DEPARTMENT OF
ELECTRICAL &
COMPUTER ENGINEERING

ENEE 621 Estimation & Detection Theory

Information Sheet

Spring 2005

Instructor:

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Dr. Papadopoulos will be **very available** during his office hours and you are encouraged to come by his office during the times indicated.

Course Synopsis:

ENEE 621 is a graduate-level introduction to the fundamentals of detection and estimation theory. The concepts and techniques we will develop are extraordinarily rich versatile and powerful, and form the basis for an enormous class of algorithms used in an extraordinarily diverse range of applications. At the same time, everyone contemplating taking ENEE 621 should understand that this is an intense, vigorously paced, and extremely demanding subject—both conceptually and in terms of its workload. However, assuming you come with the right background (*i.e.*, prerequisites) and are ready to make the serious commitment that the subject demands, it can be an extremely rewarding experience.

The material in the course constitutes a common foundation for work in the areas of statistical signal processing, communications, and control. Ultimately, the course is about getting you to develop new ways of thinking about signals and systems and solving problems that involve them. The development of the material that forms the basis of ENEE 621 has historically been driven mostly by applications. However, we emphasize that our focus on the course will not be on the applications—which form the basis for entire courses of their own—but on the common problem solving framework that they share. Nevertheless, we will cite various relevant applications as we develop the material and sometimes extract simplified examples from these contexts.

Prerequisites:

Although, strictly speaking, prerequisites are not enforced at the graduate level, ENEE 620 (or equivalent) is an official and essential prerequisite for ENEE 621. In general, ENEE 621 assumes fluency, with discrete- and continuous-time linear systems, discrete- and continuous-time stochastic processes, and some basic linear algebra. Equally important to the specific prerequisites, a high level of maturity, dedication, and commitment to understanding the concepts in depth is expected of all who take the subject. In fact, we caution any undergraduate students enrolled in the course that it is very likely that they find the intensity and demands of the course unmanageable.

Lectures:

Mondays and Wednesdays 3:30pm–4:45pm, CHE 2108.

Attendance to lectures is assumed, but not formally recorded. Lectures work best when they are highly interactive, so your participation is important and strongly encouraged. Asking questions both in class and in office hours is a sign of engagement in the material, not an expression of weakness.

Required Text:

H. V. Poor, *An Introduction to Signal Detection and Estimation,* Springer-Verlag, 1997.

Many of the students that have (taken this course in the past and) used the above text as the required text have found its notation difficult to digest. For this reason, we will try to consistently employ a different (hopefully less cumbersome) notation; you are expected, however, to be able to do the assigned reading from the book despite the notation differences.

References:

A list of references on detection and estimation theory, background material, and advanced topics is appended to this handout.

Course Handouts:

Course handouts will be be available on the course web site. A select subset of these handouts will also be distributed in class.

Problem Sets:

There will be quasi-weekly problem set assignments. Each problem set will include a collection of required problems. Some assignments will also include one or two, often (but not always) more challenging, optional problems. You can make use of these optional problems when you think you might benefit from (and you have time for) extra practice with the material. Problem set solutions will be available at the end of the due date lecture.

You are expected to do **all** the assigned problems. Although your homework will *not* be collected and, as a result, it will have no direct impact on your final grade, working through (and, yes, often struggling with) the homework is a crucial part of the learning process. As such, it will invariably have a major impact on your understanding of the material and, in turn, your exam performances and your final grade. Moderate collaboration in the form of joint problem solving with one or two of your classmates is permitted and even encouraged, provided that you struggle with the problems on your own prior to interacting with classmates. In making the exams and in assigning a final grade we will assume that you have worked **all** the assigned problems.

Exams:

There will be three exams, all of which will take place in CHE 2108. The exam dates are as follows:

Exam 1: **Wednesday, March 9, 3:30–4:45pm;**
Exam 2: **Wednesday, April 20, 3:30–4:45pm;**
Final Exam: **Wednesday, May 18, 1:30pm–3:30pm.**

All exams will be closed book. However, you will be allowed to bring **one** 8.5×11-inch sheet of notes (both sides) to Exam 1, **two** 8.5×11-inch sheets of notes (both sides) to Exam 2, and **three** 8.5×11-inch sheets of notes (both sides) to the final exam. Good exam problem suggestions from the class are always welcome (and come with an obvious benefit to you if your problem is chosen).

In the case of a dispute involving an exam grade, a *written* request to regrade must be submitted including a full explanation of the nature of the dispute.

Course Grade:

The final grade in the course is based upon our best assessment of your understanding of the material and your class participation during the semester. Roughly, the weights used in grade assignment are:

- Exams 1 and 2: 30% each
- Final exam: 40%

However, other factors such as class participation can make a significant difference in the final grade. In general, the process of assigning a final grade involves our best assessment of each student's mastery of the class material, and very often a careful review of the final exam is involved to examine the kinds of mistakes that were made. Although the focus of the course is learning, not grades, we know that the final grade is important to you, and we want you to know that we take the process seriously.

Disabilities:

If you have a disability, you should contact Dr. Papadopoulos at your earliest convenience.

Course Web Site:

You may obtain pdf versions of the course handouts at the course web site:

`http://www.enee.umd.edu/class/enee621.S2005`

Course Syllabus:

I. Review of probability and random processes (3-4 lectures)
    - probability notation
    - random vectors; covariance matrices
    - Gaussian random vectors
    - abstract vector spaces

II. Detection theory, decision theory, and hypothesis testing (6 lectures)
    - Bayesian hypothesis testing; likelihood ratio tests
    - Neyman-Pearson tests; receiver operating characteristics
    - composite hypothesis testing, uniformly most powerful tests
    - randomized tests; M-ary Hypothesis testing
    - performance evaluation; bounds

III. Parameter estimation (9-10 lectures)
    - Bayesian parameter estimation; MAP, MAP, LS
    - linear least-squares estimation; orthogonality; normal equations
    - nonrandom parameter estimation
    - sufficiency, minimality, completeness
    - minimum variance unbiased estimation
    - Cramér-Rao bound; efficiency
    - maximum likelihood estimation (MLE); properties
    - nonlinear estimation.

IV. Detection and estimation from waveform observations (3-4 lectures)
    - random processes review
    - Karhunen-Loève expansions of random processes
    - detection and parameter estimation with random processes

V. Extensions and applications (4-5 lectures)
    - Wiener and Kalman filtering
    - linear prediction; modeling
    - system identification (if time permits)

Tentative Schedule

Homework				**Lectures**		
Out	**Due**	**Day**	**Date**	**#**	**Lecture Material**	**Topic**
1		W	1/26	1	Probability review; notation	Review
		M	1/31	2	Random vectors; covariance matrices	Review
2	1	W	2/2	3	Gaussian random vectors	Review
		M	2/7	4	Vector spaces; orthonormal bases	Review
3	2	W	2/9	5	Bayesian hypothesis testing (HT); LRTs	II.A, II.B
		M	2/14	6	ROCs; LRT/ROC properties; minimax HT	II.C
4	3	W	2/16	7	Neyman-Pearson tests; composite tests; UMPs	II.D, II.E
		M	2/21	8	HT with discrete-valued obs.; randomized tests	II.C, II.D
5	4	W	2/23	9	M-ary HT; performance evaluation and bounds	III.C
		M	2/28	10	Examples; Gaussian case; correlator/matched filter	III.B, III.C
6	5	W	3/2	11	Bayesian parameter estimation; MAE; MAP	IV.A, IV.B
		M	3/7	12	Bayes LS estimation; properties	IV.B
		W	3/9	**E**	*Exam 1 (through Lecture 10)*	☺
		M	3/14	13	Linear LS estimation; orthogonality; properties	V.C
7	6	W	3/16	14	Nonrandom parameter estimation; MVUE	IV.C
		M	3/28	15	Sufficient statistics; minimality	IV.C
8	7	W	3/30	16	Complete sufficient statistics and MVUEs	IV.C
		M	4/4	17	Cramér-Rao bound (CRB)	IV.C
9	8	W	4/6	18	Efficiency; Maximum likelihood estimation (MLE)	IV.D
		M	4/11	19	Properties of MLEs; examples	Notes
10	9	W	4/13	20	Nonlinear estimation	Notes
		M	4/18	21	Random processes review; Gaussian RPs; WGN	Review
		W	4/20	**E**	*Exam 2 (through Lecture 19)*	☺
		M	4/25	22	Whitening; Karhunen-Loève expansions of RPs	VI.A, VI.B, VI.D
11	10	W	4/27	23	Detection and parameter estimation with RPs	VI.C, VI.D, VII.B
		M	5/2	24	Noncausal and causal Wiener filtering	V.D
12	11	W	5/4	25	Discrete-time Kalman filtering	V.B
		M	5/9	26	Modeling; linear prediction	Notes
	12	W	5/11	27	TBA	
		W	5/18	**E**	*Final Exam (comprehensive)*	☺

References:

- Detection and estimation theory

  1. T. S. Ferguson, *Mathematical Statistics: A Decision Theoretic Approach,* Academic Press, 1967. A rigorous yet fairly accessible treatment of detection theory.
  2. S. M. Key, *Fundamentals of Statistical Signal Processing: Estimation Theory,* Prentice-Hall, 1993. Accessible and thorough treatment of estimation theory.
  3. S. M. Key, *Fundamentals of Statistical Signal Processing: Detection Theory,* Prentice-Hall, 1993. Accessible and thorough treatment of detection theory.
  4. E. L. Lehmann, *Testing Statistical Hypotheses,* Springer-Verlag, 1997. Rigorous and thorough treatment of detection theory; a classic.
  5. E. L. Lehmann, *Theory of Point Estimation,* Springer-Verlag, 1997. Rigorous and thorough treatment of estimation theory; also a classic.
  6. J. M. Mendel, *Lessons in Estimation Theory for Signal Processing, Communications, and Control,* Prentice-Hall, 1995. A workbook type reference on estimation theory, with emphasis on communication and control problems.
  7. L. L. Scharf, *Statistical Signal Processing: Detection, Estimation, and Time Series Analysis,* Addison-Wesley, 1991. Slightly more advanced treatment of several detection and estimation topics.
  8. K. S. Shanmugan and A. M. Breipohl, *Random Signals: Detection, Estimation and Data Analysis,* Wiley 1988. Elementary treatment of detection, estimation, and random processes.
  9. H. Stark and J. W. Woods, *Probability, Random Processes, and Estimation Theory for Engineers,* Prentice-Hall, 2002. A useful reference for many topics in the course, as well as the background material.
  10. C. Therrien, *Discrete Random Signals and Statistical Signal Processing,* Prentice-Hall, 1992. Very accessible reference for many topics in the course.
  11. H. L. Van Trees, *Detection, Estimation, and Modulation Theory: Part I,* Wiley, 2001. Classic and valuable reference text on detection and estimation theory.
  12. C. L. Weber, *Elements of Detection and Signal Design,* Springer-Verlag, 1987. Introduction to signal detection theory with emphasis on signal design and performance characteristics in communication systems.

- Stochastic processes and probability theory

  1. W. Feller, *An Introduction to Probability Theory and Its Applications, Vols. I and II,* Wiley 1968. Valuable formal reference set on probability theory.
  2. W. A. Gardner, *Introduction to Random Processes with Applications to Signals and Systems,* McGraw-Hill, 1990. Useful auxiliary reference for many topics in the course, particularly stochastic processes.

   3. R. M. Gray and L. D. Davidson, *Random Processes: A Mathematical Approach for Engineers,* Prentice-Hall, 1986. Bridges the gap between formal mathematical texts and engineering texts on probability theory.
   4. M. Loève, *Probability Theory I,* Springer-Verlag, 1977. Formal but reasonably readable treatment of probability theory; a classic.
   5. A. Papoulis, *Probability, Random Variables, and Stochastic Processes,* McGraw-Hill, 1991. Standard reference on stochastic processes and probability theory.
   6. E. Parzen, *Stochastic Processes,* Holden-Day, 1962. Classic formal text on stochastic processes.

- Additional background material
   1. R. A. Horn and C. R. Johnson, *Matrix Analysis,* Cambridge, 1985. Excellent reference on linear algebra and matrix theory; a classic.
   2. A. W. Naylor and G. R. Sell, *Linear Operator Theory in Engineering and Science,* Springer-Verlag, 1982. Accessible treatment of the mathematical foundations of vector space concepts.
   3. G. Strang, *Linear Algebra and its Applications,* Harcourt Brace Jovanovich, 1990. Standard reference on linear algebra.

- Texts on advanced topics and sample applications
   1. B. D. O. Anderson and J. B. Moore, *Optimal Filtering,* Prentice-Hall, 1979. Very extensive treatment of Kalman filtering.
   2. D. H. Johnson and D. E. Dudgeon, *Array Signal Processing: Concepts and Techniques,* Prentice-Hall, 1993.
   3. T. Kailath, A. H. Sayed, and B. Hassibi, *Linear Estimation,* Prentice-Hall, 2000. Advanced and thorough treatment of Kalman and Wiener filtering with emphasis on efficient implementation forms.
   4. E. Lee and D. G. Messerschmitt, *Digital Communications,* Kluwer Academic, 1994. Advanced reading on applications in communication theory.
   5. G. J. McLachlan and T. Krishnan, *The EM Algorithm and Extensions,* Wiley, 1997. Thorough treatment of the EM algorithm and its extensions.
   6. H. L. Van Trees, *Detection, Estimation, and Modulation Theory, Part III: Radar-Sonar Signal Processing and Gaussian Signals in Noise,* Wiley, 1968.
   7. A. Wald, *Sequential Analysis,* Wiley, 1947. Sequential analysis problems in the context of detection and estimation; a classic.
   8. J. M. Wozencraft and I. M. Jacobs, *Principles of Communication Engineering,* Waveland Press, 1990. Very readable of communication theory from an engineering perspective; a classic.