

System Identification, Lecture 1

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Course code: 1RT880, Report code: 61800 - Spring 2015
F, FRI Uppsala University, Information Technology

23 March 2015

Lecture 1

- Course Outline.
- System Identification in a Nutshell.
- Applications.

Prerequisites

- Linear algebra and statistical techniques.
- 120 ECTS credits.
- Courses: Signals and systems, Automatic control I, Automatic control II.
- Ph.D. student.

Course Organisation

- 9 Lectures.
- 2 Exercise Sessions.
- 5 Computer Labs
- 1 Laboratory Session (Report Mandatory, 1 ECTS).
- Mini-projects.
 - Written Exam (3 ECTS)
 - Presentation + Report project (1 ECTS).

Course Organisation

- Lectures (Kristiaan: kp@it.uu.se , 2338)
- Exercise Sessions (Sholeh, sholeh.yasini@it.uu.se , 2238)
- Computer Labs (Sholeh)
- Process lab (? & Sholeh)

Lectures

Introduction:

- (i) Overview.
- (ii) Least Squares Rulez.
- (iii) Models & Representations.
- (iv) Stochastic Setup.

Main body:

- (v) Prediction Error Methods.
- (vi) Model Selection and Validation.
- (vii) Recursive Identification (E. Karlsson).

Advanced:

- (viii) ID for MIMO and State Space Systems.
- (ix) Nonlinear ID (T. Schön).

Problem Solving Sessions:

1. Aspects of Least Squares.
2. Aspects of Recursive Identification.

5 Computer Labs:

1. Least Squares Estimation: do's and don't's.
2. Timeseries Modeling.
3. Recursive Identification.
4. The System Identification Toolbox.
5. MIMO: Kalman Filter and Subspace ID.

Projects

- Identification of an industrial Petrochemical plant
- Identification of an Acoustic Impulse Response
- Identification of Financial Stock Markets
- Identification of a Multimedia stream
- * *

Course Material

- Lecture Notes: *Available from next week in lectures, or online.*
- Slides: *Available past lectures.*
- Solutions exercises. *Available past lectures.*
- Book: *"System Identification", T. Söderström, P. Stoica, Prentice-Hall, 1989*¹

¹see <http://www.it.uu.se/research/syscon/Ident>, ...

Desiderata

Students who pass the course should be able to

1. Describe the different **phases** that constitute the process of building models, from design of an identification experiments to model validation.
2. Explain **why** different system identification methods and model structures are necessary/useful in engineering practice.
3. Account for and apply the **stochastic** concepts used in analysis of system identification methods.
4. Describe and motivate **basic properties** of identification methods like the least-squares method, the prediction error method as well as to solve different problems that illustrate these properties.
5. Describe the principles behind **recursive** identification and its field of application.
6. Explain the usefulness of **realization** theory in the context of system identification, and how it is employed in subspace identification techniques.
7. Show **hands-on** experience with analyzing actual data, and have a working knowledge of the available tools. Reason about how to choose identification methods and model structures for real-life problems.

In order to **pass** the course, I need to have for each of the candidates:

1. Attendance of the lab. session, as well as a filled out copy of the lab report.
2. A filled out report of the computer sessions.
3. A successful written exam.
4. A project report.
5. A successful presentation of the project (possibly shared amongst partners in the group).

Final Score

$$\text{Score} = \left[\frac{1}{10}(\text{Score}_1 + \text{Score}_2) \right]$$

- Score: 1,2 (=U), 3,4,5.
- Score_1 = Score obtained on written exam (x/30)
- Score_2 = Score obtained on projects: report+presentation (y/20)
- +Mandatory parts.
- E.g.
 - $\left[\frac{1}{10}(28 + 17) \right] = \left[\frac{45}{10} \right] = 5,$
 - $\left[\frac{1}{10}(27 + 17) \right] = \left[\frac{44}{10} \right] = 4,$
 - $\left[\frac{1}{10}(21 + 13) \right] = \left[\frac{34}{10} \right] = 3,$ or
 - $\left[\frac{1}{10}(14 + 10) \right] = \left[\frac{24}{10} \right] = 2.$

System

System (\mathcal{S}): A defined part of the real world. Interaction with the environment are described by input signals, output signals and disturbances.

Dynamical System: A system with a memory, i.e. the input value at time t will influence the output signal at the future, i.e. $t' > t$.

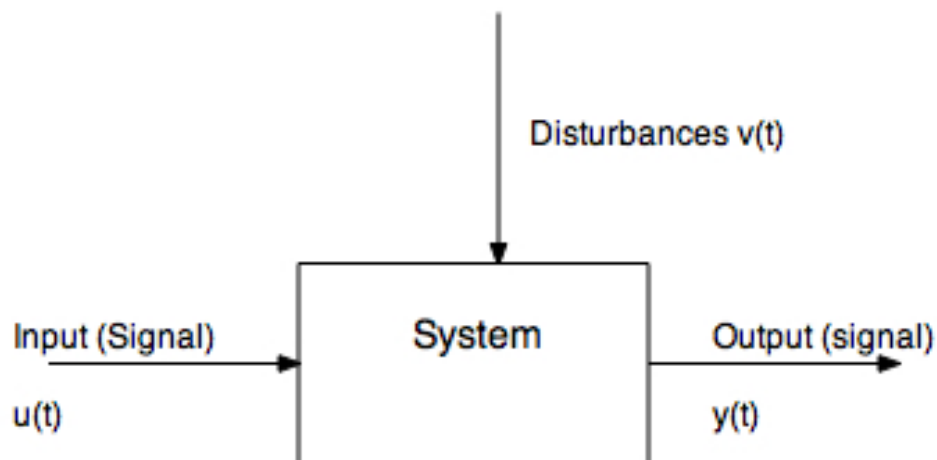


Figure 1: Schematic picture of a system

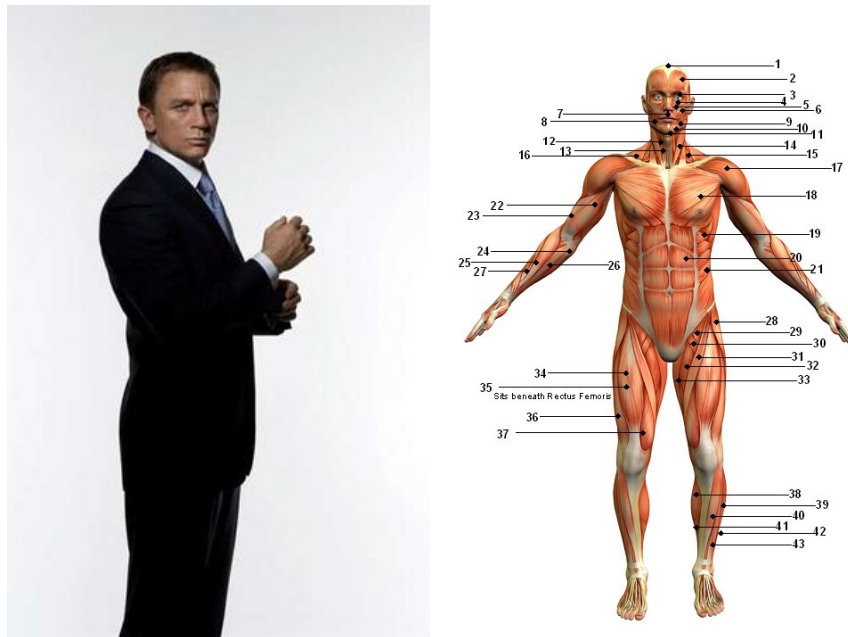


Figure 2: A System and A Model

Ex.: A Stirred Tank

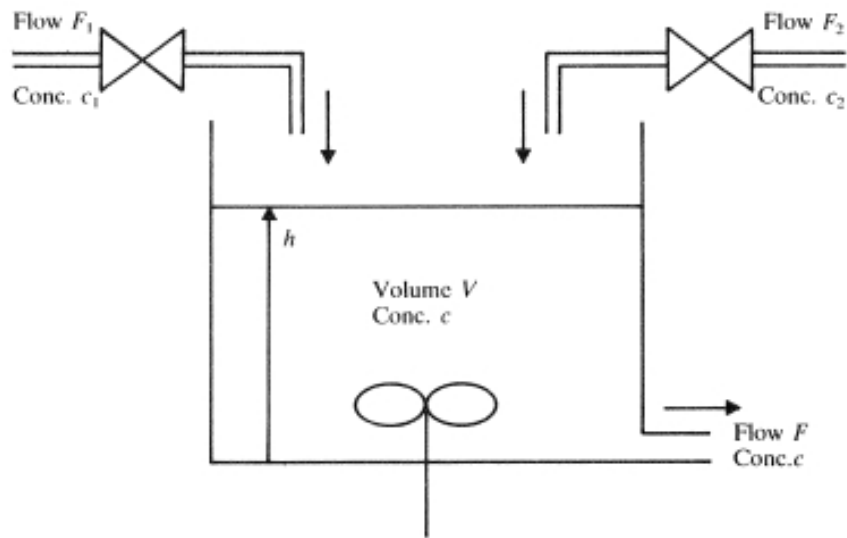


Figure 3: A Stirred Tank

Ex.: Speech

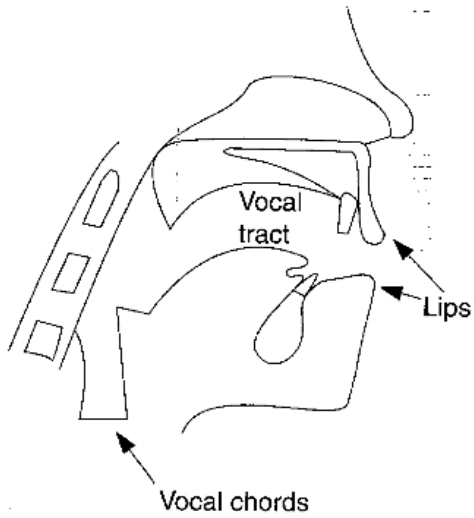


Figure 1.7 Speech generation.

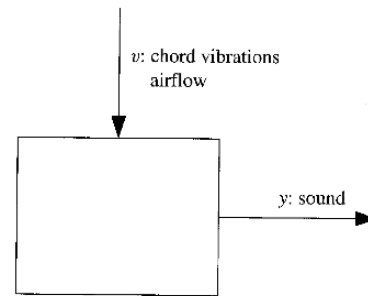


Figure 1.8 The speech system: y : output; v : unmeasured disturbance.

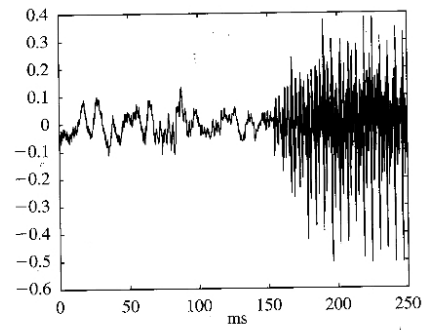


Figure 1.9 The speech signal (air pressure). Data sampled every 0.125 ms. (8 kHz sampling rate).

Ex. and...

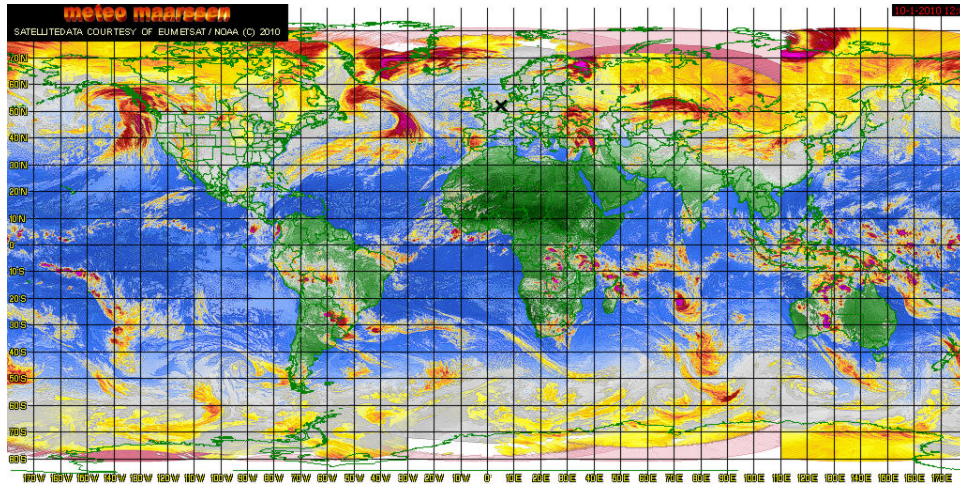
- Stock (Shock) Market



- Acoustic Noise Cancellation Headset (Adaptive filtering)



- Evolution of the Temperature in the world



- Construction (Strength)



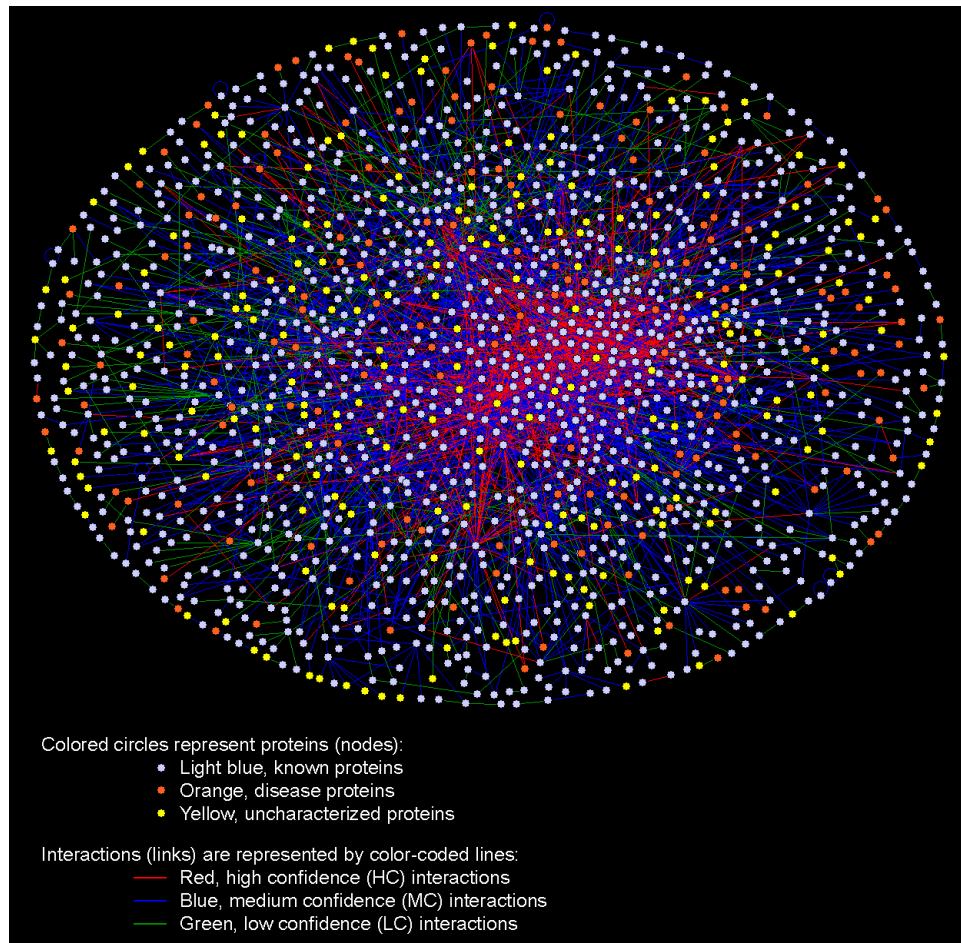
- Robots (Mechanical, Operational, Intellectual)
-



- Social Behavior of Crowd (gossip)



- A human protein-protein interaction network



Models

Model (\mathcal{M}): A description of a system. The model should capture the essential behavior of the system.

| Systems | Models |
|-------------------------------|-----------------------------------|
| Complex | Approximative (Idealization) |
| Examine real system is costly | Models can answer many questions. |

Applications

- Process Design. Ex. Designing new cars, planes,
- Control Design.
 1. Simple regulators
 2. Simple models, optimal regulators,
 3. sophisticated models.
- Prediction. Ex. Forecast the weather, Predict the Stock market.
- Signal Processing. Ex. Acoustic Echo Cancellation.
- Simulation. Ex. Train new nuclear plant operators, try new operating strategies.
- Fault Detection. Ex. VISA.

Type of Models

- Mental, intuitive or verbal. Ex. Driving a car.
- Graphs and Tables. Ex. Bode plots and step responses.
- Math. models. Ex. Differential and Difference equations.

Mathematical Models

- **Analytical Models (White-Box models)** Basic laws from physics (...) are used to describe the behavior of a phenomenon (system).
 - Know the physics.
 - Yields physical Interpretation
 - Quite general models. Often Nonlinear
- **System Identification**
 - **Black-Box models** (Konfektionsmodeller) "Choose a standard model (class) and tune up the parameters (...) to the data".
 - * Easy to construct and use.
 - * Less general. Linear (-ized)
 - *Grey-Box models* (Skräddarsydda Modellerer) "Derive the model from laws and tune 'some' parameters to data".
 - * Combines Analytical models and black-box identification.

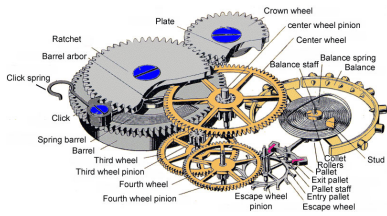


Figure 4: White-, Black- and Grey-Box Models

Examples of Models

- Nonlinear vs. Linear (superposition principle):

*"The net response at a given place and time caused by two or more stimuli is the sum of the responses which would have been caused by each stimulus individually."
(Wiki)*

- Time-continuous versus Time-discrete
- Deterministic versus Stochastic

System Identification (SI)



Def. System Identification is the study of *Modeling* dynamic *Systems* from *experimental data*.

- Statistics, Systems Theory, Numerical Algebra.
- System Identification is art as much as science.
- Software available (MATLAB)
- – Estimation (Gauss (1809)),
– Modern System Identification (Åström and Bohlin (1965),
Ho and Kalman (1966)),
– Recent System Identification (L. Ljung, 1977-1978)
– Textbooks (Ljung 1987, Söderström and Stoica, 1989).

The System Identification Procedure

1. **Collect Data.** If possible choose the input signal such that the data is maximally informative. Display data, and try to get some intuition about the problem at hand.
2. **Choose Model Structure.** Use application knowledge and engineering intuition. Most important and most difficult step (don't estimate what you know already)
3. **Choose Identification Approach.** How would a good model look like?
4. **Do.** Choose *best* model in model structure (Optimization or estimation)
5. **Model Validation.** Is the model good enough for our purpose?

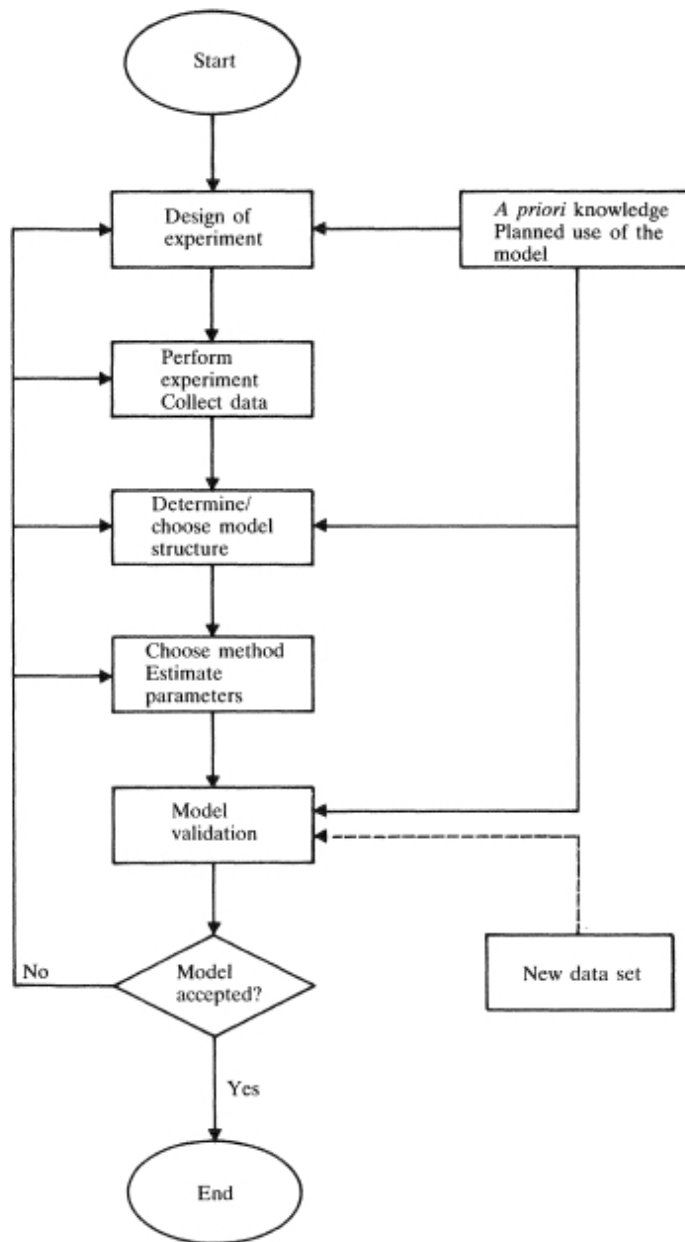


FIGURE 1.3 Schematic flowchart of system identification.

Typical Problems to Answer

- How to design the experiment. How much data samples to collect?
- How to choose the model structure?
- How to deal with noise?
- How to measure the quality of a model?
- What is the purpose of the model?
- How do we handle nonlinear and time-varying effects?

System Identification Methods

- **Non-parametric Methods.** The results are (only) curves, tables, etc. These methods are simple to apply. They give basic information about e.g. time delay, and time constants of the system.
- **Parametric Methods (SI)** The results are values of the parameters in the model. These may provide better accuracy (more information), but are often computationally more demanding.

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- (vi) Model Selection and Validation.
- (vii) Recursive Identification.
- (viii) SISO 2 MIMO.
- (ix) Nonlinear Identification.

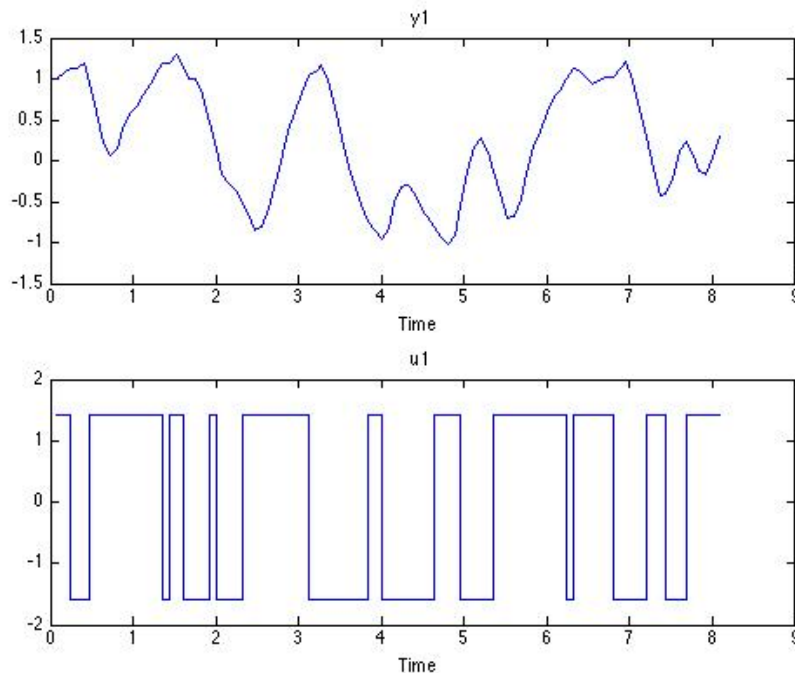
Conclusion

- System identification is the art of building mathematical models of dynamical systems using experimental data. It is an iterative procedure.
 - A real system is often very complex. A model is merely a good *approximation*.
 - Data contain often noise, individual measurements are unreliable.
- Analytical methods versus system identification (white-, black-, grey box)
- Non-parametric versus Parametric Methods
- Procedure: (a) Collect data, (b) Choose Model Structure, (c) Determine the best model within a structure, (d) Model validation.

An example

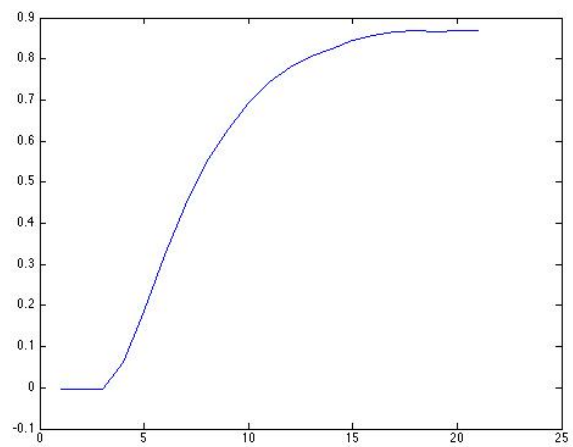
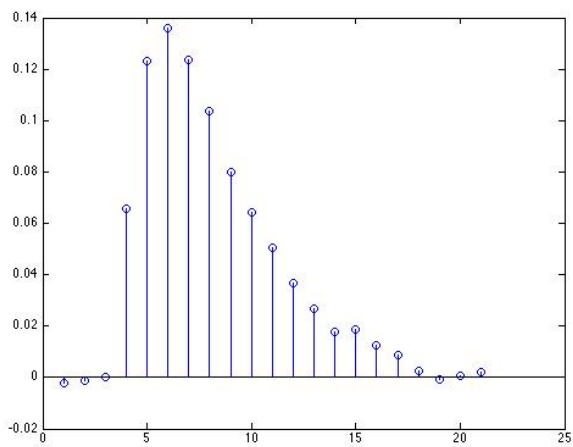
Identify a hairdryer: air is fanned through a tube and heated at the inlet. Input $u(t)$: power of the heating device. Output $y(t)$: air temperature.

```
>> load dryer2  
>> z2 = [y2(1:300) u2(1:300)];  
>> idplot(z2, 200:300, 0.08)
```



Nonparametric Modeling

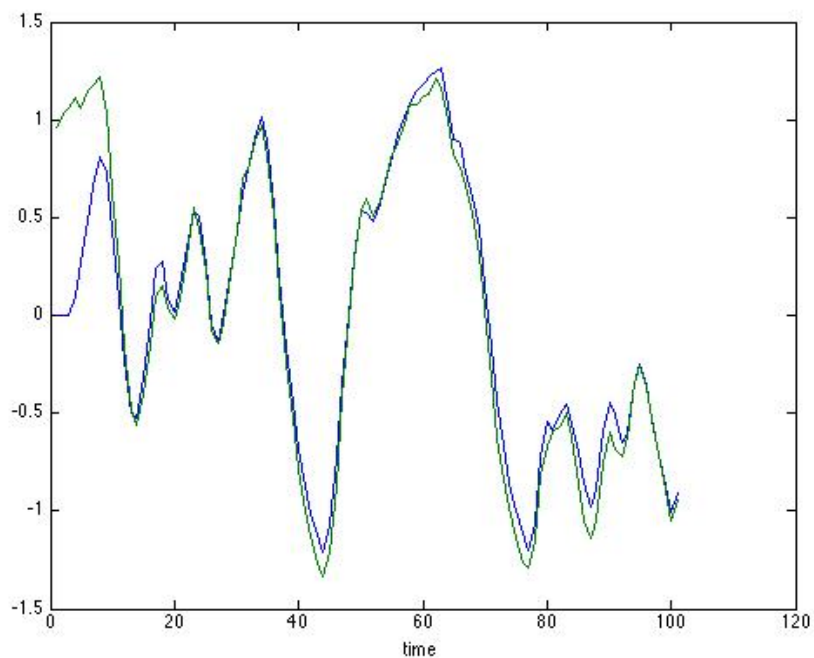
```
>> z2 = dtrend(z2);  
>> ir = cra(z2);  
>> stepr = cumsum(ir);  
>> plot(stepr)
```



Parametric modeling:

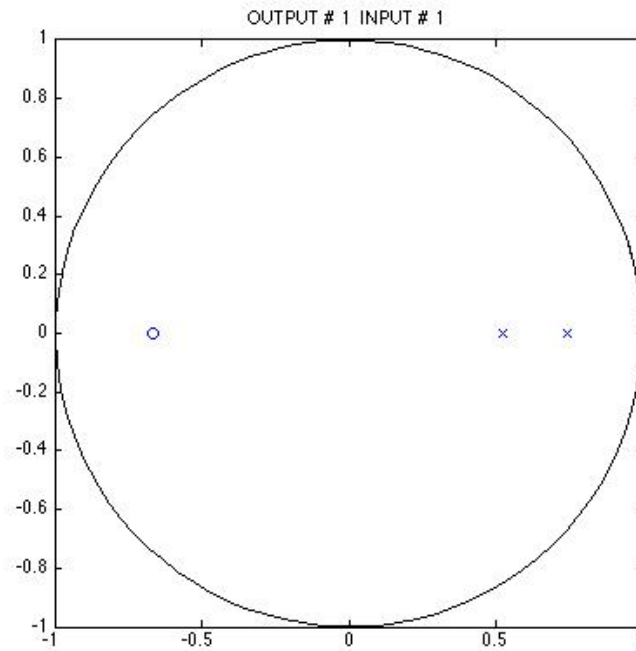
$$y(t) + a_1y(t - 1) + a_2y(t - 2) = b_1u(t - 3) + b_2u(t - 4)$$

```
>> model = arx(z2, [2 2 3]);  
>> model = sett(model,0.08);  
>> u = dtrend(u2(800:900));  
>> y = dtrend(y2(800:900));  
>> yh = idsim(u,model);  
>> plot([yh y]);
```



Pole-zero plot of the model:

```
>> zpth = th2zp(model);  
>> zpplot(zpth);
```



Compare the transfer functions obtained from non- and parametric methods:

```
>> gth = th2ff(model);  
>> gs = spa(z2); gs = sett(gs,0.08);  
>> bodeplot([gs gth]);
```

