

Luminance adaptation transform based on brightness functions for LDR image reproduction



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ABSTRACT

Tone mapping algorithms are used for image processing to reduce the dynamic range of an image to be displayed on low dynamic range (LDR) devices. The Retinex, which was developed using multi-scale and luminance-based methods, is one of the tone mapping algorithms for dynamic range compression, color constancy and color rendition. Retinex algorithms still have drawbacks, such as lower contrast and desaturation. This paper proposes a multi-scale luminance adaptation transform (MLAT) based on visual brightness functions for the enhancement of contrast and saturation of rendered images. In addition, the proposed algorithm was used to estimate the minimum and maximum luminance and a visual gamma function for local adapted viewing conditions. MLAT showed enhanced contrast and better color representation than the conventional methods in the objective evaluations (CIEDE200 and VCM).

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1. Introduction

A real world luminance range is much larger than those of digital cameras and display devices. The luminance of blue sky in the morning and shadows in an interior room is approximately 4600 cd/m^2 and less than 10 cd/m^2 , respectively. The differences in these luminance levels can be recognized by human vision. On the other hand, there are limited dynamic range problems when real scenes are captured from a digital camera and displayed on television and monitors. Fig. 1 shows the difference in the visual perception and captured image of a real scene. The digital camera needs to adjust its exposure time or shutter speed to capture the scene with a large dynamic range. Such capturing, however, causes saturation in the dark or light areas as well as changes the color appearance of the scenes. To solve these problems, tone mapping or compression methods for high dynamic range (HDR) image processing have been developed. HDR images are generally represented by different exposure images of the same scene [1] but making an HDR image is difficult when the scenes have a variation in the viewing conditions, such as tilting, shifting and moving objects. Therefore, effective methods that represent an HDR image only using a single LDR image have been developed.

Tone mapping algorithms can be divided into two different methods. One is global tone mapping and the other is local tone mapping. Typical global tone mapping algorithms use logarithmic,

power-law and sigmoid functions. Global mapping algorithms are spatially invariant methods that map the input pixel value to a display value. This can be applied easily to the global contrast enhancement of the image [2] but it is less effective for images with strong local contrast areas and details. Saturations are shown in the dark or light areas of images and noises are increased in the dark areas. On the other side, local tone mapping algorithms are spatially variant methods. They consider the relationships between the surround pixels and the input pixel value. Therefore, local tone mapping operators can enhance the local contrast and improve detailed visibility.

Retinex, which is one of the local tone mapping algorithms, was developed by Land [3] as a model of lightness and color perception

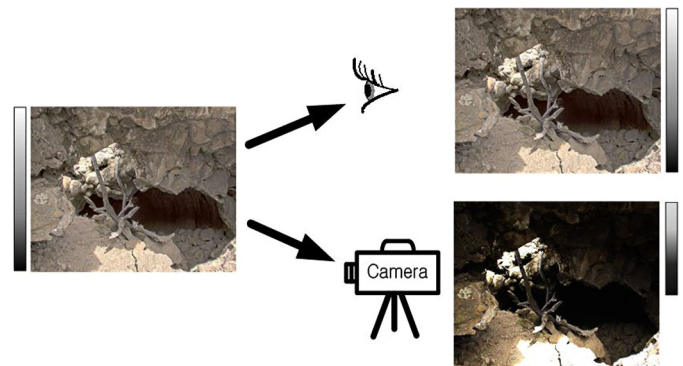


Fig. 1. Visual perception and captured image reproduction for the real scene.

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of human vision. This algorithm improves the brightness, contrast, sharpness and dynamic range compression of an image by compensating for the variations in illumination. The typical algorithm of Retinex is the center/surround method [4]. The center/surround method calculates the difference between each pixel and the weighted average value of its surrounds. Jobson et al. proposed a single-scale Retinex (SSR), multi-scale Retinex (MSR) and multi-scale Retinex with color restoration (MSRCR) [5]. SSR is based on the center/surround algorithm, which is suitable for gray-scale images. MSR was introduced to improve details rendering but it is unsuitable for color images. MSRCR is an enhanced method for correcting undesired color distortions in MSR [4]. On the other hand, MSRCR uses many parameters to compensate for color distortions and it is difficult to select the optimal value. Retinex in RGB space deals with R, G, and B signals separately, which can cause color artifacts like color shifts and desaturation [6]. Therefore, color space that can distinguish the luminance and chrominance components is needed to preserve the hue and saturation of captured images, such as HSV, YUV, PCA and CIELAB. HSV is often used in the computer graphic applications, YUV has been used in digital television and photographic applications [7]. Principal component analysis (PCA) is a statistical technique that reduces the correlation among the RGB channels of the input image [8,9]. CIELAB is an extension of the XYZ tri-stimulus of the human visual response [10]. These color spaces have the orthogonality among components and are more stable than the RGB color space for Retinex processing. The other problems of Retinex include scattered noise in dark areas and desaturation in bright areas due to the excessive enhancement for each area. Sun et al. [8] proposed a luminance-based MSR (LBMSR) for noise reduction but did not solve the desaturation problem in bright areas.

This paper proposes a single-scale luminance adaptation transform (SLAT) to enhance the local contrast and desaturation in bright areas. SLAT has a local tone mapping processing part and a chrominance compensation part. In the local tone mapping processing part, the perceptible minimum and maximum luminance levels and visual gamma values are obtained according to the adaptation luminance level. These values have been formulated from the human visual characteristics. Human vision is adapted to the viewing conditions and is quite sensitive to a change in luminance level [10]. When the luminance changes from dark to bright light, the visual gamma is also changing easily. This variation of human vision can be found in both Stevens' brightness function and Bartleson–Breneman's brightness function [11,12]. The chrominance compensation part is used for the desaturation effect through local tone mapping processing. In addition, this paper proposes a multi-scale luminance adaptation transform (MLAT) to improve the details and color rendition of the image. MLAT has a weighted sum of several SLATs with the different surround images. This paper is organized as follows. Section 2 introduces Retinex-based algorithms. Section 3 provides a brief overview of Stevens' brightness function and Bartleson–Breneman's brightness function. Section 4 explains the proposed SLAT, MLAT, and introduces the local luminance estimation parameters. Section 5 contains the simulation results using the proposed MLAT and conventional methods and the conclusions are given in Section 6.

2. Retinex-based algorithms

Human visual system recognizes objects by surface reflectance not affected spatial illuminant distribution. The Retinex models eliminate the effect of the non-uniform illuminations. First, the local illumination is estimated from the input image blurred by a Gaussian linear low pass filter. Then, the reflectance is estimated by subtracting the illumination from the input image in log domain. The center/surround method uses the difference between

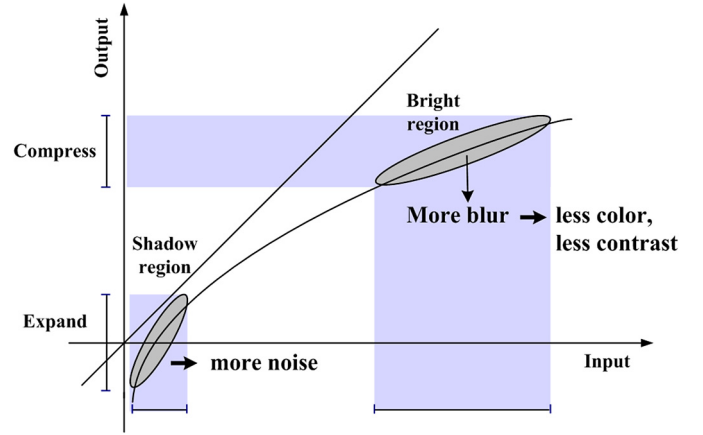


Fig. 2. Retinex-based tone mapping.

each pixel and a weighted surround image in the logarithm domain. The basic equations of the SSR can be expressed as follows:

$$R_i = \log I_i(x, y) - \log [F(x, y) * I_i(x, y)] \quad (1)$$

$$F(x, y) = K e^{-(x^2+y^2)/c^2} \quad (2)$$

where $R_i(x, y)$ is the Retinex output, $I_i(x, y)$ is the image distribution in the i th spectral band, F is the surround function, and the symbol “*” is the convolution operation. c is the Gaussian surround space constant and controls the degree of blurring. If c is smaller, the details is improved but the quality of color rendition is lower. K is selected such that

$$\iint F(x, y) dx dy = 1 \quad (3)$$

The MSR gives a remarkable balance between local and global tonal rendition to the SSR. Three different scales of Gaussian surround represent narrow, medium, and wide surrounds and the weighted sum can provide both increased local contrast and tone rendition. MSR is represented as follows.

$$R_{MSRi} = \sum_{n=1}^N \omega_n R_{ni} \quad (4)$$

where N is the number of scales, R_{ni} is the i th component of the n th scale, R_{MSRi} is the i th component of the output of MSR, ω_n is the weighting factor.

Sun et al. introduced the LBMSR. The LBMSR algorithm was processed in the luminance channel, which is obtained by the PCA. They used the sum of the convolution term to reduce the noise of the image. The LBMSR equation is as follows:

$$R_{LBMSR} = \frac{1}{N} \left[\log I(x, y)^N - \log \left(\sum_{n=1}^N F_n(x, y) * I(x, y) \right) \right] \quad (5)$$

where R_{LBMSR} is the output of LBMSR, N is the number of the surround function, F_n is the n th of the surround function that is equal to Eqs. (2)–(3), and I is the luminance channel of the input image.

The Retinex-based local process has the dynamic range compression using log-shaped curve. The logarithmic conversion occurs the noise spreading in dark regions and the blurring and desaturation in bright regions. Fig. 2 illustrates these artifacts in Retinex-based tone mapping. In bright regions, large signals are extremely compressed by the nonlinear curve and the differences between adjacent pixels are reduced and less contrast appears. Besides, human visual system is sensitive under bright conditions. So, contrast and saturation in bright regions should be enhanced. On contrary, noise is expanded in shadow regions. The details reproduction is an issue mainly in dark and bright regions.

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