SOME STUDIES ON SIGNAL MATCHED FILTER BANKS

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by

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To my husband, parents and Prof. S.D. Joshi.

Certificate

This is to certify that the thesis entitled **"Some studies on signal matched filter banks"** being submitted by **Mrs. Binish Fatimah** to the **Department of Electrical Engineering, Indian Institute of Technology Delhi**, for the award of the degree of **Doctor of Philosophy** is the record of the bonafide research work carried out by her under my supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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Abstract

Signals which possess features at multiple scales, either because of the generation process or because of the process of measurement, can be efficiently modeled using multiresolution modeling techniques. An accurate signal model could throw some light on the evolution mechanism of the underlying signal and can also provide its mathematical representation. The theory of multirate filter banks and wavelets have been exploited by the researchers to propose various multiscale modeling schemes, for both statistical and deterministic scenarios. Also, in the recent past signal dependent multiscale modeling techniques, based on signal adapted filter banks, have been explored. Signal adapted filter banks possess high energy compaction property and are thus used in a variety of signal processing applications like dimension reduction, communication, compression etc. Although different design techniques have been proposed to obtain these filter banks, a design strategy for general case, i.e. 2 channel/ M-channel/uniform/ non-uniform and which leads to an FIR implementation is still an active area. Also computationally efficient solutions for the same are required to be found.

In view of the discussion above, we state the main issues, addressed in this thesis, are as follows: 1) given a signal or its statistics, obtain a signal adapted filter bank, which yields an optimum coding gain. Also provide a computationally efficient algorithm for the same, 2) assuming the class of signals which evolve in a multiband setting, model them as generated by synthesis side of the filter bank with stationary white noise inputs and obtain the model parameters and 3) given a signal or its statistics, propose a

signal dependent approach to decompose it into M-orthogonalized components carrying different spectral information.

To achieve these objectives, we begin with the concept of a signal matched filter bank, defined in [1], and propose a variate form which yields optimum coding gain. We also propose a geometric insight into the concept of signal matched filter bank and present a family of these filter banks with different design methodologies suitable for different applications.

A concept of signal matched whitening filter bank (SMWFB) is defined, which ensures de-correlation in time as well as across various channels, to yield an optimum coding gain. We obtain the required de-correlation by solving a constrained projection problem. The constrained projection problem is first proposed in a general context, in the form of a lemma. It is then used to define the required SMWFB.

The thesis also presents a concept of signal matched synthesis filter bank, corresponding to the proposed signal matched whitening filter bank, that reconstructs the given signal only. The multi input single output (MISO) synthesis filter bank is, first, converted into a single input single output (SISO) system, which is then interpreted in two different ways: first as a reconstruction filter for the proposed SMWFB and second as a model of generation for the given signal, which can be obtained as a solution to a prediction error problem.

A Hilbert space framework is defined to provide a geometrical interpretation of the proposed signal matched whitening filter bank as well as signal matched synthesis filter bank, for the "the given data case". Using the geometric setting, we present a time and order recursive least squares algorithm for the proposed signal matched filter bank involving only scalar computations. The recursions, so obtained, can be put in a form of a lattice-like structure. The filter parameters are, however, not directly available from this structure. For the estimation of these parameters, order recursive algorithms are also presented. However, in some applications it may be more reasonable to assume statistics rather than one realization. Thus, for such scenarios we have also developed a computationally efficient, order recursive algorithm for the proposed signal matched filter bank.

As a spin-off arising from the theory, developed in this thesis, we have proposed a signal matched filter bank to decompose a given signal into orthogonal components carrying different spectral information of the signal. Using the proposed scheme the signal can be decomposed into uniform as well as non-uniform frequency bands. Fast algorithms have also been developed to obtain the decomposition in a computationally efficient manner for "the given data case" as well as for "the given statistics case". As another spin off, the concept of signal matched synthesis filter bank is re-worked to obtain a multi input multi output (MIMO) system identification framework, which can have an adaptive as well as block processing implementation. The algorithm developed, here, involves only scalar computations, unlike the conventional MIMO system identification algorithms, where one requires matrix computations.

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List of Abbreviations and Symbols

AR	Autoregressive
ARMA	Autoregressive Moving Average
DWT	Discrete Wavelet Transform
FB	Filter Bank
FIR	Finite Impulse Response
IIR	Infinite Impulse Response
LHS	Left Hand Side
LPTV	Linear Periodically Time Varying
LS	Least Squares
LTI	Linear Time Invariant
MA	Moving Average
MIMO	Multi Input Multi Output
MISO	Multi Input Single Output
MMSE	Minimum Mean Square Error
NUFB	Non-Uniform Filter Bank

PCA	Principal Component Analysis
PCFB	Principal Component Filter Bank
PRFB	Perfect Reconstruction Filter Bank
PSD	Power Spectral Density
RHS	Right Hand Side
SIMO	Single Input Multi Output
SISO	Single Input Single Output
SMFB	Signal Matched Filter Bank
SMWFB	Signal Matched Whitening Filter Bank
SMSFB	Signal Matched Synthesis Filter Bank
SNR	Signal to Noise ratio
UFB	Uniform Filter Bank
WSCS	Wide Sense Cyclo-Stationary
WSS	Wide Sense Stationary