CHE 494/598: Introduction to System Identification
Spring Semester 2011

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Prerequisite: Undergraduate control course or equivalent. Prior exposure to working with MATLAB w/SIMULINK is expected. Knowledge of basic linear algebra and complex number arithmetic is desirable; knowledge of digital control design is helpful but not required.

Office Hours (Tentative): M W 11 a.m. – noon; other times by appointment.

Course Grading:

Midterm Exam	30%
Homework (nominally 6-8 problem sets; failure to turn in more than one problem set will result in 0% credit for the entire category)	40%
Final Course Project (598); Design Assignment (494)	30%

• Letter grades will be given at the discretion of the instructor based on overall class performance and (in some instances) individual student behavior. Class performance will be periodically reviewed and discussed by the instructor.

• CHE 598 students will be required to perform additional work in the midterm exam and homework sets beyond that required of ChE 494 students. Likewise, the final course project for CHE 598 will be more demanding than the design assignment required of CHE 494 students.

• Academic dishonesty (i.e., cheating) will not be tolerated in this course. Students engaged in any level of academic dishonesty will be referred to the Dean's office for disciplinary action. A signed statement of academic integrity will be required from every student.

Textbooks:

Required: None. Notes, presentations, as well as a draft of *System Identification for Engineering Applications and Beyond*, in preparation by the instructor, will be provided to students. Extensive use will be made of the course's ***myASU*** web site for distributing notes, homework sets and solutions, and other course materials.

Students must have access to Matlab with SIMULINK, Release 2009b or higher, with the Control System, Signal Processing, and System Identification Toolboxes installed. Matlab with SIMULINK is readily available to ASU students through *myASU*. The course will also make extensive use of novel interactive software tools that are free-of-charge.

Recommended:

Ljung, L. *System Identification: Theory for the User*, 2nd Edition, Prentice-Hall, 1999 (ISBN 0-13-656695-2).

Ljung, L. and T. Glad, *Modeling of Dynamic Systems*, Prentice-Hall, 1994, (ISBN 0-13-597097-0)

B.A. Ogunnaike and W.H. Ray, *Process Dynamics, Modeling, and Control*, Oxford University Press, 1994, ISBN 0-19-509119-1.

Additional References (all available on reserve from Noble Library):

Oppenheim, Willsky, and Young, *Signals and Systems*, Prentice-Hall, 1983.

Box, Jenkins, and Reinzel, *Time Series Analysis: Forecasting and Cntrl*, Third Edition, Prentice-Hall, 1994 (2nd edition is also useful, Box and Jenkins, Holden-Day, 1976).

Jenkins and Watts, *Spectral Analysis and its Applications,* Holden-Day, 1969.

van den Bosch, P.P.J. and A.C. van der Klauw, *Modeling, Identification, and Simulation of Dynamical Systems*, CRC Press, 1994 (ISBN 0-8493-9181-4).

D.E. Seborg, T.E. Edgar, and D.A. Mellichamp*, Process Dynamics and Control*, Wiley, 1989, ISBN 0-471-86389-0 (Second Edition: 2004;ISBN 0-471-00077-9).

Åström and Wittenmark, *Computer-Controlled Systems: Theory and Design*, 3rd Edition, 1997, Prentice-Hall, ISBN 0-13-314899-8 (2nd edition is also helpful)

Godfrey, K. *Perturbation Signals for System Identification*, Prentice-Hall, 1993, ISBN: 0-13-656414-3.

Pearson, R.K. *Discrete-Time Dynamic Models*, Oxford, 1999, ISBN: 0-19-512198-8.

Nelles, O. *Nonlinear System Identification*, Springer-Verlag, Berlin, 2001, ISBN: 3-540-67369-5.

Zhu, Y. *Multivariable System Identification for Process Control*, Pergamon, 2001, ISBN: 0-08-043985-3.

Special dates:

March 14 – 18: Spring Break – *no classes*.
Midterm exam will be scheduled either late March or early April.
Tuesday, May 3: Professor Lopes dos Santos lecture on subspace system identification.
Tuesday, May 10: Final course project and design assignment reports, due at noon.

Course Topics:

1. *Signals and Systems Overview*. Background material on signals and systems that is critical to conducting successful system identification is discussed. The material in this session is revisited (within the context of specific model structures and techniques) throughout the remainder of the course. Specific topics include: differential equations, Laplace transforms, frequency responses, Z-transforms, discrete-time transfer functions, Zero-Order Hold-equivalent pulse transfer functions, difference equations, deterministic versus stochastic signals, stationarity, autocorrelation, crosscorrelation, and auto- and cross-power spectral density.

2. *Nonparametric model estimation*. Nonparametric estimation considers the use of correlation and spectral analysis to obtain estimates of the plant impulse, step and frequency responses from identification data. The effectiveness of these methods as a means for getting useful precursor models for parametric system identification is discussed.

3. *Input Signal Design and Implementation*. The use and design of random and deterministic signals as inputs for system identification is presented. Among the signals presented are pulse, step, Random Binary Sequence (RBS), Pseudo Random Binary (PRBS), multi-level Pseudo Random (m-PRS) and multisine inputs. Emphasis is given to the systematic design of "plant-friendly" input signals (i.e., signals that can be introduced while the plant is in normal operation), the effective use of *a priori* information in input signal design, and real-time implementation aspects.

4. *Prediction-Error Model Structures, Parameter Estimation and Classical Model Validation.* Fundamental requirements for parametric estimation, particularly with regards to identifiability and requirements for consistent (asymptotically unbiased) estimation, are presented. Parametric estimation using one-step ahead prediction error model structures and estimation techniques (ARX, ARMAX, Box-Jenkins, FIR, Output Error) is described. These methods rely on regression (both linear and nonlinear) to compute the model parameters; all are supported by the functionality of the System Identification toolbox in MATLAB. The validation portion of the module presents the myriad of classical techniques (simulation, crossvalidation, residual analysis, etc.) for determining adequacy of the estimated models.

5. *Control-Relevant Identification.* This portion of the course emphasizes techniques that incorporate closed-loop performance requirements in the identification procedure (control-relevant identification). Topics in the control-relevant identification discussion include control-relevant parameter estimation using prefiltering, control-relevant input signals (e.g., minimum crest factor and Schroeder-phased multisine inputs), uncertainty estimation for robust control, and integrated identification with PID and digital controller design.

6. *Closed-Loop Identification*. The discussion on closed-loop identification addresses fundamental limitations associated with the presence of feedback in the system.

Students will understand why identification from plant normal plant operating records (failing to meet certain fundamental conditions on input design and model structure) is often unsucessful in providing useful models. Topics to be discussed include identifiability requirements for closed-loop identification, signal injection points for closed-loop identification, nonparametric closed-loop identification via correlation and spectral analysis, and considerations involved in using parametric estimation methods with closed-loop data (indirect and direct approaches). If time permits, *control-relevant* closed-loop identification via iterative refinement will be discussed.

7. *Identification of Multivariable Systems*. Many issues in multivariable identification extend naturally from single-input, single-output concepts. Additional issues involved in multivariable system identification include: 1). experimental /data generation issues: (multivariable Random Binary and Pseudo-Random Binary inputs, "zippered" multisine inputs), 2) multivariable parameter estimation (MISO PEM, MIMO ARX, state-space model identification, model reduction), and 3) integration of identification and control geared to popular industrial multivariable control algorithms, i.e., model predictive control. As before, emphasis will be given to methods that complement industrial practice.

8. *Issues in Nonlinear and Semiphysical System Identification*. Similarities and differences from linear system identification are discussed. Many results from linear system identification still hold when things go nonlinear and, to some extent, this knowledge and intuition from linear system identification can be very useful. We will point out some of the most important changes and pitfalls. Some nonlinear black-box models that are generalizations of linear models (Volterra, NARX, Hammerstein) as well as "trendy" nonlinear identification techniques (neural network-based ID, Model-On-Demand) will be presented. Some simple ways to combine physical knowledge and black-box techniques will be discussed.

Goal is to cover items 1 – 3 and some of item 4 prior to spring break, and the remainder of item 4 and items 5 – 7 following. Item 8 will be discussed as time permits. Aspects of some topics (such as closed-loop and multivariable system identification) will be introduced earlier in the course, as part of the discussion of items 1 – 3.

Course Schedule (Tentative)

Weeks 1 – 4:	Signals and systems fundamentals.
Weeks 5 – 7:	Nonparametric methods and input signal design.
Weeks 8 – 9:	Classical prediction-error methods and validation
Week 10:	Control-relevant identification.
Week 11:	Closed-loop identification.
Weeks 12 and 13:	Multivariable system identification
Week 14:	Issues in nonlinear and semiphysical system identification.