Fall 2020
ME 584: System Identification

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Office Hours: **flexible by appointment**

COURSE TEXT: There is no text book for the course. Reading material will be posted on the course Brightspace site periodically. Lecture handouts will be posted to the course website before each lecture.

REFERENCES:
[1] *System Identification: Theory for the User,* L. Ljung, Prentice-Hall, 2nd Ed., 1999.
[2] *Identification of Dynamic Systems*, R. Isermann and M. Munchoff, Springer, 2011 (Available from Purdue Library online).
Other reference materials will be provided via Purdue Brightspace

PREREQUISITE: ME475/undergraduate control, linear algebra + differential/difference equations, industrial experience or the consent of the instructor.

OBJECTIVES: This course connects mathematical models to data from measurement. It is intended to facilitate the students to gain:

- Familiarity with the method of least squares and the numerical methods used to implement it. The connection between estimation and experiment design.
- An understanding of the algebra of random variables and maximum likelihood estimation adequate for connecting the real world of experimental data to the abstract world of mathematical models.
- Familiarity with various empirical and semi empirical model structures that can be identified from data including ARMAX type models, neural network models (supervised and unsupervised)
- The ability to extract physical parameters from experimental data, whether the physical system is lumped or distributed; discrete or continuous.
- Understanding the subspace algorithms underlying much estimation, and machine learning techniques with a focus on the linear dimensionality reduction solved by nonnegative matrix factorization central to most state-of-the-art algorithms. Euclidean norm minimization yields principal component analysis or PCA.
- The ability to determine if the parameters extracted from data have any predictive or extrapolative power, optimality properties, or robustness to disturbances or data collection errors.
- An understanding of implementation issues—such as designing experiments, selecting model orders, noise levels, and preprocessing data.

In the main, this course seeks to simulate the work environment of the modern engineer or scientist. It aims at familiarity with algorithmic tools, their analytical and numerical foundations, and the ability to obtain relevant information to solve practical problems.

GRADING POLICY:

COURSE PROJECT: 50% **WEEKLY QUIZZES: 50%**

The quizzes test your understanding of subject material and the project updates test your ability to apply that material. Final grading will be cluster based (but 90+ will ensure A).

Grading will be performed in the week of the project update submission or quiz and posted on BRIGHTSPACE, so you can check on your performance regularly.

You must receive a passing grade on the project to pass the course.

PROJECT POLICY:

Project reporting is scheduled as follows. ***Project updates have to be submitted via Brightspace by the following Sundays, 11:59pm EST*** **(September 6, 13, 20, 27; October 11, 18; November 1, 15, 22; December 6)**. This includes your work of the previous week and your MATLAB/SIMULINK code (clearly documented). *No late submissions will receive points without prior permission*. Projects are to be an individual effort, but study group discussion, acquiring information and code from the web and library, MATLAB/SIMULINK code sharing/reuse, and cross-checking each other's work, are strongly encouraged. Project updates must be uploaded in ASME/IEEE journal format, in pdf, and must NOT add more than 2 pages to the overall document. The final document must occupy 15 pages or less. You can trim/modify prior sections when you update the report on each submission.

Each project update will be worth 50 points. 10 points will be deducted for each of consistency, correctness, formatting/typographic/referencing, coding/code formatting, and spelling/grammar. Project updates will consist ***APPROXIMATELY*** in the following steps:

1. Problem background, motivation and formulation with references
2. Model (dynamics + uncertainty representation) to be identified from data
3. Initial experiment design/data collection/preprocessing
4. Parameter estimation or model fitting
5. Checking for convergence and consistency of estimates and distributions
6. Computational issues
7. Optimal parameterization and robustness
8. Model (in)validation
9. Real-time and closed loop state and parameter estimation
10. Experiment design and preprocessing issues

QUIZ POLICY:

Quizzes will be posted online on **Mondays (August 31, September 7, 14, 21, 28; October 5, 12, 19, 26; November 2, 9, 16, 23)** and you will have a specified time (e.g., 1 hour) between accessing the quiz and submitting your solution scan on Brightspace, to be done by Sunday night. Grading will be based on the correct answer and the correct method. Each quiz will be worth 50 points and will consist in a single question—the best 10 scores will be considered for your grade. You will receive **ZERO** points for incorrect answers or for correct answers with incorrect methods (if that happens). The questions may have multiple correct answers. The quiz will be open notes/books—you can use the internet as well—but collaboration is forbidden and ***the usual penalties*** accrue on detection.

BONUS QUESTION POLICY: These will be posted in class slides and provide credit for class participation and discussion and exceptional project updates/quiz solutions. All correct answers to bonus questions will get credit (2 points each). In case several of you give the same answer, the first person to do so on the blog will get credit.

COMPUTER USAGE:

Course communication—announcements, lecture notes, scores and averages—will be through the course website on Brightspace When you login with your Purdue Career account access you should be able to access the ME584 site. You will be expected to use MATLAB/SIMULINK for the course project. It is strongly advised that you go through a self-paced MATLAB tutorial if you are not comfortable with MATLAB.

TENTATIVE COURSE OUTLINE

1. **Introduction and Least Squares Methods** — **1 week**
   - Connecting Models and Data
   - Linear regression
   - Nonlinear regression
   - Distributions of parameter estimates
2. **Models and Identifiability** — **3 weeks**
   - Random variables, maximum likelihood estimation and principal component analysis
   - Difference equation (DE) models or ARMAX type models
   - Mapping ODE/PDE models to discrete DE models (Inverse problems)
   - Pattern recognition
   - Neural network and machine learning models
   - Identifiability
3. **Implementation Issues** — **1 week**
4. **Parameter Estimation Methods** — **2 weeks**
   - Batch methods
   - Recursive methods
5. **Convergence and Consistency—Batch methods** — **2 weeks**
   - Statistical framework—least squares and maximum likelihood
   - Prediction error and correlation approaches
   - Fitting transfer function models to frequency response data
6. **Distributions of parameter estimates** — **1 week**
   - Batch methods
   - Recursive methods
7. **Computational Issues** — **1 week**
   - Solving least squares problems
   - Subspace methods
   - Linear dimensionality reduction with nonnegative matrix factorization
8. **'Optimal' Identification Criteria** — **1 week**
   - Robustness
   - Minimizing variance
9. **Model (In)Validation** — **1 week**
   - Selection of model structure
   - Selection of model order
10. **Real-time and Closed loop System ID** — **1 week**