Industrial Automation and Robotics

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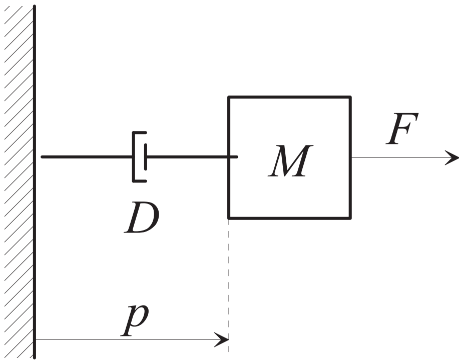
Warnings

- 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

Consider the mechanical system depicted in the picture:



The system is composed by a body of mass M subjected to a viscous friction force, proportional to the speed through the coefficient D.

1. Find the transfer function from the force F to the speed v.

We can define as state variables $x_1 =$ position, $x_2 =$ speed.

$$\begin{cases} F = M\dot{v} + Dv \\ \dot{p} = v \end{cases}$$

The input $u = F$, the output $y = v$

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -\frac{D}{M}x_2 + \frac{1}{M}u \end{cases}$$

$$y = x_2$$

In the s domain:

$$\begin{cases} sX_1 = X_2 \\ sX_2 = -\frac{D}{M}X_2 + \frac{1}{M}U \end{cases}$$

$$Y = X_2$$

$$X_2 = \frac{1}{Ms+D}U \Rightarrow G(s) = \frac{Y}{U} = \frac{X_2}{U} = \frac{1}{Ms+D}$$

2. Setting $M = 1$, $D = 2$, find the dc gain of the transfer function

$$G(s) = \frac{1}{s+2}$$

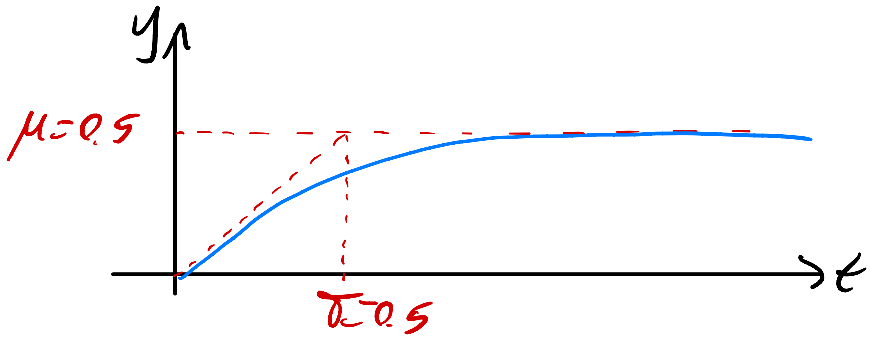
The dc gain is $\mu = G(0) = \frac{1}{2} = 0.5$

3. Sketch the plot of the step response of the above system.

The transfer function can be written as:

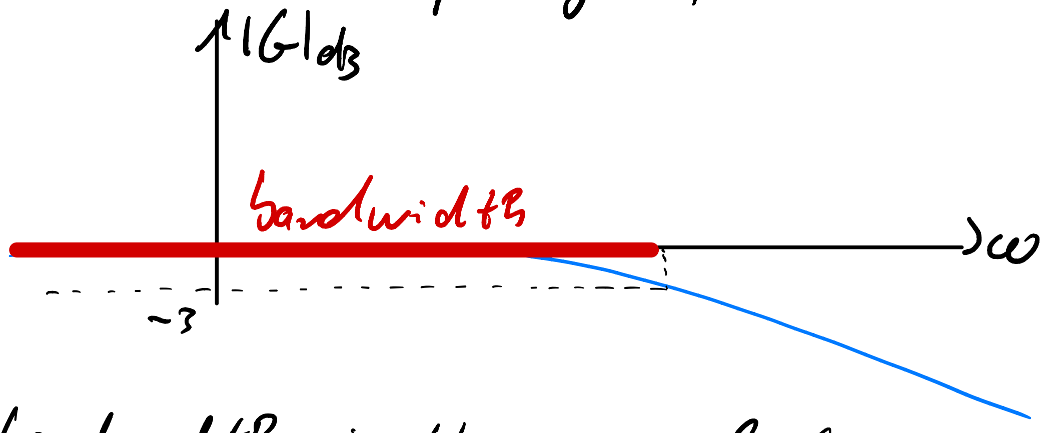
$$G(s) = \frac{1}{s+2} = \frac{0.5}{1+0.5s} = \frac{\mu}{1+s\tau} \qquad \mu = 0.5 \quad \tau = 0.5$$

The step response takes this form:



4. Define what a low-pass filter is and give the precise definition of its bandwidth.

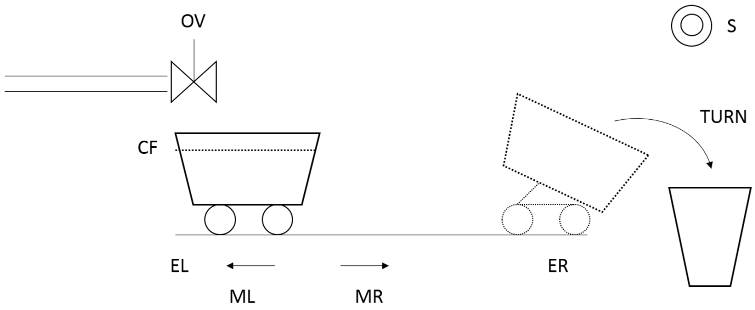
A low pass filter is a dynamic system whose amplitude of the frequency response takes this shape:



The bandwidth is the range of frequency in which such amplitude is greater than -3dB

EXERCISE 2

Consider the automatic cart depicted in the picture:



In the initial state, the cart is to the left of the rail and the valve is closed. When the operator presses a button, the valve is open until the cart is full, then the cart has to move to the right until it reaches the end of the rail. At this point the cart is rotated for 10 seconds to unload it, after which it returns to the left of the rail. Two end of rail signals (`ER` and `EL`), one signal that informs that the cart is full `CF`, and one signal corresponding to the button pressed (`S`) are available. Two commands for moving the cart to the right (`MR`) and to the left (`ML`), one for turning the cart (`TURN`) and one for opening the valve (`OV`) are available.

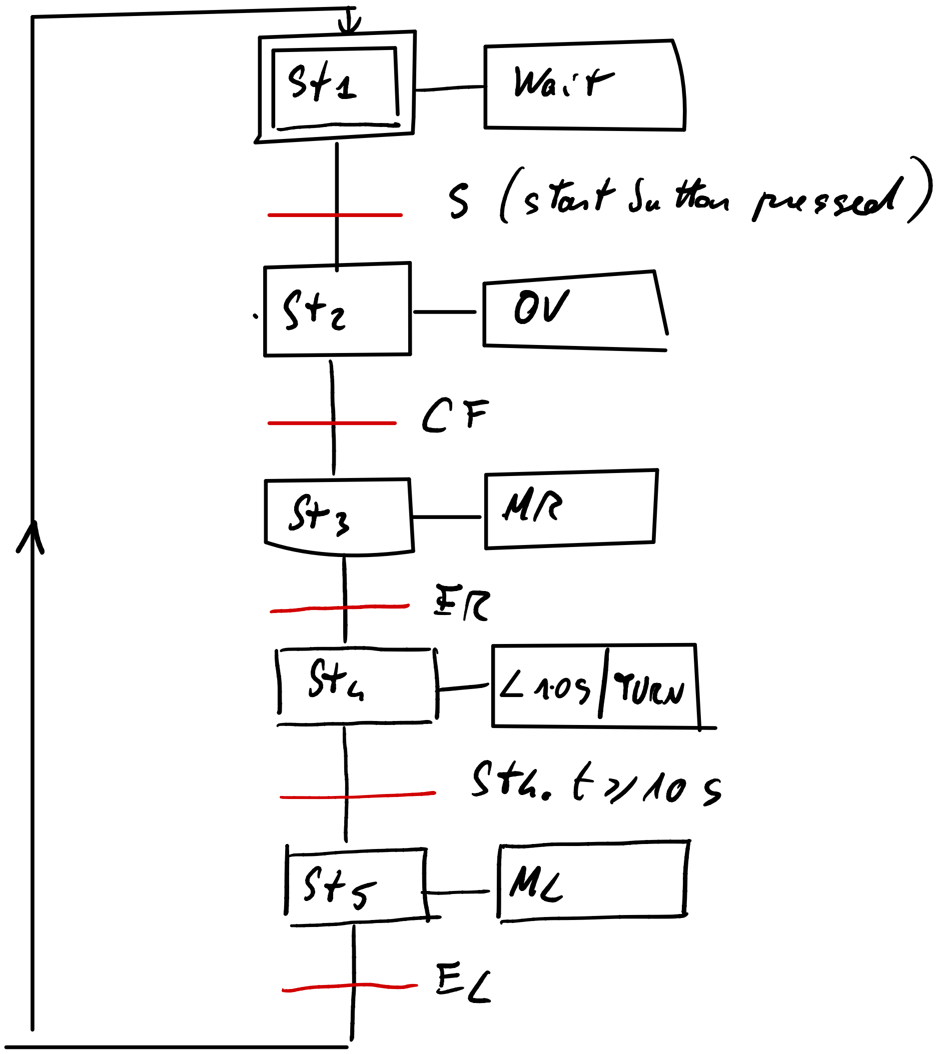
1. Explain what is a Sequential Function Chart and what are its main elements

Sequential Function Charts are a graphical programming language for PLCs.
They are made by
- steps with or w/o actions
- Transitions with logical cond.
- Oriented arcs.

2. What does it mean that a transition in a SFC is superable?

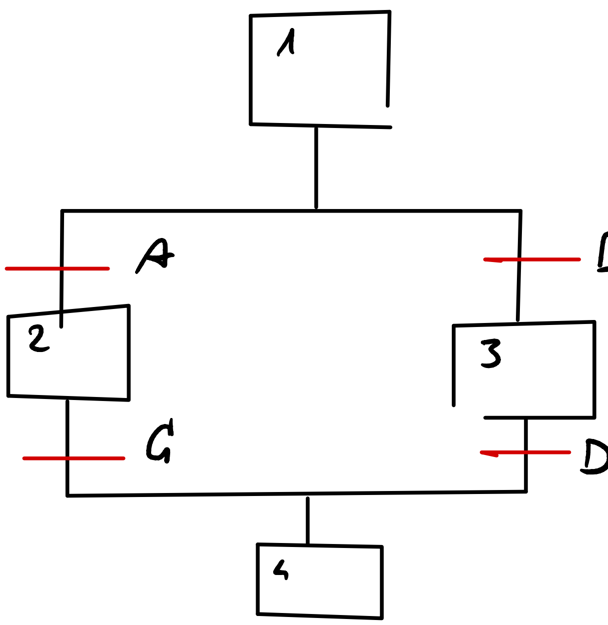
A transition is superable if all the upstream steps are active and the conditions associated with the transition are true.

3. Sketch a Sequential Functional Chart (SFC) that might be used to program a PLC in charge of the logic control of the automatic cart previously described.



4. Explain how in a SFC a IF-THEN-ELSE programming structure can be implemented.

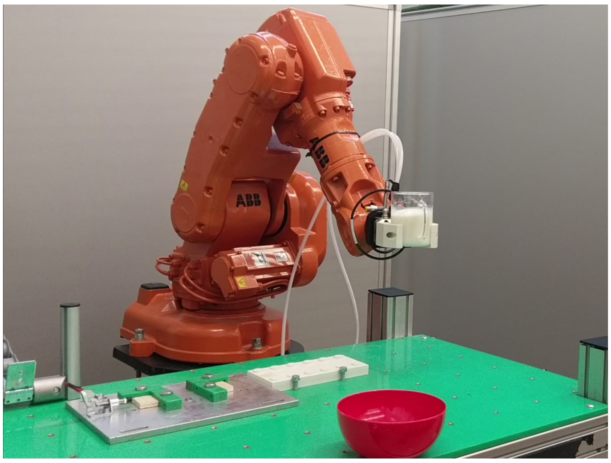
A possible scheme is



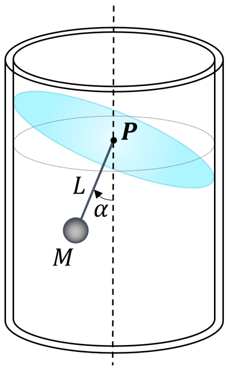
A and B must be mutually exclusive conditions.

EXERCISE 3

Consider the robot carrying a glass with liquid sketched in the picture:



The robot should be moved in such a way to avoid spilling of the liquid from the container. In a first approximation, the sloshing dynamics of the liquid can be modelled with a pendulum, see the following picture:



For simplicity, assume that the pendulum moves on a vertical plane.

1. Explain what are the direct and the inverse kinematics problems for a robotic manipulator.

Direct Kinematics: find end effector position and orientation given joint variables.

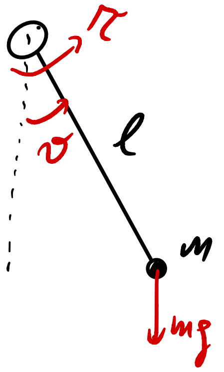
Inverse Kinematics: find joint variables given position and orientation of the end-effector.

2. How many solutions does the inverse kinematics for an anthropomorphic manipulator have? Characterize such solutions.

There are 8 solutions to the inverse kinematics problem. They are classified according to three criteria:

- elbow up or down
- shoulder right or left
- wrist up or down

3. Write the equations of a dynamic system that describes the motion of the pendulum (when the robot is still).



The motion of the pendulum is described by the equation:

$$\tau(t) = ml^2\ddot{\vartheta}(t) + mgl\sin(\vartheta(t))$$

Taking as state variables: $x_1 = \vartheta$ $x_2 = \dot{\vartheta}$ and as input $u = \vartheta$, we obtain:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -g/l \sin(x_1) + \frac{1}{ml^2} u \end{cases}$$

4. Write the general equation that allows to find the equilibrium states in a dynamic system. Apply such formula to find the equilibrium states for the pendulum at hand.

For a generic system $\dot{x} = f(x,u)$, when $u = \bar{u}$, the equilibria $\bar{x}$ are given by $f(\bar{x}, \bar{u}) = 0$.

In this case:

$$\begin{cases} \bar{x}_2 = 0 \\ -g/l \sin(\bar{x}_1) + \frac{1}{ml^2}\bar{u} = 0 \end{cases}$$