LETTER *Special Section on Smart Multimedia & Communication Systems*

An Efficient Lossless Compression Method Using Histogram Packing for HDR Images in OpenEXR Format

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SUMMARY This letter proposes an efficient lossless compression method for high dynamic range (HDR) images in OpenEXR format. The proposed method transforms an HDR image to an indexed image and packs the histogram of the indexed image. Finally the packed image is losslessly compressed by using any existing lossless compression algorithm such as JPEG 2000. Experimental results show that the proposed method reduces the bit rate of compressed OpenEXR images compared with equipped lossless compression methods of OpenEXR format.

key words: *index transformation, coding, sparse histogram, PIZ, ZIP*

1. Introduction

In recent years, there is growing interest in high dynamic range (HDR) images in various applications [1]. HDR images can express higher dynamic range of its pixel values than traditional standard low dynamic range (LDR) images. HDR images require large memory space for storage and high bit rates for transmission. Hence, it makes data compression technologies essential for usage.

So far, various approaches based on international standardized compression algorithm such as JPEG or JPEG 2000 [2] have been proposed [3]–[5]. Whereas those existing methods are for lossy coding of HDR images, this letter discusses the lossless coding of HDR images. In addition, this letter focuses on OpenEXR format [6] which has not been well studied even it is one major format for HDR images.

This letter proposes a new lossless coding method of HDR images which further reduces the bit rate of OpenEXR images in comparison with the equipped algorithms. The proposed method transforms an OpenEXR formatted HDR image to an indexed image and packs the histogram of the indexed image before lossless compression of the image.

2. Preliminaries

In OpenEXR format which was developed by Industrial Light and Magic (ILM), each pixel is composed of R, G, and B components and occupies a total of 48 bits; 16 bits per component. For each component, one bit of sign, 5-bit of exponent, and 10-bit of mantissa are used as shown in Fig. 1. From 16 bit data, a component value of a pixel in the floating-point representation is given as

$$h = \begin{cases} (-1)^S 2^{E-15}\left(1+\dfrac{M}{1024}\right), & 1 \le E \le 30 \\ (-1)^S 2^{-14}\dfrac{M}{1024}, & E = 0 \end{cases}, \qquad (1)$$

where h denotes the component value, and S, E, and M denote sign, exponent, and mantissa part values, respectively. Lossless compression is accomplished using the ZIP or ILM's 'PIZ' lossless wavelet compression, before the image is represented as floating-point numbers.

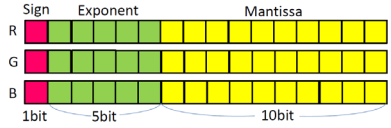

Fig. 1 OpenEXR format.

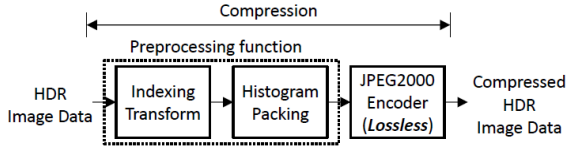

Fig. 2 Block diagram of the proposed method.

3. Proposed Method

Figure 2 shows the proposed method. This method is composed of a preprocessing function and an international standard compression technique such as JPEG 2000 or JPEG-LS [7]. The preprocessing function has two key technologies; an index transformation and the histogram packing [8].

The index transformation generates an integer-numbered indexed image from an OpenEXR image so that any ordinary image compression technique for fixed-point numbered images can compress the OpenEXR image. This transformation first interpret 16-bit words in OpenEXR format as integers instead of floating-point numbers. Then, the interpreted image is transformed to an indexed image, where indices are given according to the pixel values represented

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(a) StillLife (846×1240). (b) Tree (906×928). (c) Desk (876×644). (d) Spirals (1040×1040).

Fig. 3 Example of OpenEXR images for evaluation.

Table 1 Images for evaluation and those histogram sparsities.

Image	Image size	Averaged sparsity rate [%]
StillLife	846 × 1240	83.63
Tree	906 × 928	79.34
Desk	876 × 644	80.07
Spirals	1040 × 1040	74.80
MtTamWest	732 × 1214	86.61
Ocean	876 × 1255	75.61
Rec709	406 × 610	90.6
CandleGlass	810 × 1000	82.34
PrismsLenses	865 × 1200	81.26
GoldenGate	860 × 1262	86.82
AVERAGE	NA	82.11

as floating-point numbers to preserve the characteristic of OpenEXR images. Since the pixel values of an OpenEXR image are simply calculated by Eq. (1), original 16-bit words can be completely recovered from indexed values without any image-dependent lookup table.

Since HDR images cover wider pixel range than LDR images as described in Sect. 1, OpenEXR images at ILM's website naturally have a sparse histogram as well as HDR images with another major format [9]. Based on this fact, in the proposed method, the histogram packing [8] is applied to the indexed image. The indexed image can be recovered from the packed image by the image-dependent packing table given from the histogram packing. It is noted that the index transformation and the histogram packing are lossless processes.

Finally, by applying any lossless compression technique to the histogram packed image, the entire algorithm can become to compress OpenEXR images losslessly.

4. Experimental Results

4.1 Images for Evaluation and Those Characteristics

The effectiveness of the proposed method has been evaluated by using ten OpenEXR images which are available at ILM's website (http://www.openexr.org/). Figure 3 shows example of OpenEXR images for evaluation where LDR images generated from HDR images are shown for printing.

Table 1 summarizes the image size and sparsity rate of indexed images, where the sparsity rate is given by

$$S_r = 1 - \frac{N_e}{2^N}. \tag{2}$$

In Eq. (2), S_r denotes the sparsity rate of each color channel, and N_e and 2^N denote the number of intensity levels in the channel where the level appears at least once in the image and maximum possible intensity levels ($N = 16$ as shown in Fig. 1), respectively. The averaged sparsity rate in Table 1 represents the average of RGB channels. As a reference, the averaged sparsity rate of well-known Lena image is 18.82[%]. From Table 1, It is confirmed that the histogram of OpenEXR images is very sparse.

Table 2 Comparison of compressed HDR images.

Image	OpenEXR format (PIZ or ZIP) [bpp]	Proposed method			
		w/ JPEG 2000[bpp]		w/ JPEG-LS[bpp]	
		without packing	with packing	without packing	with packing
StillLife	28.84	33.84	24.57	29.34	**21.91**
Tree	35.36	33.18	32.06	31.50	**30.44**
Desk	34.46	29.22	27.86	28.55	**27.14**
Spirals	39.68	28.82	28.30	25.82	**25.60**
MtTamWest	29.92	29.28	27.61	28.61	**26.89**
Ocean	33.71	31.01	29.93	30.15	**28.99**
Rec709	30.04	27.32	25.63	26.87	**25.26**
CandleGlass	25.97	28.37	21.80	27.72	**21.00**
PrismsLenses	33.76	35.63	**28.26**	39.76	31.99
GoldenGate	27.23	29.05	25.92	29.05	**25.37**
AVERAGE	31.90	30.27	27.20	29.74	**26.46**

4.2 Results

Table 2 shows the bitrate of compressed HDR images in bits per pixel (bpp) for different compression methods. OpenEXR format represents the data compressed from HDR images with better equipped method, i.e., PIZ or ZIP. For the proposed method with packing, the packing table is contained as well as the compressed image itself. On the other hand, the proposed method without packing compresses indexed images and no table is required. From Table 2, it is confirmed that the proposed method with packing compresses OpenEXR images more efficiently than equipped methods even it requires a packing table. It is noted that the improvment of compression efficiency by the proposed method is not proportional to the sparsity rate, c.f., Tables 1 and 2, because the compression efficiency depends on several factors such as the shape of the histogram and the format of HDR images other than sparsity rate.

5. Conclusions

This letter has proposed a novel lossless compression method based on the histogram packing for HDR images in OpenEXR format. The proposed method is superior to equipped methods in OpenEXR format in terms of lossless compression efficiency.

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