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EDGE SENSITIVE SUBBAND CODING OF IMAGES

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ABSTRACT

In this paper, we introduce a family of novel edge preserving image coding techniques based on the discrete wavelet transform (DWT). These techniques utilize the edge map (which not necessarily contains closed curves) of the processed image or its subbands in the way that no filtering over edges is performed. This results in a reduction of power in the higher frequency bands. The achievable savings are higher than the additional bit rate needed for transmission of the edge map.

1. INTRODUCTION

In subband image coding, the subband decomposition scheme is usually chosen independently of the image content. Moreover, the available bit rate is usually distributed to the subbands according to their relative importance. When lowering the bit rate, the higher frequency information being important for the reconstruction of edges gets lost. The resulting image is blurred and shows DWT-typical artifacts such as ringing.

Region-based or contour-texture coding techniques are designed to preserve the edges in the image. The basic idea of these techniques is to segment an image into closed regions which correspond, as much as possible, to the objects in the image. The available bit rate is distributed over the segmentation information and the various region contents. The segmentation information is usually coded with a chain code. The texture information can be coded by the coefficients of a 2-D polynomial that is fitted to the surface of the region [1], by using generalized orthogonal transforms [2], or by using the discrete wavelet transform [3]. A drawback of the first two techniques is that the regions have to be rather small to be represented with satisfying accuracy. Thus, the segmentation information consumes a considerable amount of the bit rate. All three methods suffer from computational burden and memory requirements for image segmentation. In addition, natural scenes are seldom completely segmentable into closed regions that are corresponding to the elements of the scene. See the example in Figure 1.

We develop a family of novel edge preserving image coding techniques based on the DWT, that use information about the edges in the image, rather than the segmentation information. Edge detection is a task which is simple and computationally inexpensive, and can be performed as a one-pass filtering. We refer to this new method as edge sensitive subband coding (ESSBC), and according to the stage of the DWT decomposition in which the edge detection is performed, we distinguish between ESSBC-O1, ESSBC-O2, etc.

2. IMPLEMENTATION OF THE ESSBC-O1

After edge detection (e.g. with the well known Sobel algorithm), the filtering is performed separately for the rows and columns of the image. This filtering is interrupted on edges. This means, if a row or column of the image is splitted by k edges into $k+1$ edge-to-edge segments, each of these segments is filtered and downsampled separately. In order to perform support preservative decompositions of arbitrary-length segments we use linear phase filters that allow symmetric reflection at the segment boundaries. Depending on the length of the segments (even or odd) and whether they start at even or odd positions, there are four cases of processing [3], [5] (see Figure 2). Since our implementation of these four cases differs in some detail from the implementation in [3], [5], we describe the cases below.

The simplest case for processing is the case when an even-length segment starts at an odd position, see Figure 2(a). We filter the symmetrically extended segment with both the highpass and lowpass filters of our two-channel filter bank. After filtering both subbands are downsampled in the natural way, i.e. by keeping

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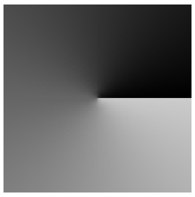


Figure 1: Worst case for segmentation.

only the coefficients on odd positions. Since the segment length is even, both subband signals have the same length.

When a segment starts at an odd position and has an odd length (Figure 2(b)), we extend it by one specially computed sample in order to get an even-length segment for filtering. The "extension sample" is determined from the samples of the segment and the coefficients of the highpass filter [5]. Its value forces the last highpass coefficient to be zero. We proceed with the filtering as in the previous case with one exception: we omit the last coefficient of the highpass band which is known to be zero. The lowpass signal now has one coefficient more than the highpass signal.

When a segment starts at an even position (Figures 2(c) and 2(d)), we first perform a two point DCT for the first two samples. The resulting highpass coefficient is placed into the highpass subband. The lowpass coefficient is used as the first sample of a modified segment starting at an odd position. Depending on the length of the segment, the subband decomposition will be performed as in the cases (a) and (b), respectively.

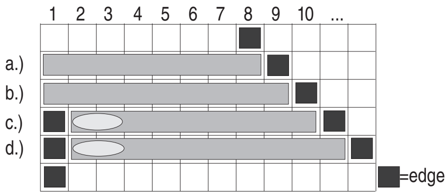


Figure 2: The four cases for filtering.

While processing the segment lines of the image as described above, a special case may occur: Segments of length one are treated separately when their position is even, and they are scaled with $\sqrt{2}$ and copied into the lowpass band otherwise. Due to the gain of the lowpass filter, this scaling is necessary for matching the statistics of the lowpass subband.

The application of the subband decomposition described above to the rows of the image results in the same number of subband coefficients as input samples, regardless of the number and lengths of the segments. The columns of the subband coefficients are processed in the same way, resulting in four subbands. In our experiments, we used a 10-band decomposition, which means that we repeated the procedure described above for three times. The edge map has to be downsampled correspondingly in both directions. Due to this simple downsampling, edge information in the subband edge maps gets lost. For the filtering in the next level it is necessary to restore it by simply marking the positions in the edge maps. Figure 3 shows the original and the downsampled edge map of the camera man image for a three-level decomposition.

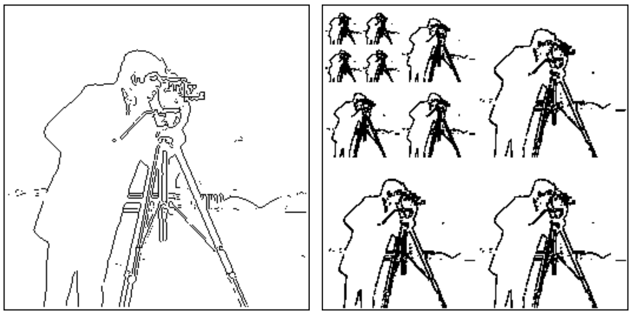


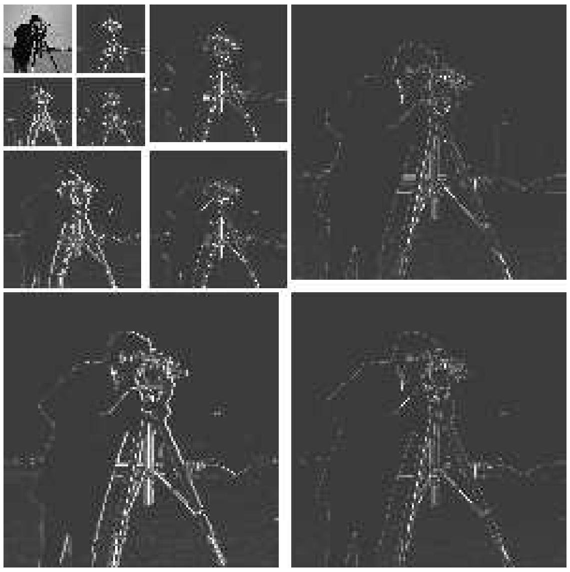
Figure 3: Original edge map and three-level downsampled edge maps of the camera man image.

Since no filtering over sharp edges is performed, the power in the higher frequency bands is considerably lower than for the Standard DWT (see Figure 4), and more coefficients in the higher subbands will be quantized to zero. As a consequence, higher compression ratios can be reached.

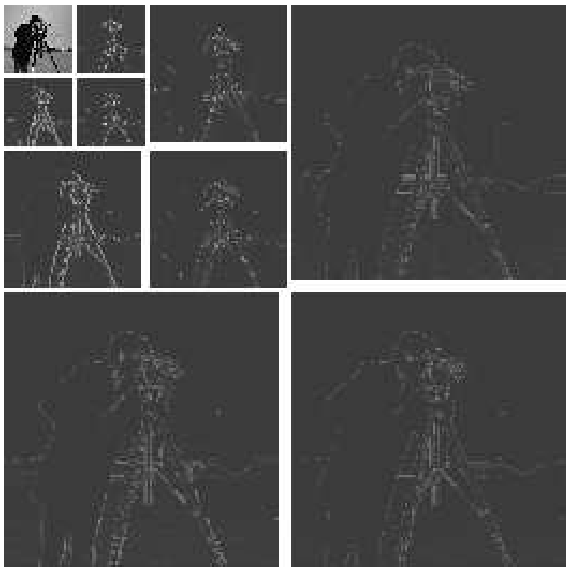
In our experiments we used a linear-phase filter pair of lengths 9 and 7 [4]. For all subbands we used linear quantizers with a dead zone around zero. The pixels on edges were processed separately. This guaranteed even more small coefficients in the higher bands. Prior to compression, we combined 2×3 blocks of the edge map (consisting of "1"s on edges and "0"s else) to 6 bit words. We compressed the transform coefficients, the pixels on edges, and the pre-processed edge map by a run-length coder which we designed for effective coding of zeros. Finally, all the information was entropy coded by an optimized Huffman coder.

3. THE ESSBC-OX FAMILY

For higher compression ratios the edge map consumes a relatively large amount of the bit rate. A good compromise between edge preservation and compression can be achieved by decomposing the image once with the Standard DWT, detecting the edges in the lowpass-lowpass



(a)



(b)

Figure 4: Three-level decomposition of the test image: (a) Standard DWT, (b) ESSBC-O1.

(LL) subband, and resuming the decomposition in the manner of ESSBC-O1. We refer to this scheme as ESSBC-O2. By analogy, in ESSBC-O3 edge detection is performed after the second level of the standard decomposition in the LLLL subband. ESSBC-O3 is useful when coding high-resolution images in more than three transform levels at very low bit rates.

4. CODING RESULTS

The performances of the ESSBC-O2 and the Standard DWT are facing each other in Figure 5. For compressing the Standard DWT coefficients we used the same method as for the transform-coefficients in ESSBC-O2. The edge map was compressed to 250 bytes, i.e. 0.03 bpp (for the 256×256 test image). The quantization steps (Q) necessary to meet the desired bit rates and the peak signal-to-noise ratios are shown in Table I:

TABLE I:
Comparison of Standard DWT and ESSBC

bit rate	$Std.\ DWT$		$ESSBC-O2$	
	Q	$PSNR$	Q	$PSNR$
0.3 bpp	25	23.9 dB	27	24.0 dB
0.2 bpp	37	21.8 dB	44	21.7 dB
0.1 bpp	62	19.2 dB	64	19.9 dB

5. CONCLUSION

In this paper, DWT-based edge preserving techniques have been presented. While yielding about the same peak signal-to-noise ratio these techniques outperform the Standard DWT in subjective visual quality, especially at lower bit rates. The edges in the coded images are much sharper, and hardly any ringing artifacts are visible.

6. REFERENCES

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(a)

(b)

(c)

(d)

(e)

(f)

Figure 5: Comparison of the performance of Standard DWT and ESSBC: (a) DWT at 0.3 bpp, (b) ESSBC-O2 at 0.3 bpp, (c) DWT at 0.2 bpp, (d) ESSBC-O2 at 0.2 bpp, (e) DWT at 0.1 bpp, (f) ESSBC-O2 at 0.1 bpp.