IMAGE CODING WITH CONTOURLET/WAVELET TRANSFORMS AND SPIHT ALGORITHM
An Experimental Study

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Abstract: We investigate the error resilience of the image coded with the wavelet/contourlet transform and the SPIHT algorithm. We experimentally verify the behaviour for two scenarios: partial decoding (as with scalable coding/transmission) and random sequence errors (as with transmission errors). Using a number of image quality metrics, we analyze the overall performance, as well as differences between each transform. We observe that error difference between transforms varies with length of decoded sequence.

1 INTRODUCTION

Image coding theory forms a foundation of today's multimedia technologies: internet web pages, digital cameras, medical diagnostics to name a few. The objective of image coding is to reduce the transmission/storage requirements, by exploiting statistical structure of images and human visual perception properties.

Current paradigm for image compression involves using a transform for recoding pixel data, then bit packing of the coefficients' data into a coded bitstream. A JPEG – 2000 standard (JPEG, 2000), is a practical formalization, focusing on wavelet transform and EBCOT (embedded block coding with optimized truncation) bit ordering algorithm. Other bit ordering algorithms have also been proposed, most notably SPIHT (set partitioning in hierarchical trees), described in (Said and Pearlman, 1996). Recently, an alternative to wavelet transform has been suggested, in the form of contourlet transform (Do and Vetterli, 2005), which has better property of representing directional image information, an important requirement for image coding applications.

In many applications we expect the image to be reconstructed from the coded bitstream with errors, which can result either from the coding system (lossy compression) or transmission medium (packet loss or errors). The former is analyzed as rate-distortion theory, and focuses on relation of bitstream length to image quality (with respect to some predefined metric). The latter is studied by observing distortion introduced by errors in coded bitstream. While there are methods that improve resilience of the bitstream, i.e. using error correcting codes (Kim et al, 2004), or post-process the image to conceal/remove errors (Kung et al, 2006), the quantitative and qualitative analysis of coding system errors of both types is the key issue in design of a compression system.

While the statistical analysis of the contourlet transform indeed suggests it is better in representing image information (Po and Do, 2006), and thus possibly better suited for image coding systems, the exact gain of using it in place of wavelet transform is still an open issue. (Belbachir and Goebel, 2005) present a straightforward approach to compress images with contourlets, but provide only brief results with limited error discussion. (Esakkirajan et al, 2006) give a more detailed analysis including different filters and wavelet to contourlet comparisons. Their approach (multistage vector quantization) is not suitable for analysis scalability errors; they also don't investigate error resilience. They report small gain for contourlet transform. (Eslami and Radha, 2004) focus on combining contourlets after wavelets with SPIHT coding. They report better results with their approach than with wavelets alone. (Liu and Liu, 2006) also focus on combination of wavelets and contourlets in sophisticated scheme. They report improved performance of contourlet over wavelet,

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with their scheme providing additional gains. The results are provided for selected bit rates.

Our experiments were motivated by the need for more throughout, than reported above, evaluation of practical difference of coding with wavelets and contourlets. The objectives were defined as:

- compare wavelets and contourlets side by side, as much as possible;
- provide detailed analysis of scalability, in the form of partial reconstruction of the coded stream;
- provide analysis of bit stream perturbations (consistent with network errors, i.e. streaming in wireless network);
- use a range of error metrics, for qualitative evaluation of introduced errors.

Our findings are:

- the wavelet-SPIHT method works better when the near-lossless operations are demanded (smaller sequences sizes), whereas when a given level of quality loss is acceptable, the contourlet method gives better image quality for smaller sequence size;
- it is possible to parameterize the SPIHT algorithm to obtain images at definite quality level;
- when certain level of image quality loss is accepted, some subsequences (refinement parts) of the output sequence can be treated as low-priority data.

This work is organized as follows: second section presents our approach and experimental framework, third section presents experiment results, last section presents conclusions.

2 THE METHOD

We investigate a coding systems consisting of two elements: image transform and bit coder. For transform, we use interchangeably wavelet transform (implemented as standard 9/7 filter bank, as in (JPEG, 2000)) and contourlet transform (implemented with surfacelet transform, using (Lu and Do, 2007)). For bit coding, we use SPIHT algorithm (Said and Pearlman, 1996). The usage is motivated by good results reported, but also by difficulties with extending other algorithms, like EBCOT, to contourlets (Głomb et al, 2007). The implementation was done in C++.

We use a number of metrics to measure image distortion. Mean square error (MSE) and Peak signal to noise ratio (PSNR) are defined as:

$$PSNR = 10\log_{10}\frac{k^2}{MSE} \quad (1)$$

where:

$$MSE = \frac{1}{N \cdot M}\sum_{i=1}^{N}\sum_{j=1}^{M}([f(i,j) - f^{'}(i,j)]^2) \quad (2)$$

k – number of image colors minus *1;*
N,M – sizes of image;
$f(i,j)$ – input image;
$f^{'}(i,j)$ – output image.

We also use average *per pixel error* (denoted PERPX), and measures related to edge degradation. The latter are included as it has been observed (Al-Otum, 1998) that edge degradation in video coding is an important component of human quality perception. For measurement of the latter, we first use a Sobel edge operator for reference and distorted image, then measure MSE and NCC (normalized cross correlation) of the edge images.

The aim of work was to evaluate the image quality as a function of decoded sequence size and to determine the resistance of the output, linear sequence to errors.

3 EXPERIMENTAL RESULTS

Within the experiments we use the typical set of images (*Baboon*, *Barbara*, *Boat*, *Goldhill*, *Lena*, *Peppers*), universally used in digital images studies.

3.1 Image Quality as a Function of the Decoded Sequence Size

The SPIHT algorithm codes more important coefficient bits first. While decoding, image quality increases progressively. Because of this, the graph of image quality as a function of the size of decoded sequence is nonlinear.

During experiments the process of decoding output sequence was being stopped at specific point, expressed in percent of the whole sequence size. The single steep was 2[%].

By comparing output images to the original ones, the qualities of output images were evaluated and the graph of image quality was obtained. Each graph expresses the average results of each measurement method for the whole set of images.

The size of output sequences for contourlet and wavelet decompositions were different. The sizes for contourlet method sequences are considerably larger. We calculated the value γ (3).

$$\gamma = \frac{avrg.\ size\ of\ seq.\ for\ conturlet\ meth.}{avrg.\ size\ of\ seq.\ for\ wavelet\ meth.} = 2{,}68 \qquad (3)$$

In order to compare both methods we place contourlet and wavelet methods' graphs together on each chart. 100[%] on X axis means 100[%] of a wavelet sequence and 100/γ = 100/2,68 = 37,3[%] of a contourlet sequence. Results are presented on Figure 2. Sample images are presented on Figure 1.

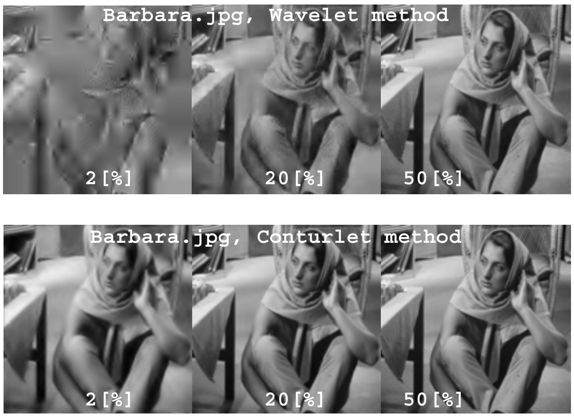

Figure 1: Sample images (Barbara.jpg) for conturlet and wavelet methods, after decoding 2[%], 20[%], 50[%] of the output SPIHT sequence.

3.1.1 Discussion

Presented results let us evaluate the methods and make a preliminary classification.

The wavelet decomposition together with the SPIHT algorithm generates smaller sizes of sequences, in compare to the contourlet ones (by average factor γ). So, in potential application, when the lossless transmissions are demanded, the wavelet method seems to be a better way. But in some cases, when a given level of quality loss is acceptable, the contourlet method gives better image quality for smaller sequence size. One can observe that on Figure 1, where for MSE, PERPX, PSNR graphs the distinct cross point occurred. It is also evident, while comparing images presented on Figure 1.

Results can be useful in case of the parameterization of the SPIHT algorithm. Based on the results, approximation function of quality from the length of sequence, can be calculated and sequences coding images on definite quality can be obtained. Examples of the approximation functions (fitting the EDGE NCC metrics) are presented on Figure 3.

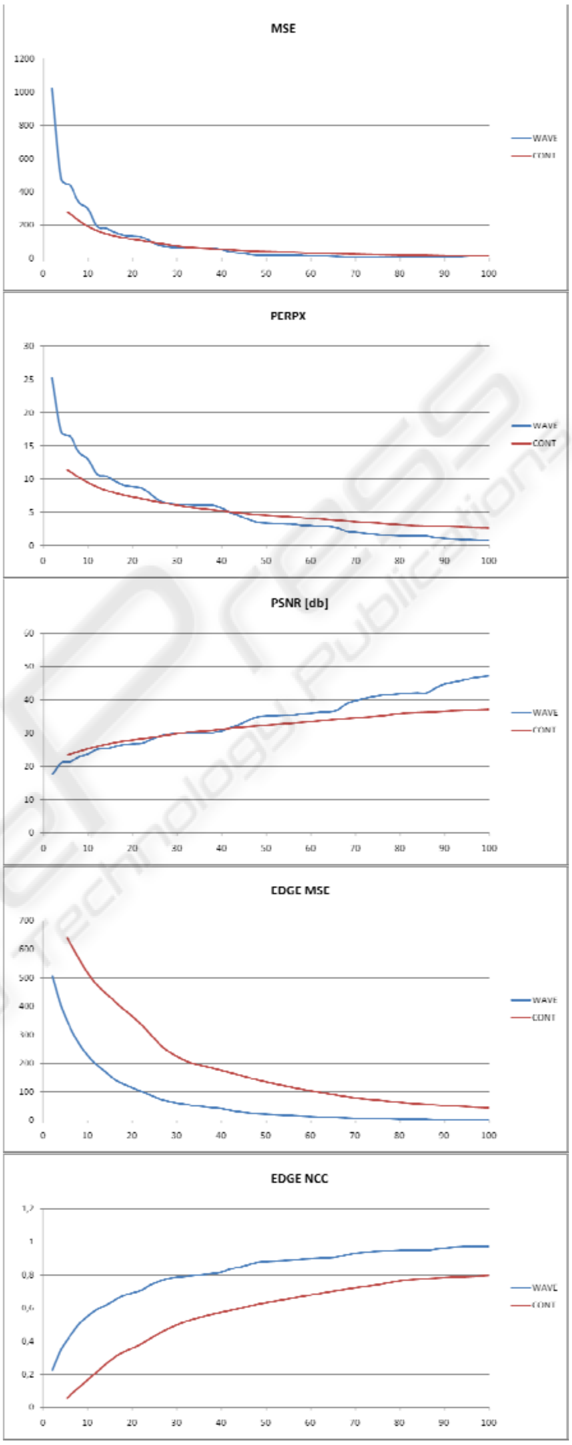

Figure 2: Image quality as a function of the decoded sequence size for contourlet and wavelet methods.

3.2 Image Quality as a Function of Distortions

The SPIHT generates two types of data. The first

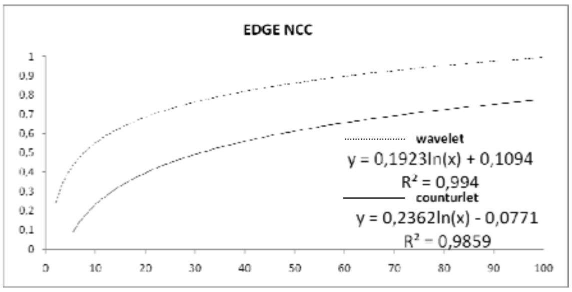

Figure 3: Approximation functions of the EDGE NCC metric for contourlet and wavelet methods.

comes from the process of hierarchical tree creation. The second consists of refinement bits. The output sequence alternately consists of "tree creation bits" subsequences and "refinement bits" subsequences.

Loss or error affected by any bit in "tree creation bits" subsequence makes the further process of decoding impossible, because the algorithm loses the correct path through binary trees. Considering e.g. network streaming, the "tree creation bits" subsequences need error protection.

The "refinement bits" subsequences affect only for single pixels and do not need special protection. After loss or error affected by single bits or even the whole subsequences, the process of decoding can be continued. Occurrences of errors within the subsequence influences to a little degree on the image quality.

When considering errors within "refinement bits" subsequences it is important to mention, that the original size of each subsequence have to be preserved. In the opposite case the algorithm also loses the correct path through subsequent stages. We consider rather errors then a loss of data.

Introducing distortions to the "refinement bits" subsequences, the graph of image quality as a function of simplified model of error level is obtained. During the experiments the probability of distortion of individual bits varied from 0[%] (no distortions) to 100[%] (every bit was distorted, and as a consequence the "refinement bits" subsequences changed to the inverted form of the original).

As in the previous experiments, the contourlet and wavelet methods are compared. The qualities of output images were evaluated and the graph of image quality (average results) was obtained. To compare results in direct way the γ value was used.

Results are presented on Figure 4 and sample images are presented on Figure 5.

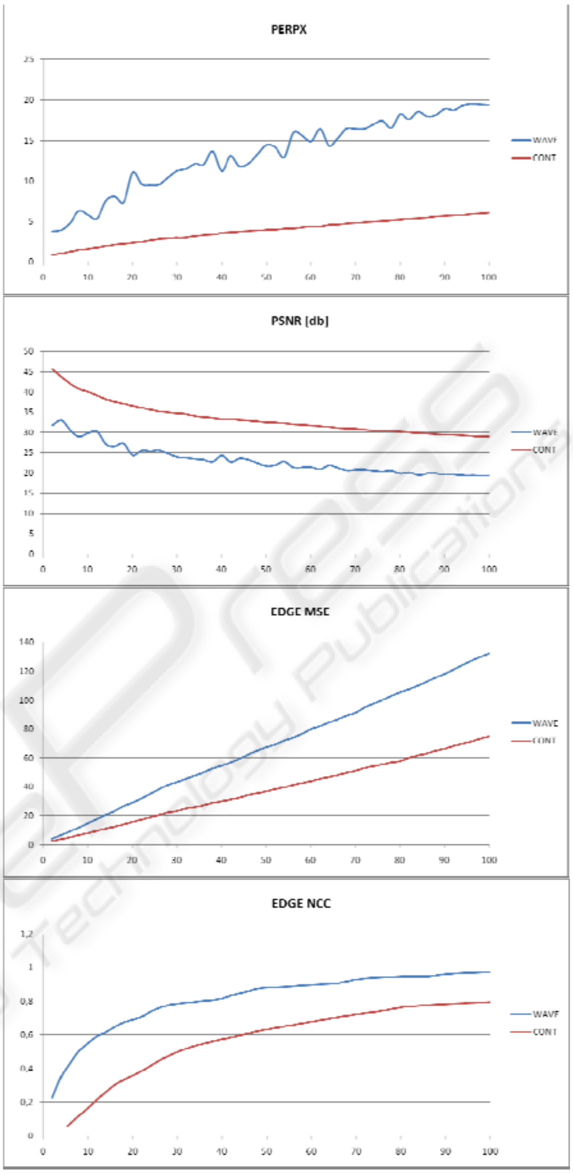

Figure 4: Image quality as a function of distortion probability of individual bits in "refinement bits" sequence.

3.2.1 Discussion

Obtained results show that bits within the "refinement bits" subsequences have little influence on image quality. The "refinement bits" subsequences constitute average about 33[%] or the SPIHT output sequence size for contourlet decomposition method and about 28[%] for wavelet decomposition method.

Considering transmission of images via network using dedicated protocols, when certain level of image quality loss is accepted, one can treat

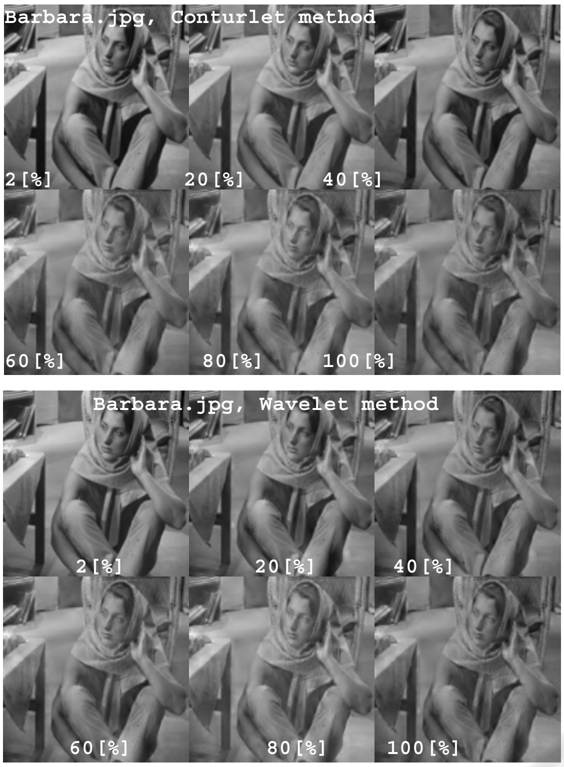

Figure 5: Sample images (Barbara.jpg) for conturlet and wavelet methods, different probability of distortion of individual “refinement bits” in sequence.

“refinement bits” subsequences as low-priority data.

In case of a transmission error (individual bits distortion or even whole block loss) retransmission of data is not necessary. In certain cases, it is possible to omit completely the “refinement bits” subsequences. Only the size of “refinement bits” subsequence have to be retained.

Replacements for it, the additional, excessive data can be introduced to the “tree creation bits” subsequences, which are necessary to follow the SPIHT algorithm.

4 CONCLUSIONS

The main goal of the work was to compare two methods of decomposition: contourlet and wavelet in employment with the SPIHT algorithm and to investigate their properties. The comparison can be helpful when new protocols for image transmission are designed, especially when a network streaming through noisy environment is considered.

The conclusions are:

- The wavelet-SPIHT method generates smaller sizes (by average factor γ = 2,68) of sequences, but the contourlet-SPIHT method gives better image quality for smaller sequence size (it should be noted that there are algorithms producing contourlet decomposition with less redundancy);
- It is possible to parameterize the SPIHT algorithm to obtain sequences coding images at definite level of quality;
- The “refinement bits” subsequences can be treated as low-priority data. Bits within that subsequences have little influence on image quality.

An important observation noted during our experiments is that while several studies report contourlet transform to be generally superior to wavelet transform, we report that the gain is closely related to image structure. Thus, in general one can expect a considerable variation of differences between the transforms depending on image source.

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