

Lifting Based Wavelet Transform for Lossy to Lossless Image Coding

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ABSTRACT: In the field of image coding many researchers demand increases for application in multimedia, communications and computer networks. It provides higher compression ratio which is desired and retaining good image quality which is needful in the present demanding environment.

Many multimedia applications are demanding for low memory disk space requirement, faster and good perceptual quality for images/video. This paper, reviewed abundant attempts made by researchers which fulfill the requirement of lossy to lossless coding. Mostly used image coding was DCT which is replaced by DWT.

This paper have presented various methods for lossy to lossless image coding domain. In the field of research there is the advancement in filter banks and wavelet transforms based lifting, image coding with filter banks is currently best suitable method in all aspects.

Keywords: Filter banks, lifting based wavelet transform, image compression techniques.

1. INTRODUCTION

Image compression method is mostly used to reduce the amount of data required to represent an image. Image compression provides the compact representation of an image, therefore reducing the image storage, transmission requirements. As there is great advancement in multimedia and internet applications, the demands and requirements of the technologies used, grew and developed. So to fulfill these demands and requirements in area of digital image compression, many efficient techniques with considerably different features have been formulated for both lossy and lossless image compression.

There are many lossy compression algorithms developed for image coding such as the predictive coding [1], the transform coding [2], the wavelet coding [3] and vector quantization [4]. To remove redundancy predictive coding deals with de-correlation of similar neighboring pixels within an image. Transform coding, an efficient coding scheme is based on employment of inter-pixel correlation which is a core technique recommended by JPEG. Another well-known form of data compression which is adapted for image and audio compression is Wavelet coding.

One of the most efficient methods of lossy compression of images and other random signals is transform coding.

From year 1971 image compression began to deal with transform coding with the application of discrete Fourier transform for achieving image compression [5]. Usually transform coding method uses the Fourier related transforms such as the KL transform [6], HADAMARD transform [7] etc. Singular value decomposition [8] is defined as the representation of the data using smaller number of variables. It had been widely used for image compression. In past few decades, Discrete Cosine Transform has been widely used for image coding which provides optimal performance and it can be implemented at a reasonable cost. Wavelets for image coding applications were used first in the year 1989. The wavelet transform has established beyond consideration to be very effective and has gained popularity over the DCT. Discrete Wavelet Transforms have the skill to solve the blocking effect that sticks in the DCT. From last few years Different wavelets and its variants were used to accomplish better compression.

2. PERFORMANCE METRICS

To evaluate the performance of image compression systems, a technique to measure compression is needed.

For this, the compression ratio (CR) metric is often employed and is defined as [9]

$$CR = \frac{\text{original image size in bits}}{\text{compressed image size in bits}} \quad (1)$$

Sometimes compression is instead quantified by stating the *bitrate* (BR) measured by compression in bpp (bits per pixel). The bit rate after compression and compression ratio are related as [9]

$$BR = \frac{\text{bits /pixel for original image}}{CR} \quad (2)$$

In the case of lossy compression, the reconstructed image is nearly equal to the original. The difference between the original and reconstructed signal is defined by approximation error or *distortion*. It is expressed in terms of *mean-squared error* (MSE) or *peak-signal-to-noise ratio* (PSNR). These are defined, respectively as in [9],

$$MSE = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (x[i, j] - \hat{x}[i, j])^2 \quad (3)$$

Where x is the original image with dimensions $M \times N$ having P bpp, and \hat{x} is the reconstructed image. Evidently, smaller MSE and larger PSNR values gives the lower levels of distortion which vary with the amount of compression. In other words, distortion is a function of compression rate (i.e., compression ratio). For this reason, plots or tables of distortion versus rate are often used to analyze lossy compression performance. Obviously, the lowest possible distortion is desired for any given rate.

3. LITERATURE REVIEW

3.1 Discrete Cosine Transform (DCT)

In DCT, the visibility of coding artifacts due to coefficient of quantization may alter due to sensitivity of DCT to phase, depending on the position of an object. As the DCT is a strictly bounded block transform, problems of transform coding at low bit rates, called blocking effect may exist. The blocking effect is a natural consequence of the independent handling of each block. Due to these visible discontinuities in features, the cross block boundaries are observed in images (in the inter frame image coding with motion-compensated frame prediction) though blocking effects are not so disturbing, but are still perceptible [10].

In literature, some methods for the reduction of blocking effects have been discussed [11]-[13]. In [11], two methods were presented: overlapping, and filtering. In the overlapping method [12], redundant information is transmitted for samples in block boundaries, as blocks overlap slightly. At receiver, the reconstructed samples are average of neighboring blocks, in the overlapping areas. The disadvantage of this approach is the total number of samples to be processed is increased, and which further causes of an increase in the bit rate. In filtering method [13], the coding process at the transmitter is maintained same, and at the receiver low boundary pixels are subject to pass through a low-pass filter. However, this method does not increase the bit rate; the signal across block boundaries is blurred. In [13], authors have presented the filtering method that avoids blurring by employing a prefilter at the transmitter [10].

3.2 Lapped orthogonal Transform (LOT)

A new family of transforms for blocking signal coding is presented which has similar advantages of the overlapping method cited above, but without an increment in the bit rate. These new transforms collectively referred to as the lapped orthogonal transform, or LOT [10],

In traditional block-transform processing, such as in image and audio coding, the signal is partitioned into blocks of M samples, and each block is made to process independently, it is well known that under an orthogonal transformation, signal energy is preserved, [14] assuming stationary signals, i.e.,

$$M\sigma_x^2 = \sum_{i=0}^{M-1} \sigma_i^2 \quad (4)$$

Where σ_i^2 the variance of output is transform coefficient and σ_x^2 is the variance of the input samples.

3.3 Generalized Linear-Phase LOT (GenLOT)

The LOT is a popular Lapped transform with $N = 2$ whose basis functions are symmetric [16], its transform matrix, representing its fast algorithm, is given by

$$PLOT = \begin{bmatrix} U_1 & 0 & D_e - D_o & (D_e - D_o)J_{M/2} \\ 0 & V_1^T D - D & - (D - D)J_{M/2} \\ 1 & E_o & E_o & 2 \end{bmatrix} \quad (5)$$

Where D_e is the $M/2 \times M$ matrix with the even-symmetric basis functions of the DCT and D_o is the matrix with the odd-symmetric ones. Examining the symmetries of D^H , it is easy to see that D_e and D_o have the entries d_{ij}^H for i even and odd, respectively. U_1 and V_1 are $M/2 \times M/2$ orthogonal matrices. $U_1 = I_{M/2}$, and approximates V_1 by $M/2 - 1$ plane rotations [16]. The GenLOT is defined as a Linear phase paraunitary Filter banks obeying

$$E(z) = K_{N-1}(z)K_{N-2}(z) \dots K_1(z)E_0 \quad (6)$$

Where E_0 is chosen to be the DCT matrix [17], which is denoted as D^H . The output of the DCT is then separated into the groups of even and odd coefficients. The GenLOT with $N - 1$ stages after the DCT has basis functions (filters) with length $L = NM$ and has its Polyphase Transfer Matrix defined as

$$E(z) = K_{N-1}(z)K_{N-2}(z) \dots K_1(z)D^H \quad (7)$$

3.4 Discrete Wavelet Transform (DWT)

The main advantage of wavelet transforms over other more traditional decomposition methods (like the DCT) is that the basis functions associated with a wavelet decomposition typically have both long and short support. The basis functions with long support are effective for representing slow variations in an image while the basis functions with short support can efficiently represent sharp transitions (i.e., edges)[19].

This makes wavelets ideal for representing signals having mostly low-frequency content mixed with a relatively small number of sharp transitions. The wavelet transform decomposes a signal into frequency bands that are equally spaced on a logarithmic scale. The low-frequency bands have small bandwidths, while the high-frequency bands have large bandwidths. This logarithmic behavior of wavelet transforms can also be advantageous. Since human visual perception behaves logarithmically in many respects, the use of wavelet decompositions can sometimes make it easier to exploit. In Wavelet based coding, advantage of overlapping basisfunction and better energy compaction property of wavelet transform is utilized to provide subsequent advancement in picture quality at low bit rate. Because of built-in multi resolution nature, wavelet based coder facilitates progressive transmission of images with grant for variable bit rate [20].

In [21], wavelets which are strictly translates and dilates of each other but still maintain all the powerful properties of first generation wavelets is presented, referring to these wavelet as second generation wavelet known as lifting scheme. The lifting scheme is a simple yet powerful tool to construct second generation wavelets. The lifting scheme is an alternative description of the discrete wavelet transform as well as an alternative way to build wavelets. Lifting provides several advantages including:

- In-place calculation of the wavelet coefficients
- Inverse wavelet transform is easily obtained
- Ability to perform integer-to-integer wavelet transform.
- Extension to domains, which are not shift-invariant.
- Extension to irregularly-sampled data

Lifting scheme directs to a faster, in-place calculation of the wavelet transform [22]

4. DESIGN AND IMPLEMENTATION

4.1 Filter Banks For Image Coding

Filter banks are mainly used to separate the input signal into multiple components and each component carrying a single frequency subband of the original signal [23], [24]. It is desirable to design the filter bank such that these subbands can be recombined to recover the original signal so that we get the original signal.

Ideal filters, inherently, are not feasible and the issue was first addressed using two-channel linear-phase filter banks and a design called quadrature mirror filter bank(QMF). To cancel aliasing resulting from the decimation and interpolation processes quadrature mirror filter bank was introduced [23], [25]. Johnston's filters are a family of QMF designed to cancel aliasing [26].

The QMF solutions do not allow perfect reconstruction (PR) of the signal and later Smith and Barnwell [27] developed the conjugate quadrature filter bank (CQF) in a formulation which does not use linear-phase filters but allows PR of the signal. Both QMF and CQF solutions have a two-channel filter bank which can be hierarchically associated in a binary-tree path in order to create filter banks with more than two channels.

A uniform filter bank is the one where all, let us say, M filters have bandpass width of π/M , thus signals of all Subband are decimated and interpolated by a factor of M [23],[24]. Fig. 1 shows an M -channel critically decimated uniform filter bank. In this figure, M is the number of filters (or number of channels or Subband), $x(n)$ is the input signal, and $\hat{x}(n)$ is the recovered signal after synthesis. The Subband signals are represented by $y_i(m)$ ($0 \leq i \leq M-1$), and the filters with impulse responses $f_i(m)$ and $g_i(m)$ ($0 \leq i \leq M-1$) correspond to analysis and synthesis sections, respectively.

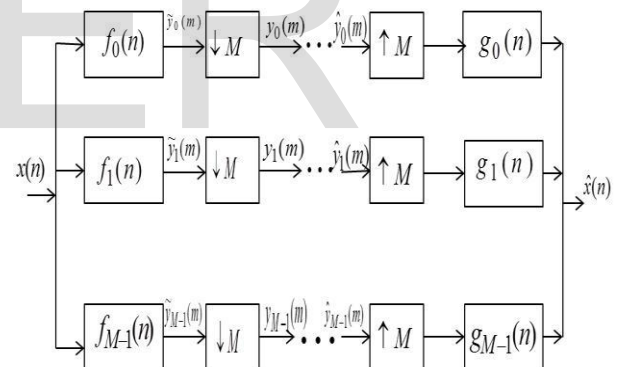


Fig 1: Critically decimated uniform filter bank. Analysis (left) and synthesis (right)].

Filter banks can also be classified into paraunitary or bi-orthogonal [24]. In paraunitary FIR filter banks, each $f_i(m)$ has a one-to-one correspondence to $g_i(m)$ [15], [25], [28], while in bi-orthogonal filter banks the set $f_i(m)$ is found from the entire set of $g_i(m)$ or vice versa [24], [28]. This is similar to the relation between orthogonal and non-orthogonal matrices, and in fact, orthogonal block transforms are a special case of paraunitary filter banks, while non-orthogonal ones belong to the class of bi-orthogonal filter banks.

In numerous applications, especially image processing, it is crucial that all analysis and synthesis filters have linear phase. Such system is called a linear phase filter bank (LPFB). Besides the elimination of the phase distortion which is often disastrous in many image

processing applications [30], LP filters preserve the locality of the edges, the key to success of hierarchy image coding algorithms [28], [29], [31], [32].

The latter Polyphase representation in Figure 2 proves to be very useful, both theoretically and practically, in filter bank design and application.

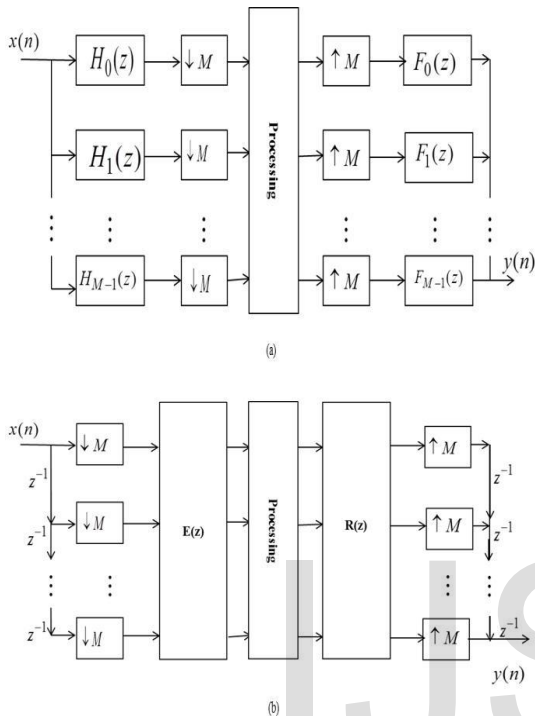


Figure 2: M-channel filter bank a) regular structure b) Polyphase structure

Not only does it allow the processing of signals at lower rates, but it also simplifies filter bank theory dramatically.

4.2 Bi-orthogonal Filter Banks (BOFBs)

PUFBs can be designed easily and also the number of design parameters is smaller than that of BOFBs. The frequency responses of PUFBs are usually worse. Also PUFB's have many restrictions compared to BOFBs. To apply FBs to lossless image coding, the lattice structure should be represented by lifting structures which has unity diagonal scaling coefficients to avoid quantization errors. Factorization of BOFBs involves non-unity diagonal scaling coefficients. Hence, they have not been applied to lossless coding directly.

In [36], degree-1 BOFBs which have unity diagonal scaling coefficients throughout the lifting structure have been proposed. In [37], order-1 building blocks in BOFBs are took forward. Though this lifting structure has more design parameters than those of the conventional order-1 PUFBs And degree-1 BOFBs, structure shown in [37] provide reduction in the number of rounding operations since a rounding operation can

be regarded as quantization noise; the number of rounding operations affects the subband energy compaction.

The structure shown in [37] has taken into account not only restriction such as paraunitary but also has rounding operation less compared to [30] and [40].

But still the structure in [37] did not consider the restrictions such as number of channels and McMillan degree. The block-lifting structure proposed in [38] covers broader family which gives best solution compared to the conventional methods. This structure is free from the restriction such as Paraunitary, number of channels and McMillan degree while maintaining less rounding operations than [39] and [40]. Compared to conventional FBs, the designed BOFBs give better Lossy-to-lossless image coding performance in both PSNRs and perceptual visual quality for the images containing a lot of high frequency components [38].

5. RESULTS

5.1 Filter coefficient

Consider $M = 4, \gamma/k = 2$ and set the initial random parameter for Lk and Uk and optimize it for maximum coding gain which gives the filter impulse reponse as Figure 3 and frequency response as Figure 4

Image coding results are as follow shown in Figure 5 which shows Original image and Figure 6 shows Reconstructed image:

The PSNR performance is 22.93 dB.

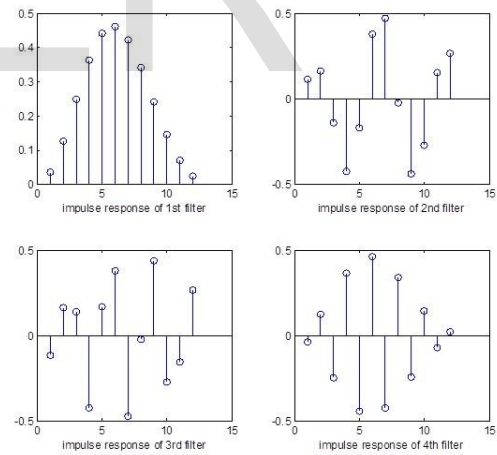


Figure3 :Impulse reponse of filter bank

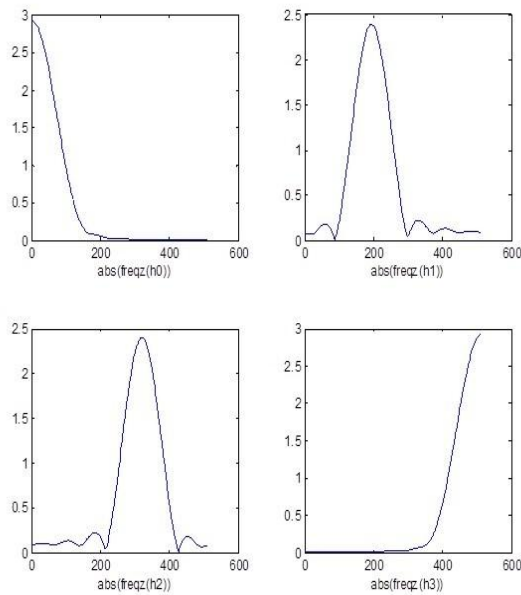


Figure4 : Frequency response of filter banks



Figure 5: Original Barbara Image

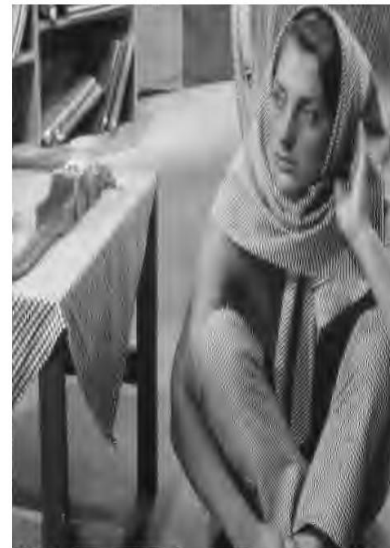


Figure 6: Reconstructed Barbara Image

6. DISCUSSION AND CONCLUSION

This paper focuses on the theory, structure, design, implementation, and application in image compression of linear phase perfect reconstruction filter banks with arbitrary M channels and arbitrary-length filters. This class of FBs is purposely chosen to have high practical values: linear phase, FIR, real (sometimes even rational and integer) filter coefficients, and exact reconstruction. The approach consistently taken throughout the dissertation is to parameterize the FBs by lattice structures based on the factorization of the analysis and synthesis polyphase transfer matrices. From a slightly different point of view, the factorization allows the construction of a highly complex system from a cascade of identical low-order building blocks, each is carefully designed to propagate structurally the most desired properties, namely linear phase and perfect reconstruction.

In other words, in the lattice representation, both of these crucial properties are retained regardless of the quantization of lattice coefficients to any desired level. The lattice structure offers a powerful characterization in both FB design and implementation. From a design perspective, the lattice coefficients can be varied independently and arbitrarily without affecting the LP and PR properties. Secondary FB properties such as high coding gain and low stopband attenuation can be further achieved using unconstrained optimization techniques. From an implementation perspective, the cascading construction provides a fast, efficient, robust, and modular structure which leads itself nicely to hardware realization in VLSI.

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