Hue Preserved Multi-scale Retinex to Improve Color Reproduction

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Abstract

In recent studies on tone reproduction with the objective of reproducing natural looking colors in digital images, an integrated multi-scale retinex (IMSR) has produced great naturalness in the resulting images. Most methods, including IMSR, work in RGB or quasi-RGB color spaces. As such, this produces hue distortion from the perspective of the human visual system. Accordingly, this paper proposes the hue preserved multi-scale Retinex (HPMSR) method to obtain a high contrast and naturalness. The proposed method enhanced the L^* and saturation values in CIELAB color space. As a result, the visibility in dark shadows in the resulting images was improved.

1. Introduction

Recently, various Retinex methods, which are tone reproduction methods, have been widely used, due to their high local contrast and improved visibility, even given the presence of artifacts, such as halo effects. Jobson and et al also developed the Retinex theory into the single-scale retinex (SSR) method and multi-scale retinex (MSR) method, as a combined form of the SSR method[1]. Initially, the MSR method had problems related to appropriate values for the parameters, chromatic unbalance, color distortion, noise, and graying out. In a recent paper, an integrated multi-scale retinex (IMSR) algorithm was introduced to improve the visibility in dark shadow areas of natural color images, while preserving a pleasing contrast without banding artifacts[2]. In this case, a Gaussian pyramid decomposition is used to reduce the computation time for generating a large-scale surround, while an integrated luminance surround value is applied to each channel to preserve the color balance in RGB color space. Other papers have also attempted to prevent color or chroma distortion by controlling the ratio of the RGB channels. However, regardless of such efforts, all existing methods lead to some perceived color distortion. Based on the assumption that the input images are directly acquired in sRGB, the execution of MSR in RGB color space does not preserve the perceived hue, that is, the hue of the original image in CIELAB color space is distorted.

Accordingly, this paper proposes the hue preserved multi-scale Retinex (HPMSR) method in a device-independent color space, namely CIELAB, to preserve the hue. First, a captured sRGB image is transformed into CIEXYZ color space and then into CIELAB color space to calculate the lightness, hue, and saturation. The IMSR is then only applied to the lightness values, thereby preserving the balance of the color components. Thereafter, the L^* values produced by the IMSR are mapped to displayable values by means of a cumulative distribution function to preserve the luminance in the high valued regions. However, since this process results in an unnatural saturation, a saturation adjustment according to the changed luminance is applied to the a^* and b^* channels. Based on an analysis of the chroma value variation with the IMSR, the ratio of the chroma variation is adjusted at the sRGB gamut boundary depending on the luminance variation to achieve color naturalness. Finally, the adjusted CIELAB values are transformed into sRGB using an inverse transform function. In experiments with real scene images, the results show a high visibility in both dark and bright regions, and natural colors without any hue distortion. Furthermore, in the case of an observer preference test, most observers perceived the images from the proposed method as more natural than previous results.

2. Integrated Multi-scale Retinex Method

The IMSR method proposed by Wang[2] is based on the adaptive scale-gain retinex developed by Kotera et al[3] with certain differences. First, the IMSR adopts a linear space without a logarithmic conversion to avoid any uncertainty for noise and the output range spreading in dark shadows. Second, the IMSR only uses the luminance channel to form the surround image, and then applies this result to each color channel to maintain the color balance. As such, the main difference is the use of an integrated multi-scale luminance surround from multiple luminance surround images using Gaussian filters with a different standard deviation.

Preserving the color balance is achieved by applying the integrated surround images S_{sum} to each channel in the IMSR. The following equation describes the IMSR process:

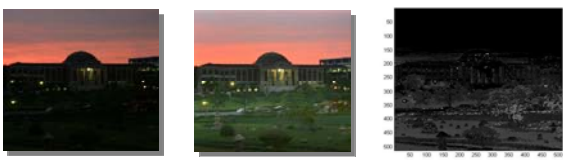
$$SSR_{sum}(x,y,\sigma_m) = A\frac{I_i(x,y)}{S_{sum}(x,y,\sigma_m)}, \qquad (1)$$

where I is the input RGB image, SSR_{sum} is the image calculated by the Retinex, i is the index indicating the RGB channel, A is the gain coefficient, and S_{sum} is the integrated surround image. S_{sum} is calculated by integrating the different surround images $S_m(x, y, \sigma_m)$ with different adaptive weights $w(\sigma_m)$ as follows:

$$S_{sum}(x,y,\sigma_m) = \sum_{m=1}^{M} w(\sigma_m) S_m(x,y,\sigma_m). \qquad (2)$$

Also, Eq. (3) shows the calculation of the surround images performed by convolution between the luminance Y images using Gaussian filters $G_m(x, y)$ with a different standard deviation σ_m.

$$S_m(x,y,\sigma_m) = \langle G_m(x,y) \otimes Y(x,y) \rangle \qquad (3)$$



(a) (b) (c)

Fig. 1. Result of IMSR and hue difference in CIELAB. (a) is the original image, (b) is the resulting image by IMSR, and (c) is the hue difference between the original and resulting image.

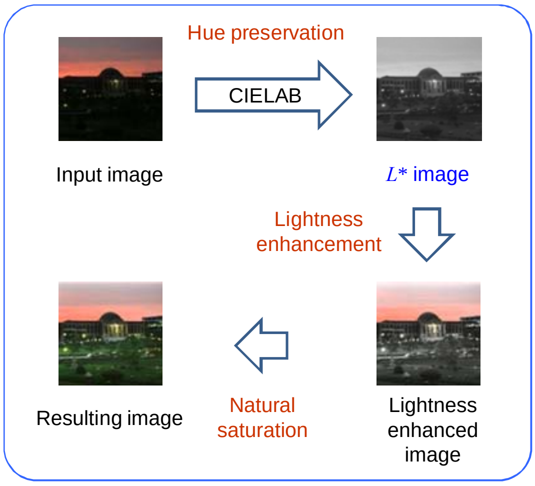


Fig. 2. Procedure of the proposed tone reproduction method.

The optimum gain coefficient A and weights w are obtained by the Trial and Error method based on human vision[2]. As such, the optimum gain coefficients and weights used in this study were based on those determined for the IMSR.

For the IMSR results shown in Fig. 1, there is less banding than with the MSR. Also, the visibility is increased with the naturalness of the colors. Nonetheless, although this algorithm can preserve the color balance in RGB color space, the perceived hue is not preserved. Thus, if the original image is a sRGB image, the perceived hue can be thought as the hue value in CIELAB color space. Sometimes, the hue values in the IMSR results are changed by almost 180°, as shown in Fig. 1(c).

3. Proposed the Hue Preserved Multi-scale Retinex Method

As mentioned above, the main objective of the proposed method is to preserve the perceived hue, and the process is represented in Fig. 2. To consider the hue values, the proposed method adopts CIELAB color space.

To obtain the lightness, hue, and saturation values respectively, the original image, which has sRGB values, is first transformed into CIELAB values using the standard equation[4]. Thereafter, only the lightness values obtained by the IMSR are used to preserve the hue values as follows:

$$L^*_{sum}(x,y,\sigma_m) = A\frac{L^*(x,y)}{S'_{sum}(x,y,\sigma_m)} \qquad (4)$$

$$S'_{sum}(x,y,\sigma_m)=\sum_{m=1}^{M} w(\sigma_m) S'_m(x,y,\sigma_m) \quad (5)$$

$$S'_{sum}(x,y,\sigma_m)=\sum_{m=1}^{M} w(\sigma_m) S'_m(x,y,\sigma_m) \quad (6)$$

$$S'_m(x,y,\sigma_m)=< G_m(x,y)\otimes L^*(x,y) > \quad (7)$$

This is actually the same process performed using RGB values in the IMSR, yet using $L^*(x,y)$ instead of $I_i(x,y)$. Thus, $L^*_{sum}(x,y,\sigma_m)$ is the enhanced lightness value, and the enhanced lightness is shown in Fig. 3(b).

Next, normalization is performed to produce displayable values. In this case, to reproduce bright regions correctly, cdfs of the enhanced lightness values are used. As a result, the value with an almost zero gradient in the cdf is used as the normalization value. Fig. 3(c) depicts the result of normalization. Nonetheless, this method leads to the existence of values outside the display gamut. Therefore, a hue preserving minimum delta E clipping algorithm (HPMINDE) is applied to the values outside the gamut[5]. The final result of the IMSR using lightness values is shown in Fig. 3(d).

As described above, saturation compensation is needed for dark regions in the original image. As the process of the IMSR with lightness values does not change any chroma values, a^* and b^*, in the case of dark regions, which are significantly enhanced, the low chroma values are preserved.

To solve the problem of low chroma values, pixel values with originally small chroma values in dark areas need to be significantly improved during a large variation of lightness by the IMSR, whereas pixel values with originally large chroma values should be minimally improved during a small variation of lightness. Therefore, in the proposed method, the ratio of the sRGB gamut boundary is applied to the enhancement of the chroma values. In the proposed procedure, the initial step is finding the sRGB gamut boundary values corresponding to the input hue(H_{in}), input lightness(L^*_{in}), and result lightness(L^*_{sum}), respectively. The ratio of these boundary values is then applied to the input chroma value. Eq. (8) shows the saturation compensation for a pixel at position (x, y):

$$C_{IMSR}(x,y)=\frac{Gb_{L^*_{sum},H_{in}}(x,y)}{Gb_{L^*_{in},H_{in}}(x,y)}\times C_{in}(x,y) \quad (8)$$

where C is the chroma value and G_b is the gamut boundary value corresponding to the lightness, L^*_{in} and L^*_{sum}, with the input hue, H_{in}.

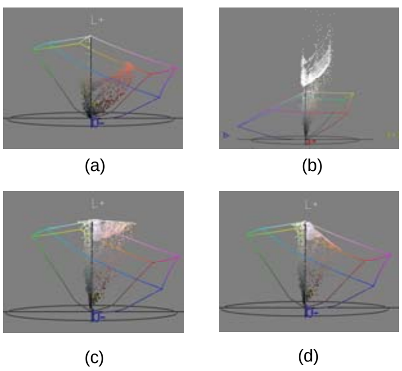


Fig. 3. Gamut data of each step. (a) is the input image, (b) is the gamut data after IMSR in CIELAB color space, (c) is the gamut data after normalization, and (d) is the gamut data after HPMINDE gamut mapping method.

4. Experiments and Results

In the experiments, sRGB images were acquired using a Cannon 10D camera. The results from the proposed method were compared with those from the MSR and IMSR methods. The parameters used for the IMSR and proposed methods were the same as those previously reported for Wang's algorithm[2].

Fig. 4 shows the experimental results. In the first column, Fig. 4 (a) Sunset, while the visibility of the MSR image (second row) is improved, the sunset area appears as bright as day, giving a very artificial feeling. Meanwhile, the IMSR image (third row) and proposed method image (fourth row) appear similar to the real scene for a sunset. However, the proposed method shows an improved visibility and contrast when compared to the IMSR results. In the second column, Fig. 4 (b) Night, while the MSR image has a better visibility than the other methods, the picture is perceived as artificial due to excessive illuminant color removal. Meanwhile, the proposed method shows an improved contrast in the buildings when compared to the IMSR results. In the third column, Fig. 4 (c) Car, the colors in the second row image (MSR) are faded out, especially the lawn and car (red wine color). Meanwhile, the IMSR images are enhanced quite well, although the dark area around the tire seems to be noisy due to lightness over-

Fig. 4. Comparison of resulting image by the proposed method and other tone reproduction methods.

enhancement. However, the fourth row image (proposed method) shows a better color rendition and reduced noise around the tire.

An objective evaluation of the hue difference is shown in Table 1, where the proposed method has the smallest average hue difference. As a final experiment, an observer preference test was performed. As shown in Fig. 5, most observers found the proposed method to have the best visibility and naturalness.

5. Summary

This paper proposed an the hue preserved multi-scale Retinex (HPMSR) method in CIELAB. The main goal of the proposed method is the preservation of the perceived hue, which means maintaining a constant hue from the original image in CIELAB

TABLE 1. Average hue angle difference between an input and a resulting images.

	MSR	IMSR	Proposed
Sunset	56.05	2.00	1.20
Night	50.30	1.85	0.27
Car	28.74	3.74	3.56

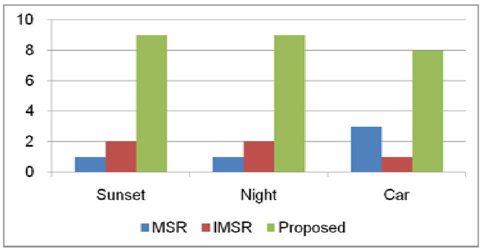


Fig. 5. Resulting data of preference evaluation.

color space (which has a linear property for the human visual system). Therefore, the IMSR method is executed in CIELAB color space with only lightness values. In addition, to ensure the appearance of a bright area, information from a cdf is used to perform lightness mapping. As a result, the hue is preserved, yet unnatural saturation occurs. Thus, to correct this phenomenon, saturation compensation is performed according to the luminance variation by applying the ratio of the chroma values at the sRGB gamut boundary with the same luminance variation during the IMSR. In experiments with test images, the hue values were preserved. Also, by using the ratio of the chroma for the saturation compensation, oversaturated areas are prevented and pleasing natural colors maintained. In an observer preference test, most observers perceived that the resulting images from the proposed method had a higher visibility and naturalness.

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5. References

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