Tone Mapping for HDR Images with Dimidiate Luminance and Spatial Distributions of Bright and Dark Regions

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ABSTRACT

This paper proposes a novel tone mapping method in consideration of characteristics of human visual perception for a high dynamic range (HDR) image with dimidiated luminance and spatial distributions of bright and dark regions. In order to represent an HDR image with a low dynamic range (LDR) display, it is necessary to appropriately compress a dynamic range of HDR image by a tone mapping. There are some HDR images which cannot be re-represented with an LDR display precisely by applying a conventional tone mapping method. In this study, we focus on an HDR image with dimidiated luminance and spatial distributions of bright and dark regions as a target image. We assume that human visual perception does not feel a sense of discomfort even if a magnitude relationship between luminance values of pixels near the boundary between bright and dark regions is reversed when these regions are definitely divided according to dimidiated luminance and spatial distributions. Under this assumption, we divide an HDR image into bright and dark regions and apply a different tone mapping function to each region independently. In experiments, we show that the proposed tone mapping method produces the image represented by using a dynamic range effectively. In addition, we confirm that the proposed tone mapping method is useful through subjective evaluation and discuss the features of the HDR images suitable for the proposed method.

Keywords: tone mapping, high dynamic range, HDR, segmentation

1. INTRODUCTION

High dynamic range (HDR) image has attracted much attention to capture and represent the real scenes precisely. In general, an HDR image is produced by the method[1,2] which combines multiple images captured with different exposure settings into a single HDR image. Each pixel of an HDR image has gradation value more than 8-bit like a normal low dynamic range (LDR) image. In order to display an HDR image on a standard LDR display which can represent gradation value of 8-bit, it is necessary to appropriately compress a dynamic range of the HDR image by using tone mapping.

A lot of related works of tone mapping have been proposed. Reinhard et al.[3] have proposed a tone mapping method which applies the traditional techniques of photographic practice, such as the Zone System and dodging-and-burning. Fattal et al.[4] have focused on the change of gradients and have developed the tone mapping method which can represent detailed textures of the HDR image by compressing the higher contrast parts more than the lower contrast parts. However, these methods implicitly have the restriction to keep a magnitude relationship between luminance values of pixels in the image, and thus a dynamic range is limited in a generated LDR image. It is difficult for the method of Reinhard[3] to represent the enough textures of bright and dark regions in an HDR image, and the method of Fattal[4] has the problem that the resulting image looks like a painting containing a gradation which does not exist in original image.

In order to overcome these problems, Yee et al.,[5] Chen et al.[6] and Krawczyk et al.[7] have proposed tone mapping methods based on local adaptation mechanism in human visual perception. They divide an HDR image into regions based on luminance distributions and then apply tone mapping according to the computed local adaptation luminance. Since a magnitude relationship between luminance values of non-adjacent pixels is allowed to be reversed, a dynamic range can be used more effectively than other conventional methods. However, in order to avoid uncomfortable feelings to the resulting image, it is necessary to keep a magnitude relationship between luminance values of adjacent pixels. In other words, since the amount of change of luminance values between adjacent pixels is limited successively over the whole image so that a

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Figure 1. An example of image with dimidiate luminance and spatial distributions of bright and dark regions.

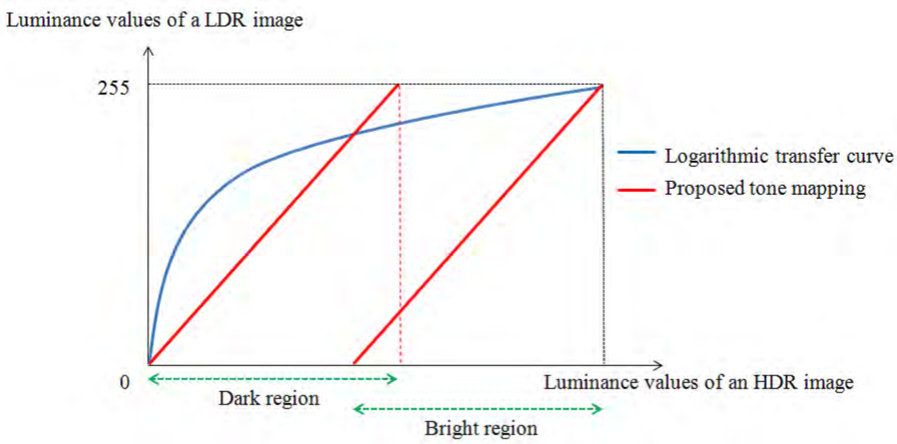

Figure 2. Tone mapping curves.

dynamic range of each region used for representation is limited, there are some HDR images which cannot represent the real scene precisely.

In this paper, we propose a tone mapping method for HDR images with dimidiate luminance and spatial distributions of bright and dark regions; for example, images captured in a scene where both outdoor and indoor regions are included. Figure 1 is such an example of HDR images with dimidiate luminance and spatial distributions of bright and dark regions. Under the condition like the scene of Figure 1, we assume that human visual perception does not feel a sense of discomfort even if the magnitude relationship between luminance values of pixels near the boundary of bright and dark regions is reversed. Under this assumption, the proposed method divides an HDR image into bright and dark regions and applies a different tone mapping method to each region independently. Figure 2 illustrates tone mapping curves which represent the relationships between luminance value of HDR image and that of LDR image. In this study, by restricting the target images, the magnitude relationship between luminance values of pixels is allowed to be reversed so that a dynamic range of each region is able to be utilized effectively.

2. TONE MAPPING APPLIED TO DIMIDIATE BRIGHT AND DARK REGIONS INDEPENDENTLY

2.1 Outline of proposed tone mapping method

Our method focuses on an HDR image with dimidiate luminance and spatial distributions of bright and dark regions and aims to produce an image which uses a dynamic range of each region effectively by applying a different tone mapping to each region independently. The proposed method consists of the following two processes.

1. Segmentation of HDR image into bright and dark regions.
2. Conversion of luminance values in bright and dark regions.

2.2 Segmentation of HDR image into bright and dark regions

In the first step, it is necessary to apply the method which divides an image into regions interactively and in consideration of the boundaries of regions, because the HDR image should be segmented based on the spatial regions which human visual perception recognizes. According to this requirement, GrabCut algorithm,[8] which is one of the interactive and robust segmentation methods in manipulation of boundaries, is employed in this study. In the first step of GrabCut,[8] segmentation using iterative graph cut is performed. This is followed by border matting in which alpha values are computed in a narrow part around the segmentation boundary. Full transparency, other than at the border, is not dealt with by GrabCut.[8] This method requires the user simple interactions and the user can indicate target regions easily. In addition, computation of alpha values used for border matting reduces visible artifacts. Figure 3 shows an example of segmentation with GrabCut[8] for the input image as shown in Figure 1.

2.3 Conversion of luminance values in bright and dark regions

In the next step, tone mapping is applied to divided bright and dark regions in the HDR image independently. Our method does not limit the tone mapping method applied to each region. In addition, if either bright or dark region consists of some small regions, the region is divided into small regions additionally and tone mapping is applied to further segmented regions independently. As a tone mapping method applied to each region in our implementation, we have employed the method of Reinhard,[3] which is one of the representative tone mapping methods and designed for wide variety of images. Figure 4 shows a resulting image by the proposed method employing the tone mapping method of Reinhard.[3]

2.3.1 Tone mapping method of Reinhard

This section briefly reviews the tone mapping method of Reinhard,[3] which scales luminance values of input HDR images according to the criterion value which is computed from a dynamic range of HDR image to be luminance value of middle part of the dynamic range in the resulting image. In addition, it works to decrease luminance values of bright regions and to increase luminance values of dark regions locally. We first show how to compute the criterion value to be the luminance value of middle part of the dynamic range in the resulting image. Like a lot of related works of tone reproduction,[9–11] we view the log-average luminance value as a useful approximation to the criterion value in the scene. This log-average luminance value $\bar{L}_w$ is computed by

$$\bar{L}_w = \frac{1}{N} \exp\left(\sum_{x,y} \log\left(\delta + L_w(x,y)\right) \right), \tag{1}$$

where $L_w(x,y)$ is the input luminance value for pixel (x,y), N is the total number of pixels in the image and δ is a small value to avoid the singularity that occurs if black pixels exist in the image. The whole image is scaled by $\bar{L}_w$ as follows:

$$L(x,y) = \frac{a}{\bar{L}_w} L_w(x,y), \tag{2}$$

where $L(x,y)$ is a scaled luminance value and a is a parameter. Parameter a has influence to the image after applying the above scaling. Besides, according to the fact that modern photography prefers applying transfer curves which mainly compress the high luminance values, the effect that high luminance values are compressed strongly is added to the Equation (2):

$$L_d(x,y) = \frac{L(x,y)}{1 + L(x,y)}, \tag{3}$$

where $L_d(x,y)$ is the luminance value after scaling. In Equation (3), high luminance values are scaled by approximately $1/L$, while low luminance values are scaled by 1. The denominator causes a graceful blend between these two scalings. This formulation is guaranteed to bring all luminance values within displayable range. However, Equation (3) is not always

Figure 3. An example of segmenting Figure 1 by GrabCut.[8]

Figure 4. Tone-mapped image generated from Figure 1 by the proposed method.

desirable in compressing high luminance values. Equation (3) can be extended to allow high luminance values to burn out in a controllable fashion by using the following equation.

$$L_d(x,y) = \frac{L(x,y)(1 + \frac{L(x,y)}{L_{white}^2})}{1 + L(x,y)}, \tag{4}$$

where L_{white} represents the smallest luminance value that is mapped to pure white. This function is a blend between Equation (3) and a standard linear mapping. If L_{white} value is set to the maximum luminance value in the scene or higher, no burn-out occurs. If it is set to infinity, then the function reverts to Equation (3). By default, we set L_{white} to the maximum luminance value in the scene.

Reinhard's[3] tone mapping method described here is originally applied to the whole image. It should be noted that in this study the log-average luminance value $\bar{L}_w$ and parameter a of each region are computed and set respectively.

3. EXPERIMENTS

3.1 Acquisition of HDR images

In experiments, we have used two kinds of HDR images as input images. One is the HDR image produced by combining multiple images captured with different exposure settings. The other is the set of benchmark HDR images.[12,13] The former is generated by combining multiple images using a high dynamic range image editing software[14] after a series of pictures with different exposure settings were taken by using the auto bracket function of the digital single-lens reflex camera(K-7, PENTAX). The latter is selected from HDR images shown in the work[12] and the website.[13]

3.2 Results of the proposed tone mapping method

In this section, we show the results of applying the proposed method to a number of HDR images and compare them with those by Reinhard's[3] and Fattal's[4] methods. Figure 5 shows the tone mapping results of three methods for HDR images generated by combining multiple images captured with different exposure settings. Figures 6 and 7 are the tone mapping results for benchmark HDR images. Generally, images generated by the method of Reinhard[3] contain regions where highlights and shadows appear since a dynamic range to represent each region run short. For example, in Figure 5(a), the indoor region has a high percentage of pixels of low luminance values. In Figure 6(a), the outdoor region mainly consists of pixels of high luminance values, so that it is difficult to recognize textures of each region.

The images generated by the method of Fattal[4] clearly represent bright and dark regions by using dynamic ranges effectively and the textures can be recognized. However, due to the nature of this method that maintains the magnitude relationship between luminance values of adjacent pixels, luminance values drastically change near the boundary of bright and dark regions. It can be observed that artifacts like gradation, which does not exist in the original image, appears near the window frame parts of Figures 5(b) and 6(b).

Compared with these two conventional methods, the images generated by the proposed method, as shown in Figures 5(c) and 6(c), are represented by effectively utilizing dynamic ranges of bright and dark regions. This is due to the tone mapping applied to each of bright and dark regions independently. The artifacts of gradation caused by the method of Fattal[4] are not generated by applying the tone mapping to each region independently. In additon, the stained grass parts in Figure 7(c) generated by the proposed method have precisely represented textures in contrast with the results of other conventional methods. From these results, we can confirm that human visual perception does not feel a sense of discomfort even if the magnitude relationship between luminance values in different regions is reversed. In the next section, we first show the results of subjective evaluation, in which we compare the proposed method with the methods of Reinhard[3] and Fattal.[4] We then discuss the features of images suitable for the proposed method.

3.3 Subjective evaluation

3.3.1 Preparation

In order to confirm the usefulness of the proposed method and investigate the features of HDR images which are suitable for the proposed method, we have conducted an experiment of subjective evaluation for tone mapped images generated by three tone mapping methods from 25 HDR images. These images consist of HDR images generated by combining a series of pictures with different exposure settings and benchmark HDR images, and we have used the resulting images generated by the methods of Reinhard,[3] Fattal[4] and the proposed method. Taking the task of tone mapping into account, such as how textures can be recognized and the presence or absence of uncomfortable feelings caused by artifacts, we have viewed overall degrees of satisfaction of 11 examinees in 5 levels; 5 is the best and 1 is the worst.

3.3.2 Results

The results of subjective evaluation are given in Figures 8, 9 and 10 in descending order of satisfaction of the proposed method. We can qualitatively summarize the results as follows. In Figures 8, 9 and 10, the average degrees of satisfaction for resulting images generated by the proposed method are totally higher than Reinhard.[3] In Figures 9(c) and 10(d), results of the proposed method are equivalent to, or lower than results of Reinhard.[3] The average degrees of satisfaction for Figures 8(a) to (d) and 9(c) generated by the proposed method are totally higher than Fattal.[4] In Figures 9(a), (b) and (d), results of the proposed method are almost equivalent to the results of Fattal.[4] Scores of the proposed method in Figures 10(a) to (d) are lower than Fattal.[4]

3.3.3 Discussion

From the observation that the average degrees of satisfaction for resulting images generated by the proposed method are totally higher than the results by the method of Reinhard[3] in Figures 8, 9 and 10, we can confirm that the framework of applying the tone mapping to each segmented region independently is effective. As the reason why there are images whose degrees of satisfaction are equivalent to or lower than the results of Reinhard,[3] we can conclude that distribution of luminance values in bright and dark region is not one-sided so that utilized dynamic ranges are not expanded enough even if applying the tone mapping to each region. Besides, reversing the magnitude relationship of luminance values near the boundary of regions as appeared in Figure 10(d) possibly makes human visual perception feel a sense of discomfort.

In comparison with the results of Fattal,[4] the reason why the degrees of satisfaction of the proposed method are equal to or lower in Figures 9(a), (b), (d) and 10(b) is because more textures of bright and dark regions can be visually recognized in the resulting images generated by Fattal.[4] The reason why the degrees of satisfaction for the results of the proposed method are higher in Figures 8(a) to (d) is due to artifacts which make human visual perception feel a sense of discomfort significantly. This implies that when HDR image, which is divided into bright and dark regions based on luminance and spatial distributions clearly, is applied the tone mapping, the method of Fattal[4] causes artifacts to make human visual perception feel a sense of discomfort in the resulting image, while the proposed method can produce a more appropriate image.

According to the results and discussion on the subjective evaluation, we can categorize images in Figures 8 as the images suitable for the proposed method, while the images in Figures 9 as the images whose results by the proposed method are equivalent to the results of Fattal,[4] and the images in Figures 10 as the images unsuitable for the proposed method. The degrees of satisfaction for images which we supposed to be suitable or unsuitable for the proposed method before conducting subjective evaluation are almost the same as we expected. However, the degrees of satisfaction of the proposed method for Figures 9(b) and (d), which were supposed to be suitable in advance, are found to be comparatively lower and that for Figures 8(c) and (d), which were supposed to be unsuitable, are actually higher than we supposed. As mentioned above, this is possibly due to the effects of highlights and shadows and sense of discomfort which may be different person by person. Therefore, it is necessary to improve the usefulness of the proposed method by examining the features of images classified through this experiment of subjective evaluation and defining the criteria for deciding what kinds of images are suitable for the proposed method.

4. CONCLUSION

In this paper, we have proposed a tone mapping method for HDR images with dimidiate luminance and spatial distributions of bright and dark regions. In this study, when bright and dark regions are definitely divided according to dimidiate luminance and spatial distributions, we have assumed that human visual perception does not feel a sense of discomfort even if the magnitude relationship between luminance values of pixels between bright and dark regions is reversed. Based on the assumption, we have applied a tone mapping method to each segmented region independently and we also have shown the experimental results which are appropriately represented by utilizing dynamic range effectively. In subjective evaluation, from the observation that the degrees of satisfaction for the resulting images generated by the proposed method are totally higher than those by Reinhard,[3] we have confirmed that the idea of applying the tone mapping to bright and dark regions independently is useful to most of HDR images. In addition, since there are some images whose degree of satisfaction are higher than Fattal,[4] the proposed method is able to produce better images than other related work for some type of HDR images that are suitable for the proposed method. For images which was supposed to be suitable for the proposed tone mapping method, the results are almost the same as we expected before experiments, but there are found some exceptions. In future work, we will investigate the criteria for deciding whether a given image is suitable for the proposed method and develop a way to classify images by examining the features of images classified in our experiments.

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(a) Reinhard[3] (b) Fattal[4] (c) Proposed Method

Figure 5. Results of tone mapping with the image supposed to be suitable for the proposed method : lab.

(a) Reinhard[3] (b) Fattal[4] (c) Proposed Method

Figure 6. Results of tone mapping with the image supposed to be suitable for the proposed method: room.[12]

(a) Reinhard[3] (b) Fattal[4] (c) Proposed Method

Figure 7. Results of tone mapping with the image supposed to be suitable for the proposed method: memorial.[12]

(a) No.1

(b) No.2

(c) No.3

(d) No.4

Figure 8. The degrees of satisfaction in subjective evaluation with HDR images suitable for the proposed method.

(a) No.5

(b) No.6

(c) No.7

(d) No.8

Figure 9. The degrees of satisfaction in subjective evaluation with HDR images suitable or unsuitable for the proposed method.

Reinhard Fattal Proposed

(a) No.9

Reinhard Fattal Proposed

(b) No.10

Reinhard Fattal Proposed

(c) No.11

Reinhard Fattal Proposed

(d) No.12

Figure 10. The degrees of satisfaction in subjective evaluation with HDR images unsuitable for the proposed method.

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