STACK-RUN-END COMPRESSION FOR LOW BIT RATE COLOR IMAGE COMMUNICATION

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ABSTRACT

A new wavelet image coding algorithm was designed for color image compression in this paper. This algorithm utilizes multi-ary symbol set to represent the meaningful coefficients in the wavelet transform domain which are necessary for the image reconstruction in the respective color channel. The scheme works first by color space conversion, followed by raster scanning the individual subband for data conversion to symbol representation. Adaptive arithmetic coder is then used to compress the symbols with high efficiency. Unlike zerotree coding or its variations which are essentially the intersubband coding approach with the complexity in addressing the location relationship across the subbands, this work is a low complexity intrasubband based coding method with context specification within the subband, and termination symbol across subbands. Compared with the zerotree refined schemes, this algorithm results in competitive PSNR values and perceptually high quality images at the same compression ratio for color image compression.

1. INTRODUCTION

Color image compression is an important technique to reduce the communication bandwidth consumption in Internet or wireless multimedia transmission and the applications for storage and archiving purposes. The most common used JPEG [1] is the current standard which is based on the block discrete cosine transform. The block artifacts are significant at highly compressed reconstructed images. Wavelet transform [2][3] based image compression algorithms [4][5][6] have achieved good compression performance and been expected to be the core technique for the next generation image communication standard [7]. Among all the approaches, Dr. Shapiro's zerotree [4] data structure has been widely used and extended to different variations and refinements. In essence, they are intersubband based approaches where intersubband relationship has been explored from the ancestor and children dependency. Contrast to the zerotree approach, our new algorithm is an intrasubband scheme where only information within the subband is needed. The algorithm is conceptually simple without addressing the relationship across the subbands and easily to implement because of the small number of symbol set. Beyond its simplicity, its performance is significantly better than JPEG standard and very competitive with the zerotree refinements.

This paper is organized as follows. In Section 2, we explain the Stack-Run-End compression in detail. In Section 3, we summarize the experiment results and outline its characteristics. Finally, we conclude our renovation with summary.

2. STACK-RUN-END COMPRESSION

The hierarchical decomposition structure of the wavelet transform and uniform scalar quantization in each subband is basically performed before the application of the proposed algorithm. However, this algorithm could be applied to different wavelet decomposition format with different quantization procedures as well. Based on the observation that the quantized transform coefficients are either zero values or nonzero values (called significants) with positive or negative sign, efficient grouping scheme and representation for those meaningful information are necessary in the data conversion procedure for image compression techniques. Our approach is different from JPEG's run grouping and similar to the more advanced approach "Stack-Run Coding" [8][9]. The refinement of Stack-Run-End (SRE) coding in this color image compression extends the original stack-run symbol set by the consideration of grouping zero value coefficients into the termination symbol representation, especially near the end of the subband. If no significant coefficients locate at the high frequency subbands, an end-of-image symbol should be used to terminate the computation and transmission.

To make a concise introduction of our algorithm, an example in Figure 1 illustrates the (stack,run) conversion approach. From Figure 1, only three nonzero transform coefficients with integer values exist after the uniform quantization. The nonzero coefficients are called "stack" and the zero values between the stacks are grouped as "run" value. For the zero values towards the end of the subband could be simply represented by an "end-of-subband" symbol. Several consecutive "end-of-subband" symbols towards the end of the image could be simplified by an "end-of-image" symbol for the encoding.

The symbol alphabet in our context for the "stack" value are denoted as the following:

"+": the binary value 1 with the sign value "+", always used in the stack's MSB.

"-": the binary value 1 with the sign value "-", always used in the stack's MSB.

"1": the binary value 1 of the significant coefficient.

"0": the binary value 0 of the significant coefficient.

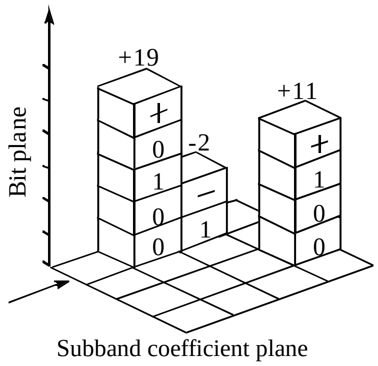


Figure 1. Illustration of the transform coefficients from the perspective view. The raster scanning follows the arrow direction. The values of the significants are +19, -2 and +11. The run values are 1, 0 and 8 with one termination symbol “EOB”.

Two symbols “+” and “-” are used to represent the "run" value. The exception for the run value located at the end of the subband is used by the termination symbol “EOB”. Several consecutive EOBs towards the end of the image will be represented by another termination symbol “EOI”. They are summarized as the following:

"+": the binary value 1 of the run value.

"-": the binary value 0 of the run value.

"EOB": the symbol for those zero values which are between the last nonzero significant coefficient and the end of the subband.

"EOI": the symbol for those zero values which are between the last nonzero significant coefficient and the end of the image.

In Figure 1, the significant coefficients +19, -2, +11 are labeled on the stacks by the above symbols. Given the requirement to distinguish the various contexts, the binary representations of the quantized coefficients are added a binary value 1 which is actually worked as the indication for the quantization compensation during the reconstruction to reduce the quantization error. So, the significants +19, -2, +11 are represented as 20, 3, 12 with the sign information on the top of the stacks. For example, +19 could be labeled as 00101 (from LSB to MSB order) in the binary representation. With the positive sign information at the MSB , the total representation for +19 is "0010+". The representation for the negative value is the same for "-2" as labeled "1-".

Those zero values in the Figure 1 will be grouped as run values or special termination symbols. The mapping relationships for the stack and run value are illustrated in Figure 2. We have noticed that the run values are always positive integers. To avoid the confusion in context representation, the MSB “+” of the run binary representation would be redundant except for the value equivalent to 2^k-1 where k is an integer. This is a very important observation to further facilitate the compression efficiency and reduce the number of the symbol representation.

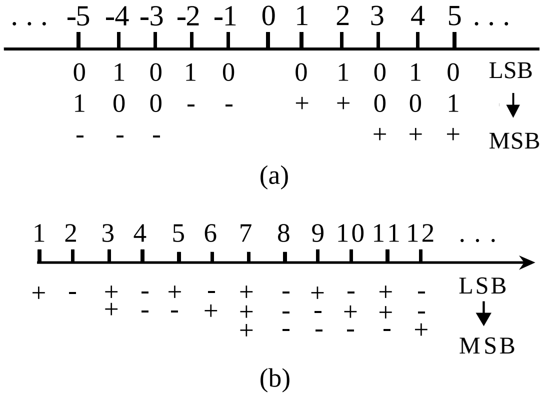


Figure 2. Mapping rule for (a) stack (b) run values

From the initial scanning point, there is a zero value before "+19", the run value is 1. Since there is no zero value between "+19" and "-2", the run value 0 is not encoded. Another run value "8" exists between the "-2" and "+11". After the significant value "+11", four zero values are left till the end of the scanning. If this is the end of the subband, an EOB symbol is used which is regardless of the run value. If the situation is no further significant values towards the end of the image, an EOI symbol is used. Assuming this is the end of the subband, the whole symbol stream could be represented as "+0010+1----001+EOB". At this point, we already successfully convert the meaningful information in the subband into a more concise data representation.

Since the information created from above example is either stack ,run or the termination symbols, it has been examined that directly applying one entropy coding scheme for the whole symbol stream could not efficiently compress those symbols. To utilize the information created from different types of data with different symbol distributions, a partition of the symbol stream for the best entropy coding is necessary. The "location list" and "stack list" are generated after the partition according to the following rules:

- Stack list is the list of stack symbols ordered sequentially from LSB to MSB. However, the LSB of the stack is not included.
- Location list is the list of the run values with the LSB of the adjacent stacks and the termination symbols EOB and EOI.

According to the above rules, the symbol stream of the example in Figure 1 will be easily separated from "+0010+1----001+EOB" into the stack list with the stream "010+-01+" and the location list with the stream "+01---0EOB" respectively. After this separation, a more compact stack and run values are closely related within the similar context list. Since the symbol is well defined and uniquely distinguishable with the prior information about the image size and the decomposition structure at both encoder and decoder, there is no confusion about the information presentation.

A zeroth order adaptive arithmetic coder [10] is applied to further compress those two lists for each subband. The coder’s counter of the symbol appearance is always reset whenever a new location or stack list occurs. The coder itself is very simple and the adaptability is very fast given the small setting of the maximum frequency for the symbol appearance. It also considers the local variation of the probability distribution to adjust the frequency order. Alternately encoding the stack list and location list for the stack-run-end compression, a subband based embedded stream could be created for the progressive transmission and display.

3. DISCUSSION

A huge amount of color image data have been tested under this new stack-run-end compression approach. In this image set which contains over 100 color images ranging from 64x64 to 736x576, we adopt the advice from [11] to exclude some over-used images like lena and pepper. We try to extend the fields and include more new images with wide varieties which are suitable for Internet communication and wireless transmission or other similar purpose uses. Since the images come from different available resources, we expect they can cover wide area of applications for color image compression evaluation.

Even the judgment of compression performance is not mainly based on the numerical metrics like the peak signal noise ratio (PSNR), those numbers are by far the most common used and the easiest way for evaluation comparison. In our experiments, current standard JPEG and the refinement of zerotree scheme from Said & Pearlman [6] (S&P) are also compared. To make the fair comparison, both SRE and S&P use the 9-tap/7-tap filter [12] in the wavelet transform and perform the hierarchical decomposition. Given the testing environment is the personal computer with Pentium MMX233 under Window NT 4.0, BMP image format with R, G, B channels is the most popular format for PC applications. From statistics, the R, G, B color channels have high correlation relationship. To decorrelate the interrelation, the whole computation has been performed under the YUV color domain to increase the efficiency. After the compression, the reconstructed images are stored in the BMP image format for display and evaluation. The overall color PSNR performance of various target compression ratio at low bit rate from over 100 color images are summarized and tabulated at Table 1.

In Table 1, the average color PSNR are calculated for each target bit rate for each tested image. For each compression technique, we get the final PSNR value by summing all the color PSNR numbers and then divided by the number of the images. Even those numbers are the overall results which do not tell the compression performance for each individual image, they still disclose the characteristics of the compression techniques in the numerical sense. We notice that SRE and S&P are far superior to JPEG method from the color PSNR metric. The PSNR difference between SR and S&P is between a few tenth of a dB variation which is negligible.

Algorithm and bit rate	0.25bpp (96:1)	0.5bpp (48:1)	0.75bpp (36:1)	1.0bpp (24:1)
SRE	24.63dB	27.46dB	29.70dB	31.61dB
S&P	24.81dB	27.72dB	29.90dB	31.88dB
JPEG	23.36dB	26.18dB	27.76dB	29.01dB

Table 1: Compression results from SRE, S&P and JPEG methods at the bit rate 0.25, 0.5, 0.75 and 1.0 bpp with the compression ratio at 96:1, 48:1, 36:1 and 24:1 respectively. The average of color PSNR from R, G, B channels are calculated over 100 color images.

In addition to PSNR metric evaluation, we also requested 2 experienced technicians to visually compare the reconstructed images and give the perceptual quality score for those three methods at high compression ratio. The conclusion is that JPEG produces significant block artifacts which is the apparent noise from the reconstructed images. SRE and S&P have much better image fidelity maintenance and both algorithms are very comparable. The interesting behaviors from the SRE and S&P reconstructed images are that SRE has the better capability to maintain the details of the object and S&P seems to keep the color distribution better.

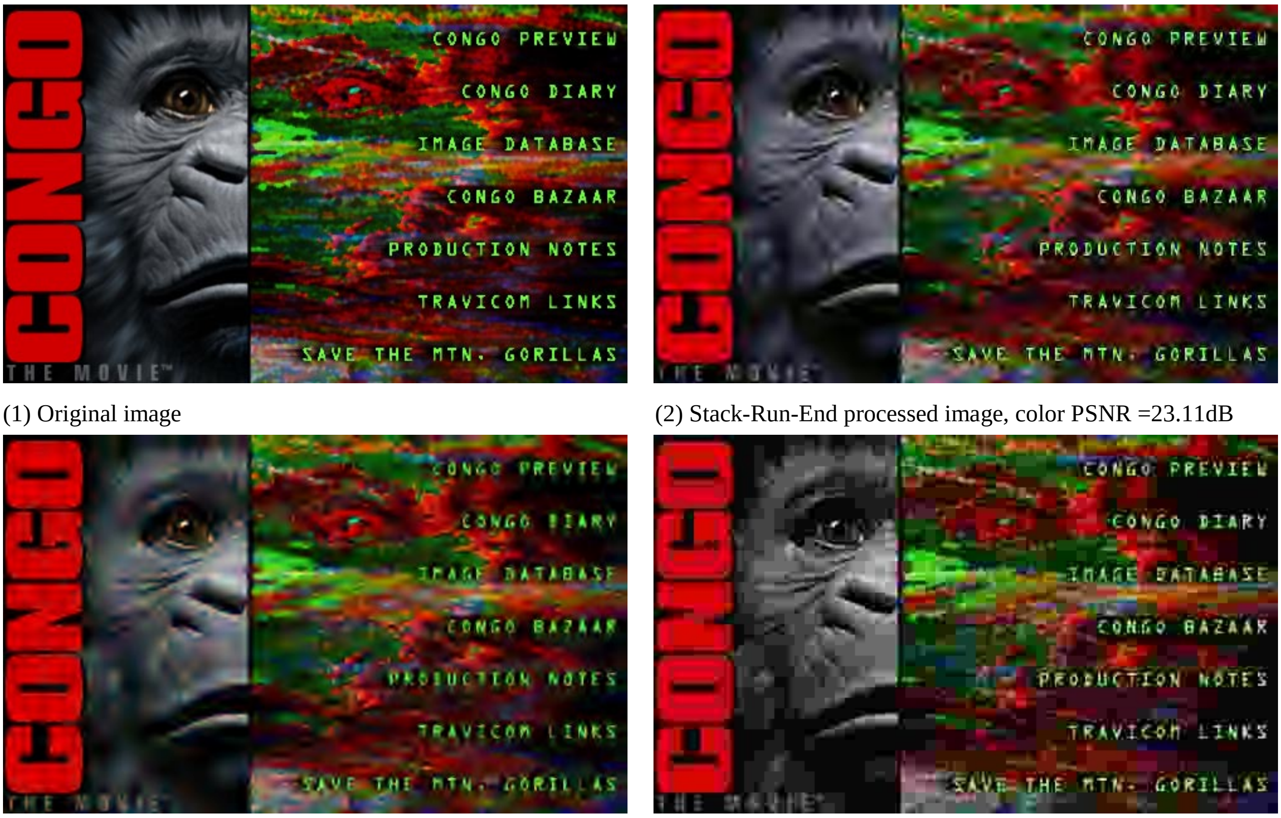
From Table 1, it can not distinguish the individual image compression result under different algorithm. We demonstrate an example in Figure 3 to illustrate the point from the perceptual observation. From the pictures at Figure 3, the reconstructed image from JPEG has obvious block artifacts and color distortion. SRE and S&P have blurred textures but still maintain the object structure. If we emphasize the text information from the reconstructed images, it is very encouraging that SRE has much stronger edge details than S&P and JPEG. This observation agrees with the conclusion from the visual test.

There is also a common critique to refer the complexity issue during the algorithm development. Since the SRE codes are not optimized yet, it is still too early to jump to the conclusion about the complexity comparison. In addition, there are many other consideration about the issues in CPU, memory or compiler during the realization. From our preliminary analysis, SRE compression has the similar complexity to the S&P method. Both methods are on the same scale of the speed with the potential for improvement, which are about 2~3 times slower than the JPEG method at the current version.

The advantage of the termination symbol design for color image coding in SRE compression is important at least two ways. The first one is that Y channel constructs the most of color content information than U, V channels. EOB and EOI symbols will be more often used for U, V channels which can benefit the reduction of the number of symbols in conversion. The other one is to speed up the reconstruction procedure for the receiver which can spare the minimum waiting time at the decoder.

4. CONCLUSION

In this paper, we introduce a new algorithm: Stack-Run-End compression for color image coding. The technique is an intrasubband wavelet based approach which is different from the zerotree type based schemes. The algorithm uses multi-ary alphabet symbol set to convert the meaningful information of the wavelet transform coefficients into a concise data structure. Two type of context lists for each subband are alternatively compressed by the zeroth order adaptive arithmetic coder with high efficiency. The bit stream has the progressive transmission



(1) Original image

(2) Stack-Run-End processed image, color PSNR =23.11dB

(3) S&P processed image, color PSNR = 23.03dB

(4) JPEG processed image, color PSNR = 21.50dB

Figure 3. Demonstration of the original 24 bit congo image and the reconstructed images by SRE, S&P and JPEG methods at the compression ratio 96:1 which is equivalent to 0.25 bits per pixel (bpp). (1) is the original congo image. (2),(3),(4) are reconstructed image by SRE, S&P and JPEG method respectively. Color PSNR values for all three techniques are also included in (2), (3) and (4).

property since it is organized at the subband order. Our experiment results shows that our approach is very competitive to the refinement of zerotree type schemes. From perceptual viewing test, high detail fidelity maintenance of the color image is achieved by our techniques.

5. REFERENCES

[1] W.B. Pennebaker, J.L. Mitchell, “JPEG - Still Image Data Compression Standard”, Van Nostrand Reinhold, New York, 1993.

[2] Daubechies, “Orthonormal bases of compactly supported wavelets,” *Comm. Pure Appl. Math.*, vol. XLI, pp. 909-996, 1988.

[3] S. Mallat, “A theory for multiresolution signal decomposition: the wavelet representation”, *IEEE Trans. Pattern Analysis Machine Intell*. 7:674-693, 1989.

[4] M. Shapiro, “Embedded image coding using zerotrees of wavelet coefficients,” *IEEE Trans. On Signal Processing*, vol. 41, no. 12, pp. 3445-3462, Dec. 1993.

[5] A. Zandi, J. Allen, E. Schwartz, M. Boliek, “CREW: Compression with reversible embedded wavelets”, *Proc. IEEE Data Compression Conference* 212:221, 1995.

[6] A. Said and W.A. Pearlman, “A new fast and efficient image codec based on set partitioning in hierarchical trees,” *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 6, June 1996.

[7] ISO/IEC JTC1/SC29/WG1 (ITU-T SG8) Coding of Still Pictures, 1997.

[8] M.J. Tsai, J.D. Villasenor and F. Chen, “Stack-Run image coding for low bit rate image communication,” *Proc. IEEE International Conference on Image Processing (ICIP’96)*, vol. 1. pp. 681-684, Sep. 16-19, 1996, Lausanne, Switzerland.

[9] M.J. Tsai, J.D. Villasenor and F. Chen, “Stack-Run image coding”, *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 6, pp. 519-521, Oct. 1996.

[10] T.C. Bell, J.G. Cleary, I.H. Witten, “Text Compression”, Prentice Hall, New Jersey, 1990.

[11] D.C. Munson, *IEEE Trans. on Image Processing*, vol. 5, No. 1, pp. 3, January 1996.

[12] M. Antonini,M. Barlaud, P. Mathieu, and I. Daubechies, “Image coding using wavelet transform”, *IEEE Trans. Image Processing*, vol. 1, No. 2, pp. 205-220, Apr. 1992.