EMBEDDED IMAGE CODING USING CONTEXT-BASED ADAPTIVE WAVELET DIFFERENCE REDUCTION

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ABSTRACT

We propose a new still image coding technique which is a highly developed version of the renowned wavelet difference reduction (WDR). This new coder inherits the important properties from the original WDR, such as embeddedness, target compression ratio, region of interest support and the simplicity. The special treatment is performed in the significant pass by using context-based adaptable scanning order to predict the new significant coefficients. The prediction model is based on the compactness in subband coefficients and also the quadtree relation between the same orientation subbands. In binary mode, the coder is consistently better than SPIHT. A new conditional arithmetic coding (AC) using array of contexts is specifically designed for WDR-based coder. Rate-distortion results of the new coder in AC mode are superior to all other WDR-based coders in the literature and are very comparable to SPIHT-AC and JPEG2000, the best coders, at all bit rates for all images in the test set.

Index Terms— Conditional arithmetic coding, context adaptive, image coding, wavelet difference reduction

1. INTRODUCTION

Wavelet difference reduction [1] is a simple embedded image coder which yields good image quality at high compression ratios, and fully supports resolution and SNR scalability properties. The performance of WDR is comparable in both objective and subjective quality with other best image coders in the literature, such as SPIHT [2] and Embedded Block Coding with Optimal Truncation (EBCOT) [3] adopted by JPEG2000 image compression standard.

Further improvement of WDR are adaptively scanned WDR (ASWDR) in [4], and context modelled WDR (CMWDR) in [5] and [6]. These two algorithms use self-similarity across scale and/or energy compaction in each subband for scanning order adaptation in order to improve the compactness of the significant coefficients in the quantization process. The coefficients that are the neighbors or children of the significant coefficients will be placed before the ones of the insignificant coefficients.

In [7], another modified version of WDR called Adaptive WDR is proposed. AWDR employs advanced scanning order adaptation with many additional features and has comparable coding performance with the original WDR and all of its variants mentioned above.

In this paper, we propose a method to improve the AWDR. The improved coding technique results in a better rate-distortion performance, especially in the arithmetic coding mode, than that of [7]. This is achieved by better-organized predefined scanning order and adaptation (see section 3), together with a more efficient arithmetic coding for bit-plane WDR (see section 4).

2. WAVELET DIFFERENCE REDUCTION

The original WDR maps the two-dimensional image coefficients into one-dimensional scanning order. Binary stream of output symbols of WDR-based coders have 4 possible symbols (+,-,0, and 1) for significance pass and 2 possible symbols (0 and 1) for refinement pass. In the significant pass, each significant coefficient is encoded with its sign (+ or – symbol) followed by distance along the scanning order between itself and the previous encoded coefficients in reduced form. The distance can be called difference reduction and are presented by string of 0 and/or 1 symbols. The further detail of WDR can be found in [1] and brief summaries can be found in [4]–[7].

3. BINARY ENCODING: CONTEXT-BASED ADAPTABLE SCANNING ORDER OF WDR

In this coding technique, called context-based adaptive wavelet difference reduction (CAWDR), the scanning order adaptation of wavelet difference reduction is based on statistical context modeling of the wavelet transform coefficients. The fundamental idea is similar to ASWDR and CMWDR. However, the context model is more advanced in taking number of significant coefficients into consideration. Moreover, a newly developed predefined scanning order and bit-plane header are integrated into the coder to provide good rate-distortion performance in binary encoding mode. The role of number of significant neighbors is utilized by priority weight. The cumulative weight for coefficients with
All-lowpass subband and all highest level subbands in each orientation can be scanned by these new scanning orders directly. However, for lower subbands, they will be separated into subblocks, each with members of $2^{(L_{\text{max}}-L)} \times 2^{(L_{\text{max}}-L)}$ coefficients. Where $L_{\text{max}}$ is the highest decomposition level and $L$ is the level of the current subband. That is, if $L_{\text{max}} = 5$, all subbands in level $L = 4$ must be separated into subblocks, each with $2 \times 2$ members, and with $4 \times 4$ in $L = 3$, and so on. The new scanning order will be assigned to inter-subblocks, then intra-subblocks.

The algorithm also allows the predicted coefficients to be moved in front of all unpredicted coefficients (even with much higher decomposition level). The idea is to scan higher potential coefficients before the lower potential ones. The LIP of predicted coefficients (LIP_N and LIP_C) for all subbands will be merged together, except for all subbands in the highest level. With this manner of prediction, the significant coefficients can be encoded with less number of bits.

With all these properties, CAWDR in the binary mode is better than binary SPIHT at all bit rates. The results are shown in table I.

4. ARITHMETIC ENCODING FOR CAWDR: MULTIPLE CONTEXTS CONDITIONAL ENTROPY

In the previous section, binary version of CAWDR performs quite well. However, a zero-order arithmetic coding [11] using only one context for each pass (four symbols for significance pass and two symbols for refinement pass) results in very little rate-distortion improvement, as can be seen in [6] and [7].

In significance pass, due to the efficient significant coefficients prediction scheme of CAWDR, each pair of sign (S Type) symbols (+ and -) are not likely to be separated by very long sequence of 0 and 1 symbols (or called difference symbol = D Type). Therefore, as length of sequence of consecutive D symbol gets longer, the probability that the next symbol is S symbol is increased and the skewness of probability in significance pass is also increased.

The probability of S symbol and D symbol at symbol $m$ (when the most recent sign symbol is located $n$ symbol away) are:

$$p(x_{m})_{n}^{S} = p(x_{m} = S | x_{m-n} = S, x_{m-1}, ..., x_{m-n+1} = D) \quad (1)$$

$$p(x_{m})_{n}^{D} = p(x_{m} = D | x_{m-n} = S, x_{m-1}, ..., x_{m-n+1} = D) \quad (2)$$

And if $n1 > n2$, then it is more likely that

$$\frac{p(x_{m})_{n1}^{S}}{p(x_{m})_{n1}^{D}} > \frac{p(x_{m})_{n2}^{S}}{p(x_{m})_{n2}^{D}} \quad (3)$$

Where $x_{k}$ is symbol at location $k$, and $x_{k,i}$ is symbol located $i$ symbols before $k$. 

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**Fig. 1.** Directional weights for neighbor and children of significant pixels

(a) weights for neighbors

(b) weights for children

$S$ = significant pixel, $N$ = neighbor of significant pixel

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**Fig. 2.** 8x8 New scanning order (a) zigzag, (b) vertical, and (c) horizontal

The new orders scan the quadtree coefficients together while well maintain the orientation of the subband. Fig. 2 shows the new scanning orders.
The more skewness will lead to smaller code length due to reduction in the entropy. Therefore, multiple-order conditional entropy coding [12] is considered. An array of contexts ($C^n_s$, all have four possible symbols) are used, one for each possible condition for encoding the output symbols.

For example: contexts for the significance pass

(First sign)

symbols: $\pm 0 1 0 - 0 + 1 0 ..$

Types: $S D D D S D S D D ..$

Contexts: $C^R_s$ $C^S_s$ $C^S_2$ $C^S_3$ $C^S_4$ $C^R_1$ $C^S_2$ $C^S_1$ $C^S_2 ..$

Where: $C^R_s$ context is used when the most recent sign $(S)$ symbol is at the $n$-th location earlier.

$C^S_s$ is a context with two possible symbols.

Note that: first symbol must be sign (only $+ \ or \ -$).

For the refinement pass output including bit-plane header section and the first sign symbol in each bit-plane, the zero-order binary arithmetic coder using only one context ($C^R$) is exploited.

With this very effective arithmetic coder, the performance of CAWDR and other WDR-based coder can be increased significantly and the results are shown in the next section.

5. EXPERIMENTAL RESULTS

In this section, the coding performance in rate-distortion sense of CAWDR is presented and compared with the performance of other coders described in this paper. The fixed weight model [7] for significance prediction is used for binary CAWDR.

Comparing different image coding techniques is always a difficult task because many papers presented results for different images even though they used the same names, such as Lena and Barbara. In order to provide a strict reference, the coding results in this paper are performed on the images from web site [7].

All test images are 512x512 bpc and are Lena, Barbara, Goldhill, and Boat. The results of CMWDR from [6] can be used for comparison straightforwardly, since these images were also used in that paper. Results of WDR&ASWDR, SPIHT and JPEG2000 are real encoding/decoding of their reference software from [8], [9] and [10], respectively. For our proposed coder, CAWDR, anyone who is interested can mail us at the authors’ mailing addresses. All images are transformed into 5-level two-dimensional discrete wavelet decomposition using the well-known 9/7 filters before encoding at 2 bpc, and then reconstructed at rate 0.625, 0.125, 0.25, 0.5, 1 and 2 bpc from its own single file of 2 bpc encoding. The rationale behind this process is to test encoder/decoder in the embedded approach. Please be noted that the encoding and decoding exactly at the same bit rate (such as 0.5 bpc) may result in different PSNR values from ones presented in this paper. However, with that manner, one can not fully mention the embeddedness of the coder.

<table>
<thead>
<tr>
<th>Image</th>
<th>WDR (new)</th>
<th>WDR</th>
<th>ASWDR</th>
<th>CMWDR</th>
<th>SPIHT</th>
<th>CAWDR</th>
<th>CAWDR (new)</th>
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<tbody>
<tr>
<td>Lena</td>
<td>33.51</td>
<td>33.30</td>
<td>33.65</td>
<td>33.89</td>
<td>33.69</td>
<td>33.93</td>
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<td></td>
<td>0.25</td>
<td>36.55</td>
<td>36.41</td>
<td>36.66</td>
<td>36.99</td>
<td>36.84</td>
<td>37.00</td>
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<tr>
<td></td>
<td>0.5</td>
<td>39.67</td>
<td>39.59</td>
<td>39.77</td>
<td>40.05</td>
<td>39.98</td>
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<td>Barbara</td>
<td>27.45</td>
<td>27.24</td>
<td>27.44</td>
<td>28.20</td>
<td>27.76</td>
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<td></td>
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<td>30.22</td>
<td>30.25</td>
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</table>

The PSNR results of all coders in binary mode are shown in table I. It is obvious that CAWDR performs better than all other coders. Especially in “Barb” image, the PSNR of CAWDR coder can reach 0.5 dB higher than PSNR of SPIHT in some bit rates. This reveals that CAWDR, which uses both neighborhood and parent-child relations, can handle orientation of wavelet coefficients better than SPIHT, which uses only parent-child relation. To demonstrate their efficiency, we also show the PSNR results of a WDR coder using only our new scanning order, bit-plane header, and the new arithmetic coder (without scanning order adaptation). This coder is called WDR (new) in all tables.

CAWDR uses the new multiple contexts conditional arithmetic encoding in significance pass. The number of contexts used is not so great (not more than 9 contexts) and depends on the size of bit-plane. The encoder and decoder can synchronously specify the size of bit-plane without any side information. This can be done by the information in the header – the total number of significant coefficients encoded in each bit-plane. The more encoded coefficients, the larger size of bit-plane and more contexts are likely to be used. WDR coder with end-marker cannot do this without extra side information. For symbol with sign symbol at $m$ location earlier, where $m$ is higher than the number of contexts (such as $m > 9$), the symbol will be encoded with the highest context available in that bit-plane.

In table II, the PSNR results of all coders in arithmetic mode are presented, and the average of all images is shown in table III. The arithmetic encoded CAWDR can outperform SPIHT and JPEG2000 in many bit rates of many images. For example, PSNR results of “Lena” of CAWDR are the best among all coders for all bit rates.
To provide full information, the total numbers of encoded significant coefficients are shown in table IV.

Based on our proposed technique, this is the first time in the literature that a WDR-based coder can reach this high rate-distortion performance. The improvement is mainly from the new conditioning arithmetic coder. This is very similar to the case [2] that special type of arithmetic coder, additional to the highly refined binary output, can significantly enhance the performance of SPIHT over its predecessor, EZW.

6. CONCLUSION

CAWDR is very competitive, in PSNR sense, to SPIHT and JPEG2000. Moreover, it has lower computational complexity than JPEG2000 and supports ROI which can not be found in SPIHT. The rate-distortion improvement from CAWDR over WDR and all other WDR variants can not be considered marginal at all. CAWDR can reach 1.5 dB higher PSNR than the original WDR and is normally 0.3 dB better than CMWDR and ASWDR in all bit rates.

7. REFERENCES


[8] WDR and ASWDR compressors are part of the FAWAV software package and can be downloaded at http://www.uwe.ac.uk/walkerj/pages/resume.html


