

Spring 2009

Schedule# 213841 ME 578 Theory and Applications of Wavelets

MW 2:30 PM to 3:45 PM

Location: 215 Hammond

Recitation T 5:45 PM to 7:00 PM

Location: 214 Reber

Instructor: Professor Asok Ray; **Office:** 329 Reber Building; **Tel:** 5-6377; **Email:** axr2@psu.edu

Web Page Address: http://www.me.psu.edu/ray/graduate_courses.html

Instructional Objectives:

The objectives of this second-level graduate course are: (1) Development of the theory and applications of continuous and discrete wavelet transforms with emphasis on signal decomposition simultaneously in time/position and scale; and (2) Preparation for advanced course work and research in time-frequency analysis for systems modeling, system identification, and control. The course is developed for advanced graduate students and researchers in Engineering, Applied Mathematics, Information Science, Statistics, Physics, Meteorology, Geo-Sciences, and Life Sciences.

Course Outline:

Review Materials: Fundamentals of: Fourier series and integrals and their applications to time-frequency analysis of signals and their reconstruction; Review of adjoint spaces, reciprocal bases, biorthogonality, and resolution of the identity with applications to signal analysis in infinite-dimensional Hilbert spaces (e.g., L_2). Band-limited signals, Shannon sampling theorem, and effects of aliasing. Heisenberg uncertainty principle. Time frequency analysis of analytic signals. Harmonic analysis and generalization of Wiener theorem. Wigner distribution. 3 weeks

Specific Topics: Time/space--frequency/wavevector analysis and synthesis using the concepts of: Windowed Fourier Transforms (WFT); Continuous Wavelet Transforms (CWT); and Discrete Wavelet Transforms (DWT). Generalized frames for signal decomposition, signal reconstruction, and identification of the consistency conditions for WFT, CWT, and DWT in the setting of separable Hilbert spaces. 3 weeks

Continuous Wavelets: Weighting functions and admissibility requirements for decomposition and reconstruction of one-dimensional signals. Frequency localization and analytic filters. Interpretation of continuous wavelets as simultaneous Fourier-space physical-space filters. 3 weeks

Discrete Wavelets: General structure of FIR filter banks and their construction — halfband filters, spectral factorization, and maxflat filters. Introduction to MultiResolution Analysis (MRA). Operational calculus for Subband Filtering. Scaling functions and wavelet functions, and their relationships to low pass (moving average) and high pass (moving difference) filtering. Daubechies' orthonormal wavelet bases — recursive construction of scaling functions in frequency domain and dyadic interpolation in physical-space domain. Biorthogonal wavelets. Fast wavelet transform. 6 weeks

Computing Laboratory: Experiments on the relationship between physical-space and Fourier-space descriptions of one-dimensional and two-dimensional signals. Usage of WFT, CWT, and DWT tools for signal analysis and reconstruction. Applications to engineering problems, for example, in Acoustics & Vibration, Fluid Mechanics, and Electromagnetics.

Prerequisite: ME 550 or Math 501 or a course in Hilbert Spaces

Reference Books (Reserved in the Engineering Library):

- R. Bartle, *The Elements of Integration and Lebesgue Measure*, Wiley, 1995 (older version, 1966).
- L. Cohen, *Time-frequency Analysis*, Prentice-Hall PTR, 1995.
- I. Daubechies, *Ten Lectures on Wavelets*, SIAM Publication #61, 1992.
- G. Kaiser, *A Friendly Guide to Wavelets*, Birkhauser, 1994.
- S. Mallat, *Wavelet Tour of Signal processing*, 2nd ed., Academic Press, San Diego, 1998.
- A. W. Naylor and G.R. Sell, *Linear Operator Theory in Engineering and Science*, Springer-Verlag, 1982.
- H.L. Resnikoff and R.O. Wells, *Wavelet Analysis: The Scalable Structure of Information*, Springer, 1998.
- W. Rudin, *Real and Complex Analysis*, 3rd ed., McGraw Hill, 1987.
- G. Strang and T. Nguyen, *Wavelets and Filter Banks*, Wellesley, Cambridge Press, 1996.
- A. Teolis, *Computational Signal Processing with Wavelets*, Birkhauser, Boston, 1998.
- P.P. Vaidyanathan, *Multirate Systems and Filter banks*, Prentice Hall, 1993.
- M. Vetterli and J. Kovacevic, *Wavelets and Subband Coding*, Prentice Hall, 1995.
- B. Vidakovic, *Statistical Modeling by Wavelets*, Wiley, 1999.