EML 6934 (section 6385) - Fall 2009
Optimal Estimation

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Class time: period 4 (10:40-11:30 am) MWF
Class location: MAE-B 229
Office Hours: 11:30 am - 12:30 pm, MWF

Course website
Please check the course website regularly for updates and announcements:
`http://humdoi.mae.ufl.edu/~prabirbarooah/EML6934F09.html`

Teaching Assistant
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Course Outline
The purpose of this course is twofold : (1) provide a firm background in the mathematical basis of parameter and state estimation methods, and (2) provide training on how to (and how not to) apply them in practice. The first few weeks of the course will be an intense crash course in probability, in which concepts such as random variables, density functions, moments, etc. will be reviewed. After that, we will start with the problem of estimating a vector of parameters $\boldsymbol{\theta} \in \mathbb{R}^n$ from noisy measurements $\mathbf{z} = H\boldsymbol{\theta} + \boldsymbol{\epsilon}$, where $\boldsymbol{\epsilon}$ is a measurement noise vector. We will then examine the general problem of estimating one random vector given the measurement of another. Finally, we will examine the state estimation problem in which the state x_k of the linear system $x_{k+1} = A_k x_k + B_k u_k + w_k$, $y_k = C_k x_k + \theta_k$ is to be estimated, where w_k and θ_k are noise sequences (called stochastic processes) affecting the dynamic evolution and measurements.

Topics to be covered:
Review of linear algebra: least squares solution of linear equations and its application to parameter estimation of dynamical systems from input-output data.

Review of Probability and Random Variables. Combinatorics, Probability spaces, random variables, density functions, moments (esp. mean and variance), concepts related to multiple random variables, joint density functions, independence, conditional density, etc.

Best Linear Unbiased Estimator and Least Squares Estimator. Recursive Least Squares. Maximum Likelihood and Maximum A-posteriori Estimators. Asymptotic properties of estimators - unbiasedness and consistency. Crámer-Rao Lower bound. Reexamination of the unbiased minimum variance estimator - conditional mean. Review of Linear Least Squares Estimation - Optimization in Hilbert Spaces and the Projection Theorem.

State estimation, the discrete time Kalman Filter, Extended Kalman Filter. Discrete time prediction and smoothing.

Course prerequisites
Very strong mathematical skills. The three main topic areas that the course draws from are probability theory, linear algebra, and linear systems theory. The following courses are useful to have under your belt: EEL 5544 (ECE: Noise in Linear Systems), MAD 6406 (MATH: Numerical Linear Algebra), and either EML 5311 (MAE: Control System Theory) or EEL 5182 (ECE: State Variable Methods). You need not have done any of them, but some familiarity with linear algebra and linear systems is assumed. Familiarity with probability and random variables will *not* be assumed, instead I'll devote the first part of the course to that topic.

Evaluation criteria
Grading will based on homeworks and in-class quizzes (25%) two exams (25% each) and a final project (25%).
The first exam is *tentatively* scheduled on September 30, 2009, in class.
The second exam is *tentatively* scheduled on Nov 9, 2009, in class.
The mid-terms are budgeted at 45 minutes each. Details of how the final projects will be evaluated will be discussed in class.

Homeworks
Homeworks will be assigned every week. A randomly chosen subset of the homework problems will be chosen and graded, and your score in that homework will be based on those.

Textbook:
There is **no required textbook** for this course. The following are recommended books/resources on estimation:

1. *Optimal Estimation of Dynamic Systems*, John L. Crassidis and John L. Junkins, Chapman & Hall/CRC, ISBN 158488391X (good book written with an MAE audience in mind than an ECE one, but does not deal with the statistical component in detail.)

2. *Lessons in Estimation Theory for Signal Processing, Communications, and Control*, 3rd Ed., Jerry M. Mendel, ISBN 0131209817 (contains all the material on estimation to be covered in the course, but poorly organized. Assumes knowledge of probability and random variables.)

3. Arthur Gelb (Editor), *Applied Optimal Estimation*. (very good text for state estimation of dynamic systems if you have some familiarity with the material, not recommended for beginners.)

4. *A tutorial introduction on Estimation and Filtering*, Ian Rhodes, *IEEE Transactions on automatic control*, vol. AC-16, no. 6, Dec. 1971, pp. 688-706. (best resource among all of the above, but extremely dense)

This course makes extensive use of (1) probability, (2) linear algebra, and (2) linear systems theory. The following are recommended as references for the first two topics:

Probability and random variables

1. *Introduction to probability*, 2nd revised edition, Charles M. Grinstead and J. Laurie Snell, American Mathematical Society, 1998. (Excellent book on probability, available for free in PDF format from

`http://www.dartmouth.edu/~chance/teaching_aids/books_articles/probability_book/book.html`

2. *A first course in probability*, Sheldon Ross, Prentice Hall, ISBN 0130338516 (undergraduate-level textbook, very good)

3. *Probability and Random Processes with Applications to Signal Processing*, Henry Stark and John W. Woods, Prentice Hall, 3rd ed., 2002, ISBN 0-13-020071-9. (good graduate level textbook, beginner-friendly, at least until the random variables part.)

4. *Probability, Random Variables and Stochastic Processes*, Athanasios Papoulis, McGraw-Hill Companies; 3rd edition, ISBN-10: 0070484775 (excellent, classic textbook, also contains many topics on estimation. However, it is extremely dense and not beginner-friendly)

Linear algebra

1. *Matrix analysis and applied linear algebra*, Carl D. Meyer, Society for Industrial and Applied Mathematics (SIAM), 2000 (very good and extensive textbook, available for free in PDF format from

   `http://matrixanalysis.com/DownloadChapters.html`)

2. Linear algebra and its applications, 3rd Ed., Gilbert Strang, ISBN-10: 0155510053.

Make up exams etc.
If you have to miss and exam, you must see the instructor and make arrangements in advance unless an emergency makes this impossible.

Computers, Calculators etc.
MATLAB is required to solve some home work problems. You may want to purchase the student version of MATLAB. The full version (including many toolboxes) is available in the MAE Undergraduate Computer Lab in NEB 109, and at CIRCA computer clusters campuswide (labs.circa.ufl.edu).

You should bring a calculator to class and to the exams. Cellular phones, PDAs, etc. will NOT be allowed in place of calculators.

Students with Disabilities
The University of Florida provides high-quality services to students with disabilities, and we encourage you to take advantage of them. Students with disabilities needing academic accommodations should 1) Register with and provide documentation to Disability Resources (392-1261), and 2) Bring a letter to the instructor from this office indicating that you need academic accommodations. Please do this as soon as possible, preferably within the first week of class.

Academic Integrity
All students admitted to the University of Florida have signed a statement of academic honesty committing themselves to be honest in all academic work and understanding that failure to comply with this commitment will result in disciplinary action. Academic honesty is therefore taken quite seriously in this class.
Homework assignments are for your benefit. The only way to learn the material covered in class well is to apply it to solve problems, and homeworks give you an opportunity to do so. If you turn in someone else's work as your homeworks, you lose this valuable opportunity. That said, collaboration on homework problems, provided its purpose is to advance your understanding and not your grade alone, can be beneficial. Such collaboration is allowed, unless it is explicitly prohibited on certain assignments. In any case, you must write up your own homework independently. On problems involving MATLAB programming, you have to write your own program.