Spring 2018

CE 603/EE 603: System Identification (4 units)

University of Southern California

The need to infer models of an unknown system from observed input and output data is ubiquitous in engineering, with applications spanning multiple disciplines. Invariably, one has to assume some structure of the model to make meaningful inferences. While many students are exposed to the topic of regression in their undergraduate courses, its applicability is severely limited.
This is a PhD level course dealing with the problem of estimating or building *dynamical* models of systems based on observed time series data. While the majority of the course focuses on techniques for linear time invariant systems, a considerable amount of time is also dedicated to nonlinear and time varying systems. The course content is heavily focused on techniques and algorithms, supplemented with periodic Matlab exercises (homework and in-class) using the System Identification Toolbox. A few lectures are also devoted to convergence analysis of some of the proposed techniques to help students gain a deeper understanding of the proposed techniques. A final class project will help students to apply the system identification techniques learned in this course to a topic of their choice.

Course Description

Methods for building linear and nonlinear dynamical models from input and output time series data; theoretical models, algorithms, and toolbox implementation.
Geared towards PhD/advanced MS students.

Learning Objectives

At the end of the course, the students are expected to be well-versed with standard system identification techniques for linear dynamical systems, in terms of algorithmic steps, theoretical properties, and practice using Matlab toolbox; and also be exposed to emerging topics in system identification of nonlinear dynamical systems. The students are expected to demonstrate comparative advantages/disadvantages of at least two techniques in the course project.

Course Instructor

Ketan Savla, KAP 254A, 213 740 0670, ksavla@usc.edu.

Class location, hours, and website

Location: WPH 205
Hours: MW 3:30-5:10 pm
The class will use the blackboard website at USC, https://blackboard.usc.edu/, as the primary medium for distribution of course material and announcements.

Prerequisites

- Linear control systems (e.g., EE 482, or AME 451)

Recommended Preparation

- Basic probability (e.g., CE 408, EE 364, or MATH 407);
- Exposure to basic optimization (e.g., ISE 330)

Grading

- 35% Homeworks
  There will be a total of six homeworks in this course.
- 25% Take home midterm exam
- 40% Course project

The course material will be derived primarily from the following books. Note that [2] can be accessed online through USC libraries, and [3] is available online for free.

Required Textbooks

[1] Ljung Lennart. *System identification: theory for the user*. Information and System Sciences Series. Prentice Hall PTR, USA, 2nd edition, 1999.

[2] Stephen A Billings. *Nonlinear system identification: NARMAX methods in the time, frequency, and spatio-temporal domains*. John Wiley & Sons, 2013. 2

[3] Peter Van Overschee and BL De Moor. *Subspace identification for linear systems: Theory—Implementation—Applications*. Kluwer Academic Publishers, 1996. 2

Class project

The purpose of the class project is to encourage students to explore material related to but outside the material covered in lectures, and possibly relate it to their own research. It is expected that the students will work individually on their projects.

Students will individually select a topic, possibly with the help of the instructor. Students are then expected to do literature review, perform theoretical or numerical research, write a report and present their results to the class. It is expected that the final output of the project will be suitable for a technical report.

Important dates for the class project

Project proposal due: February 21, 2018 (via email to the instructor)
In-class project presentation: April 25, 2018
Final report due: May 9, 2018 (via email to the instructor)

Project proposal: One page document, minimum of 10 pt, single spaced, single column, containing:

1. project topic,
2. name of the student,
3. references to the material that the student plans to cover, and
4. short description of the goals of the project.

Final report: A maximum of 8 page document, minimum of 10 pt, single spaced, single column, containing:

1. project topic,
2. name of the student,
3. review of literature,
4. final results and conclusion.

In-class presentation: A total of 20 min consisting of a 15-min presentation (maximum of 15 slides), followed by a 5 min Q & A session with the instructor and the class.

Resources for the class project: Academic licenses for the Matlab System Identification Toolbox will be distributed to the students enrolled in this class. The students will be encouraged to use data sources of their choice.

Tentative Course Schedule

The tentative schedule of the course is shown in Table 1. The list of topics to be covered during each class are listed below:

1. Introduction and LTI Models: FIR, MA, ARMA, ARX, ARMAX, Signal Spectra, Intro to Matlab System Identification Toolbox
2. Nonparametric Methods: Frequency response analysis, Fourier analysis, Spectral analysis
3. Parametric Methods I: Linear regression, Least squares method, Parameter estimation
4. Parametric Methods II: Maximum likelihood estimation, Instrumental-variable methods
5. Convergence Analysis I: Prediction-error approach, Correlation approach
6. Convergence Analysis II: Consistency, Asymptotic variance (time and frequency domain)
7. Subspace Identification I: State-space models, Kalman filter, Deterministic Identification
8. Subspace Identification II: Stochastic Identification, Combined deterministic-stochastic identification
9. Experiment Design: Persistence of excitation, Identifiability, Closed loop identification
10. Nonlinear Models: Linearization, Wiener and Hammerstein models, Fuzzy models
11. Neural Networks: Basis functions, Multi-layered models, Wavelets
12. Generalized Response Function Method: Volterra series representation, Generalized frequency response functions and its estimation
13. System Identification for Time-Varying Systems: Adaptive parameter estimation, Time-dependent spectral function, Time-varying frequency response function
14. Hands-on Case Studies I & II: Demonstration of the System Identification toolbox and practise using data repositories, e.g., http://homes.esat.kuleuven.be/~smc/daisy/daisydata.html.

Date	Topics	HW # out	HW # due
Week 1	Introduction, LTI models, System Identification Toolbox		
Week 2	Nonparametric Methods	1	
Week 3	Parametric Methods I		
Week 4	Parametric Methods II & Convergence Analysis I	2	1
Week 5	Convergence Analysis II		
Week 6	Subspace Identification I	3	2
Week 7	Subspace Identification II		
Week 8	Hands-on Case Studies I	4	3
Week 9	Mid Term Exam		
Week 10	Spring Recess - no class		
Week 11	Experiment Design, Nonlinear Models	5	4
Week 12	Neural Networks for Linear and Nonlinear Systems		
Week 13	Generalized Frequency Response Method for Nonlinear Systems	6	5
Week 14	Time-Varying Systems		
Week 15	Hands-on Case Studies II		6
Week 16	Project Presentations		

Table 1: Tentative Course Schedule

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* `https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions`. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, `http://policy.usc.edu/scientific-misconduct`.
Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* `http://equity.usc.edu` or to the *Department of Public Safety* `http://adminopsnet.usc.edu/department/department-public-safety`. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. The *Center for Women and Men* `http://www.usc.edu/student-affairs/cwm/` provides 24/7 confidential support, and the sexual assault resource center webpage `http://sarc.usc.edu` describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* `http://dornsife.usc.edu/ali`, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* `http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html` provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* `http://emergency.usc.edu` will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.