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IEICE Communications Express, Vol.6, No.1, 17–21

High dynamic range image compression with improved logarithmic transformation

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Abstract: High dynamic range (HDR) images have been developed to have almost the same dynamic range as human eye, but the huge amount of data brings a problem in storage and transmission. To compress HDR images, an efficient coding method using logarithmic transformation had been proposed in [4]. In this letter, we improve the logarithmic transformation and then derive the optimal parameter to minimize the coding error in HDR region. It is experimentally confirmed that the improved coding method has less coding error in HDR region than other existing methods.

Keywords: HDR image, lossy coding, logarithmic transformation, JPEG 2000

Classification: Multimedia Systems for Communications

References

[1] D. Taubman and M. Marcellin, *JPEG2000 Image Compression Fundamentals, Standards and Practice*, Springer, 2002.

[2] E. Reinhard, S. Pattanaik, G. Ward, and P. Debevec, *High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting*, Morgan Kaufmann Publisher, 2005.

[3] G. W. Larson, "The LogLuv encoding for full gamut, high dynamic range images," *J. Graphics Tools*, vol. 3, no. 1, pp. 15–31, 1998. DOI:10.1080/10867651.1998.10487485

[4] R. Xu, S. N. Pattanaik, and C. E. Hughes, "High-dynamic-range still-image encoding in JEPG 2000," *IEEE Comput. Graph. Appl.*, vol. 25, no. 6, pp. 57–64, 2005. DOI:10.1109/MCG.2005.133

[5] K. Watanabe and H. Kiya, "An efficient compression method based on JPEG2000 for HDR images," IEICE 26th SP Symposium, no. A8-7, pp. 149–154, Nov. 2011.

1 Introduction

Dynamic Range of images taken by general cameras is much less than that of human eye, which produces a problem called blown out highlights and blocked up shadows. To avoid this problem, HDR images have been developed to have almost

DOI: 10.1587/comex.2016XBL0148
Received August 18, 2016
Accepted September 23, 2016
Publicized October 24, 2016
Copyedited January 1, 2017

the same dynamic range as human eye [2]. The use of HDR images is expected in various fields such as photography, computer graphics and medical imaging. However, HDR images require a huge amount of data to express the wide range of pixel value. It brings a problem in storage and transmission.

To compress HDR images, there are many coding methods in [2, 3, 4, 5]. Among these methods, an efficient method had been proposed by using logarithmic transformation in [4]. However, it produces considerable coding error in HDR region, because the coding error is substantially amplified in high brightness region by the inverse logarithmic transform. To reduce the coding error, Watanabe and Kiya have proposed to use lossless coding in high brightness region, but it is difficult how to determine the high brightness region [5].

In this letter, we propose an efficient coding method using the improved logarithmic transformation. We derive an error model and obtain the optimal parameter to minimize the coding error in HDR region for each HDR image. It is shown from the experiment results that the proposed method has better coding performance than the existing methods.

2 The conventional HDR image coding

2.1 HDR image format

The dynamic range of human eye is from 100 dB to 120 dB in one scene, while that of LDR (Low Dynamic Range) images taken by a general camera is about 80 dB at highest. The difference of these two dynamic ranges produces a problem called blown out highlights and blocked up shadows. Therefore, HDR images have been developed with almost the same dynamic range with human visual system. The HDR image formats commonly used are OpenEXR, Radiance RGBE, and LogLuv formats [2, 3]. However, HDR images need more bits than LDR images. Therefore, HDR image coding technology is important.

2.2 HDR image coding using JPEG 2000

In some pioneering works, Xu et al. had proposed a lossy coding method using a logarithmic transformation for HDR images in [4]. The reason that the logarithmic transformation was selected is the Weber Fechner law in which the human visual system perceives an object to the luminance logarithmically. In encoding, HDR image is converted to LDR image by the logarithmic transformation, and encoded by the lossy mode of JPEG 2000 [1]. The logarithmic transformation is carried out in each channel independently as follows:

$$g(i, j) = \log(x(i, j)) \tag{1}$$

$$y(i, j) = \frac{g(i, j) - g_{min}}{g_{max} - g_{min}}(2^K - 1) \tag{2}$$

where $x(i, j)$ is the pixel value of HDR image, $y(i, j)$ is that of LDR image, $g_{max} = \log(x_{max})$, $g_{min} = \log(x_{min})$, and x_{max}, x_{min} are the maximum or minimum pixel value of HDR image, and K is the bit depth of LDR image. The LDR image with K bits is then encoded by JPEG 2000. JPEG 2000 accepts both lossy and lossless coding, and the former is used in this coding method. In decoding, LDR

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image is decoded by JPEG 2000, and then HDR image is gotten by the inverse logarithmic transformation.

This coding method is very effective, but has two problems. The first problem is $g(i, j) = -\infty$ if $x(i, j) = 0$. A provision in which zero is replaced with the minimum nonzero value is applied in order to avoid this issue. However, it results in an additional error. The second problem is that error in high brightness region is substantially amplified by the inverse logarithmic transform [5].

3 HDR image coding with improved logarithm transformation

To overcome the first problem above-mentioned, we introduce a positive constant τ in the logarithm transformation as follows;

$$g(i, j) = \log(x(i, j) + \tau) \tag{3}$$

Since $\tau > 0$, $g(i, j) \neq -\infty$ even if $x(i, j) = 0$. Thus the inverse transformation is given by

$$\tilde{x}(i, j) = \exp\left\{\frac{g_{max} - g_{min}}{2^K - 1}\tilde{y}(i, j) + g_{min}\right\} - \tau \tag{4}$$

It is clear that the input image can be exactly reconstructed, i.e., $\tilde{x}(i, i) = x(i, j)$ if there is no coding error ($\tilde{y}(i, j) = y(i, j)$). Therefore, it does not cause any additional error. The framework of HDR image coding proposed in this paper is shown in Fig. 1.

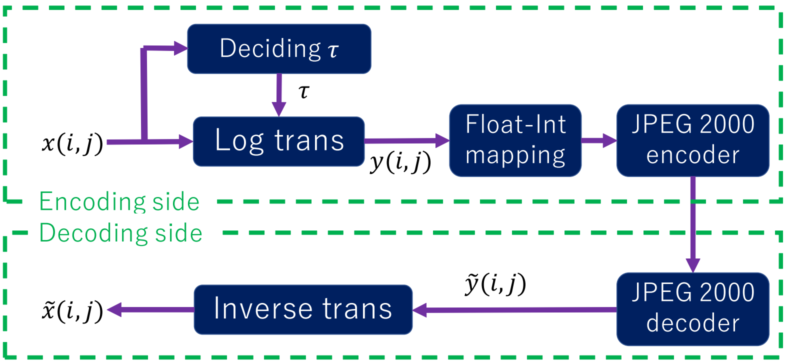

Fig. 1. HDR image coding with improved logarithm transformation

In the proposed HDR image coding, LDR image is encoded by the lossy mode of JPEG 2000. The coding error in LDR region is propagated to HDR region by the inverse transformation. We assume the coding error in LDR region is $n_L(i, j)$, that is, $\tilde{y}(i, j) = y(i, j) + n_L(i, j)$. Therefore, the coding error $n_H(i, j)$ in HDR region is

$$\begin{aligned} n_H(i, j) &= \tilde{x}(i, j) - x(i, j) \\ &= (x(i, j) + \tau)\left(\left(\frac{x_{max} + \tau}{x_{min} + \tau}\right)^{n_L(i,j)/(2^K-1)} - 1\right) \end{aligned} \tag{5}$$

Since $n_L(i, j) \ll 2^K - 1$ in general, Eq. (5) can be approximated to

$$n_H(i, j) \approx \frac{x(i, j) + \tau}{2^K - 1} \log\left(\frac{x_{max} + \tau}{x_{min} + \tau}\right) n_L(i, j) \tag{6}$$

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Assume that $n_L(i, j)$ is white Gaussian noise with zero mean and variance σ_L^2, thus we have,

$$\begin{aligned} \sigma_H^2 &= \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N} n_H^2(m,n) \\ &= \frac{1}{MN}\sum_{x=x_{min}}^{x_{max}}\left\{\left(\frac{x+\tau}{2^K-1}\log\left(\frac{x_{max}+\tau}{x_{min}+\tau}\right)\right)^2 \sum_{\{m,n\}\in S(x)} n_L^2(m,n)\right\} \\ &= \sigma_L^2 \sum_{x=x_{min}}^{x_{max}} H(x)\left(\frac{x+\tau}{2^K-1}\log\left(\frac{x_{max}+\tau}{x_{min}+\tau}\right)\right)^2 \end{aligned} \tag{7}$$

where $M \times N$ is image size, $H(x)$ is histogram of HDR image, and the set $S(x) = \{i, j : x(i, j) = x\}$. Therefore, we have

$$F(\tau) = \frac{\sigma_H^2}{\sigma_L^2} = \sum_{x=x_{min}}^{x_{max}} H(x)\left(\frac{x+\tau}{2^K-1}\log\left(\frac{x_{max}+\tau}{x_{min}+\tau}\right)\right)^2 \tag{8}$$

It should be noted that the smaller $F(\tau)$, the smaller σ_H^2 if σ_L^2 is fixed.

In Fig. 2, we show the behavior of $F(\tau)$ using R component of HDR images with Radiance RGBE format: nave, rosette, memorial, Desk, rend02, and Apartment. It is seen that $F(\tau)$ has only one minimum and the minimum is different for each image. Therefore, we must select the optimal τ to minimize $F(\tau)$ and thus the coding error in HDR region for each image.

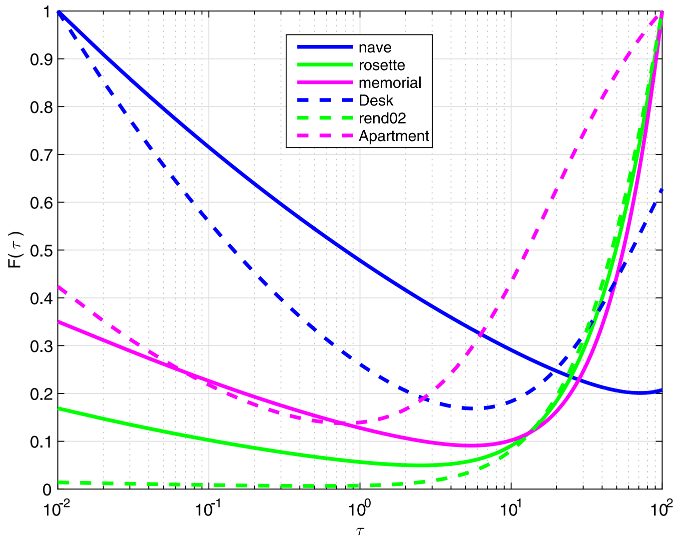

Fig. 2. Behavior of $F(\tau)$ for HDR images.

In order to obtain the minimum of $F(\tau)$, we calculate its derivative as follows;

$$\begin{aligned} \frac{dF(\tau)}{d\tau} &= \log\left(\frac{x_{max}+\tau}{x_{min}+\tau}\right)(\tau + E(x)) \\ &\quad - (x_{max} - x_{min})\frac{\tau^2 + 2E(x)\tau + E(x^2)}{(\tau + x_{min})(\tau + x_{max})} = 0 \end{aligned} \tag{9}$$

where $E(x)$ is the mean value of HDR image and $E(x^2)$ is the mean-square value.

It is clear that once x_{max}, x_{min}, $E(x)$ and $E(x^2)$ of HDR image are known, we can solve the equation in Eq. (9) to obtain the optimal τ. Since the optimal τ is

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dependent on HDR image, the method proposed in Fig. 1 is the image-adaptive coding method.

4 Experimental results

In this section, we compare the coding performance of the proposed method with the existing methods proposed in [4] and [5]. HDR images with Radiance RGBE format (nave, rosette, memorial, Desk, rend02, Apartment) are used as test images. In the proposed method, the optimal τ is obtained by solving the equation in Eq. (9) as $\tau_{opt} = 71.52, 2.51, 5.43, 5.68, 0.52, 0.79$, respectively for R channel of HDR images, and then the images are compressed at size of 60770, 117885, 311165, 315204, 471257, 2257331 bytes, while 61022, 117295, 310807, 313869, 471242, 2255955 bytes respectively in [5], both of which are almost the same. The SNR results in HDR region of the proposed and existing coding methods are shown in Fig. 3. It is seen that the proposed method has better coding performance than the existing methods.

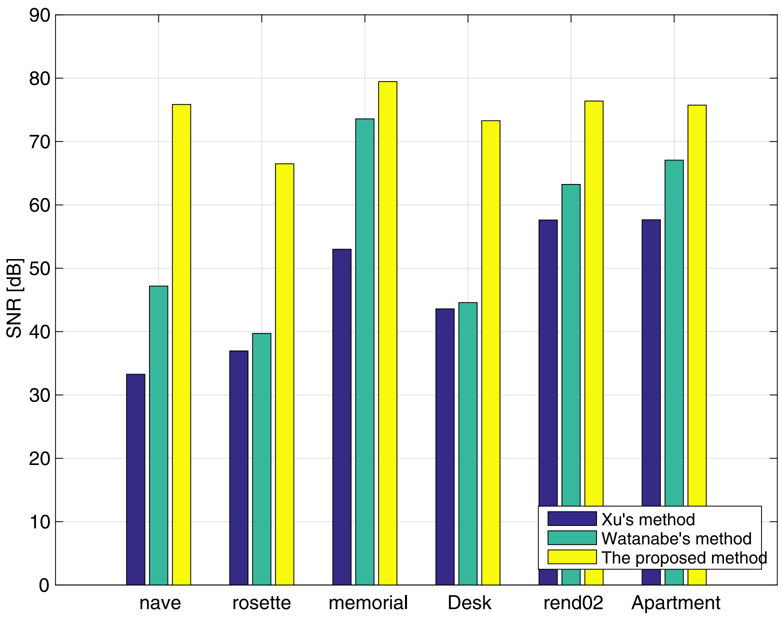

Fig. 3. SNR results in HDR region of the proposed and existing coding methods for R channel of HDR images.

5 Conclusion

In this letter, we have proposed an improved coding method for HDR images by introducing a positive constant into the logarithmic transformation. We have then derived an error model to obtain the optimal parameter which minimizes the coding error in HDR region. It has been shown from the experimental results that the proposed method outperforms the exiting methods.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number 26330128.

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Accepted September 23, 2016
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