Control of Industrial and Mobile Robots

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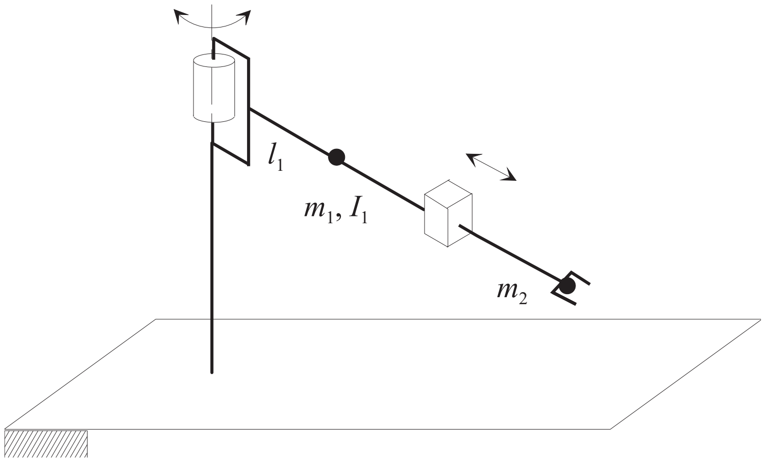
Warnings

- This file consists of **10** 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. Write the complete dynamic model for this manipulator.

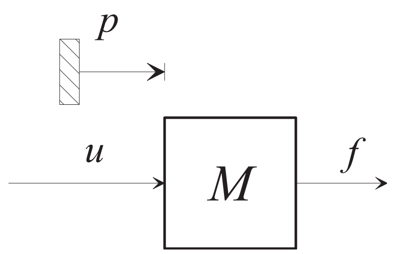
4. Show that the model obtained in the previous step is linear with respect to a set of dynamic parameters.

[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

1. Explain what is the difference between passive and active control of the interaction of a manipulator with the environment. What are the main devices used for passive control and for active control, respectively?

2. Consider now a simple mass as in this picture:



Write the expression of an (explicit) impedance controller that can assign a prescribed impedance relation.

3. Still making reference to a single degree of freedom mechanism, sketch the block diagram of an admittance controller. What is the assumption that must be enforced on the motion control system in order to claim that the prescribed impedance is actually achieved?

4. Write the general expression of a rotational impedance.

EXERCISE 3

1. Consider a unicycle robot carrying a box full of sand, centred with respect to the robot center of gravity. The robot mass and yaw moment of inertia are equal to 30 Kg and 0.8 Kgm^2, when the box is empty, and 60 Kg and 1.6 Kgm^2, when the box is full. During the motion the box is leaking sand, and the mass and yaw moment of inertia change with time according to the following relations

$$M(t) = 60 - 0.5t \qquad I(t) = \frac{8}{5} - \frac{t}{75}$$

   Write the dynamic model of the robot, assuming that there is no relative motion between the sand and the box and that the change of mass is slow compared to the motion of the robot.

2. Write the kinematic model of the robot, and the kinematic constraint one can use to derive it.

3. The robot tire lateral force-slip relations are modelled using a piecewise constant model

$$F_y = \begin{cases} C_\alpha \alpha & \alpha \leq \alpha_{lin} \\ F_{y_{max}} & \alpha > \alpha_{lin} \end{cases}$$

where C_α is the cornering stiffness, α the slip angle, and $\alpha_{lin} = 0.1$ rad. The friction coefficient is $\mu = 0.5$.
Write the lateral force-slip relation at $t_1 = 0$ and $t_2 = 30$.

4. Consider that the robot is equipped with wheel velocity controllers tuned for the case of empty box. For the design of a model-based trajectory tracking controller, assuming either the linear and angular velocity or the wheel torque are available to the controller, is it better to consider the kinematic or dynamic model of the robot? Clearly motivate the answer.

ESERCIZIO 4

1. Consider the kinematic model of a unicycle robot, and a point P at a distance p from the wheel contact point along the direction of the velocity vector. Write the expression of the feedback linearizing controller and draw the block diagram of the system composed by the robot model and the controller.

2. Show that, applying the feedback linearizing controller the kinematic model of the unicycle is reduced to two independent integrators, i.e.,

$$\dot{x}_P = v_{x_P} \qquad \dot{y}_P = v_{y_P}$$

3. According to the previous question, after the feedback linearizing controller is introduced, the heading of the robot is no more a state of the system. Clearly explain, from a system theory point of way, what happens to the heading, and how this situation affects the development of a trajectory tracking controller.

4. An experiment is executed on the real robot, performing a step response first on v_{xP} (with $v_{yP} = 0$), and then on v_{yP} (with $v_{xP} = 0$). Due to unmodelled dynamics, the two step responses appears as the response of a first order system (instead of an integrator), with unitary gain and a settling time of 0.05 seconds.
Design and tune a trajectory tracking controller. Motivate how you select the crossover frequency.