SYSTEM IDENTIFICATION

6 CFU

Academic Year: 2023/24

Instructor: Marco Casini

- M.S. in Artificial Intelligence and Automation Engineering
  (Curriculum Robotics and Automation)
  (first module of System Identification and Data Analysis)
- M.S. in Engineering Management
- M.S. in Applied Mathematics
  (first module of Data and Financial Analysis)

SYLLABUS

Part 1: Estimation theory

1.1 Random variables. Probability distributions. Mean and covariance. Conditional probability. Gaussian variables.

1.2 Estimation theory. Parametric estimation. Properties of estimators. Maximum likelihood estimators. Least squares and Gauss-Markov estimators. Minimum mean square error estimators.

1.3 Stochastic processes and time-series prediction. Distributions, mean and covariance function. Stationary processes. Frequency domain representation. Stochastic dynamic systems. Time-series models: AR, MA, ARMA. Time-series prediction.

Part 2: System Identification

2.1 System identification theory. Identification of linear systems: prediction error methods. Input-output models: ARX, ARMAX, OE, BJ. Least squares estimator for linear regression models. Model validation.

2.2 Practical system identification. Use of software tools for system identification.

BIBLIOGRAPHY

Main textbooks

- T. Soderstrom, Discrete-time Stochastic Systems, Springer London Ltd, 2nd ed., 2002.
- L. Ljung. Identification: Theory for the user, 2nd ed., Prentice-Hall, 1999.

Other reference textbooks

- A. Papoulis. Probability, random variables and stochastic processes, 3rd ed., McGraw Hill, 1991.
- L. Ljung System Identification Toolbox: Getting started, The Mathworks, 2001.
- L. Ljung. System Identification Toolbox: User's guide, The Mathworks, 2001.

PREREQUISITES

- Linear algebra and calculus
- Basics of probability theory and random variables (though there will be a very short review)
- Basics of dynamic systems theory: input-output representations; transfer function; Z-transform (discrete-time systems)
- Basics of Matlab language

HOW THE EXAM WORKS

To pass the **System Identification** exam you need to perform two steps:

- (A) the system identification **homework**;
- (B) the **oral** exam.

Step (A) must be done before step (B). Details and schedule of step (A) will be communicated by the instructor during the course.

The dates of the oral exams will be published in the *News* section of the course website (do not consider the dates in *segreteriaonline!*): to participate, you must sign up at least 7 days before the oral exam.

The oral exam involves the discussion of the homeworks and questions about **all** the topics treated during the course.

GOLDEN RULES

- The **right time** to do the exam is at the end of the course, during the winter exam session. You are strongly encouraged to do that!
- Do the homeworks **by yourself** and report them carefully. During the oral exam you will have to explain and motivate the homework solutions.

WEBSITE OF THE COURSE

http://control.dii.unisi.it/sysid/

Tentative schedule:

- Finish the course before Christmas holiday
- Assign the homework in mid December, to be delivered by Christmas break
- Oral exams in January/February

COURSE INTRODUCTION

ESTIMATION PROBLEMS

A large number of fundamental problems in engineering (and beyond) can be formulated as **estimation problems**

Examples:

- Interpolation
- Signal filtering
- Time series prediction
- Estimation of mathematical models of dynamic systems (*system identification*)

Estimation problem

Find the values of one or more unknown quantities, by using available information on other quantities related to them.

ESTIMATION PROBLEMS - UNCERTAINTY

An estimation problem is characterized by three fundamental ingredients:

- some prior information on the quantities to be estimated
- a set of data
- a criterion to assess the quality of an estimate

A key feature of every estimation problem is the characterization of the **uncertainty** associated to the estimates.

Once an uncertainty model has been defined, the estimation problems often boil down to the minimization of the uncertainty associated to the estimate.

PART 1: ESTIMATION THEORY

- Mathematical models of non deterministic phenomena:
  - random variables
  - stochastic processes
  - stochastic systems
- Estimation approaches:
  - parametric
  - Bayesian
- Application: time-series prediction

PART 2: SYSTEM IDENTIFICATION

System: object or set of objects of which we want to study properties and behaviors

Examples:

- an electrical circuit
- an industrial process
- an ecosystem
- the solar system

Possible approaches to system analysis:

1. experimental tests collecting data
2. modeling
    - mental models
    - verbal models
    - structures and material models
    - **mathematical models**

CLASSIFICATION OF MATHEMATICAL MODELS

Static	$\Leftrightarrow$	Dynamic
Stationary	$\Leftrightarrow$	Non stationary
Continuous-time	$\Leftrightarrow$	Discrete-time
Linear	$\Leftrightarrow$	Nonlinear
Deterministic	$\Leftrightarrow$	Stochastic
Lumped parameters	$\Leftrightarrow$	Distributed parameters
Continuous variables	$\Leftrightarrow$	Discrete events

CONSTRUCTION OF MATHEMATICAL MODELS

Two possible approaches:

1. Physical models
   - based on first principles and a priori knowledge
2. System Identification
   - based on the observation of the system behavior (the data)

System Identification $\longrightarrow$ estimation problem

ENJOY THE COURSE