

Industrial Automation and Robotics

PROF. ROCCO

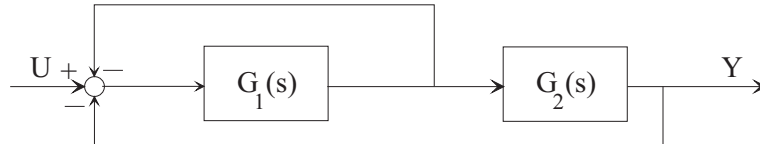
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SOLUTION

INDUSTRIAL AUTOMATION AND ROBOTICS
PROF. PAOLO ROCCO

EXERCISE 1

1. Consider the dynamical system described by the following block diagram:



Solve the block diagram by determining the transfer function from u to y .

The block diagram includes an inner feedback loop with forward transfer function G_1 and unitary negative feedback, whose closed-loop transfer function is $\frac{G_1}{1+G_1}$. In turn, this system, in series with G_2 , is closed in another unitary negative feedback. The resulting transfer function is:

$$\frac{Y}{U} = \frac{\frac{G_1 G_2}{1+G_1}}{1 + \frac{G_1 G_2}{1+G_1}} = \frac{G_1 G_2}{1 + G_1 + G_1 G_2}$$

2. Discuss whether it is necessary and/or sufficient that one or more of the transfer functions be asymptotically stable in order for the overall system to be asymptotically stable

Since both G_1 and G_2 are closed in feedback loops, it is neither necessary nor sufficient that any of them be asymptotically stable for the overall system to be asymptotically stable.

3. Setting $G_1(s) = \frac{1}{s}$, $G_2(s) = k$, assign the parameter k such that the overall system has a pole in the point -10 of the complex plane.

Substituting the expressions of G_1 and G_2 we obtain:

$$\frac{Y}{U} = \frac{\frac{1}{s} k}{1 + \frac{1}{s} + \frac{1}{s} k} = \frac{k}{s + 1 + k}$$

The single pole of this transfer function is the root of the denominator:

$$s = -1 - k$$

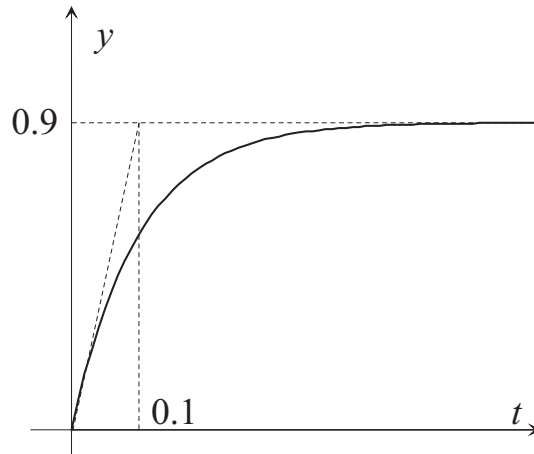
In order for this pole to be in the point -10 , k has to be equal to 9.

4. Using the value of k found at the previous step, sketch the step response from input u to output y . What is the approximate duration of the transient?

The resulting transfer function is:

$$\frac{Y}{U} = \frac{9}{s + 10} = \frac{0.9}{1 + 0.1s} = \frac{\mu}{1 + Ts}$$

with $\mu = 0.9$ and $T = 0.1$. The step response of such transfer function is known and is sketched here:



The approximate duration of the transient is 5 times the time constant T , i.e. 0.5 s.

EXERCISE 2

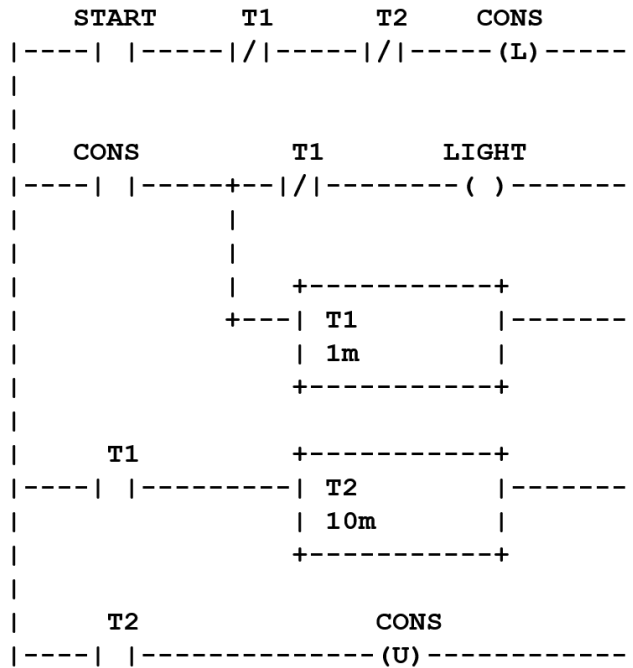
1. Consider the Ladder Diagram programming language for PLCs. List the types of timers that can be included in a Ladder Diagram, briefly explaining how they work.

Two types of timers can be used:

- The **normal** timer: it counts the time as long as there is electrical continuity at its left. After the duration indicated in the symbol of the timer has elapsed, the associated variable is set to 1. This variable is reset to 0 whenever there is no electrical continuity at the left of the timer, in which case the count of time restarts from zero.
- The **latch** timer: it counts the time as long as there is electrical continuity at its left. After the duration indicated in the symbol of the timer has elapsed, the associated variable is set to 1. This variable is reset to 0 with an appropriate reset coil. If there is no electrical continuity at the left of the timer, the count of time is suspended.

2. Consider now the following process: pressing a button **START** a light turns on for one minute. After such time interval, the light turns off and for 10 minutes pressing the button **START** cannot turn on the light. Program the system with a Ladder Diagram code.

Apart from the input **START** and an output **LIGHT**, we can use two timers with associated variables **T1** and **T2** and an internal variable **CONS**. A possible Ladder diagram is reported hereafter:



3. Explain the difference between a soft real time system and a hard real time system, citing one example for both.

Soft real-time: systems that still function even if deadlines are sometimes not met (failure to meet response time constraints leads only to a decrease of performance). For example the update of graphs in man machine interface.

Hard real-time: systems where a failure to meet response time constraints leads to a catastrophic system failure. For example safety critical real time control systems.

4. Consider now the Ethernet protocol for the digital communication on a bus: briefly describe how the access to the bus among the various agents is handled.

Ethernet adopts Carrier Sense Multiple Access with Collision Detection (CSMA/CD): if the medium is idle any node can start a transmission at any time. The transmitter monitors for collisions during transmission and, if a collision is detected, the frame is transmitted again. This protocol is not suitable for real-time applications as no bound on the transmission delay exists.

EXERCISE 3

Consider the planning of a trajectory $q(t)$ with initial and final times $t_i = 0$, $t_f = 2$, initial and final values of the position $q_i = 0$, $q_f = 20$, initial and final values of the speed $\dot{q}_i = 0$, $\dot{q}_f = 0$.

- Using a cubic polynomial for the position, find the expressions of the position, the speed, and the acceleration, compatible with the data of the problem.

The cubic polynomial for the position can be written as:

$$q(t) = a_0 + a_1t + a_2t^2 + a_3t^3$$

with boundary conditions $q(0) = 0$, $q(2) = 20$.

The second order polynomial for the speed can be written as:

$$\dot{q}(t) = a_1 + 2a_2t + 3a_3t^2$$

with boundary conditions $\dot{q}(0) = 0$, $\dot{q}(2) = 0$.

The boundary conditions at time $t = 0$ yield $a_0 = a_1 = 0$, the boundary conditions at time $t = 2$ yield the system:

$$\begin{aligned} 4a_2 + 8a_3 &= 20 \\ 4a_2 + 12a_3 &= 0 \end{aligned}$$

whose solution is $a_2 = 15$ and $a_3 = -5$. Polynomials for position, speed and acceleration can then be written as:

$$\begin{aligned} q(t) &= 15t^2 - 5t^3 \\ \dot{q}(t) &= 30t - 15t^2 \\ \ddot{q}(t) &= 30 - 30t \end{aligned}$$

- Find the maximum values of the speed \dot{q}_{\max} and of the acceleration \ddot{q}_{\max} .

The maximum value of the speed is attained in the middle point of the trajectory, the maximum value of the acceleration at the initial point:

$$\begin{aligned} \dot{q}_{\max} &= \dot{q}(1) = 15 \\ \ddot{q}_{\max} &= \ddot{q}(0) = 30 \end{aligned}$$

- Consider now a trapezoidal velocity profile. Using as cruise speed the value \dot{q}_{\max} found at the previous step, compute the acceleration time and the value of the initial acceleration for a trapezoidal velocity profile that brings q from q_i to q_f in the same time (t_f) as for the cubic profile. (*Hint*: the total displacement is the integral of the trapezoidal of the speed).

Integrating the trapezoidal of the speed we have:

$$h = 2\frac{1}{2}\dot{q}_{\max}T_a + \dot{q}_{\max}(t_f - 2T_a) = \dot{q}_{\max}(t_f - T_a)$$

The acceleration time is then obtained as:

$$T_a = t_f - \frac{h}{\dot{q}_{\max}} = 2 - \frac{20}{15} = \frac{2}{3} = 0.666$$

The initial acceleration is therefore:

$$\ddot{q}_a = \frac{\dot{q}_{\max}}{T_a} = 22.5$$

- Using the COMAU PDL2 programming language, write a motion command that makes the robot end effector move along a straight line until a position `pos`, with a linear speed of $0.8m/s$.

```
MOVE LINEAR TO pos WITH $LIN_SPD=0.8
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