Lossless Two-Layer Coding for HDR Images

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ABSTRACT

A lossless two-layer coding scheme for HDR images using a histogram packing technique is proposed for HDR images in this paper. The proposed scheme has the compatibility with the legacy JPEG for base layer as well as the normative JPEG XT standard. A histogram packing technique is applied to residual images to improve the performance of lossless compression. The experimental result for the bitrates of the encoded bitstreams demonstrates that the proposed structure gives a better coding performance than the normative JPEG XT profile C.

***Index Terms*—Lossless, Two Layer Coding, HDR images, JPEG 2000, JPEG XT**

I. INTRODUCTION

Image compression methods designed to provide coded data containing high dynamic range content is highly expected to meet the rapid growth of high dynamic range (HDR) image applications. Generally, HDR images have much greater bit depth of pixel values and much wider color gamut [1]–[6]. These characteristic of HDR images are suitable for recording and/or archiving the highly valuable contents, such as masterpieces of art. For such a valuable content, HDR images should be losslessly. In other words, they should be compressed without any loss that generated during compression procedure.

Most of conventional image compression methods, however, could not be applied to HDR image due to its greater bit depth and uncommon pixel format including a floating point based pixel encoding. Several methods have been proposed for compression of HDR images [7]–[14] and ISO/IEC JTC 1/SC 29/WG 1 (JPEG) has developed an international standard referred to as JPEG XT [15] for compression of HDR ones. JPEG XT has been designed to be backward compatible to legacy JPEG [16] with two-layer coding; a base layer for tone-mapped LDR image is compressed by the legacy JPEG encoder and an extension layer for residual data consists of the result of subtraction between a decoded base layer image and an original HDR image is compressed by the JPEG-like encoder. This backward compatibility to legacy JPEG allows legacy applications. The profile C, which is one of the coding profiles in JPEG XT, makes it possible to encode HDR images losslessly with such a two-layer coding.

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We also make use of JPEG XR [17] or JPEG 2000 [18] to reversibly compress HDR images as well as the profile C, but they can not produce codestreams with two layers. Besides, some methods [13], [14] have been proposed to achieve two-layer lossless coding for HDR ones, but they are not compatible with the legacy JPEG encoder.

This paper proposes a new lossless two-layer method for HDR images. In addition, the codestreams are compatible with legacy JPEG decoders. In Refs. [13], [14], [19]–[24], the sparseness of a histogram of an image is used for efficient compression. ‘Sparse’ histogram means that not all the bins in a histogram are utilized. It is well known that a histogram of an HDR image shows a tendency to be sparse [13], [14]. In this paper, this technique is used to improve the lossless compression performance for HDR images. The proposed method has a higher compression performance than the JPEG XT Profile C, and moreover can be carried out as one layer coding which provides the best coding performance.

II. PREPARATION

A. Two-layer coding for HDR images

Various two layer coding schemes for HDR images have been proposed so far [12]–[14]. The aim is to directly obtain LDR images from compressed HDR ones. However, some of them are not compatible with the legacy JPEG decoders [13], [14].

The JPEG working group has established a new standardization having the backward compatiblity with the JPEG standard for HDR images, named JPEG XT [15]. Figure 1 shows a block diagram of JPEG XT encoder of Profile C. The residual data of the Profile C is the subtraction between an original HDR image(RGB_{HDR}) and an inverse tone mapped image(RGB'_{HDR}), which is generated from the decoded LDR image.

B. Two-layer lossless coding

JPEG XT profile C can carry out lossless coding for HDR images. Lossless coding of half floating point samples can be realized by the following mechanisms:

- apply a one-to-one output conversion that maps integer samples to floating point samples
- use a reversible color transformation
- use a fixpoint DCT process.

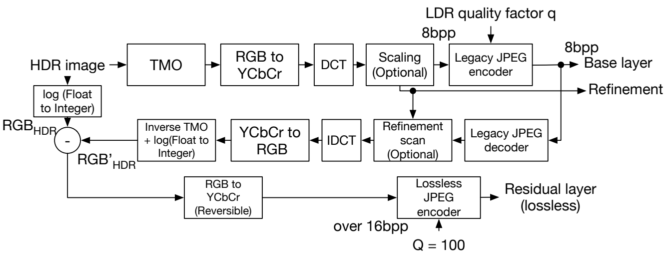


Fig. 1. Block diagram of normative JPEG XT encoder (Profile C).

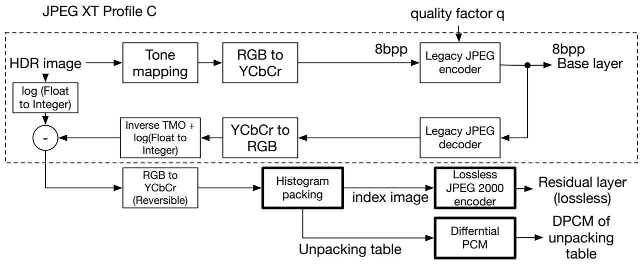
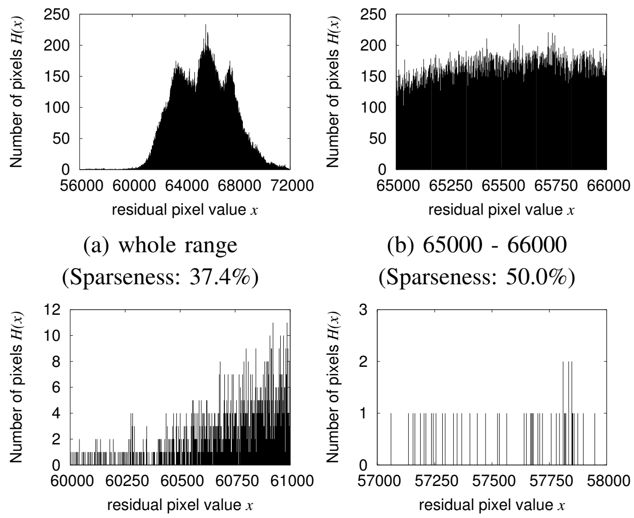
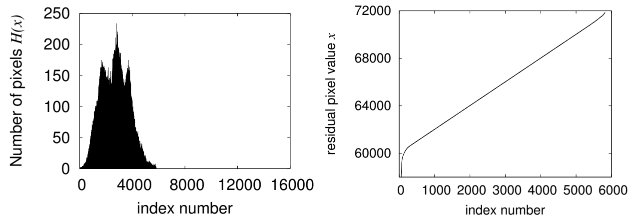


Fig. 2. Encoder block diagram for the proposed scheme



(a) whole range (Sparseness: 37.4%)
(b) 65000 - 66000 (Sparseness: 50.0%)
(c) 60000 - 61000 (Sparseness: 4.8%)
(d) 57000 - 58000 (Sparseness: 35.4%)

Fig. 3. Histogram of residual data (Y component of ‘BloomingGorse2’ $q = 50$)



(a) histogram of index image
(b) unpacking table

Fig. 4. Index image and its unpacking table(Y component of ‘Blooming-Gorse2’ $q = 50$)

As shown in Fig. 1, the refinement scan may be carried out to provide additional least significant bits to extend the precision of DCT coefficients.

III. Proposed Structure

A new two-layer coding scheme is proposed here.

A. Structure of the proposed scheme

The encoder block diagram of the proposed scheme is illustrated in Fig. 2. The base layer structure in Fig. 2 is the same as that of JPEG XT Profile C, where two options, i.e. ‘Scaling’ and ‘Refinement scan’ are not carried out in the proposed method. On the other hand, in the residual layer, lossless JPEG2000 coding and the histogram packing technique [19], [25] before the JPEG2000 coding are applied to residual images, where the fast mode that bypasses the arithmetic coder [26] is selected in the JPEG2000 coding. The codestream consists of the base layer, the residual data and the DPCM data of an unpacking table.

B. Bit length of residual data

The residual Y, Cb, Cr data have integer values with 17bits. In the lossless coding, the above all data have to be losslessly preserved. JPEG XR can not encode pixel values with 16bits over, while JPEG 2000 can encode up to values with 31 bit integers. This is the reason why we use JPEG 2000 coding to compress the residual data.

C. Histogram packing

HDR images often have sparse histograms due to the wide range of pixel values [13]. The histograms of residual data in the two layer coding are also sparse as well as HDR ones. In order to encode residual data efficiently, the proposed scheme uses the histogram packing technique [22].

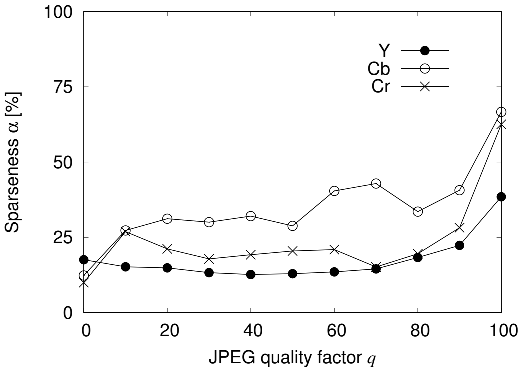
Figure 3 illustrates a histogram $H(x)$ of Y component in the residual data of the HDR image ‘Blooming Gorse2’ where x is a pixel value. In Fig. 3, the horizontal axis denotes pixel values expressed as integer numbers with the IEEE floating point representation. Figure 3(a) describes the whole range of x (56,600 to 72,368), and others focus on one part of the range, respectively. From these results, it is confirmed that histograms of residual data have a lot of sparseness.

By packing the histogram, a histogram-packed image is obtained. In this paper, the histogram-packed image is refered to as ‘index image’. Figure 4(a) illustrates $H(x)$ for the index image generated from the histogram in Fig. 3(a). The unpacking table, which is used to reconstruct the original values from the index image, is shown in Fig. 4(b). Since the data of unpacking tables are expressed as a monotonic increase functions, they are effectively compressed by using Differential PCM(DPCM).

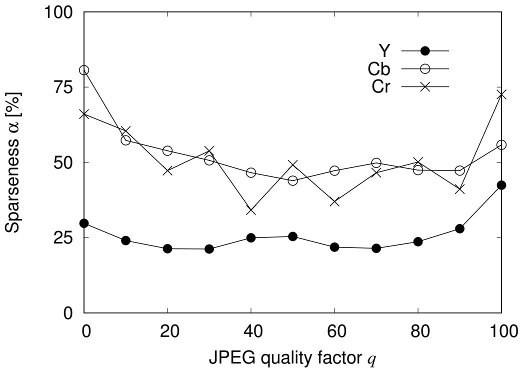
In this paper, we define the histogram sparseness by

$$\alpha = \frac{|X|}{\max_{x\in X}(x) - \min_{x\in X}(x) + 1} \cdot 100, \quad (1)$$

$$X = \{x \mid H(x) \neq 0\}, \quad (2)$$



(a) memorial



(b) MtTamWest

Fig. 5. Histogram sparseness of residual data(Y, Cb, Cr).

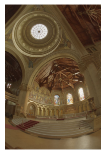
where $|X|$ denotes the total number of all the elements of a set X. The range of α is $0 \leq \alpha \leq 100$ and the smaller α means the sparser histogram.

Figure 5 shows the 'sparseness' of the residual data of two HDR images; memorial and MtTamWest. The sparseness depends on images and the JPEG q factors.

IV. Experimental Results

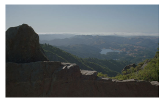
HDR images collected from some web sites as shown in Fig. 6 were used in experiments. In order to confirm losslessness of half precision float, each pixel value of the sample images was converted to a value with the half precision float.

To confirm the effectiveness of the proposed scheme, some experiments were carried out as shown in Fig. 7. In the experiments, two HDR images 'Memorial' and 'MtTamWest' were encoded by using the reference software available from the JPEG committee for the JPEG XT standard [27], or by the modified code for the proposed scheme. The solid three lines('JPEG XT', 'JPEG XT with Refinement scan', and 'Proposed') are two-layer coding schemes, otherwise the dashed two lines('JPEG XR lossless' and 'JPEG 2000 lossless') are one-layer coding schemes. In Fig. 7, the horizontal axis denotes JPEG q factors, and the vertical axis denotes total bitrates. The bitrate includes the amount of the unpacking table for the proposed method. For all q values, the proposed structure provided smaller bitrates than those of the JPEG XT encoders. In addition, the proposed one outperformed JPEG 2000 and JPEG XR that do not have two layers.



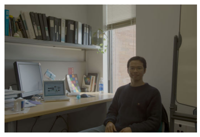
(a) memorial (512×768)

(b) BloomingGorse2 (4288×2848)

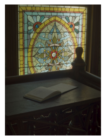


(c) MtTamWest (1214×732)

(d) Cannon (780×566)

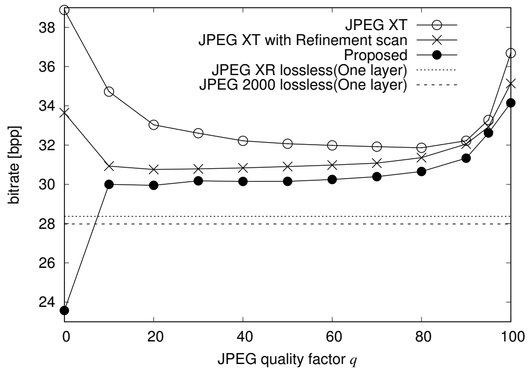


(e) WillyDesk (4288×2848)

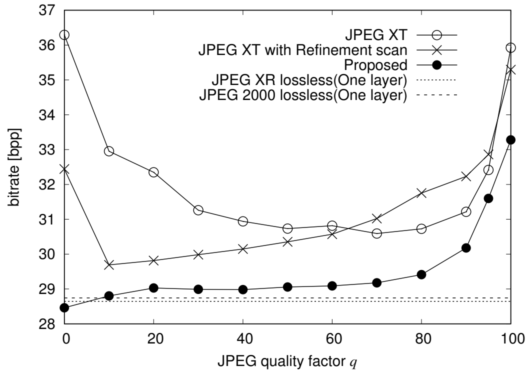


(f) Desk (644×874)

Fig. 6. Sample images



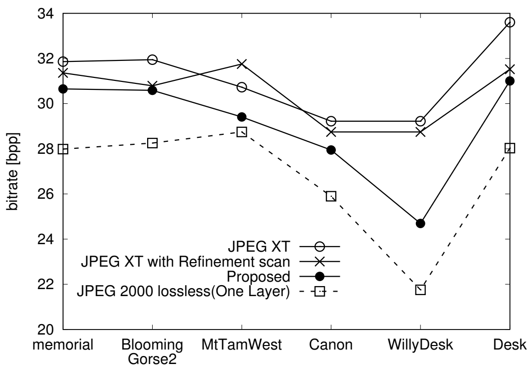
(a) memorial



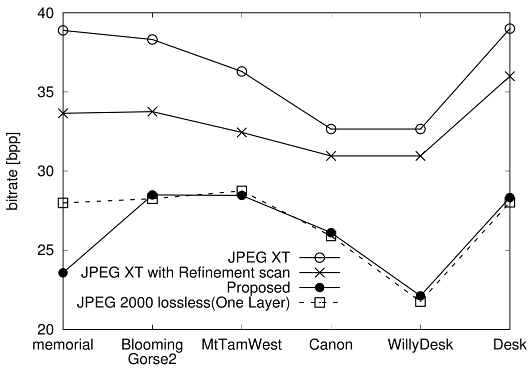
(b) MtTamWest

Fig. 7. Coding performances of JPEG XT and the proposed scheme

Figure 8(a) shows bitrates of JPEG XT and proposed coding with $q = 80$. The proposed method provided smaller bitrates than the JPEG XT encoders for all images. Figure 8(b) is the results for $q = 0$. The proposed method not only provided smaller bitrates than the JPEG XT encoders for all images, but also provided the same bitrates as the one-layer JPEG 2000 lossless coding. Especially, the results for 'memorial' and 'MtTamWest' were smaller than those of JPEG 2000.



(a) JPEG quality factor $q = 80$



(b) JPEG quality factor $q = 0$

Fig. 8. Bitrates of lossless compressed images

V. Conclusion

Lossless two-layer coding for HDR images using the histogram packing technique, the backward compatibility with the legacy JPEG for base layer, has been proposed. The histogram packing technique has been used to improve the performance of lossless compress for HDR images. Our method has achieved smaller bitrates than the JPEG XT lossless encoder in the case of including the data of an unpacking table.

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References

[1] E. Reinhard, W. Heidrich, P. Debevec, S. Pattanaik, G. Ward, and K. Myszkowski, High dynamic range imaging - acquisition, display and image based lighting, 2nd edn. Morgan Kaufmann, Burlington, 2010.

[2] A. Artusi, T. Richter, T. Ebrahimi, and R. K. Mantiuk, "High dynamic range imaging technology [lecture notes]," IEEE Signal Processing Magazine, vol. 34, no. 5, pp. 165-172, Sept 2017.

[3] A. Artusi, F. Banterle, T. O. Aydin, D. Panozzo, and O. Sorkine-Hournung, Image Content Retargeting: Maintaining Color, Tone, and Spatial Consistency. AK Peters, Ltd (CRC Press), 2016.

[4] F. Banterle, A. Artusi, K. Debattista, and A. Chalmers, "Advanced High Dynamic Range Imaging: Theory and Practice", first edition ed. AK Peters, Ltd (CRC Press), February 2011. [Online]. Available: http://vcg.isti.cnr.it/Publications/2011/BADC11.

[5] T. Murofushi, T. Dobashi, M. Iwahashi, H. Kiya, "An integer tone mapping operation for HDR images in OpenEXR with denormalized numbers," IEEE International Conference on Image Processing (ICIP), pp. 4497-4501, 2014.

[6] T. Dobashi, A. Tashiro, M. Iwahashi, H. Kiya, "A fixed-point implementation of tone mapping operation for HDR images expressed in floating-point format," APSIPA Transactions on Signal and Information Processing, vol.3, no.e11, pp.1-11, 2014.

[7] G. Ward and M. Simmons, "JPEG-HDR: A backwards-compatible, high dynamic range extension to jpeg," in ACM SIGGRAPH 2006 Courses, ser. SIGGRAPH '06. New York, NY, USA: ACM, 2006. [Online]. Available: http://doi.acm.org/10.1145/1185657.1185685

[8] R. Xu, S. N. Pattanaik, and C. E. Hughes, "High-dynamic-range still-image encoding in jpeg 2000," IEEE Computer Graphics and Applications, vol. 25, no. 6, pp. 57-64, Nov 2005.

[9] A. K. Dominic Springer, "Lossy compression of floating point high-dynamic range images using jpeg2000," pp. 7257 - 7257 - 11, 2009. [Online]. Available: http://dx.doi.org/10.1117/12.805315

[10] Y. Zhang, D. Agrafiotis, and D. R. Bull, "High dynamic range image & video compression a review," in 2013 18th International Confer- ence on Digital Signal Processing (DSP), July 2013, pp. 1-7.

[11] I. R. Khan, "Two layer scheme for encoding of high dynamic range images," in 2008 IEEE International Conference on Acoustics, Speech and Signal Processing, March 2008, pp. 1169-1172.

[12] T. Jinno, M. Okuda, and N. Adami, "New local tone mapping and two-layer coding for HDR images," in 2012 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), March 2012, pp. 765-768.

[13] M. Iwahashi and H. Kiya, , "Two layer lossless coding of HDR images," in Acoustics, Speech and Signal Processing (ICASSP), 2013 IEEE International Conference on, May 2013, pp. 1340-1344.

[14] M. Iwahashi, T. Yoshida, N. Mokhtar, and H. Kiya, "Bit-depth scalable lossless coding for high dynamic range images," EURASIP Journal on Advances in Signal Processing, vol. 2015, no. 1, 2015.

[15] "Information technology – Scalable compression and coding of continuous-tone still images - Part 1: Scalable compression and coding of continuous-tone still images," ISO/IEC 18477-1, Jun. 2015.

[16] "Information technology–Digital compression and coding of continuous-tone still images: Requirements and guidelines," International Standard ISO/IEC IS-10918-1, Feb. 1994.

[17] "Information technology–JPEG XR image coding system – Part 1: System architecture," ISO/IEC TR-29199-1, Jul. 2011.

[18] "Information technology–JPEG 2000 image coding system – Part 1: Core coding system," International Standard ISO/IEC IS-15444-1, Dec. 2000.

[19] M. Iwahashi, H. Kobayashi, and H. Kiya, "Lossy compression of sparse histogram image," in 2012 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), March 2012, pp. 1361-1364.

[20] S. Minewaki, M. Iwahashi, H. Kobayashi, T. Yoshida, and H. Kiya, "Near lossless coding of sparse histogram images based on zero-skip quantization," Multimedia Tools and Applications, pp. 1-19, Sep 2017. [Online]. Available: https://doi.org/10.1007/s11042-017-5082-2

[21] A. J. Pinho, "On the impact of histogram sparseness on some lossless image compression techniques," in Proceedings 2001 International Conference on Image Processing (Cat. No.01CH37205), vol. 3, 2001, pp. 442-445 vol.3.

[22] A. J. Pinho, "An online preprocessing technique for improving the lossless compression of images with sparse histograms," IEEE Signal Processing Letters, vol. 9, no. 1, pp. 5-7, Jan 2002.

[23] S. Jallouli, A. Masmoudi, S. Zouari, W. Puech, and N. Masmoudi, "A Preprocessing Technique for Improving the Compression Performance of JPEG 2000 for Images with Sparse or Locally Sparse Histograms," in 25th European Signal Processing Conference, Aug 2017, pp. 1962- 1966.

[24] M. Iwahashi, H. Kobayashi, and H. Kiya, "Fine rate control and high snr coding for sparse histogram images," in 2012 Picture Coding Symposium, May 2012, pp. 205-208.

[25] S. Minewaki, M. Iwahashi, H. Kobayashi, T. Yoshida, and H. Kiya, "Near lossless coding of sparse histogram images based on zero-skip quantization," Multimedia Tools and Applications, September 2017.

[26] "Information technology – JPEG 2000 image coding system: Extensions: Block coder extension" International Standard ISO/IEC IS-15444-2 Amd.4, July. 2015.

[27] "Text of CD ISO/IEC 18477-5 (Reference Software)," ISO/IEC JTC 1/SC 29/WG 1 N69019, Jun. 2015.