HIGH DYNAMIC RANGE IMAGE COMPRESSION USING BASE MAP CODING

Takuya FUJIKI† *Nicola ADAMI*⋆ *Takao JINNO*‡ *Masahiro OKUDA*†

†The University of Kitakyushu ⋆ Brescia University ‡ Toyohashi University of Technology

ABSTRACT

As the High dynamic range (HDR) images generally have more than 10 bit/1024 colors per channel, its enormous data size often needs to be reduced when transmitting or storing the images. Thus development for functional compression is one of important research topics. Recently a lot of techniques for the HDR image compression are being suggested, and several two-layer coding algorithms which separately encode a low dynamic range (LDR) image and a residual image have been studied. However, those methods are inefficient in coding performance. In this article, we suggest a new two-layer coding algorithm for the HDR images, which realizes two-layered dynamic range. Our method encodes a base map, which is a blurred version of the HDR, and LDR image produced by the base map. Our algorithm significantly improves a compression performance.

***Index Terms*—** High dynamic range image, Two-layer encoding, Tone mapping

1. INTRODUCTION

The dynamic range of the human visual system (HVS) reaches more than 200dB, and the ratio of shadows and highlights can become $100 \sim 120$dB in a real scene. However, the dynamic range of most consumer cameras is about 80dB generally at highest and cannot record all the radiance information of the scenes. The HDR image is developed to record all the brightness information of the visible range of the scene. It can support the whole dynamic range and the color gamut that the human visual system perceives, and be utilized in many fields, for example, image based lighting, in-vehicle cameras, surveillance systems, and so on.

Generally, the HDR image has more than 10 bit colors per channel, and has enormous data quantity. Therefore the data processing of HDR images needs enormous transmission effort and disk space. Hence, the development of the effective compression technique of the HDR image is one of the important research topics. Many HDR encoding techniques have been suggested so far. Spaulding[1] and Ward et al. [2] encode information independently to the LDR and residual image (which is difference or ratio between LDR and HDR images), instead of encoding the HDR image directly. It is called the two-layer coding. In the two layer coding no effort is needed to extract the LDR image in the decoder. However it is inefficient in a sense of coding performance because the quantization error of the LDR image brings the extra energy to the residual image in high frequencies. If the original LDR is used to calculate the residual image, the RD curve is easily saturated at high bit rates due to its inconsistency.

In this article, we suggest a new two-layer coding algorithm for the HDR image, using Reinhard's tone mapping [3]. In an encoder side, to realize the two-layer coding, one encodes the LDR and base map that includes fewer high-frequency components than the residual image, which makes the compression efficiency significantly improved. We explain about conventional two-layer coding for HDR in Section 2. Section 3.1 introduces summary of the proposed technique. In section 3.2, we elaborate our coding method. Finally we show the validity of our method with comparing to conventional method in Section4.

2. CONVENTIONAL METHOD

Spaulding et al. [1] proposes a two-layer encoding for gamut extended images. This is a technique for the RAW image encoding of the digital camera. They extend the dynamic range and color gamut by applying the inverse of nonlinearity to the LDR images, and then encode the difference between the extended images and the original RAW images. Later this strategy was applied to coding of the HDR images [2] and HDR video [4] in the field of Computer Graphics. In these methods, a tone mapped 24 bit (LDR) image is first encoded by JPEG and then the difference information between the LDR and the original HDR is encoded and stored in a user-available buffer of the JPEG wrapper. The difference information is obtained by dividing HDR by LDR.

$$I_r = \frac{I_{HDR}}{I_{LDR}} \tag{1}$$

In the conventional method, this I_{LDR} and the difference information I_r are coded by JPEG. In this paper we call I_r a residual image. As follows, in a decoding side, its inverse operation is performed to restore I_{HDR}.

$$I'_{HDR} = I'_{LDR} \cdot I'_r \tag{2}$$

The prime (') means an image that includes quantization error added by the compression.

This technique maintains backward compatibility with the conventional LDR image format. In the decoder side, the

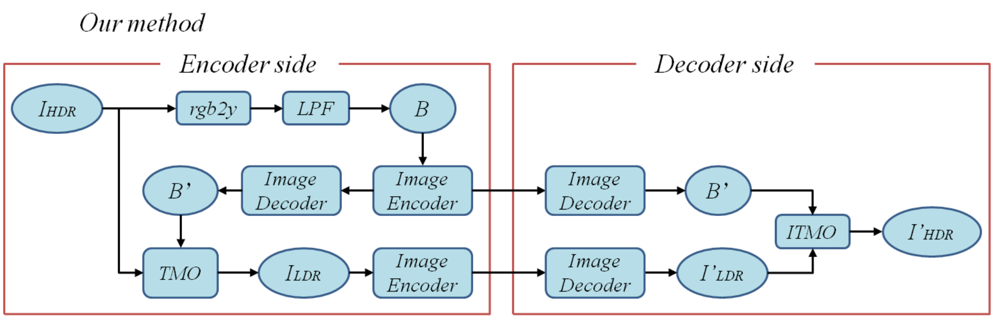

Fig. 1. The flow of the proposal technique: I_{HDR} : HDR image, I_{LDR} : Tone mapped LDR image, B : Base map image,$\square'$: image with quantization error, rgb2y : The conversion process from a color image to a luminance image, LPF : Low-pass filtering, TMO : Tone mapping operator, ITMO : Inverse tone mapping operator

LDR image that the encoder prepares can be obtained without carrying out a tone mapping operation. When the residual image is also decoded, the HDR image can also be restored.

However, this technique has some disadvantages. First, a compression efficiency deteriorates since the error image I_r containes much energy in high frequencies. The second disadvantage is the saturation of SNR. Since I_{LDR} in (1) is used as a predicted image of I_{HDR}, in order to avoid drift in decoder side, in general you should use the decoded image I'_{LDR} instead of I_{LDR} with quantization error. However, the quantization error in I'_{LDR} brings some extra energy in high frequencyies to I_r, which also causes degradation of SNR. This problem is mainly remarkable in a low luminance region. For these reasons, in the conventional method, uncompressed I_{LDR} is used as the predicted value of I_{HDR}. As a result, RD curve is easily saturated as a bit rate increases due to the mismatch. To overcome the problems, our method uses a novel two-layer coding algorithm from the above, and it can solve these two problems.

3. PROPOSED TECHNIQUE ALGORITHM

3.1. Summary and procedure

The schematic diagram of the proposal technique is shown in Fig.1. In our method, the LDR image is obtained by a tone mapping operator based on the base map B that is obtained by low-pass filtering the HDR image. That is, in the encoder side, two images are coded, the base map B and the LDR image I_{LDR} obtained by the tone mapping with B. In the decoder side, one can decode only I_{LDR}. Additionally by decoding B and applying its inverse tone mapping operation (ITMO), the HDR image can be restored. The detail of the tone mapping and the procedures of encoder/decoder side in our two-layer coding, are shown in the rest of this section.

3.2. Tone mapping

In general the HDR's dynamic range is wider than conventional output devices. Hence, an operation called "tone mapping" is often necessary, in which the dynamic range of the HDR image is reduced to displayable ranges. Many tone mapping operators have been proposed in the last decade. Many of them are based on the rod/cone photoreceptor response of the HVS. It is well-known that the rod/cone response can be approximated by Naka-Rushton photoreceptor model (also known as Michaelis-Menten model or Hill function) [5]:

$$R = \frac{I^n}{I^n + c^n}, \tag{3}$$

where R is the photoreceptor response and I is intensity stimuli, which corresponds to the LDR and HDR images, respectively. c is a constant that controls the saturation level of the curve. In our coding framework, this type of tone mapping is used. Most of the local tone mapping in this category can be used in our method [5]. Among them, we adopt Reinhard's tone mapping [3] which is one of the most well known methods due to its high quality [7][8].

Reinhard et al. has proposed the following function as a simple tone map operator, which converts the HDR into the LDR.

$$I_{LDR}(x) = \frac{I_{HDR}(x)}{1 + B(x, s(x))} \tag{4}$$

$B(x, s(x))$ is the image that is obtained by applying locally adaptive Gaussian filters $G(x, s(x))$

$$B(x, s(x)) = I_{HDR}(x) * G(x, s(x)). \tag{5}$$

$s(x)$ is a scale parameter equivalent to a standard deviation which varies depending on pixels. As $s(x)$ is small, the effect of a Gaussian filter becomes smaller. To maintain the local contrast, $s(x)$ is set small for smooth area and large around edges. For details, see [3].

3.3. ENCODER

The conventional methods [1][2] encode the residual image I_r. As mentioned at Sec.1, the quantization noises propagate to I_r when the quantized LDR image is used in (1). It worsens the coding efficiency. Furthermore, the RD curve is saturated at high bit rates when the original LDR image is used. On the other hand, in our encoder, two images are coded, the one is the base map B obtained by the Reinhard's tone mapping (5), the other is the LDR image which carried out tone mapping based on the base map image. For consistency in the encoder and decoder, the encoded/decoded version of the base map B' is used for tone mapping. It should be noted that the base map B is the low-pass filtered version of the HDR luminance and has less energy in high frequencies, and thus efficient compression is expected.

3.4. DECODER

To obtain only the LDR image, we decode the first layer. Furthermore, the decoded base map B' of the second layer enables the restoration of the HDR image. The HDR image is obtained simply by performing inverse tone mapping to the HDR by using B'

$$I_{HDR}(x) = I_{LDR}(x)(1 + B'(x, s(x))). \tag{6}$$

Thus, the restoration of the luminance component of the HDR image (I_{HDR}) is attained.

3.5. Rate-Distortion Model

One often needs to evaluate the quality of the LDR and HDR images when the LDR and the base map are compressed. Thus it is important to derive the model for the rate-distortion relationship in our method. Letting the distortion of the HDR image $e_h = I_{HDR} - I'_{HDR}$, the squared error can be obtained from (6) by:

$$\begin{aligned} E[e_h^2] &= E[\{(I_{LDR} + I_{LDR} \cdot B) - (I'_{LDR} + I'_{LDR} \cdot B')\}^2] \\ &= E[\{(I_{LDR} - I'_{LDR})(1 + B) - (B - B')I'_{LDR}\}^2] \\ &= E[\{e_L(1 + B) - e_B I'_{LDR}\}^2] \\ &\approx E[e_L^2(1 + B)^2] + E[e_B^2 I'^2_{LDR}] \\ &\approx E[e_L^2]E[(1 + B)^2] + E[e_B^2]E[I^2_{LDR}] \end{aligned} \tag{7}$$

In middle to high bit rates, the relationship between the rate and distortion can simply be modeled as

$$\begin{aligned} E[e_L^2] &= \sigma_L 2^{-2R_L} \\ E[e_B^2] &= \sigma_B 2^{-2R_B}, \end{aligned} \tag{8}$$

wehre σ is a standard deviation of the source image.

By minimizing the following cost function,

$$\begin{aligned} J &= D_H + \alpha D_L + \lambda(R_L + R_B) \\ &= (aE[e_L^2] + bE[e_B^2]) + \alpha E[e_L^2] + \lambda(R_L + R_B) \\ &= (a\sigma_L 2^{-2R_L} + b\sigma_B 2^{-2R_B}) + \alpha E[e_L^2] + \lambda(R_L + R_B), \end{aligned} \tag{9}$$

we obtain the RD model,

$$\begin{aligned} R_L &= \frac{1}{2}\log_2(a \cdot \sigma_L + \alpha) \\ R_B &= \frac{1}{2}\log_2(b \cdot \sigma_B), \end{aligned} \tag{10}$$

where $a = E[(1 + B)^2]$ and $b = E[I^2_{LDR}]$. This model is utilized for bit allocation.

4. EXPERIMENTAL RESULTS

In this section, we compare our method implemented in MATLAB with the conventional two-layer HDR encoding method of Ward et al. [2]. In [2], the JPEG compression is used for the LDR and the residual images. For fair comparison, we also use the JPEG for the LDR and base map. Fig. 2 shows some examples of images used for the experiment.

To assess the validity of our method, we use two criteria for quantitative comparison. One is PSNR of the LDR images and the other is SNR of the HDR images. The obtained RD curves are shown in Fig. 3. The upper and lower plots indicate the results of PSNR of the LDR and SNR of the HDR, respectively. In this experiment, we control the rate of both methods so that the RD curves of the LDR images (that is the upper PSNR plots of Fig.3) coincide. We compare it with the two implementations of Ward's method in the figures. One is implemented by ourselves in MATLAB. The same setting and tone mapping (that is Reinhard's method) are used for both ours and the MATLAB version of the Ward's method. The other result is obtained by the software the authors provided [5], in which their original tone mapping is used for the LDR image. Note that since in the software the original LDR image cannot be obtained, it is omitted in the PSNR plots. In the MATLAB version of the Ward's method, the original LDR image is used to calculate the residual image I_r in (1), because the RD curve becomes worse if the quantized LDR image is used. As evidenced by Fig. 3, the SNR is saturated in the conventional method when the file size becomes large, since the conventional method uses the original (uncompressed) LDR to calculate the residual image and the quantization error of the LDR becomes unignorable. Thus our method performs it especially at high bit rates.

Note that even if compression of the base map is performed at high compression rate, the degraded base map worsens the tone mapping quality. However it does not affect the quality of the HDR image since the encoder uses exactly the same map.

In Fig.4, the quality of the restored HDR image is compared with Ward's method. These two HDR images are encoded at almost same bit rate, and use the same tone mapping operator. The file size shown in the figure means the total sum of the first layer (LDR) and the second layer (added information).

As shown in Fig. 4, false color and a quantization noise are conspicuous in Ward's result. However, it turns out that a clear image is obtained in our method.

5. CONCLUSION

In this paper, we proposed a new two-layer coding using Reinhard's tone mapping. It turned out that our method is a technique suitable for preservation of local contrast. Moreover, compression efficiency which exceeds the conventional method by using the base map which removed the high frequency component was realized.

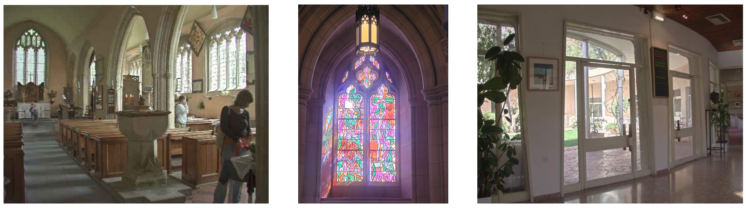

Fig. 2. Decoded LDRimages : (from left to right)Dyrhamchurch, DaniCathedral, DaniBelgium

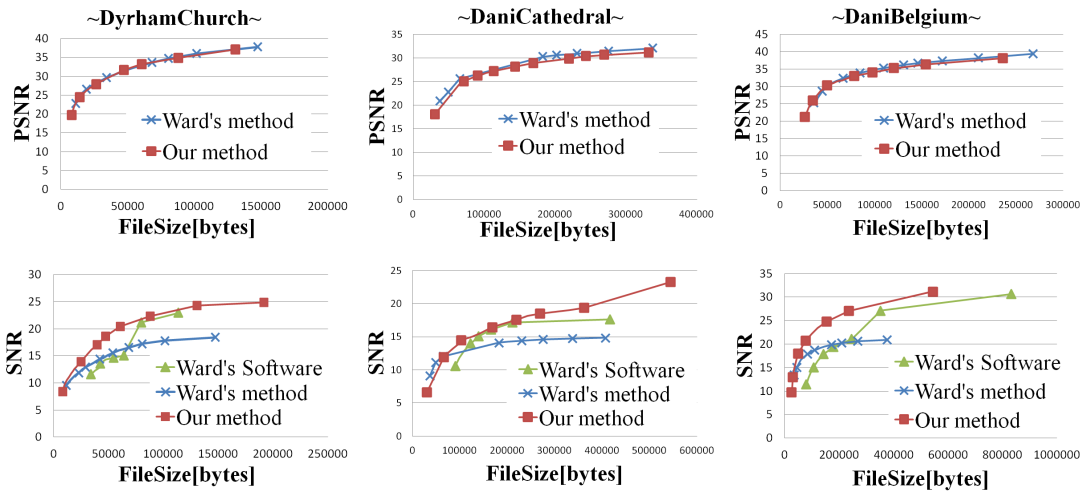

Fig. 3. R-D curve : (top)PSNR of LDR, (lower)SNR of HDR, DyrhamChurch, DaniCathedral, DaniBelgium.

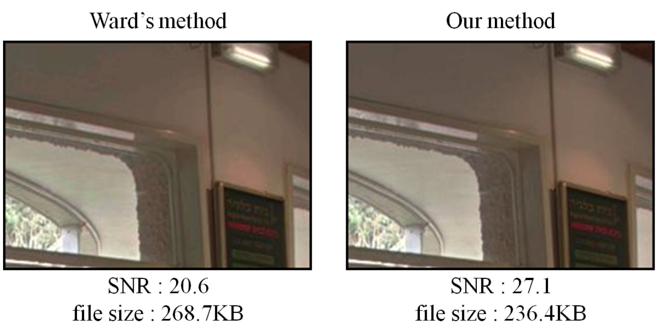

Fig. 4. Comparison of restored HDR images in decoder.

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