EFFICIENT QUANTIZATION NOISE REDUCTION DEVICE FOR SUBBAND IMAGE CODING SCHEMES

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ABSTRACT

This paper addresses the problem of the quantization noise reduction in subband image coding schemes. Two major artifacts occur for such coding schemes at high compression factors: the ringing effect around high-contrast contours and the blurred false contours in large smooth regions. The first distortion can be considerably reduced by an appropriate design of the subband filters. The second one can be eliminated by using the noise reduction technique proposed in this paper, which consists of applying a noise reduction filter to the DC subband. The advantages of this approach are as follows: First, it can be applied to any kind of subband decompositions. Second, it removes quantization noise to which the eye is most sensitive and third, it is computationally very efficient due to the small size (typically 64×64) of the DC subband. The colored quantization noise in the DC subband is rendered white by using the Roberts pseudonoise technique. The proposed noise reduction filter is a Wiener type filter with adaptive directional support. It has the advantage of reducing the noise without blurring the reconstructed image. It is shown that the proposed noise reduction filter augments the visual quality of the reconstructed image as well as its PSNR value.

1. INTRODUCTION

In recent years, subband coding (SBC) of images has become very popular. Subband coding of images was first introduced by Woods *et al.* [1]. This approach decomposes an image into several subbands using a linear analysis filter bank. Each subband is then quantized according to its statistics and its visual importance. On the receiver side the subbands are then dequantized and reconstructed using a synthesis filter bank.

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An advantage of SBC over block transform coding such as the Discrete Cosine Transform (DCT) used in JPEG [2] is the absence of the blocking effect. However, two other annoying artifacts are introduced. The first is the ringing effect which occurs around high-contrast edges due to the Gibbs phenomenon of linear filters. It is shown in [3, 4] that this artifact can be reduced or even removed by an appropriate design of the filter bank. The second artifact appears at high compression ratio and is due to the coarse quantization of the DC subband. It is shown as blurred false contours in the reconstructed image. It is this artifact that the proposed technique is aiming at removing [5]. Other techniques have been developed with the same objective [6].

For natural images most of the energy in the decomposed image is contained in the DC subband. Moreover, this subband has nearly the same statistics as the original image. Based on this observation a noise reduction filter is developed. The proposed filter is a Wiener filter with adaptive directional support. It has the advantage to filter out the noise without blurring the edges. This approach eliminates completely false contours and augments the quality of the reconstructed image. Moreover, it is as well efficient in terms of computational complexity because the filters are short and are applied only to the DC subband. In addition, it has the advantage of being independent of the employed filter banks.

The outline of the paper is as follows. Section 2 gives a brief review of subband decomposition theory. Section 3 deals with the problem of quantization noise in the DC subband. The noise reduction filter is described in section 4. Results are given in section 5 and finally, conclusions are drawn in the last section.

2. THE ANALYSIS/SYNTHESIS BLOCK

Subband decomposition divides the input signal into different subbands. The choice of the filters is an im-

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portant issue. It is shown in [4, 7] that the filters represent an important factor in the performance of the decomposition for compression purposes.

Fig. 1 shows a two–band filter bank. The input-output relationship is given by

$$\hat{X}(z) = X(z)T(z) + X(-z)A(z) \quad (1)$$

where

$$T(z) = \frac{1}{2}\left[H_1(z)G_1(z) + H_2(z)G_2(z)\right] \quad (2)$$

and

$$A(z) = \frac{1}{2}\left[H_1(-z)G_1(z) + H_2(-z)G_2(z)\right]. \quad (3)$$

Perfect reconstruction can be achieved by removing the aliasing distortion, $A(z)$, and imposing the transfer function, $T(z)$, to be a pure delay of the form $T(z) = z^{-\delta}$, where δ is the delay of the system. By choosing the synthesis filters as $G_1(z) = H_2(-z)$ and $G_2(z) = -H_1(-z)$ the aliasing component is removed. Under these constraints the system transfer function becomes

$$T(z) = F(z) + F(-z) \quad (4)$$

where the product filter is $F(z) = H_1(z)H_2(-z)$. Perfect reconstruction is obtained when the product filter, $f(k) = \mathcal{Z}^{-1}(F(z))$, is a power–complementary half-band filter. This means that every odd sample, except one sample $f(\delta)$, is equal to zero, that is

$$f[2n+1] = \begin{cases} 1/2 & 2n+1=\delta \\ 0 & otherwise \end{cases} \quad n = 0,1,2,\ldots,\frac{L-1}{2} \quad (5)$$

where L is the length of the product filter $F(z)$.

The analysis–synthesis system of Fig. 1 can be used in a tree–structure. Most often the lowpass subband is redecomposed into two more subband leading to a wavelet–type decomposition.

3. QUANTIZATION NOISE IN THE DC SUBBAND

The Probability Density Function (pdf) of the samples in the DC subband is not computable. It is known that for this subband the optimal entropy–constrained quantizer should be the uniform quantizer [8].

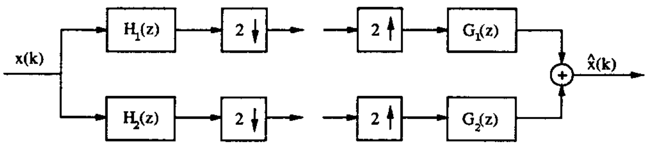

Figure 1: *Two–band analysis/synthesis filter bank system.*

However, from a visual point of view, this approach is not satisfactory. In fact, by uniform quantization of the DC subband, a signal–dependent quantization noise is introduced which gives artificial contours in the coarsely quantized image. This artifact is still present in the reconstructed image after the synthesis stage. To avoid this, it is proposed to apply Roberts pseudo-random noise technique [9] to this subband.

Let's denote $x(k1,k2)$ the image to be quantized. Suppose that we have access to a known white noise sequence, $n(k1,k2)$, with uniform pdf

$$n(k1,k2) \sim U(-\Delta/2, \Delta/2) \quad (6)$$

with Δ being the quantization step and $U(\cdot)$ representing the uniform pdf. The quantization is performed on $x(k1,k2) + n(k1,k2)$:

$$y(k1,k2) = \mathcal{Q}\left[x(k1,k2) + n(k1,k2)\right] \quad (7)$$

where $\mathcal{Q}(\cdot)$ being the quantization operator. The inverse operation is performed by the dequantization of $y(k1,k2)$ and the substraction $n(k1,k2)$:

$$\hat{x}(k1,k2) = \mathcal{Q}^{-1}\left[y(k1,k2)\right] - n(k1,k2). \quad (8)$$

Figure 2 shows the flow diagram of this procedure. This quantization method does not decrease the mean square error, however, it significantly improves the subjective quality of the quantized images. Moreover, the power spectrum of the quantization noise becomes white.

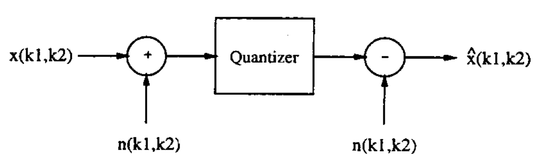

Figure 2: *Roberts pseudo–random noise technique.*

4. THE NOISE REDUCTION FILTER

An adaptive Wiener filter is going to be applied so as to reduce the quantization noise in the DC subband. In order to apply a Wiener filter, two conditions should be satisfied: (1) the signal should be of lowpass nature, guaranteed by the DC subband; (2) the noise should be uncorrelated from the signal and be additive, guaranteed by applying Roberts pseudo-random noise technique and uniform quantization. Notice that condition (1) also constrains the Wiener filtering to be effective only for the DC subband.

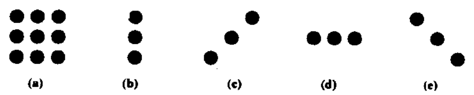

Figure 3: *The region of support of the five Wiener type filters for an edge preserving noise reduction system.*

The white noise can be optimally filtered out by a Wiener filter [10]. However, its lowpass nature will blur the reconstructed image. The DC subband has a similar statistics to that of natural images. Hence, most of its energy is concentrated in low frequency and the signal is strongly non–stationary. For a human observer it is very important that the edges are well preserved. Therefore, the objective is to design a Wiener type filter, which does not destroy edge information.

Edges have typically a dual character, they are highpass in one direction and lowpass in their orthogonal direction. The basic idea of the proposed algorithm consists in the filtering of the noise along the lowpass direction. The proposed algorithm proceeds as follows:

If the region does not contain any edges, use the $N \times N$ 2-D filter (Fig. 3: (a)); otherwise, use the 1-D filter which has the region of support with the least signal variance (Fig. 3: (b)-(e)).

In order to detect whether the pixel is an edge a simple thresholding based on the variance of a $N \times N$ region has been used. This approach reduces the noise especially in the low–frequency region without affecting the edges.

5. RESULTS

Comparing this filtering method with the adaptive Wiener filtering method [10] leads to a very satisfactory result. This approach is more efficient in both the objective and the subjective sense. Fig. 4 shows a comparison of the efficiency of the noise reduction technique on the DC subbband of the "Pepper" picture. The proposed noise reduction filter performs significantly better than the classical adaptive Wiener filtering. Moreover, visually the processed image does not appear to be blurred.

Results of the proposed noise reduction device incorporated in a subband coding scheme are shown in Fig. 5. The decomposition is in octave and the DC subband is of size 64×64 as suggested in [11]. Visually, the proposed noise reduction device is very powerful. Due to the application of Roberts pseudonoise technique on the DC subband the blurred false contours have completely disappeared. Moreover, the proposed noise reduction filtering does not introduce any blurring. The proposed noise reduction algorithm can be applied to any type of filter bank and is very effective in terms of visual quality. The reconstructed images with the proposed noise reduction seem more natural and are free of false contours. Also the objective measure based on the PSNR shows an improvement with the proposed approach. This is shown in Fig. 6. It can be observed that the proposed method shows a significant improvement especially at very low bit rates.

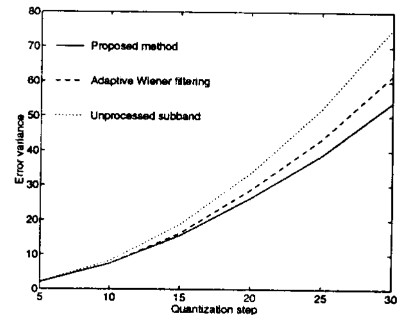

Figure 4: *Objective comparison of the proposed noise reduction filter and the adaptive wiener filtering method.*

6. CONCLUSIONS

In this paper a noise reduction device for subband image coding schemes is proposed. It is based on a subband decomposition. A uniform quantizer is used for the DC subband. Artificial contours which are visible at low bit rates can be completely removed by applying Roberts pseudorandom noise technique on only the DC subband. A novel noise reduction technique is proposed and applied to this subband. It is shown that from both visual and computational point of view the noise reduction in the DC subband is very powerful.

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Figure 5: *"Pepper"* 256 × 256 *image coded at 0.17 b/p. (Top) Original. (Middle) No noise reduction, 24.16 dB. (Bottom) With noise reduction, 25.21 dB.*

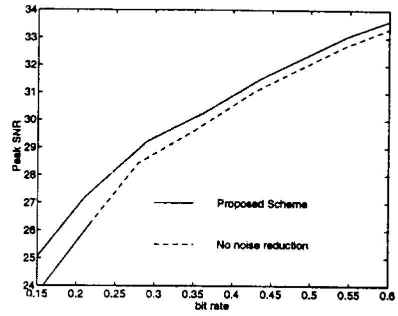

Figure 6: *Objective comparison of the proposed noise reduction filter on the "Pepper" picture* 256 × 256 *for seven subbands decomposition.*

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