Course of "Automatic Control Systems"
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Introduction – part 2

Prof. Francesco Montefusco

Department of Economics, Law, Cybersecurity, and Sports Sciences

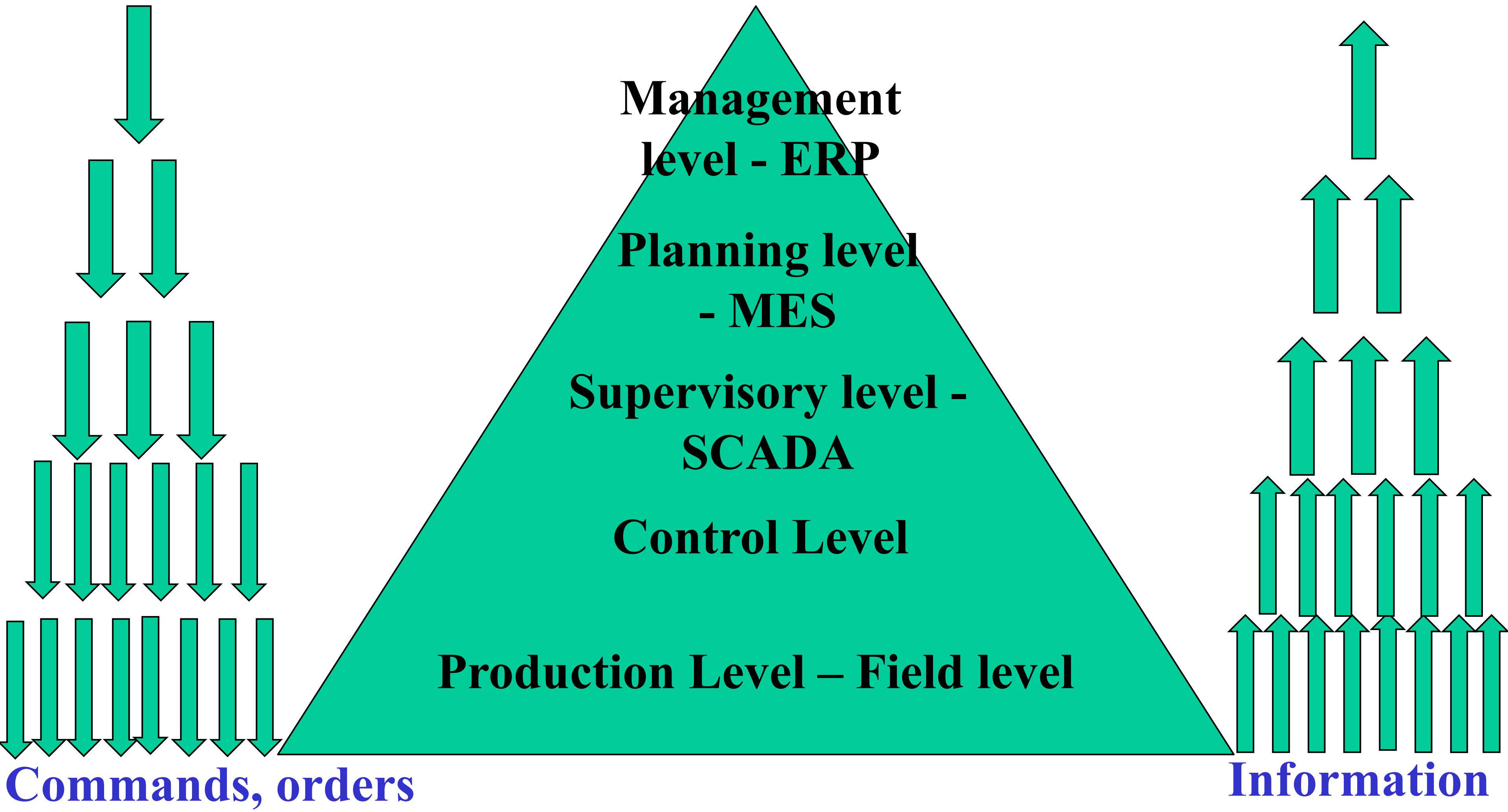
Università degli studi di Napoli Parthenope

francesco.montefusco@uniparthenope.it

Team code: **tz3jpwb**

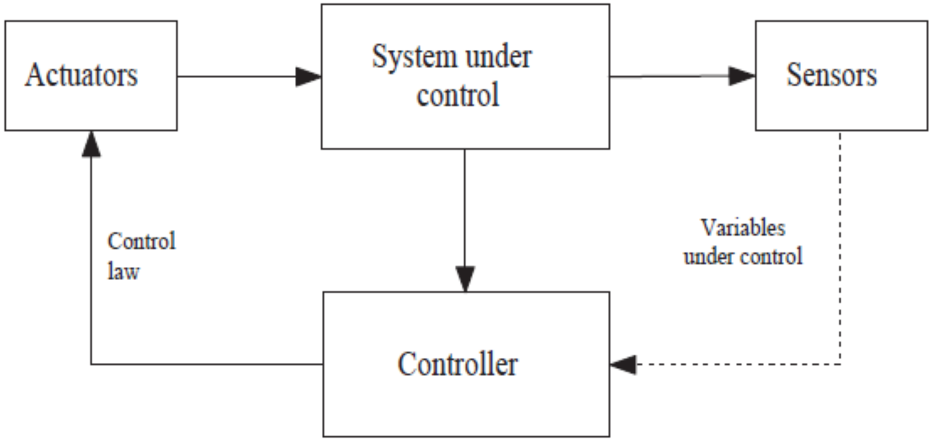
Computer Integrated Manufacturing (CIM) approach

The Automation Pyramid is a hierarchical model of industrial automation systems…



(Local) control system at field level: components

An active control system (manual or automatic) can be logically divided in three parts:



Sensors:

whose aim is to measure the quantities of interest (related to the variables under control) in order to evaluate the behavior of the system under analysis

Controller:

whose aim is to impose the desired behavior to the system under control, making use of the values of the sensed variables (if available).

Actuators:

whose aim is to implement the computed control actions on a set of ***control variables*** (related but usually not coincident to the variables under control)

Control problem

- In a control problem we need to design a controller that imposes the ***desired behavior*** to the assigned process, or ***system under control***.

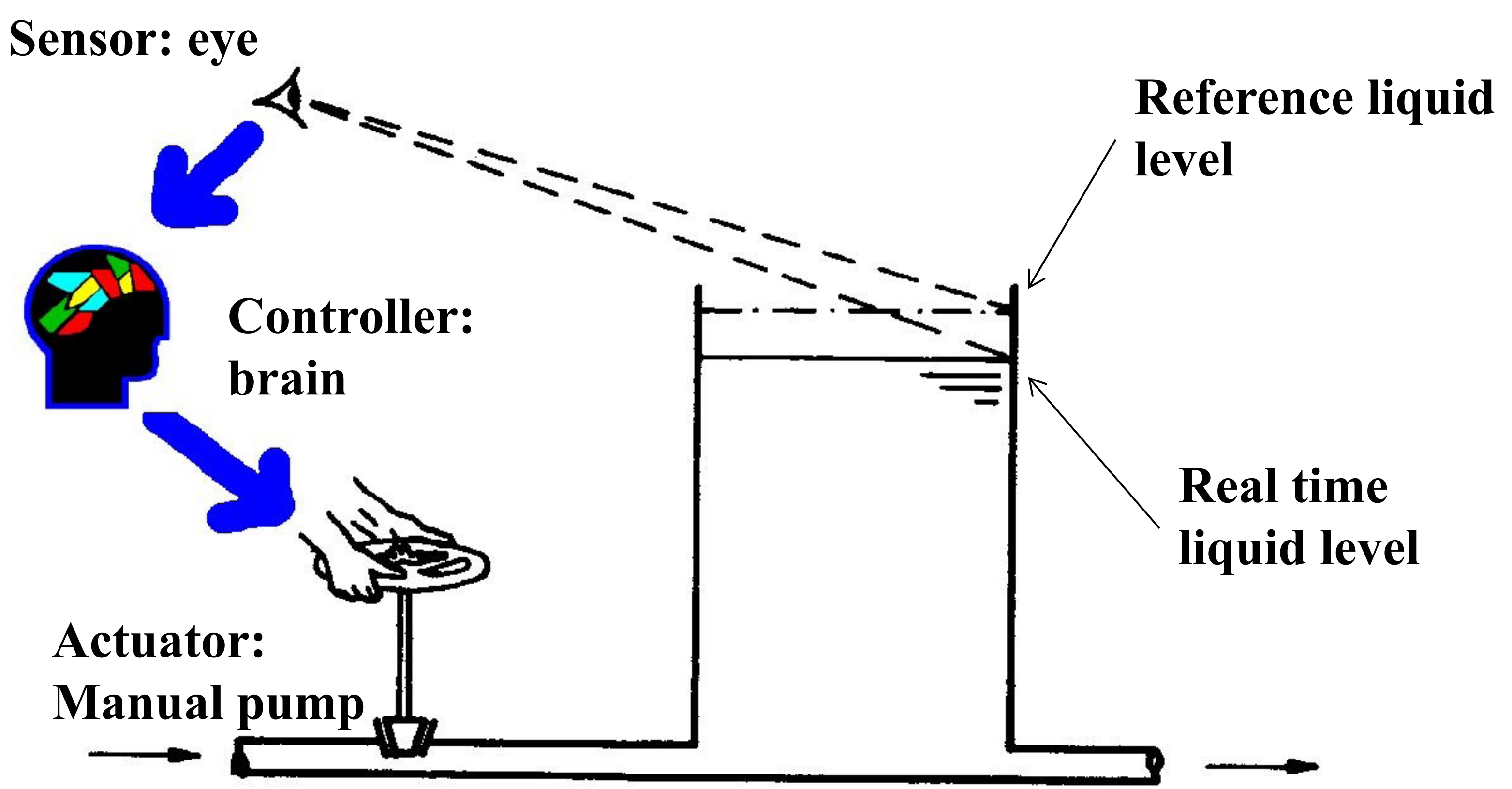
- The desired behavior consists of imposing a specified time behavior of some variables associated with the process. These variables are usually called ***variables under control*** and the desired behavior is called ***reference signal*** or ***set-point***.

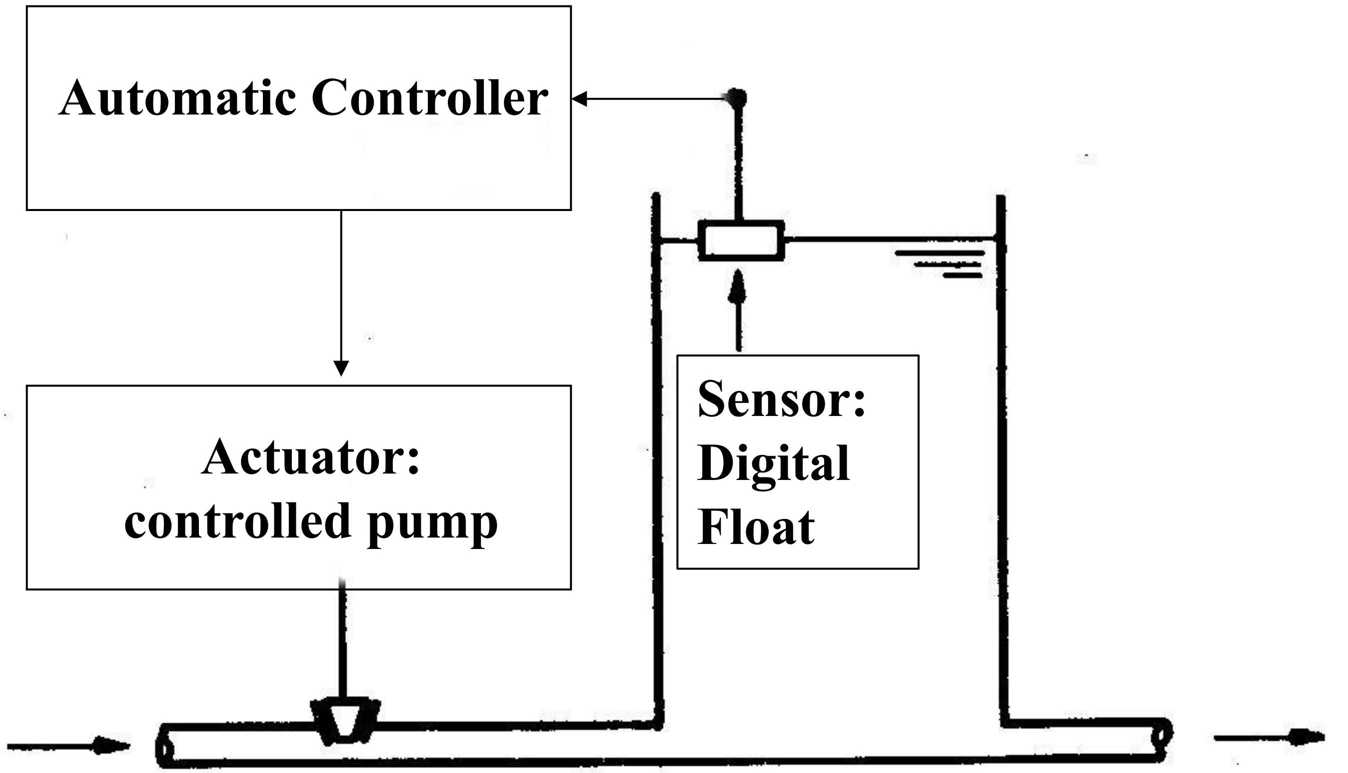
- The ideal aim of a control strategy is to find the control law such that

variables under control = reference signal (1)

Satisfying equation (1) is almost impossible in real systems for different reasons….

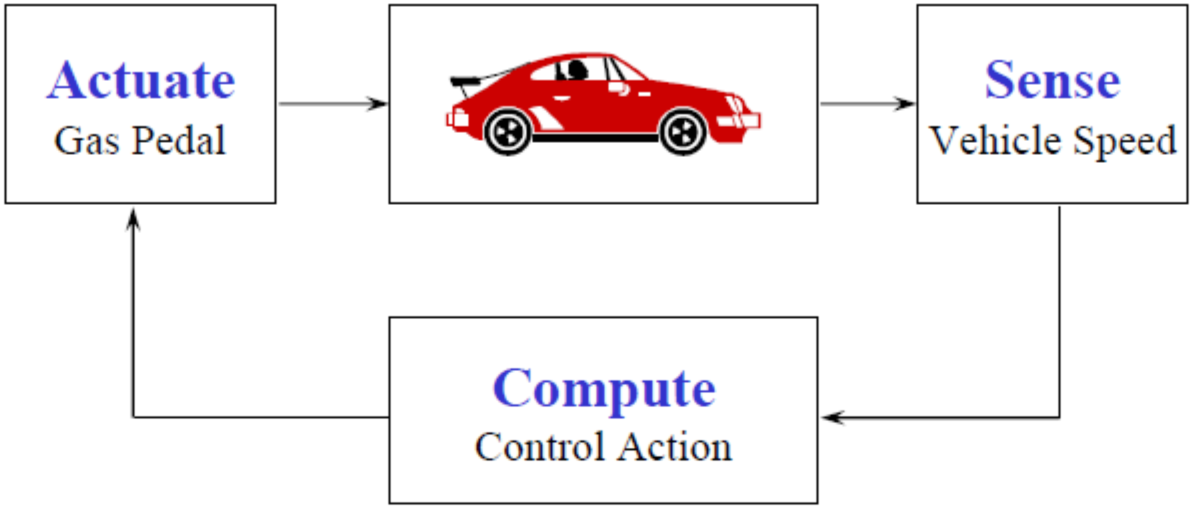
Example 1: Tank liquid level manual control




Automatic Controller
Actuator: controlled pump
Sensor: Digital Float

Example 2: planar tracking control

- Let us assume that a vehicle must be carried from a point A to a point B along an assigned planar trajectory and with an assigned velocity.
- The ***control variables*** are the angular position of the steer for the position and the gas pedal, the break pedal and the gear for the velocity:
- The ***actuator*** is the transmission system
- the ***sensors*** consist in the speed indicator for the velocity and the driver's eyes for the position.



…past issues

- Until the early 1950s, the spread of automation was limited by two factors:
  - The difficulty in creating control devises capable of executing complex algorithms.
  - The difficulty in making sensors, actuators and controllers communicate each other.
- Indeed, at first, controllers were made up of sophisticated mechanical or pneumatic devices, which allowed only the implementation of simple processing algorithms.

- New information technologies led to a revolution in automation systems.
- The availability of powerful, versatile and low-cost processing systems (microprocessors) allows the implementation of complex decision-making algorithms.
- The simplification of the exchange of information between the various devises of an automation system, via computer networks and the availability of “intelligent”/smart actuators and sensors, have made easier the problems of design and implementation, and therefore to reduce the costs of automation systems.

Automation methodologies and technologies

- Automation, as seen, is a science applied to the most different fields.
- So, is it possible to develop an automation discipline, or even an automation technology, with general characteristics rather than particular application context?
- In reality, despite the diversity of application contexts, it is possible to identify the existence of common features and problems among the various automated processes.
- It is with reference to these common characteristics that the methodologies and techniques of automation have developed.

Automation methodologies

- The goal of automation methodologies is the design, in abstract and formal terms, of the algorithms on which the control systems decide the actions to be performed on the process to be automated.

- This requires the choice of the quantities to be measured and the type of actions to be adopted on the system.

- Finally, the methodologies aim to evaluate, also in abstract terms, the performances achieved by the automated system.

- These methodologies provide with common approaches that can be applied to different problems.

- Obviously, knowledge of the main operating characteristics of the system to be automated is very important, but also the role played by automation methodologies is equally important.

Automation technologies

- The goal of automation techniques is the development of the physical devices that implement the sensors, the controllers, and the actuators.

- Sensors and actuating devises, which interface directly with the process, are closely linked to the application -> their choice, therefore, requires specific expertise on the process to be controlled.

- Regarding control devises, the use of Information Technologies (ITs) can now be considered consolidated, and this also due to the simplicity with which these devices can be made to communicate with intelligent sensors and actuators through appropriate communication networks.

- An in-depth knowledge of ITs is therefore to be considered a necessary skill for an automation expert.

- **Methodological disciplines** dealing with**:**
  - architectural design of the automation system (definition of the different control systems and their interactions);
  - design of control algorithms;
  - performance evaluation of the automation system.

Note that the design and performance evaluation are achieved in an theoretical way, using mathematical models of both the process to be regulated and the control devices (actuators, sensors, processing system and control algorithms).

A main role for designing the automatic control system is determined by "**Systems Theory**", which deals with the description of systems through mathematical models and the analysis of their behavior.

- **Technical disciplines** deal with the implementation of the automation system:
  - choice of measurement systems;
  - choice of actuation systems;
  - choice of hardware and application software of the processing system;
  - SW implementation of control algorithms;
  - assembly of the entire automation system;
  - commissioning of the system..

Course contents

- This teaching module will tackle issues concerning automation methodologies.

As shown in previous slides, a summary of the main topics will be the following:

  - Analysis of linear dynamic system in the time and frequency domains.
  - Key concepts in control: Block diagrams, negative feedback control…
    - Design method of feedback control systems: frequency shaping technique, PID controllers…

Ideal and real control problem

- Looking at Example 1-2 it should be evident that satisfying equation (1) precisely is not possible in many real control problem.

- This is due to

  1. the ***dynamics of the system under control***: the control action usually refers to the set of control variables that are related to the variables under control by means of the system dynamics.

  2. **the limits of the actuators**

  3. the possible presence of ***uncertainties*** **and** ***disturbs*** affecting both the systems and the actuators/sensors

Disturbs and Uncertainties (1/2)

- A ***disturb*** is external input of the systems that can not be controlled.

- The disturbs usually influence the value of the variables under control and so the ***aim of the controller is to neutralize their effect***.

- However, the disturbs are usually time variant and uncertain. In the control design it is assumed to know the ***nominal value*** and some information about the type and the intensity of the disturbs.

Disturbs and Uncertainties (2/2)

- The ***uncertainties*** in a real system are in general due both to the sensor/actuator blocks (*measurement uncertainties*) and to the model of the system.

- The first cause of model uncertainties is related to the necessity to consider ***simplified version of complex system*** for the controller design.

- Another cause of uncertainty is the presence of ***unknown parameters in the model***.

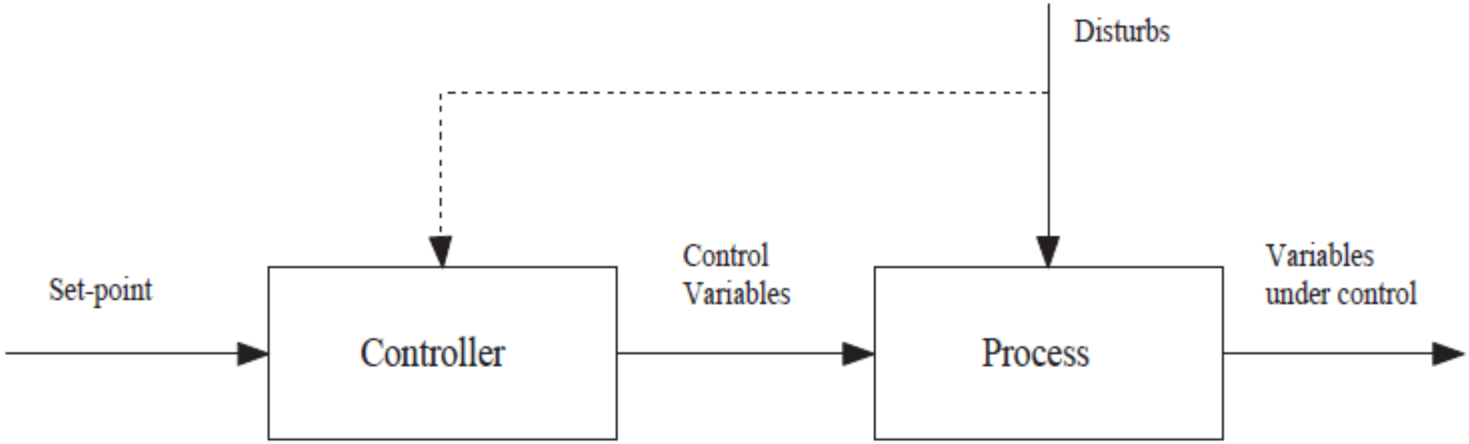
In case of uncertainties and disturbs, robust control strategies are used to guarantee a limited loose of performance of the controller.

Closed and open loop control (1/2)

- The control systems are usually classified depending on the information they use to evaluate the control law.

- In an ***open loop control strategy*** , the controller inputs are the set point at each instant of time and, in some cases, information concerning the disturbs.

- These information, together with the knowledge of the mathematical model of the system, allows the control system to elaborate the control law.

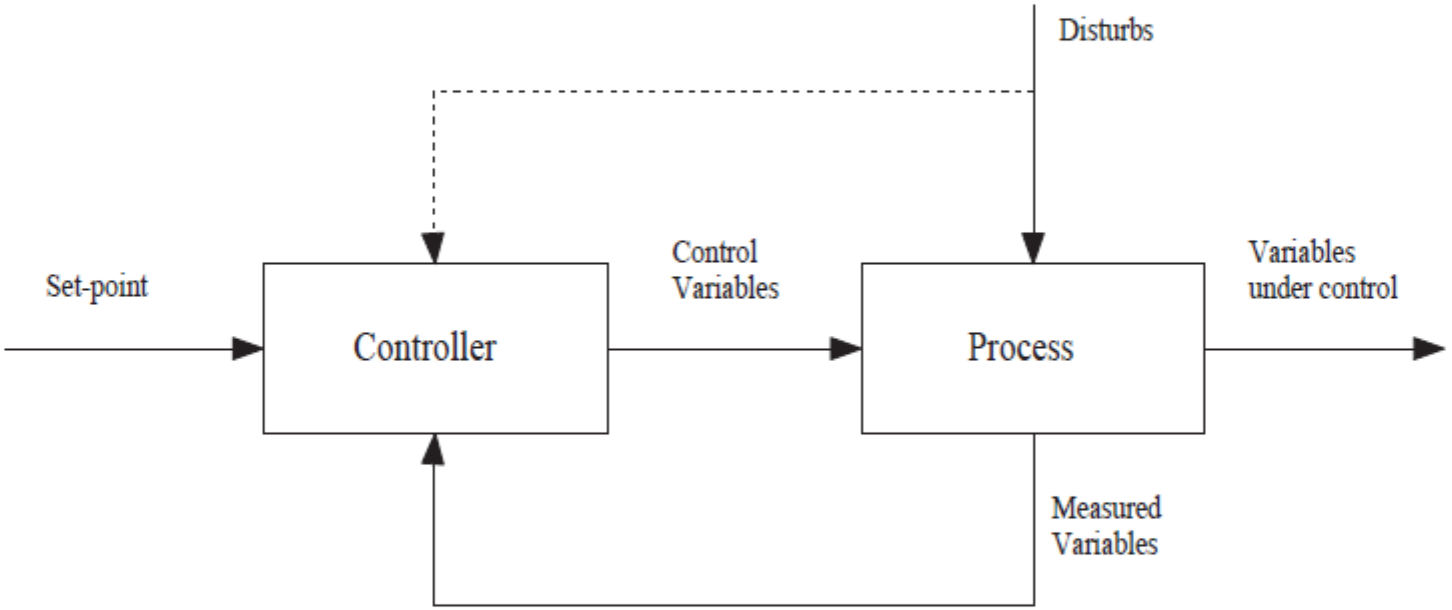


Open loop control strategy

Closed and open loop control (2/2)

- If the knowledge of the system is precise, there aren't any uncertain parameters and the disturbs assume their nominal value an open loop controller will work correctly. ***However, an open loop control strategy is not robust.***

- In a ***closed loop control strategy*** , the controller uses the real time values of the sensed variables in order to define a robust control law.



Closed loop control strategy

Mathematical model

- The ***mathematical model*** of the system describes its evolution starting from an initial condition. A mathematical model of a system is composed by

1. ***State variables*** $\boldsymbol{x} = [\, x_1 \;\; x_2 \;\; \dots \;\; x_n \,]^T \in R^n$: set of variables describing the state of the system in a given instant of time
2. ***Input variables*** $\boldsymbol{u} = [\, u_1 \;\; u_2 \;\; \dots \;\; u_m \,]^T \in R^m$: set of variables describing the interaction of the system with the environmental.
3. ***Dynamic equations:*** set of differential equation describing how the system evolves starting from an initial state $\boldsymbol{x_0}$ at the time t_0 under the input $\boldsymbol{u}$

$$\dot{x}(t)=\boldsymbol{f}(\boldsymbol{x}(t),\boldsymbol{u}(t),t) \qquad \boldsymbol{x}(t\_0)=\boldsymbol{x\_0}$$

4. ***Output variables*** $\boldsymbol{y} = [\, y_1 \;\; y_2 \;\; \dots \;\; y_p \,]^T \in R^p$: set of measured variables and variables under control related to the state variables of the system. The relation of the outputs with the state of the system can be expressed as

$$y(t)=\boldsymbol{g}(\boldsymbol{x}(t),\boldsymbol{u}(t),t)$$

First part of the course

- The first part of the course will focus on the ***analysis in the time and frequency domains of linear time invariant (LTI) systems*** in the form

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t) + Du(t)$$

with $A \in R^{n\times n}$, $B \in R^{n\times m}$, $C \in R^{p\times n}$, $D \in R^{p\times m}$, where $x(t)$ is the state vector, $u(t)$ is the input vector and $y(t)$ is the output vector of the system.

Then by exploiting the **Laplace transform**

$$U(s) \longrightarrow \boxed{W(s)} \longrightarrow Y(s)=W(s)U(s)$$

and by the ***harmonic response function,*** $W(s)|_{s=j\omega}$

$$u(t)=U_0\sin(\omega_0 t+\varphi) \longrightarrow \boxed{W(s)} \xrightarrow{y(t)}$$

$$y_{ss}(t)=U_0\left|W(s)\right|_{s=j\omega_0}\sin\left(\omega_0 t+\varphi+\angle W(s)_{s=j\omega_0}\right)$$

Second part of the course

- Then, the course will tackle the ***closed loop control of LTI systems.***