A Tone Mapping Method by Local Contrast and Detail Enhancement for High Dynamic Range Images

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Keywords : tone mapping, high dynamic range, local contrast

Abstract

In this paper, tone mapping method by local contrast and detail enhancement for High Dynamic Range (HDR) is proposed. By applying Piecewise Dynamic Range Histogram Adjustment (PDRHA) and Detail Enhancement Volume (DEV) with decomposed layers, tone mapping is performed effectively. The experimental results show that the proposed method preserves local contrast and overall impression with naturalness of original images.

1. Introduction

The dynamic range of real world scenes span over 9 orders (10^{-4} to 10^{5} cd/m^2) of luminance values. A high dynamic range (HDR) images are designed to contain full visual dynamic range of real world scenes. However, HDR images are not suitable for commercial display devices because dynamic range of HDR images do not match with one of low dynamic range (LDR) display devices. To reproduce a tone of HDR images for LDR displays, tone mapping methods have been proposed such as local and global tone mapping [1][2][3]. Global tone mapping methods compress the luminance value of image pixels using a tone reproduction curve. These approaches have the advantage of being simple and fast. However, histogram based methods, such as histogram adjustment [2][3], introduce the significant luminance change when the dynamic range is especially large [4]. And, visual details are lost in tone mapping process [5]. The local tone mapping approaches which convolve the spatial context manipulation of local neighboring pixel values are more flexible than global ones [2]. Bilateral filtering based methods [1][2], which use the decomposed base and detail layers, preserve a local contrast across the shadow and highlight region of HDR image. But, these methods introduce the halo artifact with the luminance changes in the decomposed layers. Therefore, it is necessary to preserve the overall impression with the naturalness of HDR image and to enhance visual details and local contrast of original images.

In this paper, we propose a tone mapping method by local contrast and detail enhancement for HDR images. This paper is organized as follows. In section 2, the proposed method is discussed, and the experimental result and conclusions are given in section 3, and 4, respectively.

2. The proposed method

The major objective of the proposed method is to preserve the naturalness and enhance the local contrast and details of an input image. The proposed method consists of overall impression enhancement and local contrast and detail enhancement. The flow chart of the proposed method is shown by Fig. 1.

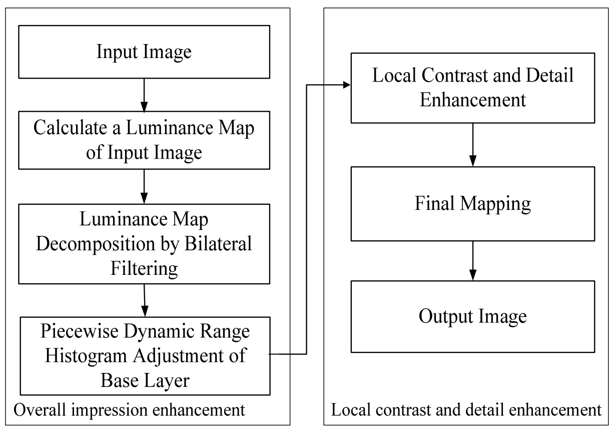


Fig. 1. The flow chart of the proposed method

A. Overall impression enhancement

In the first step of the proposed method, we calculate a world luminance component $L_w(x, y)$ [2]

that indicates the brightness of an image which is captured in a real world scene.

$$L_w(x,y) = 0.2126R(x,y) + 0.7152G(x,y) + 0.0722B(x,y) \quad (1)$$

where R(x, y), G(x, y), and B(x, y) represents the red, green, and blue value of image pixel respectively.

The world luminance component is decomposed into a base layer and a detail layer by the use of bilateral filtering [1]. The base layer contains overall impression of dim and bright, and the detail layer indicates the local contrast and details [3]. The decomposed base layer and detail layer is given as follows

$$L(x,y) = \log_{10}\left(L_w(x,y) + 0.0001\right) \quad (2)$$

$$L_{base}(x,y) = F_{bilateral}\left(L(x,y)\right) \quad (3)$$

$$L_{detail}(x,y) = L(x,y) - L_{base}(x,y) \quad (4)$$

where $F_{bilateral}(\ )$ is the bilateral filter of [3], and $L(x, y)$ is a logarithmic scale of $L_w(x, y)$. To avoid the singularity where black pixels are present in the image, the threshold of human vision, 10^{-4}cd/m^2, is added. The base layer $L_{base}(x, y)$ is the result of the bilateral filter and the $L_{detail}(x, y)$ is the difference of the logarithmic luminance $L(x, y)$ and base layer.

After decomposing the base layer and the detail layer in order to apply Piecewise Dynamic Range Histogram Adjustment (PDRHA) in base layer for overall enhancement, we generate a Probability Distribution Ratio (PDR) which is defined by (5)

$$PDR_k = \sum_{j=SDR_k}^{SDR_{k+1}} h_{base}(b_j) / N \quad (5)$$

where $h_{base}(\ )$ represents the histogram of the base layer, SDR is the length of Separated Dynamic Range, k is the separation level, b_j is the j_{th} logarithmic luminance level of input, and N is the total number of pixels in the image, respectively. Fig. 2. shows the SDR into 4 separation level with the same length of dynamic range.

And then, we redistribute the SDR for overall impression and enhancement. The Redistribution of Separated Dynamic Range (RSDR) is proportional to its PDR. It can be defined as the multiplication of the base layer dynamic range and PDR:

$$RSDR_k = PDR_k \times DR_{base} \quad (6)$$

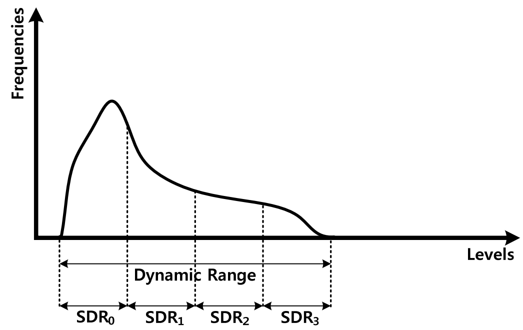


Fig. 2. Dynamic range separation (*k*=4)

where DR_{base} is $DR_{base} = L_{max\_base} - L_{min\_base}$, L_{max_base} and L_{min_base} denote maximum and minimum value of $L_{base}(x, y)$.

Finally, the PDRHA is performed as (7)

$$L'_{base}(x,y) = L_{min\_base} + \left(L_{base}(x,y) - SDR_k\right) \times PDR_k + \sum_{i=0}^{k-1} RSDR_i \quad (7)$$

where $L'_{base}(x, y)$ is output pixel value and k is the separation level, which is given by 0, 1, 2, and 3. Fig. 3. shows the redistribution of separated dynamic range and piecewise dynamic range histogram adjustment.

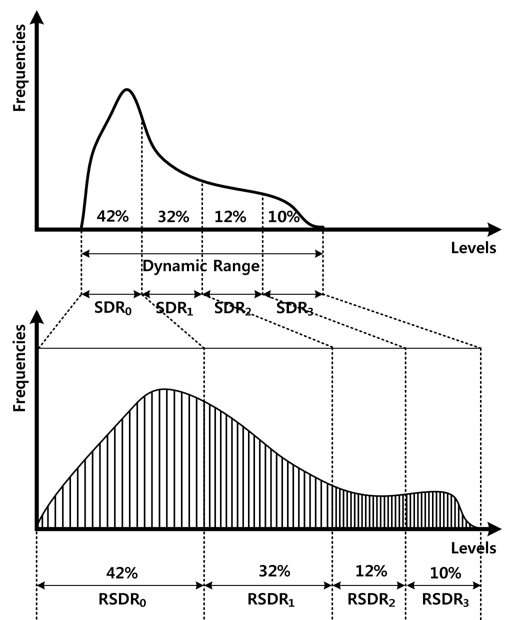


Fig. 3. The redistribution of separated dynamic range and piecewise dynamic range histogram adjustment (*k*=4)

B. Local contrast and detail enhancement

In this stage, the main issues are the suppression of halo artifact that caused by luminance change in decomposed base layer and the enhancement of the local contrast and details. To determine the Detail Enhancement Volume (DEV) of local contrast and detail, the information of the overall enhanced base layer and original decomposed layers are required as (8)

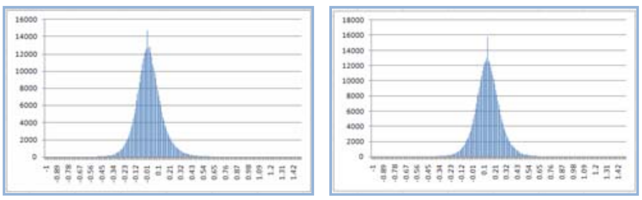
$$DEV(x,y) = \left| I_{detail}(x,y) - I_{mean}(x,y) \right| \times \frac{I'_{base}(x,y)}{I_{base}(x,y)} \quad (8)$$

where $I_{detail}(x,y) = 10^{L_{detail}(x,y)}$ is an exponential function of $L_{detail}(x, y)$, $I_{mean}(x, y)$ is a mean value of $I_{detail}(x, y)$ and its surround pixels, and $I'_{base}(x, y)$ and $I_{base}(x, y)$ is the exponential function of $L'_{base}(x, y)$ and $L_{base}(x, y)$ respectively. The absolute difference of $I_{detail}(x, y)$ and $I_{mean}(x, y)$ represents edge information of original image. The quotient of $I'_{base}(x, y)$ and $I'_{base}(x, y)$ denotes the luminance change.

And then, DEV is added to enhance local contrast and detail of the detail layer as follows:

$$L'_{detail}(x,y) = L_{detail}(x,y) + \alpha DEV(x,y) \quad (9)$$

where $L'_{detail}(x, y)$ is enhanced detail layer, α is scale factor that has the value between 0 and 0.4. Fig. 4 (a) and 4 (b) show the difference of original detail layer histogram and enhanced detail layer histogram with EV.



(a) (b)

Fig. 4. Original detail layer histogram and EV added detail layer histogram

To reintroduce the details, we apply the base layer compression [1] and decompose the decompressed base layer and local contrast enhanced detail layer

$$L'(x,y) = D\big(L'base(x,y)\big) + L'_{detail}(x,y) \quad (10)$$

where $L'(x, y)$ is reintroduced luminance image and $D(\,)$ is the base layer decompression.

In order to maintain the brightness of the reintroduced image, the output image is the colored up as (11)

$$R_{out} = \left(\frac{R_w}{L_w}\right)^{\lambda} L_{out}, \quad G_{out} = \left(\frac{G_w}{L_w}\right)^{\lambda} L_{out}, \text{ and} \quad G_{out} = \left(\frac{G_w}{L_w}\right)^{\lambda} L_{out} \quad (11)$$

where L_{out} is a normalized value of L' and set to [0, 1], L_w is the input luminance value, and λ is the color saturation factor which is usually set between 0.4 and 0.6 [3].

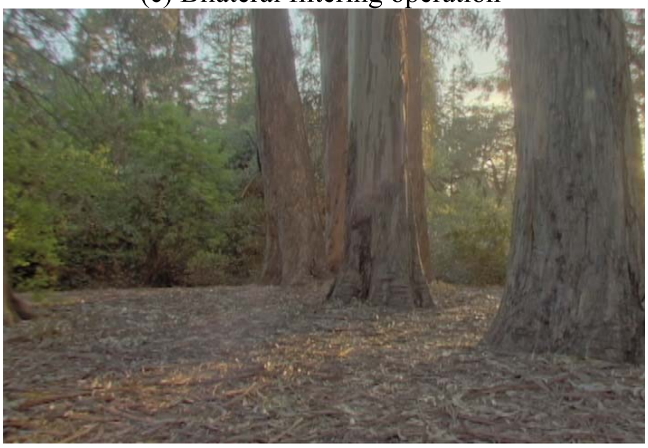
3. Experimental results

We present the experimental results of the proposed algorithm compared with the conventional methods [1][2]. The source image for experiment is a *groveC* that has a dynamic range of 131,131 : 1 (L_{max} : 878.58, L_{min} : 0.0067). Fig. 5 (d) shows a result image that is processed by proposed method. When comparing the results of histogram adjust [2] and bilateral filtering operation [1], as shown in Fig. 5 (b) and Fig. 5 (c), the proposed method preserves more overall impression with the naturalness and enhances the local contrast and detail in both the shadow and highlight region of original image while conventional ones have the significant luminance change and the other introduce the halo artifact.

(a) Original HDR image at different exposure time (Image courtesy of Paul Debevec)

(b) Histogram adjustment

(c) Bilateral filtering operation



(d) Proposed method (k=4, α=0.3)

Fig. 5. Image of experimental results

4. Conclusion

In this paper, tone mapping method by local contrast and detail enhancement for high dynamic range images is proposed. PDRHA in base layer enhances the overall dim and bright impression. And EDV enhances the local contrast in detail layer. The experimental results showed that the proposed method preserved the overall impression with the naturalness and enhanced the local contrast and detail. It might be suitable to be applied for LDR display devices, FPD (Flat Panel Display) system such as LCD, PDP TV and so on.

5. References

This work was supported by BK21.

6. References

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