Adv. Digital Signal Processing - Multirate and wavelets - Video course

COURSE OUTLINE

The subject of wavelets has received considerable attention over the last twenty years, with contributions coming from researchers in electrical engineering, mathematics and physics.

The word "wavelet" refers to a little wave, and implies functions that are reasonably localized both in the Time Domain and in the Fourier Domain.

The idea stems from the limitation posed by the Uncertainty Principle, which puts a limit on simultaneous localization in the time and frequency domains. As in the case of the Uncertainty Principle of Physics, the implications are seen more when one would like to make a microscopic analysis of signals.

In a number of signal processing situations, one does indeed need to look at local features: in fact, the requirement of simultaneous localization is far more widespread than often perceived. For example, there are many situations in audio, image and video where, for the purpose of analysis, one very often wishes to focus one's attention on a specific time/ space range and frequency range simultaneously.

A number of problems in digital communication also point to the implications of this uncertainty, and the need to address it suitably. The origin of the wavelet transform is in trying to achieve this to the best extent possible while working within the limits posed by the uncertainty principle. In fact, one may relate the idea of the wavelet transform to the use of a positional notation in the context of real numbers.

The wavelet transform allows a generalization of the positional notation for the context of functions. In fact, another aspect of the whole subject is multiresolution analysis - the process of analyzing phenomena and information with a scale/ fineness, matched to the content being analyzed.

This issue has important implications in waveform and signal synthesis and design, in data compression, in the analysis of signals coming from geophysical sources and biomedical sources, in locating and analyzing singularities in signals and functions, in interpolation and in many other areas.

The whole idea of wavelets manifests itself differently in many different disciplines although the basic principles remain the same. The aim of this course is to introduce the idea of wavelets, and the related notions of time-frequency analysis, of time-scale analysis, and to describe the manner in which technical developments related to wavelets have led to numerous applications.

A discussion on multirate filter banks will also form an important part of the course. The relation between wavelets and multirate systems will be brought out; to illustrate how wavelets may actually be realized in practice.

COURSE DETAIL

Module No.	Topics
1	A Beginning with some practical situations, which call for multiresolution/ multiscale analysis - and how time-frequency analysis and wavelets arise from them. Examples: Image Compression, Wideband Correlation Processing, Magnetic

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Electronics & Communication Engineering

Pre-requisites:

1. Basic engineering mathematics courses should have been done, typically in the first and second year of a typical four-year engineering programme.
2. A course on Basic Signal and Systems Theory/Applications and a course on first principles of Digital Signal Processing should have been completed.

Additional Reading:

1. Barbara Burke Hubbard, "The World according to Wavelets - A Story of a Mathematical Technique in the making", Second Edition, Universities Press (Private) India Limited 2003, Mathematics, Copyright 1998, ISBN 81-7371-450-9, Published by Universities Press (India) Private Limited, 3-5-819, Hyderguda, Hyderabad 500 029 (AP), India.
2. Stephen Welstead, Fractal and Wavelet Image Compression Techniques, Prentice Hall of India, New Delhi – Eastern Economy Edition, ISBN 81-203-2827-2, c 1999 by Society of Photo-Optical Instrumentation Engineers (SPIE).
3. George Bachman, Lawrence Narici, Edward Beckenstein, “Fourier and Wavelet Analysis, Springer International Edition (SIE), c 2000, Indian Edition, ISBN 81-8128-276-0. This book

	Resonance Imaging, Digital Communication.
2	a. Piecewise constant approximation - the Haar wavelet. b. Building up the concept of dyadic Multiresolution Analysis (MRA).
3	a. Relating dyadic MRA to filter banks. b. A review of discrete signal processing. c. Elements of multirate systems and two-band filter bank design for dyadic wavelets.
4	a. Families of wavelets: Orthogonal and biorthogonal wavelets. b. Daubechies' family of wavelets in detail. c. Vanishing moments and regularity. d. Conjugate Quadrature Filter Banks (CQF) and their design. e. Dyadic MRA more formally . f. Data compression - fingerprint compression standards, JPEG-2000 standards.
5	a. The Uncertainty Principle: and its implications: the fundamental issue in this subject - the problem and the challenge that Nature imposes. b. The importance of the Gaussian function: the Gabor Transform and its generalization; time, frequency and scale - their interplay. c. The Continuous Wavelet Transform (CWT). d. Condition of admissibility and its implications. e. Application of the CWT in wideband correlation processing.
6	a. Journey from the CWT to the DWT: Discretization in steps. b. Discretization of scale - generalized filter bank. c. Discretization of translation - generalized output sampling. d. Discretization of time/ space (independent variable) - sampled inputs.
7	a. Going from piecewise linear to piecewise polynomial. b. The class of spline wavelets - a case for infinite impulse response (IIR) filter banks.
8	a. Variants of the wavelet transform and its implementational structures. b. The wavepacket transform. c. Computational efficiency in realizing filter banks - Polyphase components.

introduces Fourier and Wavelet analysis in a mathematically rigorous manner – and could be

Coordinators:

Prof. V.M. Gadre
Department of Electrical EngineeringIIT Bombay

	d. The lattice structure. e. The lifting scheme.
9	An exploration of applications (this will be a joint effort between the instructor and the class). Examples: Transient analysis; singularity detection; Biomedical signal processing applications; Geophysical signal analysis applications; Efficient signal design and realization: wavelet based modulation and demodulation; Applications in mathematical approximation; Applications to the solution of some differential equations; Applications in computer graphics and computer vision; Relation to the ideas of fractals and fractal phenomena.

References:

1. Howard L. Resnikoff, Raymond O. Wells, “Wavelet Analysis: The Scalable Structure of Information”, Springer, 1998: available in Indian Edition.
2. Raghuveer M. Rao, Ajit S. Bopardikar, “Wavelet Transforms: Introduction to
3. K. P. Soman, K. I. Ramachandran, "Insight Into Wavelets - From Theory to Practice", Prentice Hall of India, Eastern Economy Edition, Prentice Hall of India Private Limited, M-97, Connaught Circus, New Delhi - 110 001, Copyright 2004, ISBN Number 81-203-2650-4.
4. Michael W. Frazier, “An Introduction to Wavelets Through Linear Algebra”, Springer, ISBN 3-540-780-75-0, c 1999, Reprint for sale in India, Pakistan, Bangladesh, Nepal, Sri Lanka only, at a reasonable price.
5. P. P. Vaidyanathan, “Multirate Systems and Filter Banks”, Pearson Education, Low Price Edition, ISBN 81 – 7758 – 942 – 3. This book introduces multirate systems and filter banks, making the connection to wavelets, very elegantly and systematically. It is written in a very lucid and student- friendly manner. The author’s own contributions to the field of multirate systems and filter banks are phenomenal, and well respected.