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Image Processing Algorithms and Techniques III

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Image Processing Algorithms and Techniques III

James R. Sullivan
Majid Rabbani
Benjamin M. Dawson
Chairs/Editors

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Conference 1657, *Image Processing Algorithms and Techniques III,* was part of a five-conference program on Image Processing held at SPIE/IS&T's Symposium on Electronic Imaging Science and Technology, 9–14 February 1992, in San Jose, California. The other conferences were:

Conference 1658, *Nonlinear Image Processing III*
Conference 1659, *Image Processing and Interchange: Implementation and Systems*
Conference 1660, *Biomedical Image Processing and Three-Dimensional Microscopy*
Conference 1661, *Machine Vision Applications in Character Recognition and Industrial Inspection*

Program Chair: **Roger M. Morton,** Eastman Kodak Company

Introduction

The Image Processing Algorithms and Techniques III conference was one of five conferences in the Image Processing program in the 1992 SPIE/IS&T Symposium on Electronic Imaging Science and Technology. The purpose of the conference was to update the image processing community on recent developments in the areas of image coding, image rendering, restoration, and enhancement, and image segmentation and modeling. The conference was divided into three sessions spanning three and one-half days.

The first session, Image Coding, chaired by Nasser Nasrabadi from SUNY/Buffalo, started with six papers on multiresolution techniques and included papers on subband coding, progressive image transmission, pyramid coding, and multiresolution Markov models. This was followed by a wide array of papers on using neural networks to design vector quantization codebooks; lossless image compression of binary image data using arithmetic coding, Lempel-Ziv coding with preprocessing, run length coding, and a method called "base-bit + overflowing-bit" coding; lossless predictive coding of color graphics; three papers on the compression gains in JPEG; constraint-based coders; and a very interesting paper on using special look-up tables to increase the decoding speed of JPEG and MPEG. The Image Coding session was well attended and highly interactive, with excellent papers.

The second session, Image Rendering, Restoration, and Enhancement, chaired by Stanley Reeves from Auburn University, was divided into a section each on restoration and on image rendering and enhancement that both included nine papers. The image restoration papers were very strong, covering a wide range of applications such as medical imaging, motion sequences, low-light imaging, and synthetic-aperture radar. Of particular note were papers on the use of stabilizing functionals to preserve edges in image restoration by M. E. Zervakis from the University of Minnesota and a selective-deconvolution algorithm for multiresolution image data by Van Droogenbroeck and Vandendorpe from the University Catholique de Louvain (Belgium). The image rendering and enhancement papers included two papers on halftoning, three papers on color systems and quantization, two papers on interpolation for image magnification, and two papers on image enhancement using morphological operators and adaptive filtering. The papers on color quantization from Balasubramanian, Bouman, and Allebach of Purdue University and Chau et al. from the University of Regina (Canada) demonstrated good image quality for color printing with reduced color palettes, and the paper by Vhrel and Trussell of North Carolina State University on color filter design for illuminant correction was well formulated and presented with excellent results.

The third session, Image Segmentation and Modeling, chaired by Lawrence Ray of Eastman Kodak Company, contained eighteen papers on a variety of techniques in image analysis, edge and object detection and characterization, and source modeling. The diversity of papers was thought-provoking, but the attendance was sporadic. A particularly interesting paper in multidimensional surface reconstruction was presented by Jin, Yeap, and Cox from the University of Otago (New Zealand), wherein novel solutions to depth perception in smooth image regions and polygonal representations of surfaces were proposed. A second paper that was well received was by Zhang and

Gerbrands of Delft University of Technology (Netherlands) on developing long-awaited metrics for assessing the performance of image segmentation algorithms.

Overall, the authors and session chairs are to be complimented for an excellent program. Their efforts and expertise provided for a refreshing and highly instructive conference.

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Contents

(continued)

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SESSION 1

Image Coding

Chair
Nasser M. Nasrabadi
SUNY/Buffalo

Software Implementation of an Efficient Image Subband Coder

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Abstract

After a short review of IIR based subband coders, we describe the features of a software implementation of an efficient image subband coder (SBC). The efficiency of an SBC is heavily dependent upon the filter bank implementation. Experience has shown that at least 90% of the execution time of SBCs is spent in the filter bank. First we present our implementation based on extremely simple multiplier-free IIR filters. Subsequently, we discuss the implementation task from a programmer's point of view, emphasizing the algorithm implementation using only integer arithmetic. The experiments show that our IIR SBC's execution time is ten times faster than that of an efficient SBC based on FIR filter banks. Furthermore, our coder is twice as fast as the July 91 release of the Free Software Foundation's JPEG implementation, while maintaining comparable performance; – our SBC coded images had somewhat higher signal to noise ratio (SNR) than those coded with JPEG at the same bit rate. The subjective quality was found to be comparable.

1 Introduction

Straight forward digitization of images gives rise to enormous amounts of data. Image data compression, – the representation of digital images with a minimum of bits while maintaining as good visual quality as possible, has received considerable attention lately. This interest has manifested itself in several standards or standard proposals for the coding of both digital still images [1] and digital video [2, 3]. Common to these are their basis in transform coding employing the DCT. During the last 5 years another related technique, – *subband coding*, has also been the subject of considerable interest [4, 5, 6, 7, 8, 9, 10]. The two techniques are similar in the sense that both make use of the fact that different spatial frequencies of an image have unequal perceptual importance. The data compression achieved in both techniques is thus obtained by spending a very small number of bits on the perceptually less important frequency ranges and more bits on the more important ones. Transform coding is a *block oriented* technique, whereas subband coding is a global technique operating on the whole image as a single entity. In this lies an important difference between the two techniques that has implications on the appearance of images coded at low bit rates.

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Until quite recently, subband coding has been considered as a computationally complex image coding strategy. Recent research into low-complexity subband schemes are in the process of proving this conception to be wrong [11, 7, 12]. In fact, it has been shown that the operation count of IIR based SBCs are substantially lower than that of FIR based coders. In this paper we show that these computational advantages, – expressed in terms of operation count, do indeed lead to significant speed gains in a practical software realization of an image subband coder.

We have organized our paper as follows: Section 2 briefly explains subband coding based on efficient recursive filters. Results pertaining to the computational complexities of DCT coding, FIR and IIR based SBC are quoted. Subsequently, our approach to the software implementation is given. In the following section we present simulation results indicating the relative performance of IIR and FIR based SBC as well as DCT based coding, – here exemplified by the JPEG algorithm, in terms of coding/decoding speed and quality of the decoded images at low bit rates. Finally, in Section 5 we summarize and conclude the paper.

2 Efficient IIR Subband Coding of Images

In this section we briefly outline the principles underlying IIR based SBC emphasizing the filtering operations necessary. Subsequently, we present two basic methods of representing the subband signals in a bit efficient manner. Complexity figures, in terms of operation count, for FIR and IIR based SBCs and DCT based coding are also quoted.

2.1 Filter banks based on infinite impulse response (IIR) filters

In Fig. 1 we show a one-dimensional two-band analysis/synthesis filter bank system based on 2-point DFTs (discrete Fourier transforms) and first order allpass filters[1] of the form

$$A(z) = \frac{a + z^{-1}}{1 + az^{-1}}. \quad (1)$$

In this structure the signal $x_0(m)$ represents the low-frequency content and $x_1(m)$ the high-frequency content of the input signal. This system is a *perfect reconstruction system* since the IDFT and the DFT cancels out and allpass filters possess the property $A(z)A(z^{-1}) = 1$. More than two subbands are obtained by successive application of the basic two-band analysis filter bank in a tree structure as indicated in Fig. 2. The separable extension to two-dimensional signals is straight forward [11]. In our studies we employ an 8×8 subband split, giving rise to a total of 64 subbands.

The important feature of this class of filter banks is that the computational complexity is very low compared to filter banks based on FIR filters which are frequently used in image subband coding. This is evidenced by considering the basic filtering equation

$$y(n) = \sum_{k=0}^{K-1} h(k)x(n-k) \quad (2)$$

[1] I.e. filters having unity amplitude response for all frequencies.

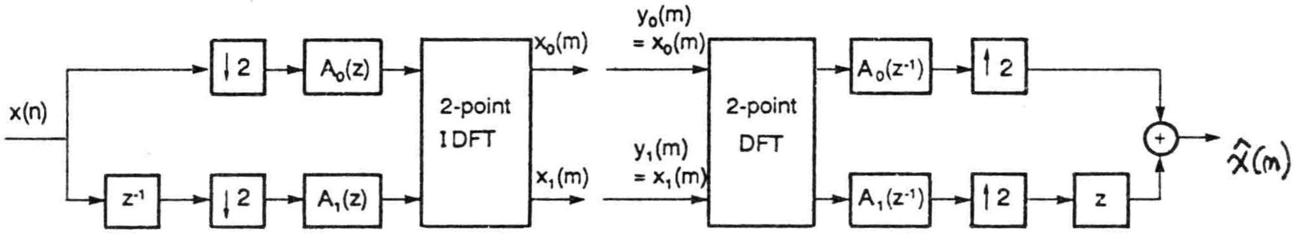

Figure 1: Perfect reconstruction analysis/synthesis IIR QMF system.

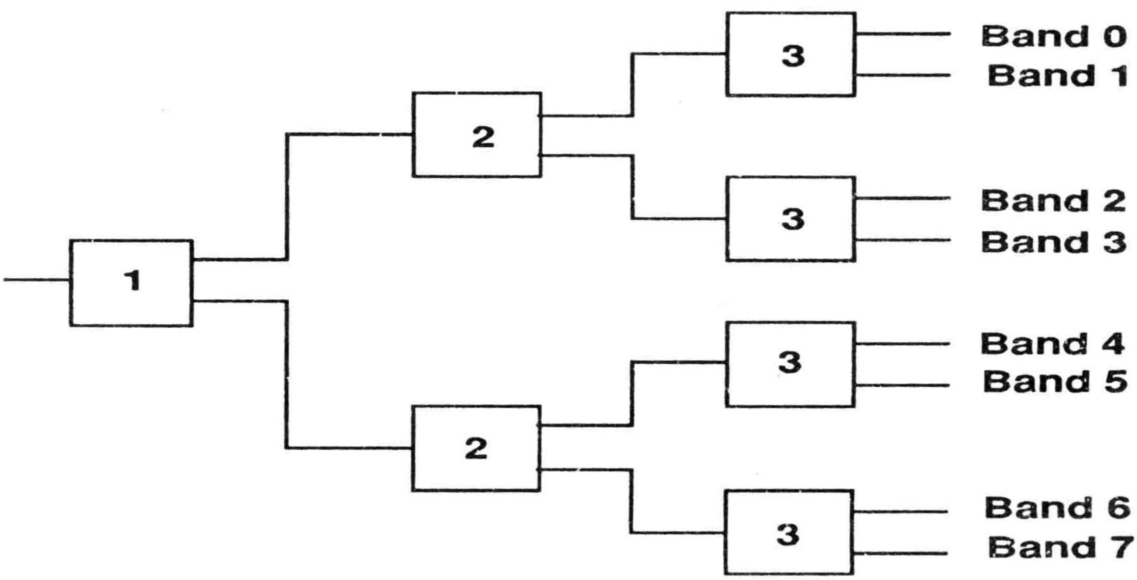

Figure 2: Tree structured filter bank. Each block represents a basic two-band analysis filter bank as shown in the left hand portion of the previous figure.

Filter Bank	Operations per Output Sample	
	Multiplications	Additions
DCT (8×8) [14]	4	6.5
DCT (16×16) [14]	5.5	9.25
FIR tree structure, 16 tap filter [7]	48	48
IIR tree structure, general filter coeffs. [7]	6	18
IIR tree structure, simple filter coeffs. (f22) [7]	0	30
IIR tree structure, very simple filter coeffs. (f21) [7]	0	15

Table 1: No. of multiplications and additions for the DCT and some 8×8 band FIR/IIR filter banks with simple coefficients [7].

which is required for FIR based filter banks and comparing it to the one required for allpass based IIR filter banks:

$$y(n) = a(x(n) - y(n-1)) + x(n-1). \tag{3}$$

Since K is typically 16 in the former equation the computational advantages of the latter equation is evident. Furthermore, good IIR based filter banks can be obtained with filter coefficients, a, being selected so that the multiplications of Eq. 3 can be realized by combinations of additions and bit-wise shift operations. To substantiate this, we show in Fig. 3 channel responses of four different 8 band filter banks built around:

- The 16B FIR filter of Johnston [13].
- IIR allpass filters $A_0(z) = \frac{0.1576+z^{-1}}{1+0.1576z^{-1}}$ and $A_1(z) = \frac{0.6148+z^{-1}}{1+0.6148z^{-1}}$.
- IIR allpass filters $A_0(z) = \frac{0.125+z^{-1}}{1+0.125z^{-1}}$ and $A_1(z) = \frac{0.625+z^{-1}}{1+0.625z^{-1}}$. This filter bank will be denoted f22.
- IIR allpass filters $A_0(z) = \frac{0.5+z^{-1}}{1+0.5z^{-1}}$ and $A_1(z) = 1$. This filter bank will be denoted f21.

We note that the latter two filters are easily implemented with no multiplications.

To give quantitative figures for the computational complexity involved in performing the DCT and the filtering involved in IIR and FIR based SBCs, we present in Table 1 some figures indicating the number of additions and multiplications required to produce one transform coefficient/one subband sample. The numbers are taken from [7, 11] in which a thorough complexity analysis is presented.

The key observations to be made from this table are as follows:

- FIR based subband coders are considerably more complex than those based on IIR filters and DCT based coders.
- By selecting simple (or very simple) coefficients in the IIR based subband coders, we can completely eliminate multiplications. Depending on the type of realization aimed for, there seems to be a potential for efficiency advantages for IIR SBC realizations, – also when compared to DCT based realizations.

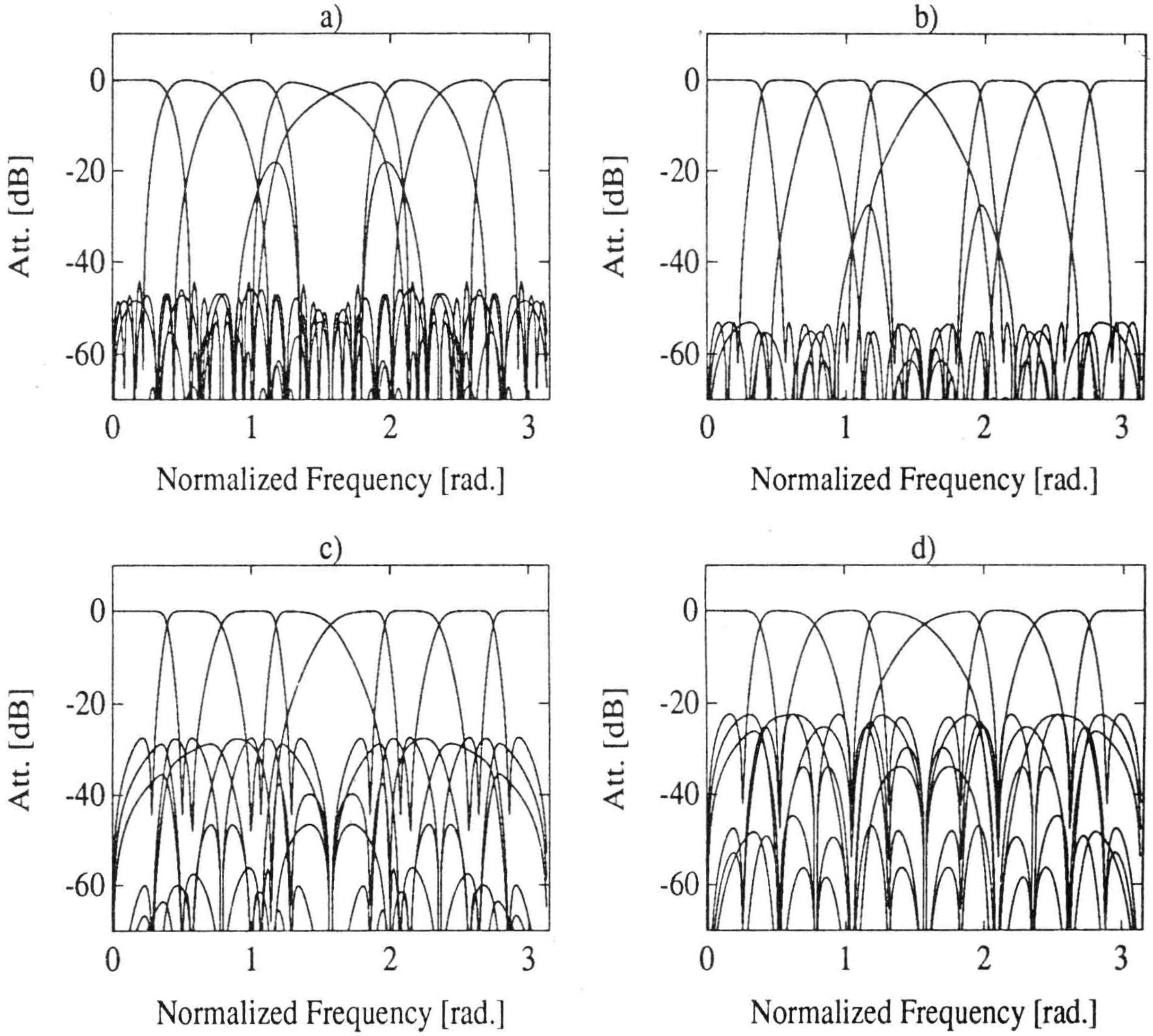

Figure 3: Magnitude response for eight-band tree structured filter banks based on a) FIR filter 16B of Johnston [13], IIR allpass filters with coefficients b) 0.1576 and 0.6148, c) 0.125 and 0.625, and d) 0.5 and $A_1(z) = 1$.

Although some argue that these figures are primarily of "theoretical value", we show in our experiments that the computational gains referred to above indeed make efficient software implementations for IIR based SBCs feasible.

2.2 Bit efficient representation of the subband signals

It is well known that the major part of the signal energy is concentrated in the subbands representing the low-frequency content of the image. This seems to suggest that we allocate bits according to perceptual importance of the various subbands. Two possible strategies for the representation of the subbands [11] are:

- We might distribute the bits according to measured energy of the subband signal samples. This technique is called *explicit bit allocation.*
- We might utilize the a priori information that the perceptual importance (as well as the energy) of subband sample coefficients tend to drop off as the spatial frequencies which they represent increase. This observation, - originally made for transform coders, led to the well known *zigzag scanning/threshold coding* scheme in which one-dimensional arrays are formed by arranging transform coefficients in order of increasing spatial frequency [15]. The same idea is employed to subband samples in [11, 7]. These arrays, – of subband samples, are thresholded and quantized by a uniform quantizer. Since this will, typically, result in a large number of *clustered zeroes* in the one-dimensional arrays, coding gains can be realized by run-length coding. Further gains are obtained by applying an *entropy code* to the codewords resulting from the run-length coding.

Since the latter method is considerably more efficient in terms of computational complexity and also has somewhat better performance than the former [11], – we have used the *zigzag scanning/threshold coding* scheme in our implementation. An adaptive Huffman coder was used for the entropy coding.

3 The efficient software realization

The computational complexity of an 8×8 tree structured separable filter bank (i.e. 3 stages in the filter tree) is proportional to $6Mc$ where M is the number of pixels in the image to be subband coded and c is some constant denoting the complexity associated with the filtering operations in the basic building blocks of the filter bank. In employing IIR filters as opposed to FIR filters we attempt at lowering the c. This c is furthermore reduced by employing filters implementable with no multiplications[2].

In Fig. 4 we have redrawn the basic two-band analysis and synthesis filter banks in a way that is more readily implementable than what is the case for Fig. 1. In particular it is noted that we employ a *sample advance* rather than a sample delay in the analysis bank. Furthermore, the filters $A_{0,1}(z^{-1})$ of the synthesis filter bank in Fig. 1 are substituted with $A_{0,1}(z)$ since we apply *time-reversed* subband signals to the synthesis filter bank [16]. This means that the only two filtering

[2]This is somewhat dependent on the architectures on which the algorithms are to be implemented, but is true for typical micro processor architectures.