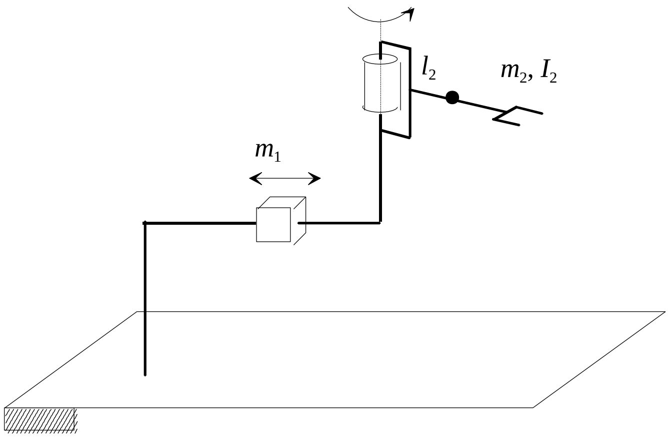
Warnings:

- 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].

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[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 Compute the expression of the Coriolis and centrifugal terms for this manipulator[2].

1.3 Check 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 Explain what is the property on matrix ***N*** which is always satisfied, regardless the way matrix ***C*** is built.

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[2] The 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 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 = 60, with $\dot{q}_{\max} = 50$, $\ddot{q}_{\max} = 25$. Find the minimum positioning time.

2.4 What kind of parameterization is used in the dynamic scaling of the trajectories for a robot manipulator?

Exercise 3

Consider the design of the position/speed control for a servomechanism affected by elasticity. The following physical parameters are known:

$J_m = 0.3 \times 10^{-3}$ $Kg\ m^2$ [moment of inertia of the motor]

$n = 100$ [transmission ratio]

3.1 Making an experiment where the motor is mechanically locked and the load is perturbed, a lightly damped oscillation of the load is obtained, with period $T_1 = 0.0419$ s. Making instead an experiment where the motor-transmission-load is free to vibrate, a lightly damped oscillation of the load is obtained, with period $T_2 = 0.0209$ s.

Based on these data, estimate the values of the moment of inertia J_l of the load and of the stiffness constant K_{el} of the transmission.

3.2 Find the values of the proportional gain K_{pv} and of the integral time T_{iv} of the speed controller in such a way to approximately maximize the damping of the closed loop poles.

3.3 Write the expression of the loop transfer function of the position control in case the load position is fed back.

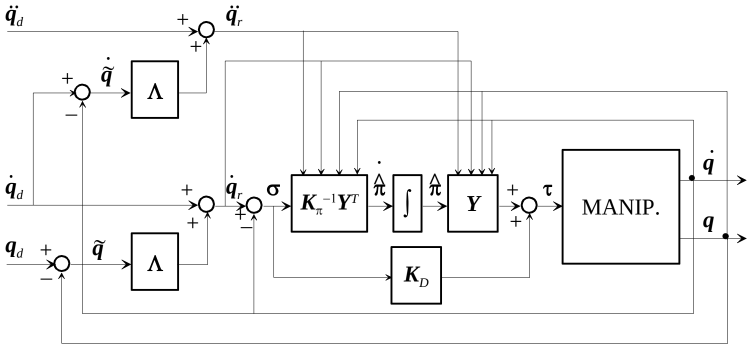
3.4 Explain what is the main difference of the control configuration where load position is fed back and the one where motor position is fed back. Which one is most common in industrial robotics and which one in machine tools?

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:



Comment the main parts of such controller and in particular explain what is the adaptation rule of the estimates of the parameters.

4.4 Explain when it is appropriate to use a robust controller and when it is appropriate to use an adaptive controller.