Control of Industrial Robots

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NAME:	
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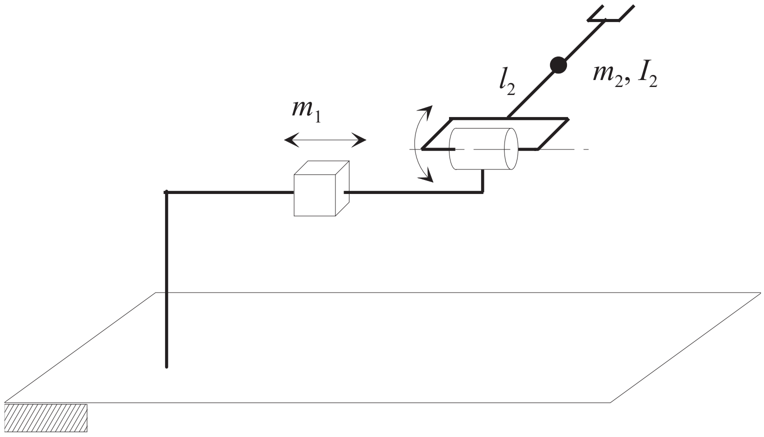
Warnings

- This file consists of **8** pages (including cover).
- 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.

EXERCISE 1

1. Consider the manipulator sketched in the picture:



Find the expression of the inertia matrix $\mathbf{B}(\mathbf{q})$ of the manipulator.

2. Write the complete dynamic model for this manipulator.

3. Consider the adoption of an inverse dynamics controller for this manipulator. Write the expressions of the two control variables.

4. Assume that the inverse dynamics controller assigns the same dynamics in closed loop to both joints of the manipulator. Compute the gains of the controller in such a way that both eigenvalues are equal to -10.

EXERCISE 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. The parametric form of a harmonic trajectory for kinematic scaling is given by:

$$\sigma(\tau) = \frac{1}{2}\left(1 - \cos(\pi\tau)\right)$$

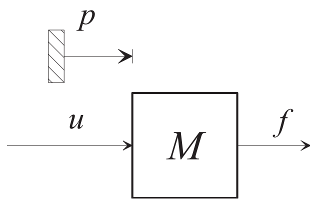
   Find the expressions of the maximum velocity and maximum acceleration for such trajectory in terms of the positioning time T and the total displacement h.

3. Consider the design of a harmonic trajectory from $q_i = 10$ to $q_f = 30$, with $\dot{q}_{\max} = 10$ and $\ddot{q}_{\max} = 20$. Find the minimum positioning time.

4. For the harmonic trajectory computed in this exercise, sketch the plot of the speed $\dot{q}(t)$, assuming that the trajectory starts at time $t_i = 0$.

EXERCISE 3

1. Consider a single mass affected by an external force f and a control force u:



Write the expression of an impedance control law that makes the system react to the external force f like a mass-spring-damper system, with all parameters assignable.

2. Assume now that the mass is position controlled. Sketch the block diagram of an admittance controller that allows to obtain the same result as the impedance control law designed before.

3. Consider a manipulator where a system of forces is applied at the end-effector. Discuss the statics of the manipulator, i.e. find analytically the relation between this system of force and the joint torques at the equilibrium.

4. Write the expressions of a translational impedance and the expression of a rotational impedance.