NEW LOCAL TONE MAPPING AND TWO-LAYER CODING FOR HDR IMAGES

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ABSTRACT

This paper proposes a two-layer High Dynamic Range (HDR) coding scheme using a new tone mapping. Our tone mapping method transforms an HDR image onto a Low Dynamic Range (LDR) image by using a base map that is a smoothed version of the HDR luminance. In our scheme, the HDR image can be reconstructed from the tone mapped LDR image. Our method makes use of this property to realize a two-layer HDR coding by encoding both of the tone mapped LDR image and the base map. This paper validates its effectiveness of our approach through some experiments.

Index Terms— High dynamic range image, Two-layer HDR coding, Tone mapping

1. INTRODUCTION

HDR images can preserve wide dynamic range of real scenes without any saturation. Since the HDR image has wider dynamic range than conventional LDR one, in many applications the dynamic range is reduced by tone mapping before it is viewed on conventional output devices. Many tone mapping methods have been proposed, in which the dynamic ranges of the HDR images are reduced to displayable ranges [1]. These operations aim at reducing the high dynamic range without loss of detail.

Since the sizes of the HDR images are often huge, development for functional compression is one of the research topics. Spaulding [2] proposes a two-layer encoding for gamut extended images. In the first layer, an image with clipped gamut is encoded. And then in the second layer, the residual information that represents the difference between the original gamut extended image and the decoded image in the first layer is encoded. The main advantage of this approach is the backward compatible format to existing file formats, and no extra efforts are needed to extract the 24 bit image. In the field of Computer Graphics, similar concepts are adopted for the high dynamic range image compression [3], [4].

Most of the two-layer coding methods use a residual image calculated by dividing the HDR image by the tone mapped image. The residual image is not compressible, since it contains much energy in high frequencies. This paper proposes a tone mapping method and a new two-layer HDR coding scheme using the tone map. Our tone mapping method uses a base map that is a lowpass filtered HDR luminance, and use it as meta data for the two-layer coding. Our approach is partly similar to Moroney et al.'s work [5] that can be regarded as tone mapping. However, since the method is designed for conventional 24 bit images, it is hard to realize high contrast and efficient coding performance. Although using global tone-mapping operators such as [6], it is possible to restore the HDR images by applying its inverse operation, there is a trade-off between the accuracy of the inverse operation and contrast preservation capability. This paper shows some results and compare it with some conventional work to confirm the validity of the method.

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2. CONVENTIONAL METHOD

Spaulding et al. proposed the two-layer coding method for RAW images of digital cameras [2]. This method encodes the conventional 24 bit image by JPEG as a first layer, and a difference image between the extended first layer and the original RAW image for a second layer. The second layer is also coded by JPEG, and it is embedded in a JFIF Application marker of the first layer. Ward et al. [3] proposes a HDR coding scheme that supports this two-layer functionality. This method encodes a residual image as the second layer which is calculated by dividing the HDR image by the tone mapped LDR:

$$I_r = \frac{I_{hdr}}{I_{ldr}}. \tag{1}$$

Those conventional methods decode I_{ldr} and I_r, and reconstruct the HDR image I_{hdr} by $I'_{hdr} = I'_{ldr} \cdot I'_r$, where $\cdot'$ means decoded image which includes quantization error. Those methods have backward compatibility to the conventional LDR image format. Users can acquire the tone mapped LDR image without any tone mapping process, and when they decode the residual image, then they can also acquire the HDR image. Some variations of the two-layer coding method can be found in [4].

Those methods, however, have some drawbacks. First,

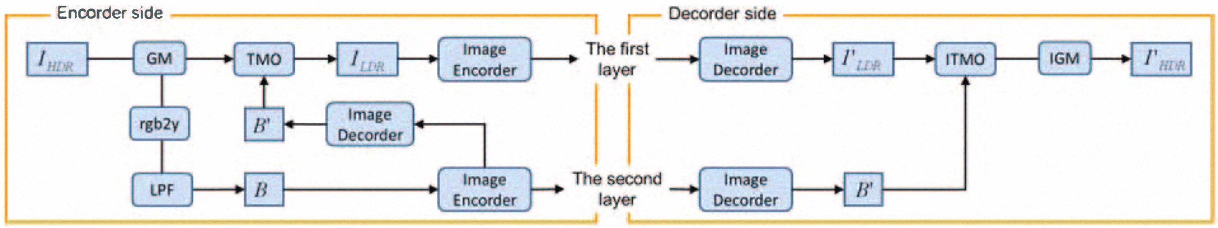

Fig. 1. The flow of our method

I_{hdr}: HDR image, I_{ldr}: tone mapped image, $\cdot'$: decoded version of $\cdot$, GM: gamma mapping, IGM: inverse GM, rgb2y: calculating luminance function, LPF: lowpass filtering, TMO: tone mapping operator, ITMO: inverse TMO.

the residual image has much energy in high frequencies and is not very compressible. Moreover the dynamic range of the residual image often becomes large, which results in high bit consumption.

In the prediction step (1), we have two options for the denominator, the original image I_{ldr} or its encoded/decoded version I'_{ldr}. Since the original LDR image I_{ldr} is not available in the decoder, in general the encoded version I'_{ldr} is used. However the quantization error, which often has much high frequency components, is propagated to the residual image I_r in (1). In the end, the use of I'_{ldr} degrades the coding performance. The use of the original LDR image gives better results in many cases especially for low to medium bit rates, and many methods use this scheme. However in this case the I'_r essentially contains the quantization error of I'_{ldr} as well as its own noise, and thus the R-D performance is easily saturated when bit rate increases.

3. ALGORITHM

To address the problems described in the previous section, we propose a new approach for the two-layer coding. Our method is based on an original tone mapping method. The basic architecture of our encoder/decoder are illustrated in Fig.1. Our tone mapping is based on the simple two-line curves as illustrated in Fig.2. The curve varies pixel by pixel, depending on a base map. The base map B in Fig.1 is calculated by applying a lowpass filter to the HDR luminance. Our method encodes a tone mapped image I_{ldr} and the base map B, as the first and second layer, respectively. Our decoder can decode the first layer when only the tone mapped image is required. To decode the HDR image, we decode the second layer B' and inversely tone maps the first layer I_{ldr} with it. The following subsections explain details of our method.

3.1. Coding Scheme

As is well known, brightness the Human Visual System (HVS) perceives is not proportional to the illuminance of scene, that is, differences in highlights are less perceivable than dark backgrounds, while the HDR images that we treat has linear responses to the illuminance. The first step of the encoder is to apply the gamma mapping (GM in Fig.1) to the HDR images to mimic the HVS's nonlinearity. In the next step, we apply lowpass filtering to the nonlinear HDR luminance that yields the base map B. Our method uses this base map for the tone mapping, and encodes it as the second layer. Since this map is used for inverse tone mapping in the decoder as well, the encoder also needs to use the decoded base map B' for the tone mapping for consistency with the decoder. Due to its consistency, the quantization error of the base map does not affect the quality of the decoded HDR image. That is, the final quality of the HDR image depends only on the fidelity of the LDR image I'_{ldr}. On the other hand, since the fidelity of the base map affects the quality of the tone mapped image, one needs to consider the tone mapping quality as well as the rate-distortion performance when encoding B.

Finally we encode the tone mapped LDR image by a conventional image encoder and transmit the LDR and the base map to the decoder as the first and second layer, respectively. The decoder can obtain the LDR image directly without any tone mapping operations. It additionally receives the base map. The inverse tone mapping method is performed by using the LDR and the base map. It should be noted that our forward/inverse tone mapping method is invertible in the presence of B' if the quantization error of the LDR is negligible. Finally after the inverse tone mapping, the inverse gamma mapping is applied to obtain the I'_{hdr}.

3.2. Base map

As is discussed later, our method maps the HDR pixel value to the LDR one by using a tone mapping function composed of two linear transforms as is depicted in Fig.2. To acquire the base map, we perform lowpass filtering to the nonlinear HDR luminance. Thus a pixel value in the base map approximately indicates the local illumination. The key of our method is that the base map acts as meta data, and the function in Fig.2 varies pixel by pixel depending on the base map. The detail of the tone mapping is discusses in the next section.

We have several options for the lowpass filter. In the case that we use an edge-preserving lowpass filter, such as the bilateral filter and the anisotropic diffusion, the base map discards small details and has only large edges, which prevents halo artifacts. In our framework, the base map is encoded and transmitted to the decoder. Thus we want to suppress energy in the high frequencies of the base map. In that sense, a linear lowpass filter is desirable. After some tests, we adopt the linear Gaussian lowpass filter. In our experiments, the halo artifacts can be reduced by using the mapping scheme in the next section, and coding efficiency is improved as well.

3.3. Tone mapping

Our method performs the local tone mapping, that is the tone mapping functions adaptively varies pixel by pixel by taking the local illumination into consideration. In our case the local illumination is approximately given by the base map.

Our tone mapping function is composed of two linear transforms as is shown in Fig.2. Our method separates the HDR luminance region into two ranges, and maps the luminance in each range by the corresponding line. We denote the mapping functions in low and high luminance ranges, l_1 and l_2, respectively (see Fig.2).

The tone map consisted of those two lines are calculated by following.

$$\begin{cases} l_1: \quad Y(i) = \frac{Y_t(i)}{X_t(i)} X(i), & \text{if } X(i) \leq X_t(i) \\ l_2: \quad Y(i) = \frac{Y_{limit} - Y_t(i)}{X_{max} - X_t(i)} X_{l_2}(i) + Y_t(i), & \text{else} \end{cases} \tag{2}$$

where $X_{l_2}(i) = X(i) - X_t(i)$, i is the pixel index, X_{max} is the maximum pixel value of X, and (X_t, Y_t) is the coordinates of the intersection between the two lines. X_t,Y_t and Y_{limit} are calculated by

$$X_t(i) = \bar{B}' + \alpha_X \left(B'(i) - \bar{B}'\right), \tag{3}$$

$$Y_t(i) = \left\{\bar{B}' - \alpha_Y \left(B'(i) - \bar{B}'\right)\right\} \frac{Y_{limit}(i)}{X_{max}}, \tag{4}$$

$$Y_{limit}(i) = \frac{X_{max}}{1 + B'(i)}, \tag{5}$$

where $\bar{B}' = \exp\left\{\frac{1}{N}\sum_{i=1}^{N} \log\left(B(i) + \epsilon\right)\right\}$, α_X and α_Y are parameters which control tone mapping effects, N is a number of pixels, and ϵ is a prescribed small value. X_t, Y_t and Y_{limit} construct the tone map, and those parameters change according to the base map.

When the value $B'(i)$ of the base map at a pixel is smaller than the average $\bar{B}'$, that is, the pixel is located at a dark area, the intersection (X_t, Y_t) slides to the left along the x-axis by $\alpha_X|B'(i) - \bar{B}'|$, and slides up along the y-axis by $\alpha_Y|B'(i) - \bar{B}'|\frac{Y_{limit}(i)}{X_{max}}$. In this case, if the HDR luminance $X(i)$ is smaller than $B'(i)$, which is the local average, then it is mapped to a smaller value, and vice versa (Fig.2(a)). Similarly when $B'(i)$ is larger than $\bar{B}'$, it exerts the opposite effects as is shown in Fig.2(b).

The inverse tone mapping is simply performed by applying the inverse function of (2) based on the decoded base map B'. We need the maximum value of HDR luminance X_{max} for the inverse process, which is transmitted as a side information. Since the inverse of (2) is determined at the decoder, the tone mapping is invertible in the presence of B' and X_{max}, even though the B' is coarsely quantized. Note that although the encoding precision of B' does not affect the invertibility, the low quality of B' leads to the degradation of the tone mapped image.

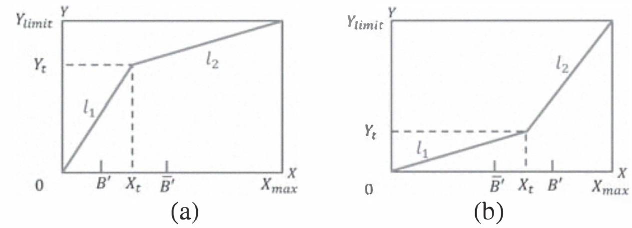

Fig. 2. examples of tone mapping

Table 1. bit rate of each results in Fig.3

	"Desk"	"memorial"	"DaniBelgium"
Conventional method[3]	0.25189	0.51256	0.44763
Our method	0.24173	0.48067	0.47766

4. RESULTS

This section shows some examples to validate our method and compare it with the standard two-layer HDR coding method proposed by Ward et al.[3]. We use JPEG for the image coding method in Fig.1 for the consistency with Ward's approach[1]. Fig.3 illustrates the tone mapped results of our algorithm and the conventional method with the bit rate given by Table.1. The local contrasts can be seen more clearly than the conventional one both in low and high luminance range.

To compare our coding performance with the conventional method quantitatively, this paper uses two criteria, the SNR and a nonlinear SNR. The nonlinear SNR is introduced to evaluate the visual quality of the image. For the calculation, the nonlinearity proposed by Daly [7] is applied to the image and then the SNR is calculated. This nonlinearity mimics the nonlinear characteristic of the HVS's response to luminance.

Fig.4 shows the quantitative results for the three images in Fig.3. Our method outperforms the conventional method except for the image 'Desk' in the SNR. 'Desk' has much detail in a large high luminance region. Since our method tends to compress the high luminance range where the HVS is insensitive. The normal SNR does not consider the HVS's property, the SNR of our method is sometimes superior to such images, while our method has better coding performance for the nonlinear SNR, where the HVS property is taken into consideration. As is mentioned in Sec.2, the the R-D curve of the conventional method is easily saturated as the bit rates becomes high, while our method does not have the problem.

5. CONCLUSION

This paper proposes the novel scheme for the two-layer HDR coding. We confirms with the experimental results that our proposed tone mapping can preserve the local contrast and the visibility of details. Our method also achieves the high coding efficiency, since our method uses the base map which are filtered the high frequency for the second layer.

[1]We use the software attached in [1] for the Ward's results

Fig. 3. decoded tone-mapped images: (upper line)Ward's method[3], (lower line)our method. (left)Desk, (center)Memorial, (right)DaniBelgium.

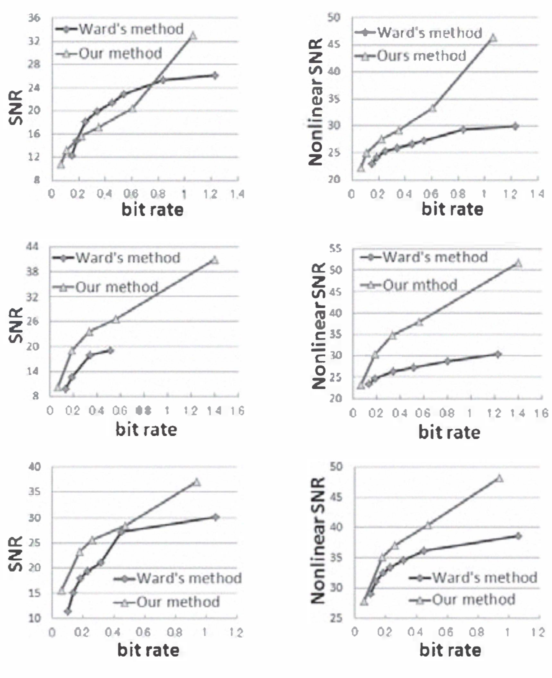

Fig. 4. R-D curve: (left row)SNR, (right row)nonlinear SNR. (upper)Desk, (center)Memorial, (lower)DaniBelgium.

6. REFERENCES

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