A BPGC-BASED SCALABLE IMAGE ENTROPY CODER RESILIENT TO ERRORS

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ABSTRACT

In this paper, we present a new entropy coder, Context-based Bit Plane Golomb Coder (CB-BPGC) for scalable image coding, which achieves better coding performance with lower complexity compared to the state-of-the-art JPEG 2000 entropy coder EBCOT. Because of the direct output *lazy bit planes*, applying the partial decoding on the corrupted bit planes, and the better compression ratio which may lead to corruption to the less important codestream, CB-BPGC appears more resilient to errors when simulated on the wireless channel based on Rayleigh fading model.

1. INTRODUCTION

With the increasing demands from modern image application, lots of interests have been focused on wavelet based embedded image coder. Current image coders emphasize not only on generating an embedded bitstream with modest coding efficiency but also on other attractive functionalities such as scalability, random access and error resilient. The state-of-the-art image coding standard JPEG2000 specifies such an image coder [1].

JPEG2000 is based on discrete wavelet transform, quantization and the entropy coder, embedded block coding with optimal truncation (EBCOT). EBCOT is an independently block coded, context based adaptive bit plane coder, by which spatial correlation of the wavelet coefficients are finely modeled for each subband and each bit is fractional bit plane coded by the binary adaptive coder (MQ coder). A Post Compression Rate Distortion Optimization algorithm (PCRD) is then applied to organize each code block bitstream in an optimal way to minimize the distortion subject to the bit rate constraints and thus generate the output bitstream [1][2].

As robust transmission of compressed multimedia data over noisy channels has become an increasingly important requirement, JPEG2000 adopts error resilience at the entropy coding level which contains individually coded blocks, termination coding for each coding pass, reset of contexts, bypass coding and segment markers, and in packet level where resynchronization markers are included [2][3]. When the decoder detects errors in a certain bit plane, JPEG2000 replaces the current and the following bit planes by zeros to prevent error propagation. Extension work is ongoing in the new standard JPWL (JPEG2000 for Wireless Applications) which targets at efficient transmission of JPEG2000 codestream over error-prone channels [4].

Although EBCOT is a delicate context adaptive entropy coder, inefficiency still exists. For example, low resolution blocks often have few coefficients where the MQ coder tends to end coding before adapting to the local properties. Besides, bits in some lower order bit planes of the higher energy blocks are often uniformly distributed, where the context adaptive coder sometimes causes expansion rather than compression. EBCOT specifies a bypass mode which outputs raw bits of the lower bit planes, but it has no systematic way to tell from which bit plane direct output is more efficient. Error resilient in JPEG2000 can also be improved. The authors in [5] point out there are dependencies among the coding passes of a code block, where partial decoding of the corrupt bitstream can be added to improve error resilience performance. For example, if an error is detected in the current magnitude refinement pass, instead of setting the current and remaining bit planes to zeros we can further decode its following significant propagation passes and clear up passes when termination for each coding pass is set.

In this paper, we propose the new entropy coder, Context-based Bit Plane Golomb Coder (CB-BPGC). By combining the Bit-Plane Golomb Coding (BPGC) [6], an embedded coding strategy for Laplacian distributed sources such as wavelet coefficients in HL, LH and HH subbands, with image context modeling techniques, CB-BPGC provides better compression performance and also more resilient to errors compared to EBCOT.

2. CONTEXT-BASED BPGC

The idea of BPGC is first presented in [6]. Consider a Laplacian distributed source X,

$$f_X(x) = e^{-|x|\sqrt{2/\sigma^2}}/\sqrt{2\sigma^2} \quad (1)$$

The magnitude of sample $X_i (i=1,2\ldots N)$ is binary represented by bit planes. If the source X is independent and identically distributed (i.i.d), the approximate probability of the bit $b_{j,i(j=m,m-1...0)}$ in bit plane B_j can be described as,

$$Q_j^L = \begin{cases} 1/(1+2^{2^{j-L}}) & j \geq L \\ 1/2 & j < L \end{cases} \quad (2)$$

$$L = min\{L' \in Z | 2^{L'+1} N \geq A\} \quad (3)$$

where m is the most significant bit plane, N is the number of samples and A is the absolute sum of the samples. By simply calculating the N and A, parameter L divides the bit planes into two parts: *lazy bit planes* where bits '0' and '1' have a probability of 1/2 and can be directly outputted to the codestream; *non-lazy bit planes* (m bit plane to the L bit plane) whose skew probabilities are specified by the distance *D2L:* $j - L$ by (2) and then coded by the static arithmetic coder.

It is said in [6] the BPGC gives an identical compression performance to that of the Golomb code for non-negative integer sources with geometrical distributions. The BPGC-based entropy coder is now included in the latest MPEG-4 Audio Scalable Lossless Coding(SLS) standard [7]. However, it is based on the constraint that the coding source is i.i.d. and the fact that the audio signal is a 1-D signal, while image wavelet coefficients are heavily spatial correlated. BPGC static probability model whose probability is specified by only *D2L* would obviously lose some coding efficiency. So, we combine BPGC with the image context modeling techniques, by which bits probabilities differ from each other according to *D2L* and neighborhood contexts.

Table 1. D2L Contexts

Ctxt.No.	0	1	2	3	4	5	6
D2L	≤ -3	-2	-1	0	1	2	≥ 3

Table 1 lists the 7 *D2L* contexts in CB-BPGC. Context 0 is for the *lazy bit planes*. For the neighborhood contexts, part of contexts in EBCOT is adopted [2]: 9 contexts for coefficients which are about to be significant; 3 contexts for those already significant. We output the sign bits directly to reduce complexity while 5 contexts are used for sign adaptive coding in EBCOT. Codebooks for the probabilities can be trained offline and pre-saved for different contexts.

CB-BPGC uses the same Post Compression Rate Distortion Optimization as EBCOT to pack the codestream after embedded coding. For the embedded coding part, Fig.1 illustrates the block encoding process. As shown in Fig.1, in order to model the blocks better, they are classified to LOWE blocks ($L < 0$) and SIG blocks ($L \geq 0$) before coding. Blocks with the same class share the same codebook. The three fractional bit plane codings are then applied bit plane by bit plane for fine embedding. A static binary arithmetic coder then compresses all the bits with the looked up probabilities from the codebook.

The proposed coder is implemented with the Java implementation of JPEG2000 (*JJ2000* [8]). We train the code-

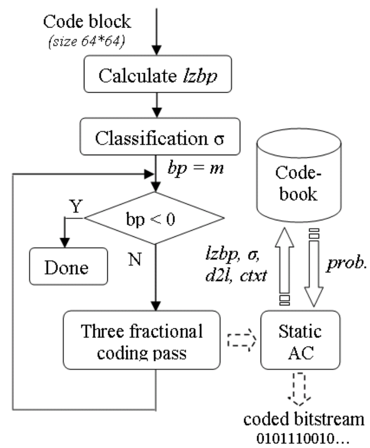


Fig. 1. CB-BPGC encoding a block

books from a sets of natural grayscale images and ten typical JPEG2000 testing images are evaluated. Table 2 shows the results of lossless compression performance of 5 level 5/3 reversible wavelet decomposition at block sizes of 64×64 and 16×16. Positive numbers in *Perc.* columns indicate the percentage of CB-BPGC better than EBCOT while the negative ones are inverse. The average lossless results show that CB-BPGC is more efficient than EBCOT, especially for those images which are hard to compress, e.g. *baboon* and *cafe*, where the adaptive coding procedure probably fails to learn the complicated texture-like blocks well and as well as the ineffectiveness of the *lazy bit planes*. In addition, CB-BPGC is more efficient at smaller code block size.

Table 2. Lossless results for 5/3 reversible DWT (bbp)

Image	Size	64×64			16×16		
		J2K	BPGC	Perc.	J2K	BPGC	Perc.
baboon	500×480	6.166	6.020	2.36%	6.626	6.412	3.22%
barb	720×576	6.249	6.143	1.69%	6.728	6.553	2.61%
fruits	640×512	4.149	4.168	-0.46%	4.538	4.451	1.91%
goldhill	720×576	4.645	4.609	0.78%	5.058	4.937	2.39%
lena	512×512	4.620	4.568	1.12%	5.022	4.871	3.01%
monarch	768×512	3.845	3.894	-1.28%	4.237	4.150	2.04%
woman	512×640	4.238	4.234	0.10%	4.619	4.532	1.89%
café	1024×1280	5.673	5.570	1.80%	6.148	5.966	2.95%
tool	1280×1024	4.402	4.414	-0.28%	4.826	4.708	2.44%
actors	1280×1024	5.408	5.320	1.62%	5.873	5.690	3.12%
average		4.957	4.894	0.75%	5.390	5.227	2.56%

Table 3. PSNR average results (dB)

bpp	0.125	0.25	0.5	1	2	4
J2K	25.92	28.25	31.25	35.18	40.51	47.69
CB-BPGC	25.90	28.28	31.32	35.31	40.76	48.09

The average scalable compression results (5 level 9/7 decomposition, block size: 16×16) are listed in Table 3, which show that CB-BPGC outperforms EBCOT in terms of PSNR except at very low bit rates. It is probably because coefficients in the LL subband are Rayleigh distributed while BPGC is derived from Laplacian distribution. PSNR of CB-BPGC is about 0.13dB better for bitrate 1 bpp and 0.25dB for bitrate 2bpp on average.

Compared to EBCOT, CB-BPGC also has lower complexity. For the grayscale natural images lossless and lossy encoding, about 11.04% and 9.02% of the JPEG2000 encoding runtime are saved in CB-BPGC on average. That is probably because in CB-BPGC we use a static arithmetic coder rather than an adaptive one in EBCOT and a recent arithmetic coder complexity report [9] shows that for binary coding, the encoding time of the static arithmetic coder is only about 58.6% of the MQ coder. In addition, fewer contexts are used in CB-BPGC and direct output the sign bits and bits in the *lazy bit planes* further reduce the complexity.

3. ERROR RESILIENCE OF CB-BPGC

In this section, the performance of CB-BPGC in terms of error resilience is investigated and then verified by the simulation results.

CB-BPGC coded bitstreams are hierarchically organized by subbands, blocks and bit planes for resynchronization which are the same as JPEG2000 error resilience at packet level. Fig.2 illustrates the error resilient strategies used in our entropy coding procedure. The static arithmetic coder terminates at each fractional bit plane to stop error propagation, followed by the segment marker '1010' after the coding pass 3 and segment marker '10' after the coding pass 1 and 2. Whenever a mistake appears in decoding markers, an error is detected. Therefore no extra redundancy is added in CB-BPGC for error resilience.

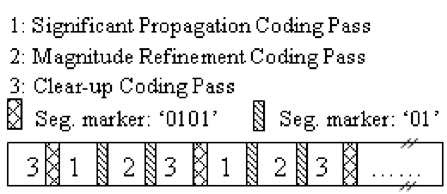


Fig. 2. Error Resilient Segment Markers

CB-BPGC then conducts the partial decoding [5] for the following bit planes of the error blocks, which can be described as follows,

<u>Case 1:</u> Error detected in coding pass 1. No further coding pass 1 and 3 can be decoded. But coding pass 2 in the current bit plane can proceed.

<u>Case 2:</u> Error detected in coding pass 2. No further coding pass 2 can be decoded, but coding pass 1 and 3 in the current and the following bit planes can proceed.

<u>Case 3:</u> Error detected in coding pass 3. No further coding pass 1, 2 and 3 can be decoded.

Note that the error resilient PSNR gain reported in [5] is based on the assumption that there is an external error detection mechanism to tell the decoder from which byte in a certain fractional bit plane is corrupted by errors, which leads to a more complicated partial decoding applied on the fractional bit plane level instead of the bit plane level, i.e. additional information outside of the JPEG2000 decoder helps to guide the decoder to decode much more corrupted codestream. Our test results show that by only using the internal error detection method in CB-BPGC, substantial PSNR improvement can be obtained when the image is transmitted through a Rayleigh channel.

Fig.3 shows the average CB-BPGC PSNR gains of ten images compared to standard JPEG2000 at BER 10^{-4}, 10^{-3} and 6×10^{-3} for different bit rates (5 level 9/7 decomposition, block size: 64×64, resolution-layer-component-position progression order). Each image is simulated over a Rayleigh channel for 500 times. CB-BPGC uses the error resilient tools described above and EBCOT is set with BYPASS, RESET, CAUSAL, ERTERM, RESTART properties. In both bitstreams, LL subband layers are protected from error corruption, which are the most important information in the embedded stream and often transmitted through a more reliable channel. As shown in Fig.3, CB-BPGC is more resilient to errors with improved PSNR for all the bit rates with averages at 0.731dB, 1.514dB and 2.097dB for BER at 10^{-4}, 10^{-3} and 6×10^{-3} respectively. Fig.4 gives an example of the comparison of the average PSNR of the error free and error corrupted decoding at BER 10^{-3} for image *lena* and *tools* at several bit rates. Subjective results of the image *lena* and *peppers* at BER 10^{-3} and 1 bpp are shown in Fig.5, which shows not only a better PSNR dBs but also a substantial improvement of subjective effect.

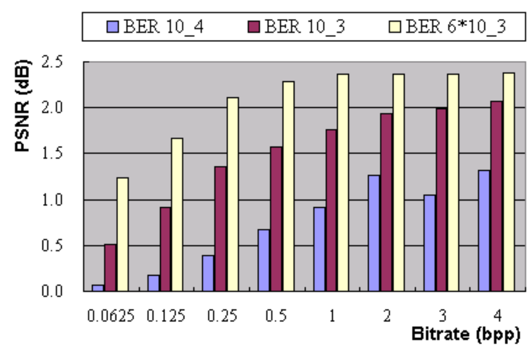
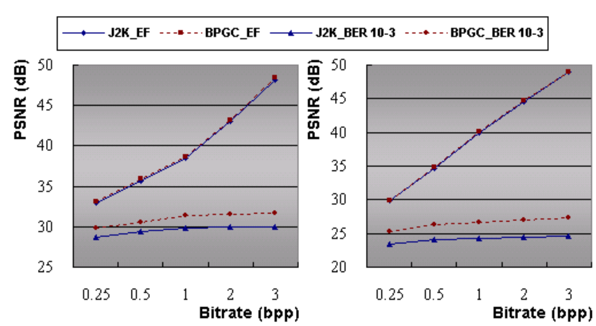


Fig. 3. Average PSNR improvement for different BER

The improvement of the error resilient performance of CB-BPGC is not only gained by adding the partial bit plane decoding, but also by the more efficient scalable coding. As the PCRD algorithm organizes codestream according to the



(a) *lena* 512×512 (b) *tools* 1280×1024

Fig. 4. PSNR comparison at BER 10^{-3}

(a) Error free lena (256×256)

(b) J2K (32.153 dB)

(c) CB-BPGC (34.080 dB)

(d) Error free peppers (256×256)

(e) J2K (27.251 dB)

(f) CB-BPGC (29.254 dB)

Fig. 5. Subjective results of image lena (a-c) and peppers (d-f) at bit rate = 1 bpp and BER = 10^{-3}

contribution of reducing distortion, i.e., in a decreasing order, more efficient compression enables CB-BPGC to consume less bytes to embed the codestream while still providing the equivalent distortion reduction. Hence, when a transmission error occurs, it corrupts the less important bitstream of CB-BPGC and the PSNR result is better. Directly outputting *lazy bit planes* also improves error resilience performance. In spite of errors that occur in the *lazy bit plane*, we can further decode the remaining coefficients because the errors are isolated to certain coefficients instead of propagation to the others. In addition, CB-BPGC use a partial decoding method to fully decode the corrupted codestream. Further improvement of error resilience can be achieved by employing some error concealment techniques such as edge based concealment in [10].

4. CONCLUSION

In this paper, we proposed a Bit-Plane Golomb Coding based scalable image entropy coder, CB-BPGC, which provided not only better lossless and lossy scalable coding performance but also greater resilience to transmission errors compared to the JPEG2000 standard.

5. REFERENCES

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