EC5.201 Signal Processing

Initial Project Report

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1 Project Topic

Two-channel digital and hybrid analog/digital multirate filter banks with very low-complexity analysis or synthesis filters

Reference Document

2 Project Distribution Flowchart

A. Digital Filter Banks

1. Review of 2 channel Digital filter banks
2. Proposed Filter Banks
   i. Analysis Filter Bank
   ii. Synthesis Filter Bank
   iii. Distortion and Aliasing
3. Filter Bank Design
   i. Analysis Filter Bank
   ii. Synthesis Filter Bank
4. Design Examples

B. Hybrid Analog/Digital Filter Banks

1. Review of Analog/Digital filter banks
2. Proposed Filter Banks
   i. Analysis Filter Bank
   ii. Synthesis Filter Bank
   iii. Distortion and Aliasing
3. Filter Bank Design
   i. Analysis Filter Bank
   ii. Synthesis Filer Bank
   iii. Approximate PR and PMR

3 Overview

Multirate signal processing systems have the capability of modifying the sampling rate for computational reasons. They comprise of analysis (using Discrete time and analog) and synthesis (Digital Filter) filter banks for conversions before and after processing. There are two types of outputs that's usually obtained:

Perfect Reconstruction (PR) – The Aliasing terms are zero and distortion in output is seen only in form of a delayed version of input.

Perfect Magnitude Reconstruction (PMR) – Here if the distortion function is a general all-pass function the magnitude is constant for all frequencies, but we will have phase distortion.

The filter banks are usually expected to achieved one of the above. When we try to achieve this, traditional filter banks aren't preferred if the objective is to minimize the complexity of the analysis/synthesis filter banks. Therefore, in the hybrid banks, we achieve to minimize the order and complexity of the filter.

The paper tries to achieve the digital and hybrid filter banks with a lower complexity. We try to control distortion and aliasing by applying linear programming and algorithms.

4 Digital Filter Bank

Analysis Filter Bank – This filter bank is made up of half-band, IIR low-pass and high-pass filters using Cauer Filter Pairs which have very low complexity. The two components of the analysis filters are linear phase filters with symmetric and antisymmetric impulse responses.

Synthesis Filter Bank – Digital synthesis filters are always FIR filters which are designed in two steps. Firstly, non-linear programming is used to equalize the phase distortion. Then the linear programming is used to equalize magnitude distortion.

Design – We take the filters in accordance to the analysis filters so as to obtain PMR/ PR. We improve the filter to obtain better phase response by using all-pass IIR filter (phase equalizer) in

cascade with filter. In the design, we also come consider two cases of filter where the aliasing function is exactly 0 and when it is arbitrarily small.

Overall Approach for Digital Filter Banks – The IIR analysis filter banks are first optimized to meet their requirements then optimized the FIR synthesis filters to meet requirements of distortion function. The optimization in the synthesis filters can use linear programming to find optimal or can also use the Parks-McClellan-Rabiner Algorithm.

5 Hybrid Filter Bank

The aim of designing the Hybrid ADC filter bank is that for an input signal strictly bandlimited to π/T, it is possible to eliminate aliasing completely in the filter bank.
However, if the filter bank has PR, the aliasing in the filter bank can be determined with an antialiasing filter preceding the filter bank.

Proposed Analysis Filter – We use two stable all pass filters, one with an odd order and the other with an even order, leading to the overall order of the system always being odd. Expressing the analog filter as a sum and difference of the two filters isn't necessary but will reduce the number of free parameters in these filters which is advantageous from the design point of view.

Design – The Analysis filter is first optimized. Requirements for the transfer functions in terms of passband and stopband attenuations are set according to application.

Proposed Synthesis Filters – We use a pair of Low pass and High pass filters composed of one nonlinear phase FIR filter and two linear phase FIR filters.

Design – With the analysis filter fixed, we move on to Synthesis filter design. Optimizations are first carried out on the nonlinear phase FIR filter and then on the two linear phase FIR filters.

Distortion and Aliasing – The details and formulation of the general form of the distortion and aliasing frequency responses will be explored in further project reports.

Approximate PR and PMR Filter Banks – Approximate PMR is a special case when there are no specifications on phase response for distortion and aliasing frequency responses. An approximate PR bank on the other hand includes specific phase requirements for the frequency responses.

6 Project Timeline

We aim to implement the following to give a brief overview of Multirate Signal Processing –

1. MATLAB Implementation of Decimation and Expansion
2. Show Resampling and Standard Analysis
3. Synthesis Filters explanation and demonstration.
4. Demonstration of Perfect Reconstruction Filter Banks
5. Equiripple Cauer Half Band Filter
6. Optimized filter design with Equiripple Filter using the Parks-McClellan Algorithm.

7 Other References

1. P. P. Vaidyanathan, Multirate Systems and Filter Banks. Englewood Cliffs, NJ: Prentice-Hall, 1993
2. Finite impulse response filter design," in Handbook for Digital Signal Processing
3. "Multirate Analog-Digital Systems for Signal Processing and Conversion," Proc. IEEE., Vol. 85, pp.242–262, Feb. 1997.
4. Digital Signal Processing 4th Edition by John Proakis, Dimitris Manolakis (Multirate Signal Processing Chapter)