UNIVERSITÉ DE LORRAINE

POLYTECH NANCY

Data-driven learning/identification of dynamic systems

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An engineer's perspective

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Course organization and prerequisites

- Organization
  - Lectures: 8h (4h HG+4h MM)
  - Tutorials: 4h (HG)
  - 2 mini-projects: 10h (6h HG+4h MM)
  - Oral presentation: 2h

- Prerequisites
  - Linear systems theory
  - Control theory
  - Linear algebra and matrices
  - Optimization theory and methods
  - Basic programming proficiency in Matlab

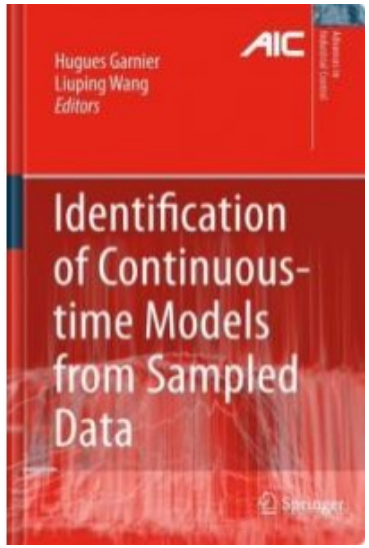
- Skill assessments

  In pairs, you will work on a data-driven modelling mini-project using data coming from real-life systems
  - 2 scientific reports on the mini-projects (2*0,3 – 1HG + 1MM)
  - Oral presentation of the results obtained on HG's mini-project (0,4)

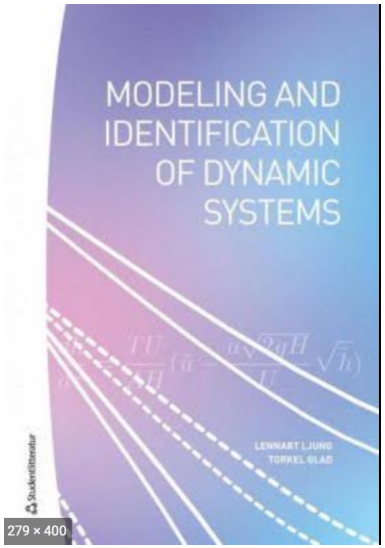
Course website & recommended textbooks

- Website of the course
  - w3.cran.univ-lorraine.fr/hugues.garnier/?q=content/teaching

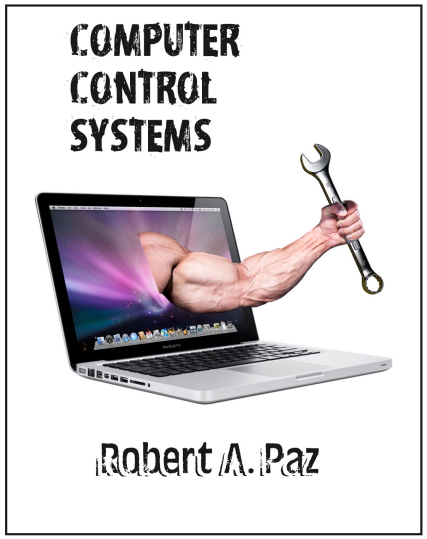
- Recommended textbooks



H. Garnier & L. Wang (Eds)
2008



L. Ljung & T. Glad
2016
New version in 2021



2010

System identification is part of Data science and is connected to Machine learning

- From Wikipedia
  - Data science *is an interdisciplinary field that uses scientific methods, processes, algorithms and systems to extract knowledge and insights from data in various forms*
  - Machine learning *is a field of study in artificial intelligence concerned with the development and study of statistical algorithms that can learn from data and generalize to unseen data*
  - System identification *uses statistical methods to build mathematical models of dynamical systems from measured data*

System identification is part of Data science and is connected to Machine learning

Vocabulary system theory vs. neural networks/machine learning:

- Estimate = train
- Identify = learn
- Validate = generalise
- Model structure = network topology (architecture)
- Estimation data/identification data = training set
- Validation data = generalisation set
- Overfit = overtraining
- Output = target

System identification is part of Data science and is connected to Machine learning

- (Triennial) IFAC Symposium on System identification
  - Well-established research area within Automatic Control
  - The term *System identification* first introduced by Lofti Zadeh in 1957 !
  - The first IFAC Symposium on System Identification was organized in Prague in 1967. This is now the longest running IFAC symposium series
  - the 21st SYSID edition will be held in Lyon in July 2027

- (Annual Learning) for Dynamics & Control (L4DC) Conference
  - The 7th L4DC edition will be held in Ann Arbor (USA) in June 2025

https://sites.google.com/umich.edu/l4dc2025

The cost of the modelling phase in a control-design project

- The modelling phase of an unknown system can be quite time-consuming and is often a significant part of a control-design project
  - *Normally modelling costs account for over 75% of the expenditures !*
- This is true in particular for Physics-based modelling
- Convenient alternative: data-driven modeling via system identification

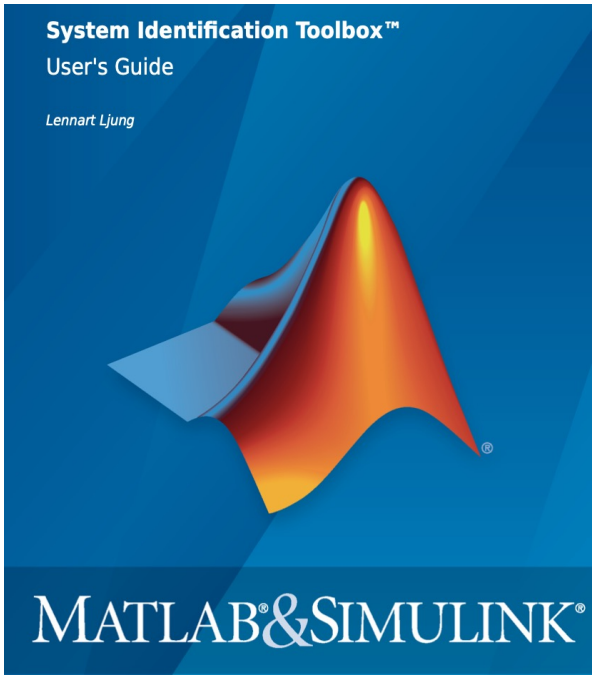
Software tools for data-driven system identification

- System identification is typically an iterative procedure, where the insights and judgements of the user can be mingled with:
  - extensive data handling
  - sophisticated parameter optimization algorithms
  - practical considerations and user experience

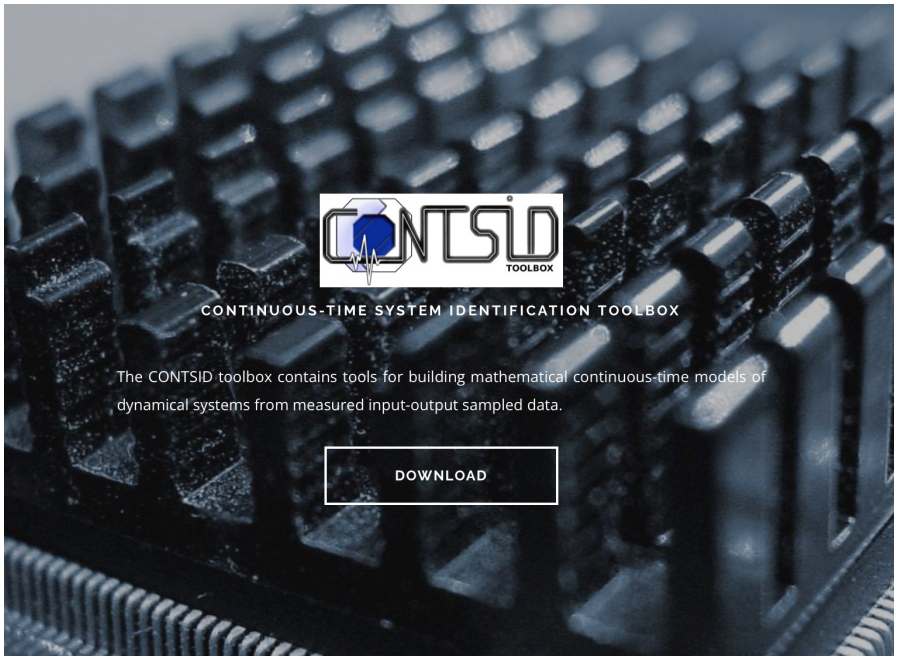
- To make the application of the system identification procedure successful:
  - it is *necessary to exploit some user-friendly software tools*

Software requirements for the course

We will make use of the Matlab SYSID toolbox and the CONTSID toolbox



The principal architect of the toolbox is Prof. Lennart Ljung, a recognized leader in the field of system identification



Developed by the CRAN team at Polytech Nancy (mainly Hugues Garnier and his PhD students)
`www.contsid.cran.univ-lorraine.fr`

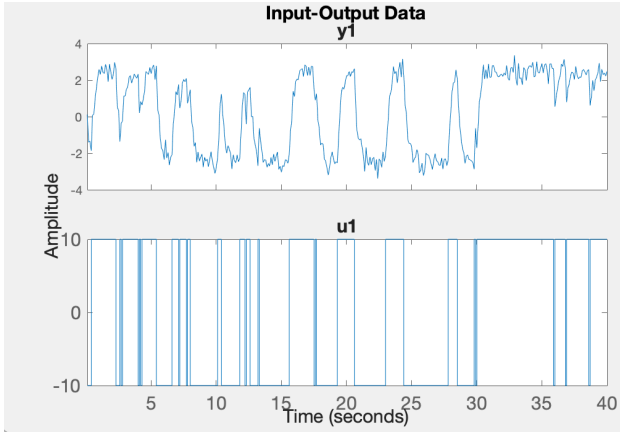
A lot can be learned from the demos available

```
>>doc ident
```

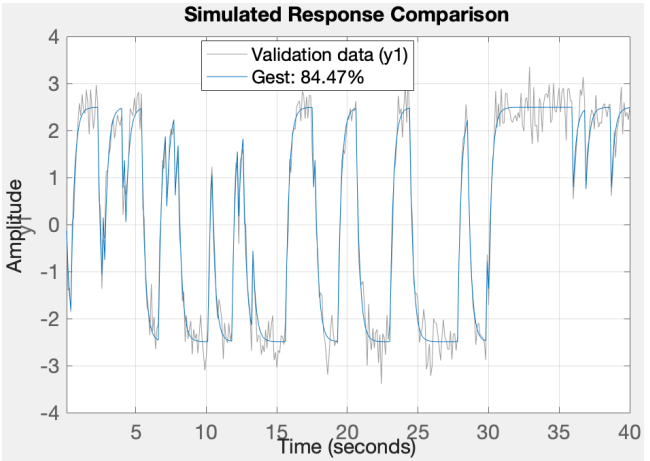
```
>>contsid_demos
```

A typical session with Matlab

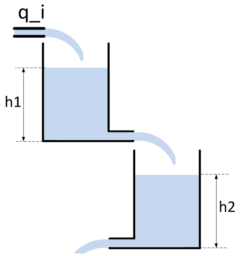
```
% Load the data
load dcmotor;

% Plot and examine the data
data=iddata(y,u,Ts);
idplot(data);
```

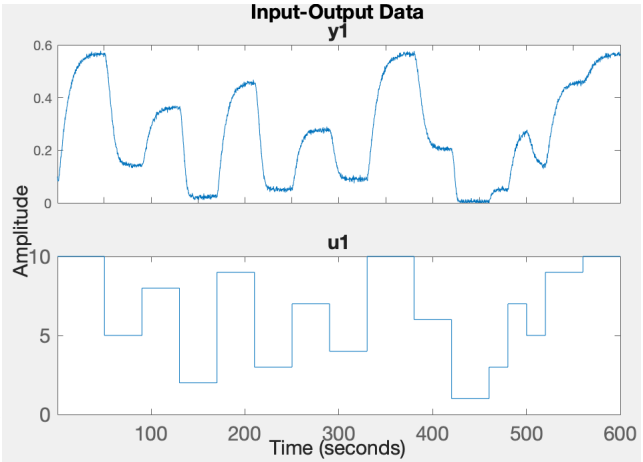



```
% Choose a model structure and estimate the parameters
% Let us test a 1st-order transfer function with no time-delay
Gest = tfsrivc(data,1,0,'TdMax',0);
present(Gest)
Gest =
  From input "u1" to output "y1":
   1.037 (+/- 0.02287)
  ----------------------
  s + 4.161 (+/- 0.0994)

% Validate the model
compare(data, Gest);
```

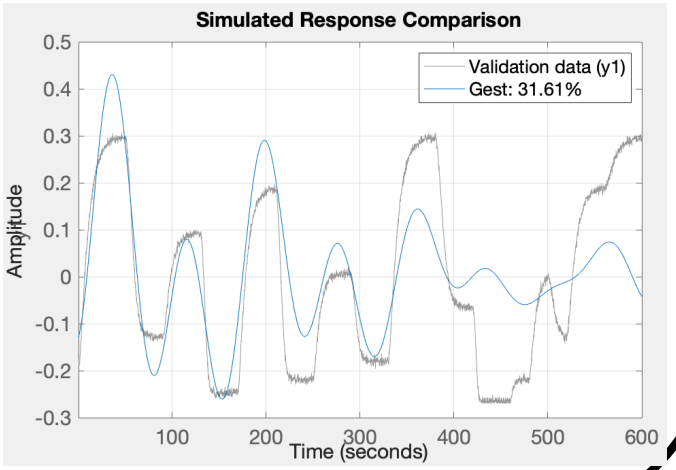


Another typical session with Matlab





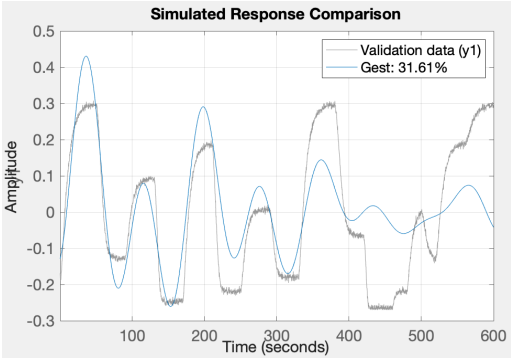

```
% Load the data
load twotankdata;

% Plot and examine the data
data0=iddata(y,u,0.2);idplot(data0);

% Suppress the mean of both input and output
Data=detrend(data0);

% Choose a model structure and estimate the parameters
% Let us test a 2nd-order transfer function with no time-delay
Gest = tfsrivc(data,2,0,'TdMax',0);
present(Gest)
Gest =
  From input "u1" to output "y1":
             0.001657 (+/- 5.6e-05)
  ---------------------------------------------
  s^2 + 0.21 (+/- 0.0083) s + 0.036 (+/- 0.0012)

% Validate the model
compare(data, Gest);
```



Not too bad !
But nonlinear effects not well captured by a linear model

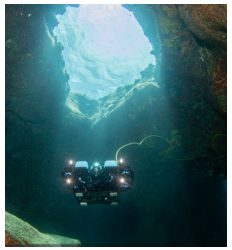
Course philosophy

- Experimental philosophy—like a lab course
- Some math, but « proof » and discovery mainly by Matlab
- Learn and understand by doing, failing, succeeding, and experiencing
- Apply methods in an investigative manner



What goes wrong and why?

Course outline

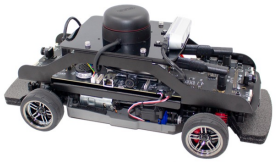


I. Data-driven linear system identification – A refresher

- Application to the Blue Robotics T200 Thruster

II. More advanced aspects for linear system identification

- Identification in closed loop
  - Application to the Tello Drone
- Identification of LPV systems
  - Application to the Qcar
- Identification of state-space MIMO systems
  - Application to flexible robot arm
  - Application to a dual-rotor helicopter



III. Data-driven model learning of lithium-ion batteries *(from Michel Mensler, Nissan)*

- Application for state-of-charge estimation in battery electric cars