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 should over-enhance them. In many conventional two-layer coding methods, it causes degrading compression efficiency. In contrast our method can achieve both of the high contrast and high compression efficiency. Moreover this paper tries to add two tone-mapping effects in the first layer, where they are over-enhanced image and natural enhanced one. 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 [?], [?],To preserve and visualize many minute details, the tone-mapping methods should over-enhance them. The leading-edge tone-mapping method [?] can over-enhance them. The over-enhanced images, however, seem non-natural, thus most of applications also need natural tone-mapped images. This paper first proposes a high contrast tone-mapping method which 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 [?] with less computational effort.

On the other hand, in image compression, a two-layer coding for the HDR image/video is often useful and some two-layer coding methods have been proposed so far [?], [?], [?], [?]. 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. Our two-layer coding can achieve both of the high contrast and high computational efficiency.

II. Conventional two-layer HDR coding

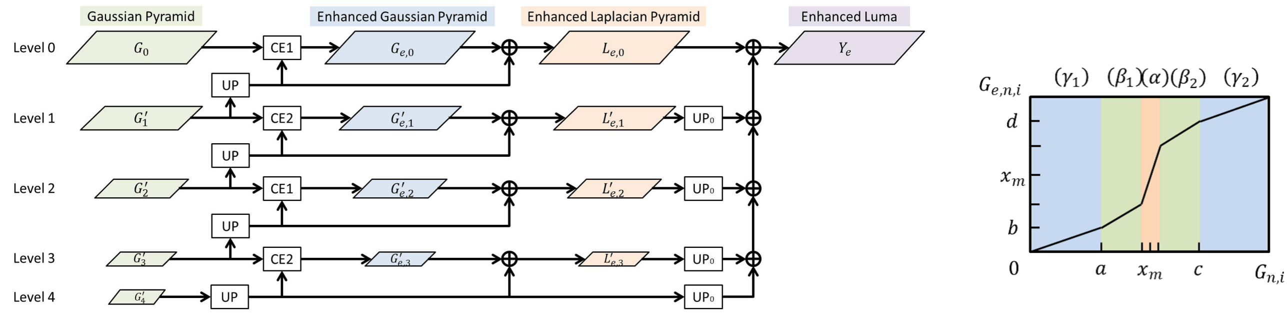
Many two-layer HDR coding methods have been proposed so far [?], [?], [?], [?]. Most of them use the tone-mapped image for the first layer, and for the second layer, a residual between the original HDR image and the first layer. One of the most well-known two-layer HDR coding method is Ward's method [?]. 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 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 apply 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 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.



(a) The flow of our multi-scale processing : (UP) one level up-sampling, (UP0) up-sampling to original size, (CE)contrast enhancement

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

Fig. 1. Our multi-scale contrast enhancement

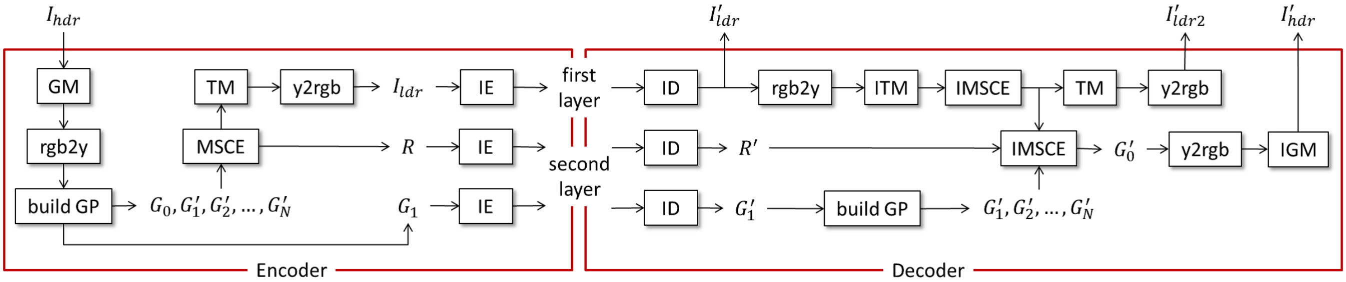


Fig. 2. The block diagram of our two-layer HDR coding method at N-level: (GM)gamma mapping, (IGM)inverse GM, (rgb2y)calculating luminance, (y2rgb)colorization, (build GP)building Gaussian pyramid, (MSCE)multi scale contrast enhancement, (IMSCE)inverse MSCE, (TM)tone-mapping, (ITM)inverse TM, (IE)image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

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 is the over-enhanced image. 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 tone-mapping process of the encoder, our method adds two tone-mapping effects in the first layer. Our decoder cuts out only over-enhancement effect, and then acquires the natural enhanced image in the middle of the decoding process of the HDR image.

A. Tone-mapping with Multi-scale contrast enhancement

Fig.**??** 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 [**?**] 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.**??**.

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 Human Visual System (HVS), and then set it as the input $G_0 = (Y_{hdr})^\gamma$ in Fig.**??**. Our method enhances the contrasts of this nonlinear HDR luma map G_0. Our method constructs the N-level Gaussian pyramid $G_0, G_1, ..., G_N$, where G_N is only used for the contrast enhancement at the $(N-1)$-th level. Each level of the pyramid is enhanced by a mapping function as shown in Fig.**??** individually. The mapping functions at a 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.**??**. 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) : $x \le x_m - h_{\alpha,\beta}$
(β_1) : $x_m - h_{\alpha,\beta} < x \le x_m - h_\alpha$
(α) : $x_m - h_\alpha < x \le x_m + h_\alpha$
(β_2) : $x_m + h_\alpha < x \le x_m + h_{\alpha,\beta}$
(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 a enhanced Laplacian pyramid $L_{e,n}$ by

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

where $UP(.)$ is the one level up-sampling operator, and $n = 0, 1, ..., N-1$. The enhanced Laplacian pyramid derives a 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 $UP_0(x)$ up-samples the size of x to the original size. The enhanced luma map Y_e has contrast enhancing effects of each level.

To add two tone-mapping effects in a tone-mapped image, our method set the parameters of even and odd level contrast enhancement to over-enhancement effect value and natural enhancement one, respectively. CE1 in Fig.**??** over-enhances the contrasts by using the parameters $h_\alpha = 0.001$, $h_\beta = 0.01$, $h_\gamma = 0.2$, $v_\alpha = 0.02$, $v_\beta = 0.01$ and $v_\gamma = 0.1$. CE2 in Fig.**??** enhances the contrasts naturally by using the parameters $h_\alpha = 0.001$, $h_\beta = 0.01$, $h_\gamma = 0.2$, $v_\alpha = max(h_\alpha, 0.02/(n+1))$, $v_\beta = 0.01$ and $v_\gamma = 0.1$, where n is a current level of the Gaussian pyramid. 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 weak and natural. Y_e is over-enhanced luma, and it becomes natural 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 should be tone-mapped as following equation.

$$Y_{ldr} = \frac{Y_e}{1+Y_e}. \quad (4)$$

This tone-mapping method is very simple, and it is easy to perform its inverse processing.

B. our two-layer HDR coding

Our method applies the multi-scale contrast enhancement in Sec.**??** to a detail preserving two-layer HDR coding. Fig.**??** 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 in the second layer, which is the key of our coding method. Our method describes it more in detail as follows. First, as described in Sec.**??**, our method first performs the gamma mapping, and then calculates the nonlinear luma map $Y^\gamma_{(hdr)}$. For the multi-scale processing, our method builds the Gaussian pyramid. Our method encodes G_1 and sends it as a 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 natural enhanced luma Y'_{e2} by applying

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

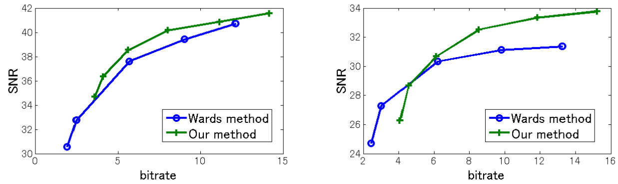


Fig. 4. R-D curve : (left) HancockKitchenInside, (right) dani belgium

Removed only the over-enhancement effects, Y'_{e2} becomes natural enahnced 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

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

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

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

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 add G_1 to the second layer.

IV. RESULTS

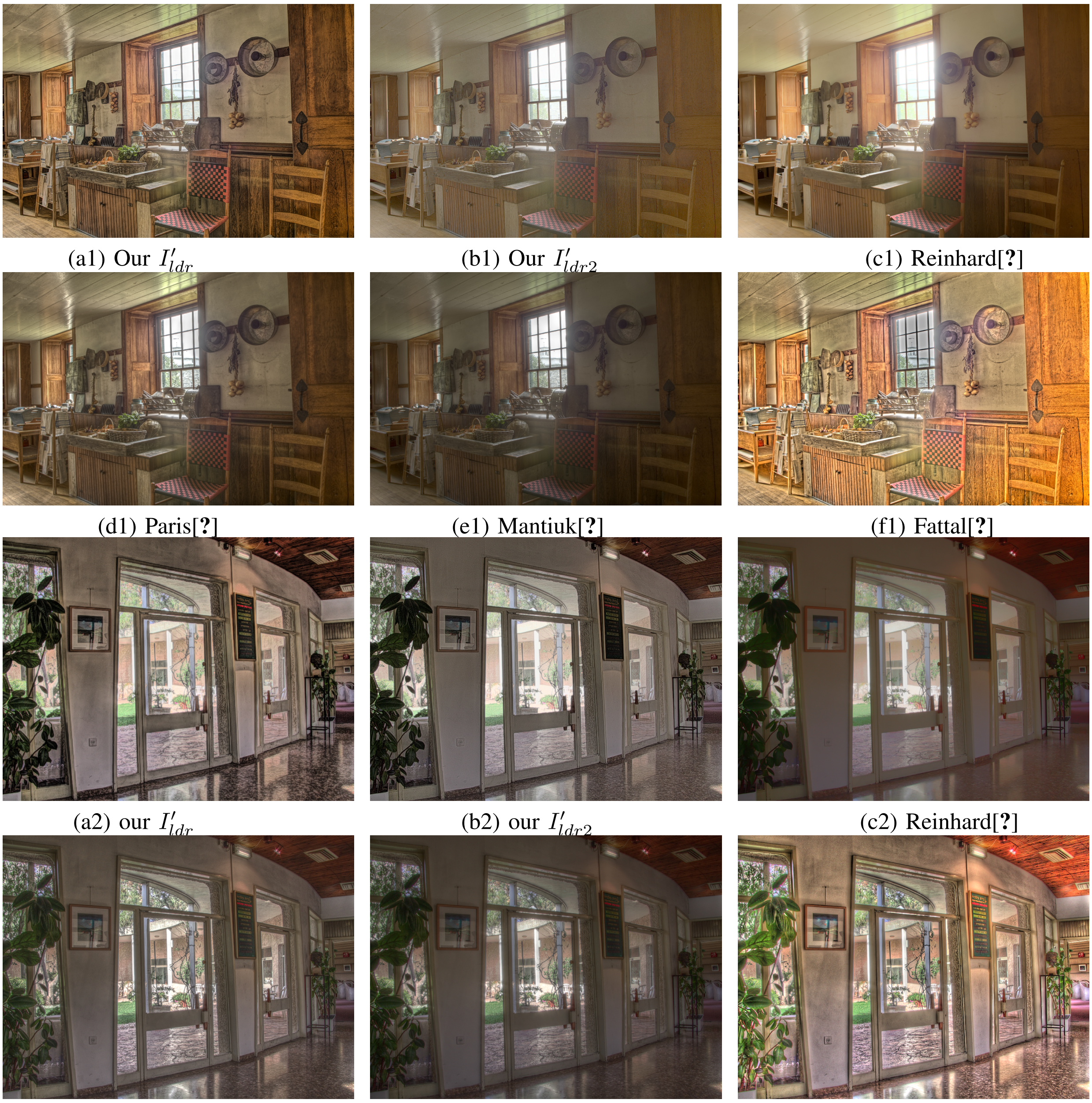
This paper apply our method to some HDR images. Fig.**??** shows our tone-mapping results and the conventional one [**?**], [**?**], [**?**], [**?**]. Our over-enhanced image can visivalize the minute details as well as the conventional complexity methods, and our natural enhanced image seems natural as one of most famous tone-mapping method [**?**].

Fig.**??** describes the Rate-Distortion curves for both of our method and the conventional one as shown in Sec.**??**. Both of them use our over-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.

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 two different tone-mapping effects easily.

Our future works are increasing the tone-mapping effects, and applying this methods to a multiple bit-depth representation.



(a1) Our I'_{ldr} (b1) Our I'_{ldr2} (c1) Reinhard[?]

(d1) Paris[?] (e1) Mantiuk[?] (f1) Fattal[?]

(a2) our I'_{ldr} (b2) our I'_{ldr2} (c2) Reinhard[?]

(d2) Paris[?] (e2) Mantiuk[?] (f2) Fattal[?]

Fig. 3. Compariing with tone-mapping effects : (a1)-(f1) HancockKitchenInside.hdr, (a2)-(f2) dani belgium.hdr

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