Logarithmic Tone Mapping for High Dynamic Range Imaging

Joohyun Lee, Gwanggil Jeon, and Jechang Jeong

Department of Electronics and Computer Engineering
Hanyang University
Seoul, Korea
E-mail: {saint81, windcap315, jjeong}@ece.hanyang.ac.kr

ABSTRACT

High dynamic range image can describe the real world scenes that have a wide range of luminance intensity. To display high dynamic range (HDR) image into conventional displayable devices such as monitors and printers, we proposed the logarithmic based global mapping algorithm that consider the features of image using mapping parameters. Based on characteristics of image, we first modify input luminance values for reproducing perceptually tuned images and then displayable output values are obtained directly. The experimental results show that the proposed algorithm achieves good subjective results while preserving details of image, furthermore proposed algorithm has fast simple and practical structure for implementation.

Keywords: high dynamic range imaging, tone mapping, tone reproduction

1. INTRODUCTION

High dynamic range (HDR) imaging is an attractive technique to mimic the capabilities of the human eye, which can capture real world luminance in the scene for each pixel. Moreover, we can record more than the eyes can see using HDR technique. Example applications for HDR imaging are scientific and medical visualization, satellite imagery, physically-based rendering, and digital cinema. However, compared with the range of real world luminance that ranges from 10^8:1, from bright sunlight to starlight as shown in Fig. 1, display devices such as plasma/CRT/LCD displays, and projectors have the low dynamic range (LDR) from 10^2:1 candela per meter squared (cd/m^2) [1].

To display an HDR image to within a displayable range, we should adjust an image in dynamic range to below two orders of magnitude. The discrepancy between the wide ranges of luminance that can be captured and the small ranges that can be reproduced by existing displays makes the accurate display of the images of the captured scene. Due to these limitations, we need proper tone mapping or tone reproduction techniques to transform HDR images into display devices that have LDR while preserving details depending on the characteristics of the original HDR image.

In previous works, tone reproduction techniques have been developed focused on compression and quality evaluation of HDR image for visualizing high dynamic range images. Tone reproduction can be classified as global operator (spatially uniform) [2] that the same mapping function is applied in all regions or local operator (spatially varying) [3] that different tone reproduction functions are applied depending on neighboring pixels of current pixel through the modeling of spatial adaptation.

The former tone reproduction technique, global operator, consists of monotonic tone mapping function to match HDR values to LDR values. By using realistic image theory, a tone global operator transferred HDR luminance to displayable luminance range in [4]. After that, Drago et al. [5] suggested adaptive operator with logarithmic mapping for displaying high contrast scenes. Although, these global mapping algorithms are simple to transform pixels into LDR values, these algorithms cannot preserve local edge contrasts in images well. In most cases, we want to emphasize and preserve all local contrasts for displaying LDR clearly without producing perceivable artifacts. Ward et al. described a more sophisticated approach to globally adjust contrast with respect to luminance histogram [6]. Nevertheless, image details are lost in the bright and dark regions while adjusting the contrast of an image.

The latter tone reproduction technique, local operator technique, uses spatial modeling function using neighboring pixels based on the retinex theory [7]. Operation functions are taken by the average luminance value of local neighboring pixels of the transformed pixel value in each pixel. In these kinds of algorithms, however, it is difficult to determine the size of the local neighborhood area correctly and computationally expensive to transform pixels. Moreover, it is easy to cause various artifacts such as halos depend on methods to be used. Most authors are interested in computational efficiency, ignoring characteristics of human visual system (HVS).

This paper is organized as follows. Section 2 provides basic concept of HDR and tone mapping. In Section 3, we present the proposed tone mapping method, which can reproduce HDR image into LDR image. Several experimental results prove the performance of proposed method in Section 4. Finally, we conclude our paper with an overall discussion in Section 5.

2. RELATED WORK

For HDR file format, there is more than bit depth to defining the difference between HDR and LDR images. A 24-bit RGB image is usually defined as an output-referred coordinate, because output colors are associated with specific target device. In contrast, most HDR images are a scene-referred coordinate, because their pixels have a dire relation to radiance in a scene. From a scene-referred HDR image, the run-length encoded input values are converted to floating point numbers of linear RGB value. Then, RGB values are converted to CIE XYZ color space, standard matrix such as that specified by ITU-R BT.709 [8] given by

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \tag{1}$$

First, we should find a minimum value and a maximum value of the pixels in image using Y components in the XYZ format that equal to luminance. A representation of luminance is obtained by computing a linear combination of the red, green, and blue components according to the second row of (1) as follows:

$$Y = 0.2126 \times R + 0.7152 \times G + 0.0722 \times B. \tag{2}$$

Based on the luminance values that we get from (2), we extract the characteristic of an image and reproduce the image to fit into displayable range using the parameters from the characteristic of an image.

The displayable luminance range of an image for a conventional device is almost two orders (10^2) of magnitude as shown in Fig. 1, which each pixel consists of the red, green, and blue components. Therefore, it is not possible to directly display images into conventional display devices with a much higher dynamic range. Moreover, for display to exhibit realism, the images should be faithful visual representations of the scenes when images are reproduced from HDR to LDR. For example, Fig. 2(a) and Fig. 2(b) show the LDR images using linear scaling operator and using tone reproduction operator, respectively. Such simple scaling without tone reproduction operator generates images with complete loss of the detail and contrast in the resulting display as shown in Fig. 2(c) compared with Fig. 2(d). Hence, simple scaling or compression of the luminance range and the contrast range is not sufficient to reproduce the proper visual appearance of the scene.

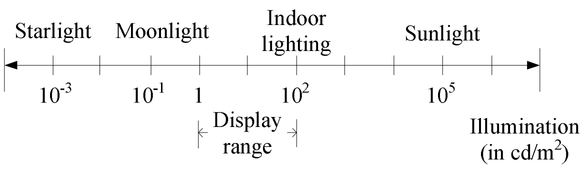

Fig. 1: The luminance ranges of some real world scenes.

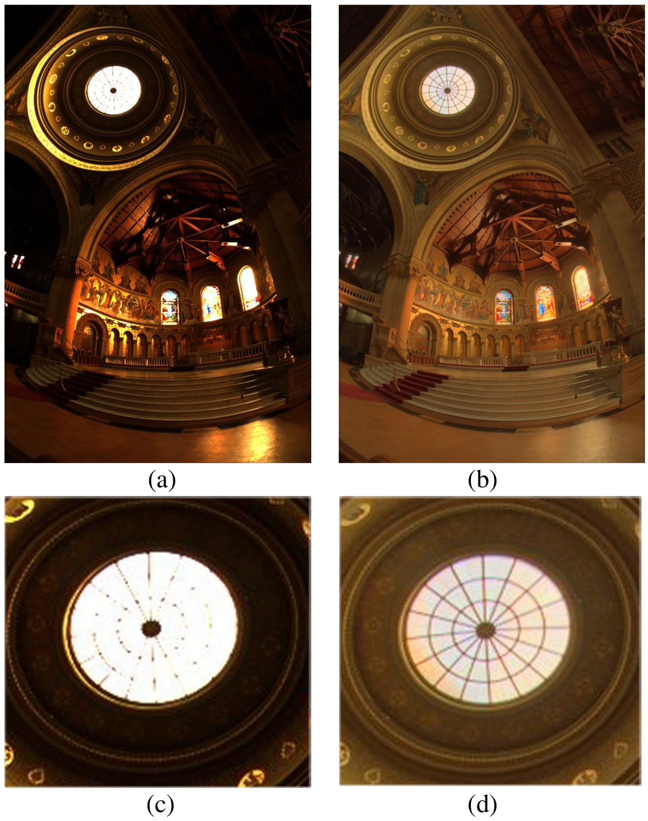

Fig. 2: Result comparison between linear scaling and tone reproduction: (a) image using linear scaling; (b) image using tone reproduction; (c) detailed part of using linear scaling; (d) detailed part of using tone reproduction.

3. PROPOSED METHOD

The real world luminance that HVS can recognize is impressively wide, high dynamic range, from the scotopic threshold to the glare limit. Experimental model of perceiving the luminance value shows that HVS cannot operate over impressive dynamic range simultaneously. Moreover, subjective brightness is a logarithmic function of light intensity on HVS. So, based on logarithmic mapping function,

The key values of a scene can be estimated from a histogram. Based on the minimum and maximum luminance values, we can empirically get the log average luminance value that correlates to the peak found in histogram is calculated as

$$L_{av} = \frac{1}{N} \sum_{x,y} \log\left(\delta + L_w(x,y)\right). \tag{3}$$

where $L_w(x,y)$ is the input luminance value and δ is small constant value to avoid log function error when $L_w(x,y)$ equals 0.

The key value a can be estimated using the following equations:

$$f = \frac{(L_{av} - \log_2 L_{\min}) + (L_{av} - \log_2 L_{\max})}{\log_2 L_{\max} - \log_2 L_{\min}} \tag{4}$$
$$a = 2^f .$$

In eq. (4), f represents the distance difference between minimum luminance (L_{min}) and maximum luminance (L_{max}) relative to the log average luminance (L_{av}) in image. To make a value positive, a value is two to the power of f.

For the proposed method, first step is to adjust the input luminance information according to the key value of image that we estimate in eq. (4), as follows.

$$L'_w(x, y) = aL_w(x, y) . \tag{5}$$

To apply output values from (5) to RGB values, we consider the HVS characteristic for improving quality of an image. The HVS has a complex mechanism with some features that have to be considered when preparing an image for display. Most tone reproduction techniques focus on reducing dynamic range of an image while keeping the HVS's response to the reduced set of intensities constant. There are various approaches that aim at preserving brightness, contrast, and appearance according to luminance information. Most operators derive a luminance component from input RGB values and then reduce the luminance range, which exclude a comprehensive modeling of the color components. In this point of view, to consider color appearance of a scene, compressing the luminance component is executed with color components together as follows.

$$\begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} = \begin{bmatrix} L_d \left(\frac{R_w}{L_w} \right)^s \\ L_d \left(\frac{G_w}{L_w} \right)^s \\ L_d \left(\frac{B_w}{L_w} \right)^s \end{bmatrix} . \tag{6}$$

In eq. (6), the factor s is given as a user parameter that takes values from 0 to 1. In experiments, we set s as 0.45. We can obtain displayable output values (R_d, G_d, B_d) where L_d and R_w, G_w, B_w mean mapped value from eq. (5) and original floating point R, G, B values, respectively. L_d denotes linear scaled value from L'_w and L_w denotes input luminance value. From eq. (6), we finally obtain mapped LDR image.

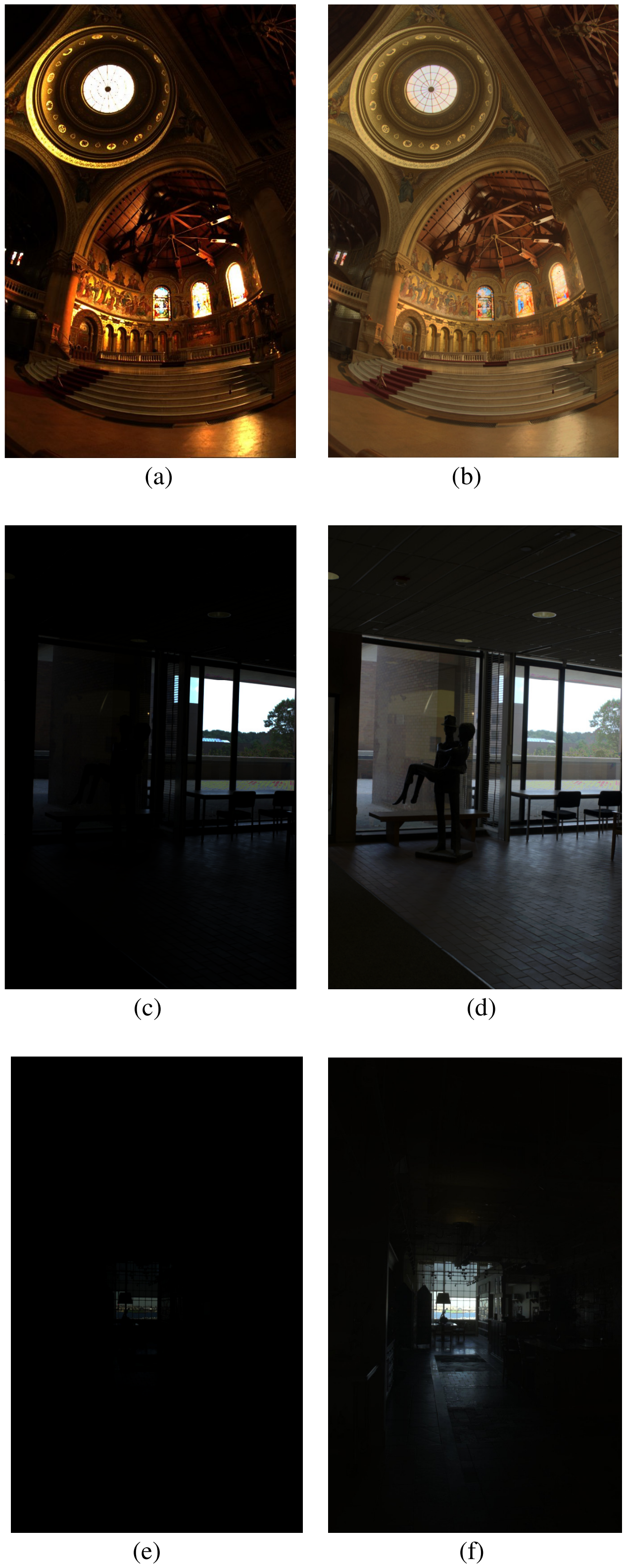

Fig. 3: Tone mapped images: (a), (c), and (e) show the result images of linear mapping. (b), (d), and (f) show the result images of proposed mapping.

4. EXPERIMENTAL RESULTS

All experiments were carried out with Microsoft Windows XP on a 2.4 GHz Intel Pentium IV processor with 1 GB RAM memory. In our tone reproduction method, the HDR format, which is originally known as the Radiance picture format (.hdr, .pic), was used and computation time increases according to size of an image.

Fig. 3 shows subjective comparisons of proposed tone mapping algorithm for the different sizes and scenes. The proposed tone mapping algorithm achieves good subjective quality compared with linear tone mapping. Fig. 3(a), (c), and (e) show the result images mapped by linear mapping algorithm with memorial church, couple, and design center images, respectively. Fig. 3(b), (d), and (f) show the result images of proposed method with memorial church, couple, and design center images, respectively.

The experimental results describe that the proposed algorithm reproduces image from HDR to LDR while preserving detail parts of image. Furthermore, proposed algorithm has fast simple and practical structure for implementation. The Propose method can be used for practical application because of these features.

5. CONCLUSIONS

High dynamic range image is an emerging technique which can describe the real world scenes that have a wide range of luminance intensity. To display high dynamic range image into conventional displayable devices which have LDR such as monitors and printers, we have to reproduce HDR image into LDR image. Based on characteristics of image, the proposed tone mapping algorithm reproduces reasonable images while considering features of image using mapping parameters. The experimental results show that the proposed algorithm achieves good subjective results and proposed algorithm has fast simple and practical structure for implementation.

Acknowledgments

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2004-005-D00164)

REFERENCES

[1] K. Devlin, “A review of tone reproduction techniques,” Technical Report CSTR-02-005, Computer Science, University of Bristol, 2002.

[2] T. Mitsunaga and S. K. Nayar, “High dynamic range imaging: spatially varying pixel exposures,” in *Proc. of IEEE Conf. on Computer Vision and Pattern Recognition*, vol. 1, pp. 472-479, 2000.

[3] P. Choudhury and J. Tumblin, “The trilateral filter for high contrast images and meshes,” in *Proc. of the Eurographics Symposium on Rendering*, pp. 186-196, 2003.

[4] J. Tumblin and H. Rushmeier, “Tone reproduction for realistic images,” *IEEE Computer Graphics and Applications,* vol. 13, pp. 42-48, 1993.

[5] F. Drago, K. Myszkowski, T. Annen, and N. Chiba, “Adaptive logarithmic mapping for displaying high contrast scenes,” *The Journal of Computer Graphics Forum*, vol. 22, no. 3, pp. 419-426, 2003.

[6] G. Ward, H. Rushmeier, and C. Piatko, “A visibility matching tone reproduction operator for high dynamic range scenes,” *IEEE Trans. Visualization and Computer Graphics*, vol. 3, no. 4, pp. 291-306, 1997.

[7] K. Chiu, M. Herf, P. Shirley, S. Swamy, C. Wang, and K. Zimmerman, “Spatially nonuniform scaling functions for high contrast images,” in *Proc. of graphics Interface*, pp. 245-253, 1993.

[8] ITU-R Recommendation BT.709, Basic parameter values for the HDTV standard for the studio and for international program exchange, Technical Report BT.709, ITU, 1990.