OVERVIEW OF THE SYSTEM IDENTIFICATION COURSE, JAN. 2011

KRISTIAAN PELCKMANS

Abstract. Many engineering tasks start from an appropriate mathematical model of the studied system. This is the case in many simulation, control, prediction or monitoring applications. This course teaches you how such models can be obtained based on measurements collected from, and experiments carried out with the studied system. Both theoretical issues and practical case studies are used to provide insight in this fascinating research area. Follow this course if: (i) You want to learn how to set up a successful identification experiment of a dynamical system. (ii) How can you verify the use of your estimated models. (iii) What are key concepts lying on the basis of a statistical analysis of such techniques? (iv) What are the different steps in making the techniques 'work' on a real case?

1. General Description

- Course Code: 1RT875
- Established: 2011-01-01
- Established by: Teknisk- naturvetenskapliga fakultetsnämden
- Revised: 2011-01-01
- Requirements: 120 ECTS credits and passing courses on Reglerteknisk I & II, Signals and Systems
- Level of Education: Advanced Level
- Grading System: U Fail, 3 Pass, 4 Pass with Credit, 5 Pass with Distinction
- Main Area of Studies: Technology

1.1. **Prerequisites.** This course builds on a reasonable knowledge of linear algebra and statistical techniques. Prerequisite are 120 ECTS credits and courses Signals and systems, Automatic control I, Automatic control II.

1.2. **Required Attendance and Homeworks.** In order to pass the course, I need to have for each of the candidates:

(1) A project report.
(2) A successful presentation of the project (possibly shared amongst partners in the group).
(3) A report with solutions for the exercises appointed to working out at home.
(4) Attendance of the lab. session, as well as a filled out copy of the lab report.
(5) A filled out report of the computer sessions.

1.3. **Desiderata.** Students who pass the course should be able to

- Describe the different phases that constitute the process of building models, from design of an identification experiments to model validation;
- Explain why different system identification methods and model structures are necessary in engineering practice;
- Account for and apply the stochastic concepts used in analysis of system identification methods;
- Describe and motivate basic properties of identification methods like the least-squares method, the prediction error method, the instrumental variable method, as well as to solve different problems that illustrate these properties.
- Explain the advantages and challenges when identifying feedback systems in closed loop.
- Describe the principles behind recursive identification and its field of application;
- Explain the usefulness of realization theory in the context of system identification, and how it is employed in subspace identification techniques.
- 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;

1.4. **Examination.** Part project work (50%) and part written exam (50%). The written exam will consist of 5 questions (exercises) similar to the one given in the problem solving sessions. The course counts for 10 ECTS points:

- Part I: 4 ECTS pts.
- Mandatory report (labs) 1 ECTS pt.
- Projects 4pts).

2. Lectures

There will be 12 lectures, each of 2 hours.

Part I: Basic

(1) Overview, Aim and Relations of System Identification.
(2) Least Squares Rules.
(3) Model representations: Non-parametric & Parametric.
(4) Stochastic Setup.
(5) Prediction Error Method.
(6) Model Selection and Validation.
(7) Recursive Identification.

Part II: Advanced

(1) Recursive Identification.
(2) State Space Systems.
(3) Subspace Systems.
(4) Design of Experiments.
(5) Instrumental Variables.

(6) Nonlinear Identification: a flash forward.

2.1. **Course Material.** Most material, as well as a message board is available at `http://www.it.uu.se/edu/course/homepage/systemid/vt11`

(1) Lecture Notes and Slides (available on website).
(2) Book 'System Identification, Söderström & Stoica' from UTH-gard.
(3) Exercise Compendium (available on website).
(4) Computer and laboratory lab instructions (available at every session).
(5) Project Manual (available on website).

3. Problem Solving Sessions

(1) Aspects of Least Squares.
(2) Statistical Aspects: what can go wrong with OLS?
(3) Prediction Error Methods.
(4) Recursive Identification.

At the end of each problem solving session, an exercise is given to the students which has to be solved at home. Those 4 exercises+solutions are to be handed in at the last session.

4. Computer Labs

(1) Least Squares Estimation: do's and don'ts.
(2) Timeseries Modeling.
(3) Recursive Identification.
(4) The System Identification Toolbox.
(5) MIMO: Kalman Filter and Subspace ID.

5. Laboratory Work: Identification of a fan process

6. Project Works

6.1. **General Instructions.** The aim is to acquire hands-on experience with the tools for system identification for working with actual (real-life) data. Specifically, use of the MATLAB SI toolbox, and learning to organize different available tools in a successful application are central. The emphasis will be on identification of Multiple-Input, Multiple-Output (MIMO) systems. The projects will be organized in small groups (depending on the number of participants to the course), with indication of individual contribution. The work will culminate in a report containing workflow, design decisions, details of the implementation, and results of simulations. It is allowed and encouraged to work in small groups (2-5 persons) on the same task. But it is required that each individual hands in her/his own report (named). A successful project will consist of five steps, each of which are to be documented in the report.

(1) Visualize the data, point out characterizing properties and state the problem you're after.

(2) Do some simple (possibly naive) simulations: e.g. what is the best constant prediction (mean). This can often be done using the `ident` tool.
(3) What is a proper method for identification of the system, perform the simulations. Most importantly, verify the result: why is this result satisfactory? How does it compare to the naive estimates of (2)?
(4) Describe a full identification experiment: why is this (not) possible in practice? What would be the benefit if it were possible? What are further important todo's?
(5) Summarize your contribution in an 'abstract' and 'conclusions' of your report.

Those different steps (sections) should show up in the report to be handed in. The evaluation of the project work will come

(1) Report: A well-manicured report describing the achieved results, motivating the design decisions and verifying the estimated models. Make sure sufficient care is given to
    - Avoid Typos.
    - Use of the English language: think about what you write and how you write it up.
    - Be concise: reread your own text and throw out what is not needed for supporting the conclusions.
    - Figures: name axes, and give units. Add a legend explaining the curves we see, and add a caption explaining what we see and should conclude from the present figure.
    - A guideline would be a report of 3-4 single column, 11pt, letter pages.
(2) Presentation: each group is assigned a slot of 10 minutes to defend their results. Specifically, try to convince the audience of the following bullets:
    - What are the conclusions of the effort, and how do you get there?
    - How do you improve over earlier/simpler solutions?
    - What is the contribution of each of the groupmembers?
    - What are possible applications for your work?
    - Suppose I were your manager at a company: why should I invest 1000$ to implement your model?
    - Suppose I were your teacher: why would I award you a grade 5 for your work?

    After and during the presentation, I will ask some questions for each of you evaluating your insights in SI as used in the project.

The following four projects are prepared:

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

Of course it is possible (even encouraged) to come up with your own case study in system identification.

7. Timeline

Table 1. Timeline

Lectures (I: Jan. - March 2011, II: March-May 2011)			
Number	Date	Hour	Name
I.1	Jan. 10		Overview.
I.2	Jan. 10		Least Square Rules.
I.3	Jan. 10		Model Representation.
I.4	Jan. 10		Stochastic Setup.
I.5	Jan. 10		PEM.
I.6	Jan. 10		Model Selection.
I.7	Jan. 10		Design of Experiments.
II.1	March. 22		Recursive Identification.
II.2	March		State Space Systems.
II.3	March		Subspace Systems.
II.4	March		Instrumental Variables.
II.5	March		Nonlinear Identification.
Problem solving Sessions (Jan. - March 2011)			
Number	Date	Hour	Name
1	Jan.		Aspects of Least Squares.
2	Jan.		Statistical Analysis.
3	Jan.		PEM.
4	March		Recursive Identification.
Computer Lab (Jan. - March 2011)			
Number	Date	Hour	
1	Jan.		Least Squares.
2	Jan.		Timeseries.
3	Jan.		MATLAB `ident` GUI.
4	March.		Recursive Identification.
5	March.		MIMO.
Lab Work (March 2011)			
Number	Date	Hour	
Project Work (May 2011, 2 weeks)			
Number			Name
			Petrochemical Plant.
			Acoustic Impulse Response.
			Financial Stock Market.
			Multimedia.