Stochastic Processes and Signal Processing

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Overview

This course is a graduate level course in statistical signal processing. We will discuss mostly linear second-order theory of random processes, and also approaches for filtering, estimation and detection of random and non-random parameters and processes with noise. This course will help students interested in signal processing applications to communication, control and biomedical engineering. While the course sets the foundations and will not focus on these applications, we will draw examples form many of these areas. The exposition will be mostly theoretical, though students may opt to do projects involving computational aspects of signal processing.

Prerequisites are a basic understanding of basic probability theory, basic linear algebra and signals & systems, all at undergraduate level.

Syllabus

The following list of topics is tentative, and may vary depending upon backgrounds and interests of students who attend the course.

1. **Stochastic Processes & Second-order Theory**
   - Review of Probability Theory
   - Vector spaces of Random Variables
   - Stochastic Processes
     - Fundamentals of Stochastic Processes: Gaussian and Markov processes
     - Second-order characterizations: wide-sense stationarity, autocorrelation, Wiener-Khinchine theorem, power spectral density
     - Stochastic Processes in linear systems
     - Representations: Kahrunen-Loeuve expansions

2. **Signal Detection Theory**
   - Bayesian and Neyman-Pearson Hypothesis Testing
   - M-ary hypothesis testing
   - Detection from waveform observations

3. **Signal Estimation Theory**
   - Bayesian estimation of random vectors, linear least squares estimation
   - Parameter Estimation, minimum variance unbiased estimators, Cramer-Rao bounds
   - Estimation from waveform observations
   - Wiener and Kalman filtering

4. **Advanced topics** (time permitting)
   - Non-linear estimation
   - Compressive Sensing
   - Particle Filtering

BOOKS

No text-books are required for the course. Lecture notes will be provided at the end of each lecture. It is suggested, however, that students browse through the table of contents for the Reference Books listed below under "Background Material" to see if they have the appropriate background. Other Reference books listed below are completely optional. We will not assume you have access to any of these books during the term.

Reference Texts

1. Background Material

While none of the references below are required, it is suggested that students browse through the table of contents (on Amazon, or Harvard library, or the publisher's website) of at least one book in each category to make sure they have the appropriate background. Some background will also be provided in the course.

- Basic Probability: Any one of the following books, or equivalent:
  - Leon-Garcia, A., *Probability, Statistics, and Random Processes for Electrical Engineering.* 3rd Edition, Pearson Prentice Hall, 2004. ISBN 0-13-147122-8. Chapters 1-4, 8, 9
  - Drake, A.*Fundamentals of Applied Probability Theory.* McGraw-Hill, 1967. ISBN: 0-07-017815-1
  - Helstrom, C. W. *Probability and Stochastic Processes for Engineers.* Macmillan, 1991. ISBN: 0-02-353571-7.
  - Stark, H., and J. W. Woods. *Probability, Random Processes, and Estimation Theory for Engineers*. 2nd ed. Prentice-Hall, 1994. ISBN: 0-13-728791-7. Chapters 1-4, Chapters 7,8.
  - Berteskas and Tsitsikilis. *Introduction to Probability.* Athena Scientific, 2002. ISBN: 1-886529-40-X.

- Signals and Systems: Any basic text on Signals and Systems, such as:
  - Oppenheim and Willsky. *Signals and Systems.* Prentice Hall, 1996. ISBN: 0-13-814757-4. Chapters 1-5
- Linear Algebra: Any basic text on Linear Algebra from an engineering point of view, such as:
  - Strang. *Linear Algebra and its Applications.* Harcourt College Publishers, 1998. ISBN: 0-03-010567-6, Chapters 1-6.

The following are for reference only. It will be assumed that you don't have access to any of these texts during the course.

2. Probability Theory

- A. Papoulis, *Probability, Random Variables, and Stochastic Processes,* McGraw-Hill, third ed., 1991, ISBN: 0070484686. (This is a very comprehensive text in Probability Theory & mostly can be used as a reference for the future).

3. Stochastic Processes & Second-order Theory

- Gray, R.M and Davisson, L.D., *An Introduction to Statistical Signal Processing,* Cambridge University Press, 2004, ISBN: 0-521-83860

4. Estimation & Detection Theory:

- Kay, S. M. *Fundamentals of Statistical Signal Processing and Estimation Theory.* Prentice-Hall, 1993. ISBN: 0-13-345711-7.
- Stark, H., and J. W. Woods. *Probability, Random Processes, and Estimation Theory for Engineers*. 2nd ed. Prentice-Hall, 1994. ISBN: 0-13-728791-7

5. Advanced Texts:

- Poor, H.V, *An Introduction to Signal Detection and Estimation,* Springer-Verlag 1994, ISBN: 3-540-94173-8
- Scharf, L. L. *Statistical Signal Processing: Detection, Estimation, and Time Series Analysis*. Addison-Wesley, 1991. ISBN: 0-201-19038-9.