Lighting Condition Adaptive Tone Mapping Method

Jiangyan Han
Northwestern Polytechnical University
Xi'an, China
hanjiangyan@mail.nwpu.edu.cn

Ishtiaq Rasool Khan
University of Jeddah
Saudi Arabia
irkhan@uj.edu.sa

Susanto Rahardja
Northwestern Polytechnical University
Xi'an, China
susanto@nwpu.edu.cn

ABSTRACT

We propose an adaptive tone mapping method for displaying HDR images according to ambient light conditions. To compensate the loss of perceived luminance in brighter viewing conditions, we enhance the HDR image by an algorithm based on the Naka-Rushton model. Changes of the HVS response under different adaptation levels are considered and we match the response under the ambient conditions with the plateau response to the original HDR scene. The enhanced HDR image is tone mapped through a tone mapping curve constructed by the original image luminance histogram to produce visually pleasing images under given viewing conditions.

CCS CONCEPTS

• **Computing methodologies → Image manipulation**; *Image processing*;

KEYWORDS

adaptive tone mapping, lighting condition, human visual system, luminance compensation

ACM Reference Format:

Jiangyan Han, Ishtiaq Rasool Khan, and Susanto Rahardja. 2018. Lighting Condition Adaptive Tone Mapping Method. In *Proceedings of SIGGRAPH '18 Posters.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3230744.3230773

1 INTRODUCTION

Perceived luminance of a displayed image can vary significantly under different lighting conditions due to the light adaptation mechanism of human visual system (HVS). Generally, increasing the surrounding light reduces the perceived luminance. Therefore, to improve the visual quality of displayed images under different intensities of surrounding light, images need to be pre-processed before displaying.

Various techniques have been suggested to solve this problem, but most of them deal with low dynamic range (LDR) images. Compared with LDR images, high dynamic range (HDR) images contain more details, which can be used to have better visualizing experience under different lighting conditions. Most of the existing tone-mapping operators don't consider ambient light adaptation in their algorithms. [Mantiuk et al. 2008] proposed a display adaptive tone mapping method that minimized perceived contrast distortion due to changes in the display conditions. More recently, Wang et al. proposed an ambient light adaptive tone mapping method to improve brightness [Wang and Jung 2017], but the effect seems to be less significant than Mantiuk's method.

In this work, we propose a method which compensates the luminance of the HDR image to match the viewing conditions according to the Naka-Rushton (N-R) model. This is followed by a histogram based adaptive tone mapping method. Result images and a user study shows that the proposed technique effectively improves visibility of the displayed images under different lighting conditions.

2 METHOD

The HVS response under the light intensity I can be described by the N-R model [Dowling 1987]:

$$R = R_{max} \frac{I^n}{I^n + \sigma_b^n} \tag{1}$$

where R is the photoreceptor response, R_{max} is the maximum response, n is a sensitivity-control exponent, and σ_b, the semi-saturation constant, is the intensity that causes the half-maximum response. σ_b is a function of adaptation level I_b, described as

$$\sigma_b = I_b^\alpha + \beta \tag{2}$$

where α and β are constants. This model explains that when the surrounding intensity increases or decreases, our eye's response curve shifts to the right or left, respectively. This can be observed in Figure 1, where the blue curve shifts to the red one when the background luminance increases to 10000 lux. This causes a decrease in our eye's response to the same luminance, which is the reason for perceived luminance loss in a bright background.

When viewing real scenes, the HVS can adapt to a large range of luminance levels, allowing us to see both dark and bright regions in the same scene. In this situation, photoreceptors are exposed continuously to different background intensities, thus the momentary response indicated by the response curves gradually returns toward a plateau response, as shown by the black curve in Figure 1. Therefore, for an HDR scene observer, the HVS response is the plateau response under each luminance value itself.

Based on this model, we compensate the input image to match the HVS response under the ambient conditions with the plateau response to the original HDR scene to provide a similar viewing experience. We consider each pixel value $L(x, y)$ independently, and obtain a corresponding semi-saturation point $\sigma_b(x, y)$ and a plateau response from equation (1), represented by

$$R_p(x, y) = \frac{L(x, y)^n}{L(x, y)^n + \sigma_b(x, y)^n}. \tag{3}$$

SIGGRAPH '18 Posters, August 12-16, 2018, Vancouver, BC, Canada

ACM ISBN 978-1-4503-5817-0/18/08.
https://doi.org/10.1145/3230744.3230773

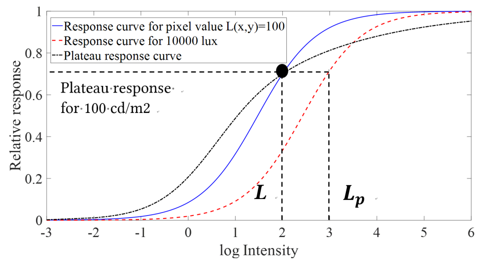

Figure 1: Response curves.

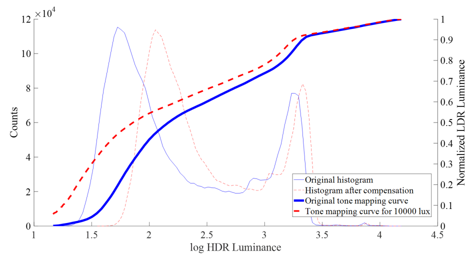

Figure 2: Luminance compensation results.

For a display observer, a global adaptation level is adequate since the eye adaptation level is constant when viewing an image on a display, so we calculate one semi-saturation point σ_{bs} for the viewing condition. The luminance $L_p(x, y)$ that would produce a response value $R_p(x, y)$ under the given ambient light can be calculated by the inverse of the above response function as:

$$L_p(x, y) = \sigma_{bs}\left(\frac{R_p(x, y)}{1 - R_p(x, y)}\right)^{1/n}. \quad (4)$$

For pixel values larger than the given adaptation level, we set $L_p(x, y)$ equal to $L(x, y)$ to avoid negative compensation. Figure1 shows an example of plateau response for $L(x, y)$=100 and its corresponding luminance $L_p(x, y)$ under 10000 lux.

Next, we calculate the compensation rate determined by the difference between $L(x, y)$ and $L_p(x, y)$ in log scale similar to that used in [Kim et al. 2017]. The compensated luminance $L_c(x, y)$ can be calculated as

$$L_c(x, y) = L(x, y) \times (1 + log(L_p(x, y)) - log(L(x, y))). \quad (5)$$

Figure 2 shows histograms of a typical HDR image before and after compensation under 10000 lux, by blue and red curves respectively. We can see that the luminance histogram moves to the right with dark regions compensated by relatively larger factors than bright regions. This is desirable since perceived luminance loss in dark regions is more serious than in bright regions under strong intensity.

It should be noted that if the compensated luminance of an HDR image is tone-mapped by a tone mapping curve constructed based on its compensated histogram, the effect of the above-mentioned shift will be nullified and the produced LDR image will be best viewed under normal lighting conditions. To obtain luminance compensated tone-mapped LDR images, we move the luminance of the HDR image to the right by compensation and use the tone-mapping curve based on the original HDR luminance. The proposed algorithm can be applied with any tone-mapping operator. In this work, we use a recent histogram-based method proposed by [Khan et al. 2018]. Original and adaptive tone mapping curve are shown

Figure 3: Tone mapped images under 1, 500 and 10000 lux (shown in the reading order). Radiance map courtesy of Paul Debevec.

Figure 4: Result images under 10000 lux using the proposed method and Mantiuk's method and zoomed images of the skylight respectively (shown in the reading order).

in Figure 2, by thick blue and red curves respectively. It can be seen that the tone mapping curve adapted for 10000 lux can enhance LDR luminance, especially in dark regions. For higher luminance values, the curve is close to the original, thus image details in bright regions can be well preserved.

3 RESULTS AND DISCUSSION

Figure 3 shows the results of the proposed method under background luminance of 1, 500 and 10000 lux, respectively. It can be seen that luminance of resultant images is significantly increased with increasing ambient light. More result images are included in the supplementary file. The resultant images of our method and [Mantiuk et al. 2008] under 10000 lux are compared in Figure 4. From the zoomed images in Figure 4, we can see that details of the skylight window seem over-exposed in the tone mapped image using [Mantiuk et al. 2008], while they are well preserved in the image generated by the proposed method.

We conducted user studies to evaluate our method and compare it with [Mantiuk et al. 2008]. The results are consistent with those shown in Figure 3 and Figure 4. The proposed method can enhance visibility of displayed images under given lighting conditions and produce better visual effect than those of [Mantiuk et al. 2008].

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