HIGH CONTRAST TONE-MAPPING AND ITS APPLICATION FOR TWO-LAYER HIGH DYNAMIC RANGE CODING

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***Abstract*—Many applications for High Dynamic Range (HDR) images require tone-mapping operations that preserve details in whole luminance range. This paper proposes a high contrast tone-mapping operator using a multi-scale contrast enhancement, and uses it for a high efficiency two-layer HDR coding. To visualize minute details, the high contrast tone-mapping operator often results in hard enhancement. In many conventional two-layer coding methods, it degrades compression efficiency. In contrast our method can achieve both of the high contrast and high compression efficiency. Moreover this paper can perform two types of tone-mapping which generates the images with strong enhancement and natural look. This paper shows the validity of our methods through some experimental results.**

I. Introduction

HDR images can store details of scenes in the entire radiance range without over- or under-exposure. The preserved details in the HDR images are useful for various applications, e.g. surveillance system, in-vehicle camera, medical sensing, and high contrast photography. The common output devices, however, cannot display the HDR images directly because these have lower dynamic range and bit-depth than the HDR images. Many range compression methods called tone-mapping have been proposed [1]-[7]. To preserve and visualize many minute details, the tone-mapping methods should enhance them hard. The state of the art tone-mapping method [3] can perform the hard enhancement. The hard-enhanced images, however, seem non-natural, thus most of applications also need the tone-mapped images with natural look. In this paper, ideal tonemapped images with natural look are defined that an image which preserve global contrast of the scene and accord with the Human Visual System (HVS). This paper first proposes a high contrast tone-mapping method, and it can add two effects in a tone-mapped image. Our method is based on multi-scale contrast enhancement with piecewise linear mapping that has low computational complexity and achieve as high contrast as the state-of-the-art [3] with less computational effort.

On the other hand, in image compression, a two-layer coding for the HDR image/video is often useful. Some two-layer coding methods have been proposed so far [1], [8], [9]. One can decode the tone-mapped image when it receives the first layer, and then decode the original HDR image when it additionally receives the second layer. The compression efficiencies of the conventional two-layer coding methods tend to decrease when the first layer has the high frequency components and the high contrast. Moreover many conventional methods apply only one tone-mapping effect. This paper proposes an efficient two-layer HDR coding using the proposed high contrast tone-mapping method which can add two effects in at tone-mapped image.

II. Conventional two-layer HDR coding

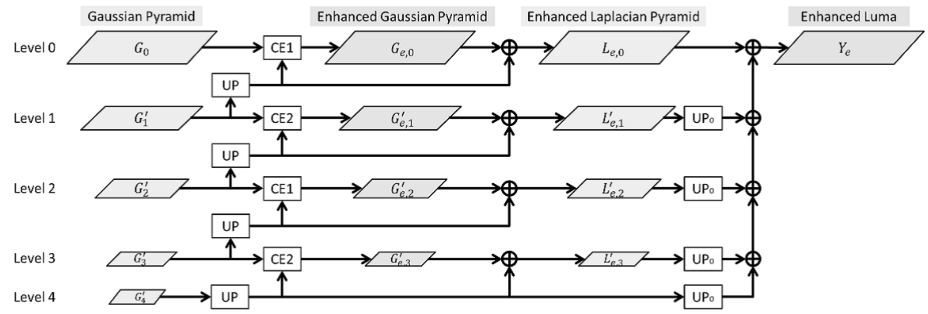
Many two-layer HDR coding methods have been proposed so far [1], [8], [9]. Most of them use the tone-mapped image for the first layer, and for the second layer, a residual between the original HDR image and the first layer. One of the most well-known two-layer HDR coding methods is Ward's method [9]. This method calculates the residual which is a division between the tone-mapped image and the original HDR image. This method encodes both the tone-mapped Low Dynamic Range (LDR) image and the residual by using a conventional image encoder such as JPEG. A data size of the residual generally increases when the tone-mapped LDR image is very different from the original HDR image.

When the tone-mapped image has high contrast, the conventional two-layer coding method becomes inefficient, since a lot of high frequency components remain in the residual. Although the residual significantly affects the quality of the decoded HDR image, this paper uses the lossy JPEG 2000 and the lossless one for the image encoders of the first layer and the second layer, respectively.

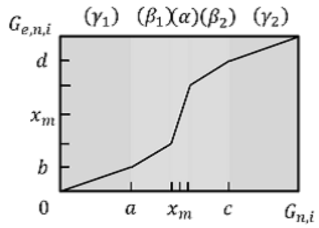
To overcome this problem, this paper proposes the high contrast tone-mapping method that focuses on a visibility of the details in the tone-mapped images and applies it to the two-layer coding, which achieves both of the high contrast tone mapping and efficient two-layer coding.

III. Our method

This paper first proposes the high contrast tone-mapping method which can perform an inverse processing by using



(a) The flow of our multi-scale processing : (UP) up-sample operator, (UP0) 0-th level up-sample operator, (CE) contrast enhancement



(b) The mapping function of our contrast enhancement : $x_m = G_{(n+1),i}$

Fig. 1. Our multi-scale contrast enhancement

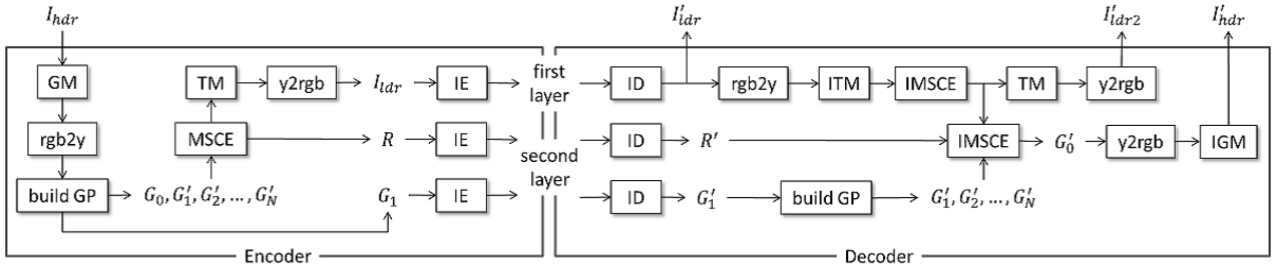


Fig. 2. The block diagram of our two-layer HDR coding method at N-level: (GM) gamma mapping, (IGM) inverse GM, (rgb2y) calculating luminance, (y2rgb) colorization, (build GP) building Gaussian pyramid, (MSCE) multi-scale contrast enhancement, (IMSCE) inverse MSCE, (TM) tone-mapping, (ITM) inverse TM, (IE) image encoder, (ID) image decoder

side information. It can reconstruct the original HDR image from the tone-mapped image and the side information. Our method uses the side information instead of the residual for the second layer, and it is the down-sampled HDR luma map. Since our second layer is calculated from only the original HDR luminance, it is not affected by the first layer, that is, its compression efficiency does not degrade even if the first layer has the high frequency components and the high contrast. Our tone-mapping method is based on the multi-scale contrast enhancement, and enhances each scale images individually by using Gaussian pyramid. Individual processing makes it possible to perform a partial inverse processing. In the tone-mapping process of the encoder, our method adds two tone-mapping effects in the first layer. Our decoder cuts out only hard enhancement effect, and then acquires a tone-mapped image with natural look in the middle of the decoding process of the HDR image.

A. Tone-mapping with Multi-scale contrast enhancement

Fig.1(a) shows a block diagram of our method (This paper show only a 4-level hierarchy due to the limited space). Note that our tone-mapping resembles the past work [3] in some part. However our method achieve very high contrast tone-mapping with less computational complexity, and more importantly, our method can be applied to the two-layer coding as described in Sec.III-B.

This contrast enhancement is performed in the luminance field. First of all, our method applies the gamma mapping to the original HDR luminance Y_{hdr} to mimic the nonlinearity of the HVS, and then set it as the input $G_0 = (Y_{hdr})^\gamma$ in Fig.1(a). Our method enhances the contrasts of this nonlinear HDR luma map G_0, and then it constructs the N-level Gaussian pyramid $G_0, G_1, ..., G_N$, where G_N is not enhanced. Each level of the pyramid is enhanced by a mapping function shown in Fig.1(b). The mapping functions at an n-th level varies depending on the up-sampled $(n+1)$-th level of the Gaussian pyramid. It consists of five lines as shown in Fig.1(b). Six parameters h_α, h_β, h_γ, v_α, v_β and v_γ control these five lines.

$$CE(x) = \begin{cases} g_\gamma(x-a)+b & : \text{if } (\gamma_1) \\ g_\beta(x-a)+b & : \text{else if } (\beta_1) \\ g_\alpha(x-x_m)+x_m & : \text{else if } (\alpha) \\ g_\beta(x-c)+d & : \text{else if } (\beta_2) \\ g_\gamma(x-c)+d & : \text{else (i.e.}(\gamma_2)) \end{cases}, \quad (1)$$

where $g_\alpha = v_\alpha/h_\alpha$, $g_\beta = v_\beta/h_\beta$, $g_\gamma = v_\gamma/h_\gamma$, $v_{\alpha,\beta} = v_\alpha + v_\beta$, $h_{\alpha,\beta} = h_\alpha + h_\beta$, $a = x_m - h_{\alpha,\beta}$, $b = x_m - v_{\alpha,\beta}$, $c = x_m + h_{\alpha,\beta}$, and $d = x_m + v_{\alpha,\beta}$.

(γ_1) : $x \leq x_m - h_{\alpha,\beta}$
(β_1) : $x_m - h_{\alpha,\beta} < x \leq x_m - h_\alpha$
(α) : $x_m - h_\alpha < x \leq x_m + h_\alpha$
(β_2) : $x_m + h_\alpha < x \leq x_m + h_{\alpha,\beta}$
(γ_2) : $x_m + h_{\alpha,\beta} < x$

Additionally, $x = G_n$ and $x_m = UP(G_{n+1})$ in this paper.

This contrast enhancement yields an enhanced Gaussian pyramid $G_{e,0}$, $G_{e,1}$, ..., $G_{e,N-1}$ from the original one. Our next step calculates an enhanced Laplacian pyramid $L_{e,n}$ by

$$L_{e,n} = G_{e,n} - UP(G_{n+1}), \quad (2)$$

where $UP(.)$ is the up-sampling operator, and $n = 0, 1, ..., N-1$. The enhanced Laplacian pyramid derives an enhanced luminance map Y_e as follows.

$$Y_e = UP_0(G_{e,N}) + \Sigma_{n=1}^{N-1}\{UP_0(L_{e,n})\} + L_{e,0}, \quad (3)$$

where $UP_0(x)$ is 0-th level up-sample operator that converts x to the original size. The enhanced luma map Y_e has contrast enhancing effects of each level.

To fulfill the two tone-mapping effects, our method uses two different parameter sets for contrast enhancements (CE) shown in Fig.1(a). One results in hard enhancement, and the other results in moderate enhancement. Our method applies the hard enhancement parameter set to the contrast enhancements of even-level Gaussian pyramid (Fig.1(a) CE1), and it is $h_\alpha = 0.001$, $h_\beta = 0.01$, $h_\gamma = 0.2$, $v_\alpha = 0.02$, $v_\beta = 0.01$ and $v_\gamma = 0.1$, where n is a current level of the Gaussian pyramid. On the other hand, the moderate enhancement parameter set to the contrast enhancements of odd-level Gaussian pyramid (Fig.1(a) CE2), and it is $h_\alpha = 0.001$, $h_\beta = 0.01$, $h_\gamma = 0.2$, $v_\alpha = max(h_\alpha, 0.02/(n+1))$, $v_\beta = 0.01$ and $v_\gamma = 0.1$. These parameters are decided by trial and error. The CE2 turns down the contrast enhancement effect at lower resolution level, and then it makes the multi-scale contrast enhancement effect weak, that is, odd-level contrast enhancements are moderate. Y_e is hard-enhanced luma, and it becomes moderate-enhanced luma when the even-level contrast enhancement effects are removed from it.

The enhanced luminance map Y_e still has the high dynamic range, thus it is tone-mapped as following equation.

$$Y_{ldr} = \frac{Y_e}{1+Y_e}. \tag{4}$$

B. our two-layer HDR coding

Our method applies the multi-scale contrast enhancement in Sec.III-A to a detail preserving two-layer HDR coding. Fig.2 illustrates the procedure of our two-layer HDR coding method. One of the features of our contrast enhancement is that the HDR image can be restored by the inverse processing with Y_e and G_1. Thus our method encodes and sends three images, the LDR image in the first layer, and G_1 and the residual R in the second layer, which is the key of our coding method. As described in Sec.III-A, our method builds the Gaussian pyramid by using nonlinear luma map $Y^{\gamma}_{(hdr)}$. Our method encodes G_1 and sends it as side information in the second layer. To use the same data in both encoder and decoder, our encoder also uses the decoded version of G_1 in order to avoid drift at the decoder. Therefore our Gaussian pyramid consists of $G_0, G'_1, G'_2, ..., G'_{N-1}$ in the encoder, where the prime $x^{'}$ denotes the decoded version of x.

The inverse process of our multi-scale contrast enhancement is performed with the tone-mapped image and G'_1. The decoder calculates enhanced Laplacian pyramid $L'_{e,1}, L'_{e,2}, ..., L'_{e,N-1}$ by applying the multi-scale contrast enhancement to G'_1, and then acquires moderate-enhanced luma Y'_{e2} by applying

$$Y'_{e2} = Y'_e - \Sigma_{n=1}^{\lfloor N/2 \rfloor}\{UP_0(L_{e,2*n})\}. \tag{5}$$

Removed only the hard enhancement effects, Y'_{e2} becomes moderate-enhanced luma. The decoder can make a second tone-mapped image I'_{ldr2} by using Y'_{e2}. Our method finally acquires $G'_{e,0}$ by applying

$$G'_{e,0} = Y'_{e2} - \Sigma_{n=0}^{\lfloor N/2 \rfloor}\{UP_0(L_{e,2*n+1})\}. \tag{6}$$

Although the decoder can calculate G'_0 by using the inverse contrast enhancement, a large error might occur near large edges because of the compression errors of I_{ldr} if our method uses the mapping function which has radical enhancement effects. To treat this problem, our method adds a residual map R between G_0 and $G'_{e,0}$ to the second layer. It is calculated by

$$R = \frac{G_0}{1+G'_{e,0}}. \tag{7}$$

This residual preserves more the large errors than the small one. Our residual R only has the compression error of I_{ldr} and a difference between G_0 and $G_{e,0}$, therefore it has higher compression efficiency than the conventional one as described in even if our method should send two gray-scale images G_1 and R. In our method, G_1 and R are encoded, respectively.

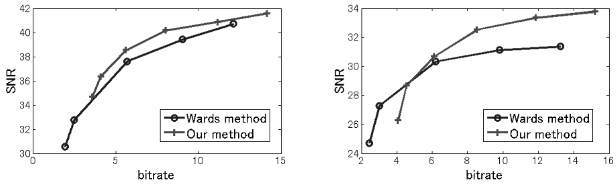


Fig. 3. R-D curve : (left) HancockKitchenInside, (right) dani belgium

IV. RESULTS

This paper applies our method to some HDR images. Fig.4 shows our tone-mapping results and the conventional one [2]-[5].Fig.4(a), (d), (e) and (f) illustrate that our method can visualize the minute details as well as the conventional complexity methods[3]-[5]. Fig.4(b) and (c) shows our moderately-enhanced image seems as natural as one of the most famous tone-mapping method [2]. Our results (Fig.4(b)) has more detail in local contrast than the conventional one (Fig.4(c)), and has as large global contrast as the conventional one, which makes it more natural.

Fig.3 describes the Rate-Distortion curves for both of our method and the conventional one shown in Sec.III-B. Both of them use our strongly-enhanced image for the first layer. Ward's method has high compression efficiency in low bitrate region, however our method has higher compression efficiency than the conventional one in high bitrate region. Additionally, users can extract two types tone-mapping images in HDR decoding process, but the conventional method yields only a single tone-mapping image. Our method has larger file size than the conventional one in low bitrate region since our method needs to encode three images, and many bits are spent for encoding rough structures of the three images. However, R has less high frequency components than the residual image in the conventional one, and the size of G1 is quarter size. Therefore our method achieves high compression efficiency in high bitrate region.

V. CONCLUSION

This paper proposes the new high contrast tone-mapping method and the two-layer HDR coding using it. Some experimentally results shown in this paper indicates that our method can preserve the details and has higher compression efficiency. Additionally, our method can decode the two different tone-mapped images in the decoder, that is, the decoder can select

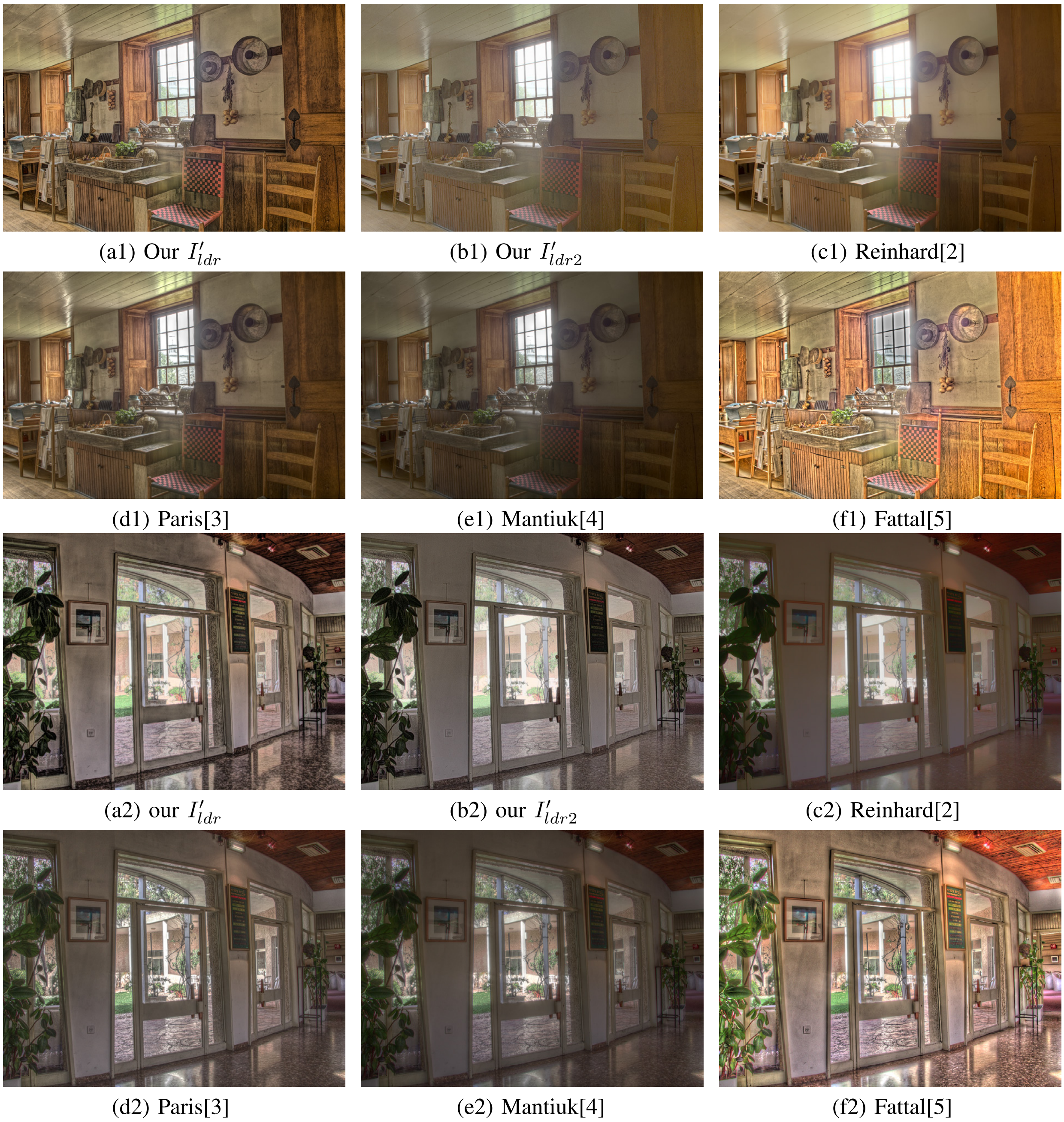


Fig. 4. Comparing with tone-mapping effects : (a1)-(f1) HancockKitchenInside.hdr, (a2)-(f2) dani belgium.hdr

two different tone-mapping effects easily. Our future works are to increase the tone-mapping effects, and applying this method to a multiple bit-depth representation.

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