Modified Multi-scaled Retinex Using Chromaticity of Highlight Region for Correcting Color Distortion

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Abstract

As digital still cameras become popular and accordingly their image quality becomes more of a concern, there are increasing studies in reducing the gap between human-observed scenes and images captured by digital still cameras. The dynamic range of a digital camera is narrower in contrast to the one of the scene, thus it is hard to recognize an object in the shadow region of a captured image. The Retinex algorithm is generally used to improve detail and local contrast of the shadow region in an image by dividing the image by its local average image, regarded as a local illuminant, using a Gaussian filter. The result by retinex algorithm depends on the scale of the Gaussian filter. The smaller the Gaussian filter, the more improved the local contrast, but brings the graying-out and halo artifact. Thus, to reduce those artifacts, a multi-scaled retinex algorithm was developed based on the weighted sum of several resulting images from the retinex algorithm by various-scaled Gaussian filters. However, if the chromatic distribution of the original image is not uniform and dominated by a certain chromaticity, the chromaticity of the local average image depends on the dominant chromaticity of the original image, thereby the colors of the resulting image divided by the local average image are shifted to a complement color to the dominant chromaticity of the original image. In this paper, a modified multi-scaled retinex method to reduce the influence of the dominant chromaticity in the image is proposed. For this, first, the local average images are divided by the average chromaticity values of the original image. And then, the local average images are multiplied by the chromaticity of the global illuminant, which is estimated by the averaged chromaticity values within the highlighted region, to consider its influence on the local illuminant. In addition, to compensate for the graying-out effect, the chroma value of the output image is enhanced based on that of the original image in the CIELAB space. Experimental results show that the proposed method improved the local contrast and detail without color distortion, thereby improving the color rendition.

Introduction

The sensitivity function of human visual system is adaptively shifted to recognize an object in the scene contained both bright and shadow regions. However, in a digital camera, it is hard to represent the detail of both regions simultaneously because the sensitivity function of a digital camera is fixed for the illumination of a scene. Thus, a post-correction process is necessary to enhance the local contrast and detail in both regions. In general, a histogram equalization and the nonlinear transform by a logarithmic or a power law function have been used to improve the local contrast and detail in an image [1,2]. The histogram equalization is based on the idea of transforming the input image to output image that contains uniform luminance distribution. Thus, this method shows a good performance for the input image which has the distribution of its histogram stretched to the dark or bright region, but, in case of the input image with the distribution of its histogram stretched to both side, the histogram equalization method does not work so well. In a nonlinear transform method, a logarithmic and a power law function usually increases the visibility in the dark area by sacrificing visibility in the bright area. Thus it is hard to enhance the detail of both regions simultaneously. In addition, the results of these methods depend on the input image because they utilize pixel-to-pixel processing without considering a spatial illumination distribution of the image [3-5].

Retinex theory, as a model of the lightness and color perception of human vision, introduced by Land is evolved into center/surround retinex model by the ratio of the lightness for a small central field of the region of interest to the average lightness over and extended field [6]. Single scale retinex using a Gaussian filter is proposed to improve the image appearance based on the center/surround retinex model. However, in the single retinex algorithm there are the several defects, such as halos and graying-out, generated in large areas with uniform chromatic distribution. Thus, the multi-scaled retinex algorithm proposed by Jobson [7,8]. Through the weighted summing resulting images of single retinex processes with various- scale Gaussian filters, the halo artifact is considerably reduced and the local contrast is improved. In addition, the color restoration process by adding the chromaticity of the original image to the resulting image of multi-scaled retinex algorithm is supplemented to reduce the graying-out of resulting image [9]. However, after the color restoration process, the saturation of the resulting image is unnatural compared to the original image, because the variation of the lightness is not considered. Moreover, if the chromatic distribution of the image is not uniform and dominated to certain chromaticity value, the average chromaticity of the resulting image is shifted toward complement chromaticity to the dominant chromaticity, thereby inducing the undesirable color distortion, because it is based on the gray world assumption.

In this paper, the modified multi-scaled retinex using the chromaticity of highlight region is proposed to improve the color rendition. First, to reduce the influence of the dominant chromaticity in the image, the local average images in multi-scaled retinex are divided by the average chromaticity values of the original image. Then, the local average images are multiplied by the chromaticity of the global illuminant which is estimated by the averaged chromaticity values within the highlighted region, because the chromaticity from the highlighted region is independent to the dominant chromaticity of the image [10]. The output image is obtained by a weighted sum of images which are obtained by dividing the original image by the local average image. In addition, to reduce the graying-out induced, the chroma value of the output image is compensated based on that of the original image in CIELAB space.

In the following section, the single scale retinex algorithm and multi-scaled retinex is briefly described. Next, the modified multi-scaled retinex algorithm is discussed for the method of estimating the uniform illuminant, collecting undesirable shift, and the chroma compensation process.

Single scale retinex model

In general, the perceived color by the human eye can be considered the product between the reflectance of object and the illuminant. Thus, the reflectance is calculated by estimating the illuminant component from the perceived color. The illuminant should be regionally estimated, because the illuminant component has usually a nonuniform distribution and different chromaticity locally. The single scale retinex is the color constancy model under nonuniform illuminant. The Gaussian filter is used to estimate the illuminant component, and the reflectance is calculated by the difference between the original image and its Gaussian filtered image in logarithmic space as follows:

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

where $I_i(x,y)$ is the original image in the i-th spectral band for each coordinate position (x,y), $F(x,y)$ is the Gaussian filter, and the symbol "*" denotes the convolution operation. The Gaussian filter is given by

$$F(x,y) = Ke^{-(x^2+y^2)/\sigma^2} \text{ and } \iint F(x,y)dxdy = 1, \quad (2)$$

where K is the normalized constant coefficient, and σ represents the standard deviation for the scale. Thus, the determine of parameter, σ, is very important, because the performance of single scale retinex is dependent on standard deviation, σ, in the Gaussian filter. Its small scale shows the result of a good dynamic range compression, contrastively the large scale shows the result of good color rendition. In addition, because the result for a scale is also depended on the input image, it is hard to determine the scale.

Multi-scaled retinex

To solve the trade-off between dynamic range compression and color rendition, the multi-scaled retinex is proposed. It is computed by the weighted sum of resulting images of single retinex processes with several scales as follows:

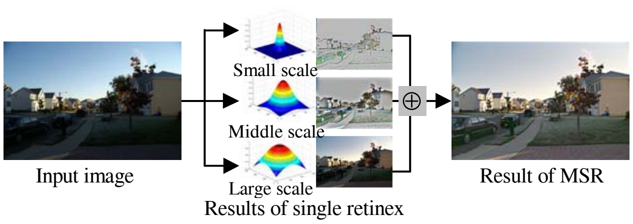
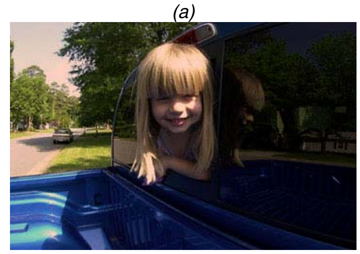
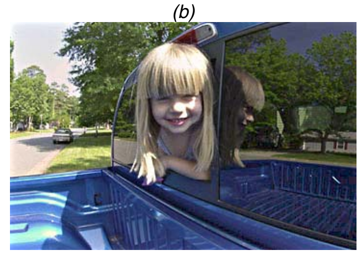


Figure 1. *Multi-scaled retinex process.*

(a)



(b)



(c)

Figure 2. *Comparison between (a) original image, (b) resulting image by gray world assumption, and (c) resulting image by multi-scaled retinex.*

$$R_i(x,y) = \sum_{n=1}^{N} \omega_n \{\log I_i(x,y) - \log\{F_n(x,y) * I_i(x,y)\}\},$$

$$F_n(x,y) = Ke^{-(x^2+y^2)/\sigma_n^2}, \text{ and } \iint F_n(x,y)dxdy = 1, \quad (3)$$

where ω_n represents the weight for n-th scale. The result of single retinex using the small scale Gaussian filter has only the detail with graying out. In contrast, the result of single retinex using the large scale Gaussian filter has more information for the chromaticity. Thus, the local contrast and color rendition could be simultaneously obtained by weighted summation of those results, as a shown in Fig. 1. However, if the original image has high distribution for some chromaticity value, i.e. the average chromaticity of scene excluding the chromaticity of illuminant is not a gray, the chromaticity of the result is distorted toward the complement chromaticity, because the multi-scaled retinex is based on a gray world assumption. Fig. 2 shows the color distortion in multi-scaled retinex process. The average chromaticity of the image, Fig. 2(a), is dominated by a blue color of the car. Thus, in multi-scale retinex process, the chromaticity of locally averaged image is dominated by the blue, and the complement chromaticity, the chromaticity of magenta is added by the difference between the image and the locally averaged image. Accordingly, as shown in Fig. 2(c), the chromaticity resulting image is distorted, especially in the region of the sky and lawn, like a result of the gray world assumption, Fig. 2(b).

Modified multi-scaled retinex algorithm

Fig. 3 shows the flowchart of the proposed method. Gamma correction should be performed with a factor of 2.2 to linearize the color space, because images for display purpose are gamma corrected. Then the chromaticity value of the illuminant is estimated using the dichromatic reflection model within the highlight region. Next the multi-scaled retinex algorithm is modified by the chromaticity of the local average image is correcting with the chromaticity of the estimated illuminant. Lastly, the inverse gamma correction is processed. Further explanation for each step is described in the following sections.

Estimation of chromaticity for uniform illuminant

In general, the gray world assumption, one of the best-known algorithms for color constancy, is based on the assumption that the average of reflectances in the image are gray and can be considered to be a random variable drawn from the range [0,1]. The chromaticity values of the image are divided by its average chromaticity values to remove the illuminant component. Thus, it works well in the image with a sufficiently large number of different colors, i.e. reflectances are uniform distributed. However, if the chromatic distribution of the image is dominated by a certain chromaticity, the resulting image based on the gray world assumption becomes a grayish although the chromatic distribution of the image is not closed to the gray color. Accordingly, instead of averaging the chromaticity values to estimate the illuminant component, the chromaticity of illuminant is simply estimated by the averaged chromaticity value within the highlight region based on the assumption that the image has specular reflections in the highlight region. In addition, the highlight region is extracted in Gaussian filtered image to reduce the noise. The histogram of the Gaussian filtered image is used to extract the highlighted region in the image. The histogram for the each channel is represented as follows:

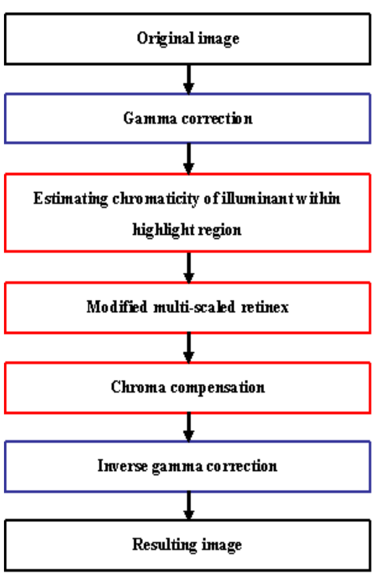


Figure 3. *Flow chart of proposed method.*

$$H_i(k) = histo\{F(x,y) * I_i(x,y)\}\ . \tag{4}$$

The highlight region in histogram is extracted by b such that

$$N \times p \le \sum_{k=1}^{b} H_i(k)\ , \tag{5}$$

where N is the total number of image pixels, p is the ratio for highlight region in the image, and k indicates the index of bucket in histogram. Base on the b-th bucket, the highlight region is separated. The chromaticity of illuminant is then estimated by the average chromaticity value in the highlight region for each channel, as follows:

$$c_i = \frac{1}{N_h} \sum_{k=b}^{k_{\max}} H_i(k) \times I_k\ , \tag{6}$$

where N_h is the number of total pixels in highlight region and I_k indicates the intensity for k bucket. The average values of intensity for each channel represent the chromaticity of the illuminant.

Correction for locally averaged images

The locally averaged images by Gaussian filtered image are regarded as the local illuminant component in multi-scaled retinex algorithm because it is based on the gray world assumption. Thus the local illuminant is estimated by low pass filtering with various-scale Gaussian filters, as shown in Fig. 4. However, if the image has a dominant chromatic distribution to a certain chromaticity, the chromatic distribution of the difference images between the image and its locally averaged images obtained by various-scale Gaussian filtering is moved toward the complement chromaticity to the dominant chromaticity, thereby provoking the undesirable color distortion. Accordingly, to correct the undesirable color distortion, the chromatic distribution of locally averaged images should be closed to the chromaticity value of the illuminant in the scene. Thus, first, the average chromaticity for the images is computed as follows:

$$a_i = \frac{1}{N} \sum_{y} \sum_{x} I_i(x,y)\ . \tag{7}$$

The chromatic distribution of the locally averaged image should be neutralized to reduce the influence of the dominant chromaticity of the image. Thus, the locally averaged image is divided by the average chromaticity and multiplied by the chromaticity value of estimated illuminant for each channels preserving the intensity for each channel as follows:

$$\begin{aligned} L_{red,s}(x,y) &= \{F_s(x,y) * I_{red}(x,y)\} \times \frac{a_{green}}{a_{red}} \frac{c_{red}}{c_{green}}, \\ L_{green,s}(x,y) &= \{F_s(x,y) * I_{green}(x,y)\}, \\ L_{blue,s}(x,y) &= \{F_s(x,y) * I_{blue}(x,y)\} \times \frac{a_{green}}{a_{blue}} \frac{c_{blue}}{c_{green}}, \end{aligned} \tag{8}$$

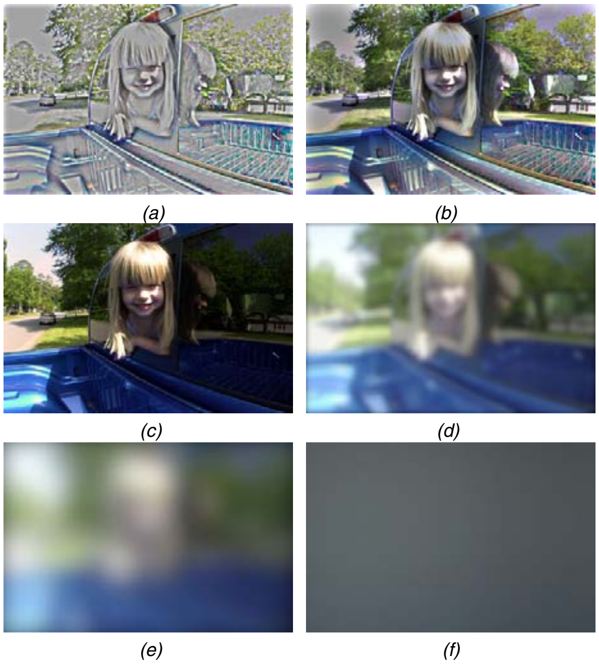


Figure 4. *In multi-scaled retinex process, resulting images of single scale retinex with (a) small scale, (b) middle scale, and (c) large scale, and Gaussian filtered images with (d) small scale, (e) middle scale, and (f) large scale.*

where c represents the chromaticity of the estimated illuminant. Then, the chromatic distribution of the locally averaged image is shifted toward the chromaticity value of the estimated illuminant within highlight region. However, the resulting image of retinex algorithm by large scale Gaussian filter has more information for chromaticity, while the resulting image of retinex algorithm by small scale Gaussian filter has less chromaticity and more detail. Thus the shifting ratio is controlled by the scale of the Gaussian filter as follows:

$$\begin{aligned} L'_{red,s}(x,y) &= (1-\gamma_s)\times\{F_s(x,y) * I_{red}(x,y)\} + \gamma_s \times L_{red,s}(x,y), \\ L'_{green,s}(x,y) &= L_{green,s}(x,y), \\ L'_{blue,s}(x,y) &= (1-\gamma_s)\times\{F_s(x,y) * I_{blue}(x,y)\} + \gamma_s \times L_{blue,s}(x,y), \end{aligned} \tag{9}$$

where γ_s is the shifting ratio depending the scale of the Gaussian filter. Then, chromatic distributions of Gaussian filtered images are then corrected toward the estimated chromaticity of illuminant. Lastly, to enhance the local contrast, the resulting image is obtained by weighted sum of the difference images between the image and modified Gaussian filtered images in logarithmic space, as follows:

$$R_i(x,y) = \sum_{s=1}^{S} \omega_n \{\log I_i(x,y) - \log L'_{i,s}(x,y)\} \tag{10}$$

Chroma compensation

The undesirable color shift is corrected via modified multi-scaled retinex process. However the saturation of the resulting image by modified multi-scaled retinex is still lower than the original image, because the output of retinex using small scale Gaussian filter has a very low saturation. Thus, to restore the low saturation preserving the lightness and hue, first, the color space is converted to the CIELAB space to consider the human visual system. Assuming that the color space is sRGB color space, the RGB value is converted CIEXYZ stimulus space with the 3×3 conversion matrix for sRGB color space as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \tag{11}$$

Then, the XYZ value is reconverted to CIELAB value as follows:

$$\begin{aligned} L^* &= 116\left[f\left(\frac{Y}{Y_n}\right) - \frac{16}{116} \right] \\ a^* &= 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right] \\ b^* &= 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right] \\ &\text{where } f(s)\begin{cases} = s^{1/3} & s > 0.008856 \\ = 7.787\,s + 16/116 & \text{otherwise} \end{cases} \end{aligned} \tag{12}$$

where X_n, Y_n, and Z_n represent the maximum values of each other. In the CIELAB space, the chroma is given by,

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}}\ . \tag{13}$$

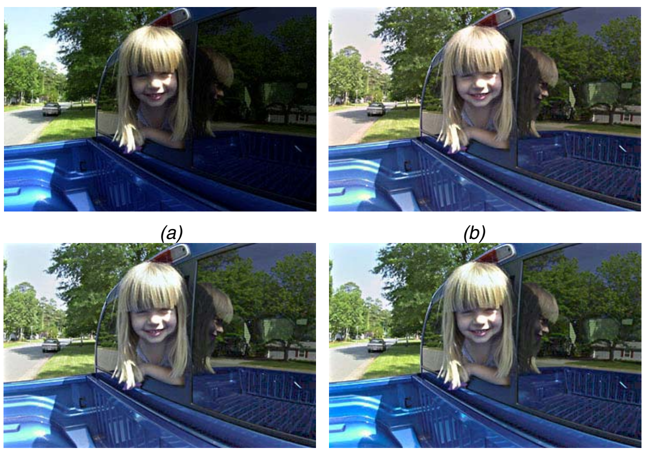
Based on the chroma value of the output image of retinex algorithm using a large-scale Gaussian filter, the chroma value of the resulting image by modified multi-scaled retinex algorithm is compensated with the difference between chroma values as follows:

$$\hat{C}^{*MSR}_{ab} = C^{*MSR}_{ab} + (C^{*L}_{ab} - C^{*MSR}_{ab})\ . \tag{14}$$

Experiment and evaluations

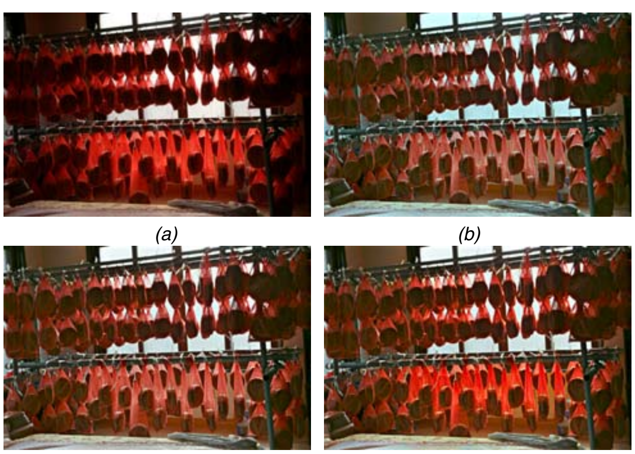
The result of multi-scaled retinex is very sensitive to the scale parameter of the Gaussian filter, σ_n, and the weight, ω_n, in Eq. (3). Thus the locally averaged images using parameters, $\sigma_n = (5, 20, 240)$, proposed by Jobson was used for stabilizing and enhancing the result of the process and the weight, $\omega_n = (0.3, 0.1, 0.6)$, is applied to reduce the halos in the resulting image for good color rendition[8].

Fig. 5, 6, and 7 shows the original image and resulting images by the multi-scaled retinex, proposed method, and proposed method with chroma compensation process. The chromatic distribution of original image, Fig. 5(a), is dominant on the blue and green. Thus, in Fig. 5(b), the resulting image of the multi-scaled retinex seems that it is a little added the chromaticity value of magenta over all although the detail is good represented in the window. Especially the color of the sky and the load is shifted toward the magenta. In contrast, the resulting image of proposed method without chroma compensation process, Fig. 5(c), the color of sky and load is not shifted to the magenta color enhancing the detail in region of the window. In the resulting image by proposed method with chroma compensation, Fig. 5(d), the saturation preserving lightness and hue is recovered without color distortion. In contrast, the chromatic distribution of the original image, Fig. 6(a), is dominant on the red color. Therefore, in the resulting image by multi-scaled retinex, Fig. 6(b), the colors of the windows and the floor are changed into the blue color because of red color from the red plastic bags. However, in the resulting image by proposed method, Fig. 6(c), the colors of the windows and the floor is preserved without color distortion. In addition, in Fig. 6(d), the saturation is increased. Lastly, in the resulting image by multi-scaled retinex, Fig. 7(b), the color of the sky becomes a little reddish because the original image, Fig. 7(a), has large region for blue sky. In contrast, in the resulting image by proposed method, Fig. 7(c), the color of the sky is blue with a little graying out. Moreover, in Fig. 7(d), the graying out is removed by the chroma compensation process.



(c) (d)

Figure 5. *Resulting images for 'blue-car' image; (a) original image, (b) multi-scaled retinex, (c) proposed method without chroma compensation, and (d) proposed method with chroma compensation.*



(c) (d)

Figure 6. *Resulting images for 'soybeans' image; (a) original image, (b) multi-scaled retinex, (c) proposed method without chroma compensation, and (d) proposed method with chroma compensation.*

(c) (d)

Figure 7. *Resulting images for 'street' image; (a) original image, (b) multi-scaled retinex, (c) proposed method without chroma compensation, and (d) proposed method with chroma compensation.*

Conclusions

The multi-scaled retinex shows the good performance for the local contrast enhancement, however, in the case of the image with dominant chromatic distribution to certain chromaticity, the chromaticity of the resulting image are sifted undesirably because it is based on the gray world assumption. To reduce the undesirable color distortion, the modified multi- scaled retinex algorithm using the chromaticity of the highlight region is proposed. The color distortion is corrected based on the chromaticity of uniform illuminant estimated by dichromatic reflection model with highlight region. Additionally, the low saturation of resulting image caused by small scale Gaussian filtered image in multi-scaled retinex process is compensated based on the image in CIELAB space. In experimental results, the proposed method shows a good performance for not only local contrast enhancement but also color rendition.

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