Control of Industrial Robots

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UNIVERSITY ID NUMBER:

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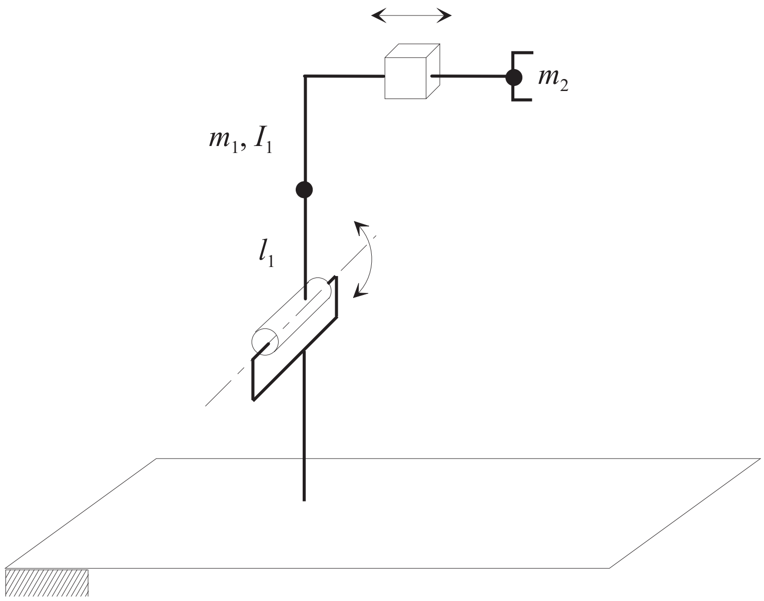
Warnings

- 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, where the mass of the second link is assumed to be concentrated at the end-effector:



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

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

3. Ignoring the gravitational terms, write the complete dynamic model for this manipulator.

[1] The general expression of the Christoffel symbols is $c_{ijk} = \frac{1}{2}\left(\frac{\partial b_{ij}}{\partial q_k} + \frac{\partial b_{ik}}{\partial q_j} - \frac{\partial b_{jk}}{\partial q_i}\right)$

4. For this specific manipulator, wtite the expression of the kinetic energy. Is it possible that this kinetic energy is zero for joint velocities different from zero?

EXERCISE 2

1. Explain why for the kinematic scaling of trajectories it is possible to consider each joint separately, while for the dynamic scaling this is not possible.

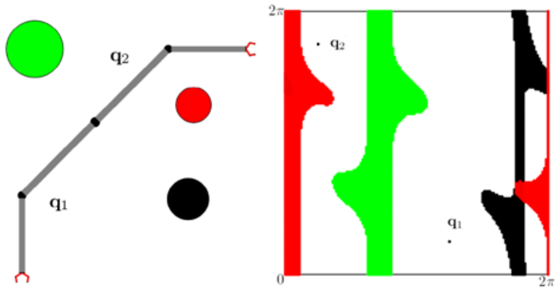
2. Consider the following equation:

$$\tau_i(t) = \alpha_i\left(r(t)\right)\ddot{r}(t) + \beta_i\left(r(t)\right)\dot{r}^2(t) + \gamma_i\left(r(t)\right)$$

   Explain whether such equation is used in the kinematic scaling or in the dynamic scaling and define all symbols used in the equation.

3. Assume now that, in a robot that is not affected by gravity, trajectories have been planned such that the torque of one joint exceeds its limit by 44% (the torques of the other joints are within their limits). Explain how the trajectory can be scaled and what should be the scaling factor. What is meant with “variable scaling” in this context?

4. With specific reference to the following picture, define the concept of “configuration space” in the path planning with obstacle avoidance problem. What do the irregular shapes in the right hand side picture represent?

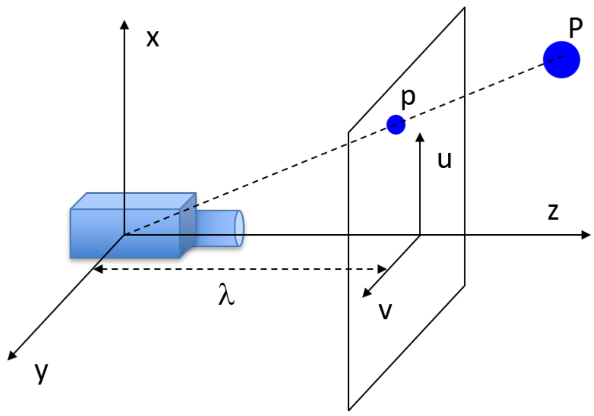


EXERCISE 3

Consider a robot that uses a camera.

1. Explain what are the extrinsic and the intrinsic calibrations, making in particular reference to the notion of camera intrinsic matrix.

2. With reference to the following sketch, define what an image feature is and write the equations of the perspective projection method.



3. Define the interaction matrix and the image Jacobian for a vision-based robotic system, in terms of the quantities that each of the two matrices relate. Then write the relation between the two matrices.

4. What is the size of an interaction matrix when the image features are the coordinates of a single point? Explain the meaning of the null-space of such matrix, providing also physical interpretation,