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Color Correction by Estimation of Dominant Chromaticity in Multi-Scaled Retinex

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Abstract. *In image capture a scene with nonuniform illumination has an influence on the image quality, especially the contrast and detail in dark regions. Generally, the tone curve or histogram of an image is modified to improve the contrast and detail, yet this is insufficient as the intensity and chromaticity of the illumination vary with geometric position. Thus, the multi-scaled retinex algorithm has been proposed, where the influence of nonuniform illumination is reduced by partitioning the original image using local average images that are estimated based on Gaussian filtering of the original image. However, the multi-scaled retinex algorithm produces color distortion as the local average images are independently estimated for each channel. In particular, if the chromatic distribution of the original image is not uniform and is dominated by a certain chromaticity, the local average image includes not only the intensity and chromaticity of the illumination but also the dominant chromaticity through the Gaussian filtering, thereby distorting the color. Accordingly, this article proposes a multi-scaled retinex using a modified local average image to reduce the color distortion by the dominant chromaticity of the original image. As with the multi-scaled retinex algorithm, the local average image is obtained through Gaussian filtering of the original image. The local average image is then divided by the average chromaticity value of the original image to reduce the influence of the dominant chromaticity. However, because the average chromaticity value includes the dominant chromaticity of the original image and the chromaticity of the illumination, the chromaticity removed from the illumination in the local average image needs to be compensated. Therefore, the chromaticity of the illumination is estimated based on the chromaticity of the highlight regions in the original image. The chromaticity of the local average image is then modified by the estimated chromaticity. In experiments, the proposed method was found to improve local contrast and reduce the color distortion.* © *2009 Society for Imaging Science and Technology.*
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INTRODUCTION

The dynamic range of a digital camera is much narrower than that of a real scene. While the dynamic range of the human eye is also somewhat narrower than that of a real scene, the human visual system compensates using light and dark adaptations. Thus, the sensitivity of the human eye varies adaptively according to the brightness of a scene. However, in the case of a digital camera, since the sensitivity of the digital camera sensor is fixed, dynamic range compression methods, such as histogram equalization and gamma transformation, are generally utilized.[1–3]

These methods modify the contrast in an image to improve the detail of dark and bright regions. Yet, such contrast corrections are limited, insofar as the sensitivity of the human eye changes locally according to the position of an object and the illumination in the scene. Therefore a spatially adaptive method is needed to overcome these limitations,[4] which has led to the recent development of the center/surround retinex model,[5,6] based on the retinex theory as a model of human vision perception. The center/surround retinex model utilizes the ratio of the lightness for a small central field in the region of interest to the average lightness over an extended field. Accordingly a Gaussian filter is generally used to obtain the average lightness of an image. However, the center/surround retinex model has several problems, such as halos and graying-out, as its result is dependent on the scale of the Gaussian filter, which varies according to the input image.

Thus, to solve these problems and stabilize the performance of the retinex model, a multi-scaled retinex algorithm was proposed by Jobson.[7,8] If a small scale of Gaussian filter is used, the local contrast and detail in the resulting image are enhanced even though the artifacts are increased and vice versa. Thus, with the multi-scaled retinex algorithm, several images are created with the center/surround retinex algorithm using various scales of Gaussian filter, and these images are then weighted and summed to reduce the halos and enhance the local contrast. Meanwhile, a color restoration process is added to reduce the graying-out caused by enhancing the contrast and averaging the image resultings.[7] In this case, the chromaticity of the original image is added to the resulting image to enhance the saturation, thereby significantly reducing any halo artifacts while improving the local contrast and saturation of the resulting image.

However, when using the multi-scaled retinex algorithm, the local illumination information is estimated by averaging the intensity values for each channel. If the chromatic distribution of the image is not uniform and dominated by a certain chromaticity value, this dominant chromaticity can then affect the estimated chromaticity of the local illumination, resulting in an undesirable color distortion. Furthermore, as the added chromaticity in the color restoration process includes the chromaticity of illumina-

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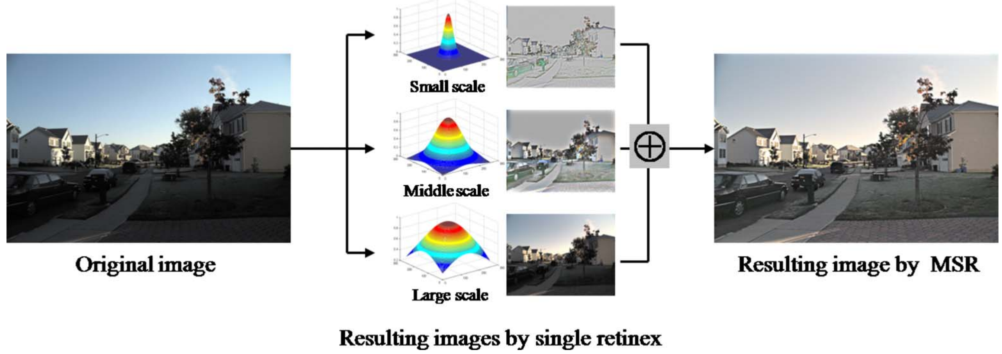


Figure 1. Multi-scaled retinex process.

tion, when the input image has been captured under a certain illumination, the chromaticity of illumination removed by the multi-scaled retinex process might be recovered.

On the other hand, to avoid these problems a multi-scaled retinex using only the luminance channel, instead of using three RGB channels, was proposed by Wang.[2] As the local contrast of luminance preserving the color balance is enhanced by the multi-scaled retinex process, the result is stable and has high saturation. However, as only the single luminance channel is used, the chromaticity of illumination could not be removed and the enhanced saturation is unnatural when compared with the original image.

Accordingly, this article proposes a multi-scaled retinex using a modified local average image to improve the color rendition. The dominant chromaticity component of the original image is estimated in the local average image using the average chromaticity value and chromaticity value of the illumination.[9,10] The estimated dominant chromaticity component is then removed from the local average image by Gaussian filtering. Thereafter, the output image is obtained using the ratio between the original image and the modified local average image. In addition, to reduce the induced graying-out, the chroma of the output image is compensated based on that of the original image in CIELAB space. In the remainder of this article, the following section provides a brief description of the single-scale retinex algorithm with a center/surround model and a multi-scaled retinex. Thereafter, the proposed multi-scaled retinex algorithm is presented. Finally, experiments are used to compare the proposed method with other methods based on the multi-scaled retinex method.

SINGLE-SCALE RETINEX MODEL

Under a perfectly uniform illuminant, the color perceived by the human eye can be considered to be the product of the object reflectance and the illuminant. As such, the reflectance can be calculated by estimating the illuminant component from the perceived color. However, this is impossible in the case of real scenes, as the illuminant is never perfectly uniform and needs to be regionally estimated. A Gaussian filter is used to estimate the illuminant component, and the reflectance is calculated based on the difference between the original image and the Gaussian filtered image in logarithmic space as follows:[4]

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

where $I_i(x,y)$ is the original image in the ith 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

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

where K is the normalized constant coefficient and σ represents the standard deviation for the Gaussian function. Determining the parameter σ is very important, as the performance of a single-scale retinex depends on the standard deviation, σ, of the Gaussian filter. Thus, a small scale produces an enhanced local contrast with more artifacts, whereas a large scale removes the chromaticity of the illumination without changing the local contrast. Consequently, determining the appropriate scale is difficult, as the result of the choice of a particular scale also depends on the input image.

MULTI-SCALED RETINEX

The idea of a multi-scaled retinex was introduced to stabilize the result single-scale retinex model.[7] Thus, results for Gaussian filters with various scales are averaged with different weights using the following computation:

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

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

where ω_n represents the weight for the nth scale. While the result of a single retinex using a small scale Gaussian filter only includes the detail with graying-out, the result of a single retinex using a large scale Gaussian filter includes more chromaticity information. Thus, the local contrast and color rendition can be simultaneously obtained based on a weighted summation of these results as shown in Figure 1. However, if the chromatic distribution of the original image is concentrated on a particular chromaticity value, i.e., the original image has a dominant chromaticity value, the

Figure 2. Comparison with (a) original image, (b) image resulting by the method based on gray world assumption, and (c) image resulting by multi-scaled retinex.

complementary chromaticity is then distorted in the resulting image by the dominant chromaticity as the illumination component is estimated by averaged values of neighbor pixels.

Figure 2 shows an example of color distortion resulting from the multi-scaled retinex process. The average chromaticity in Fig. 2(a) is close to the blue color of the car even though the chromaticity of the illumination is not blue. Thus, in the multi-scale retinex process, the chromatic distribution of the local average image is dominated by the blue color, which also enhances the magenta by the difference between the original image and the local average image. As a result, as shown in Fig. 2(c), the chromaticity of the resulting image is distorted, especially in the region of the sky and lawn, similar to the result of the method based on gray world assumption in Fig. 2(b).

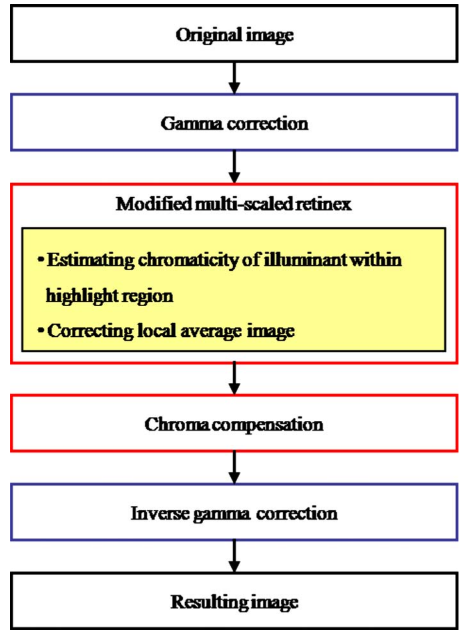


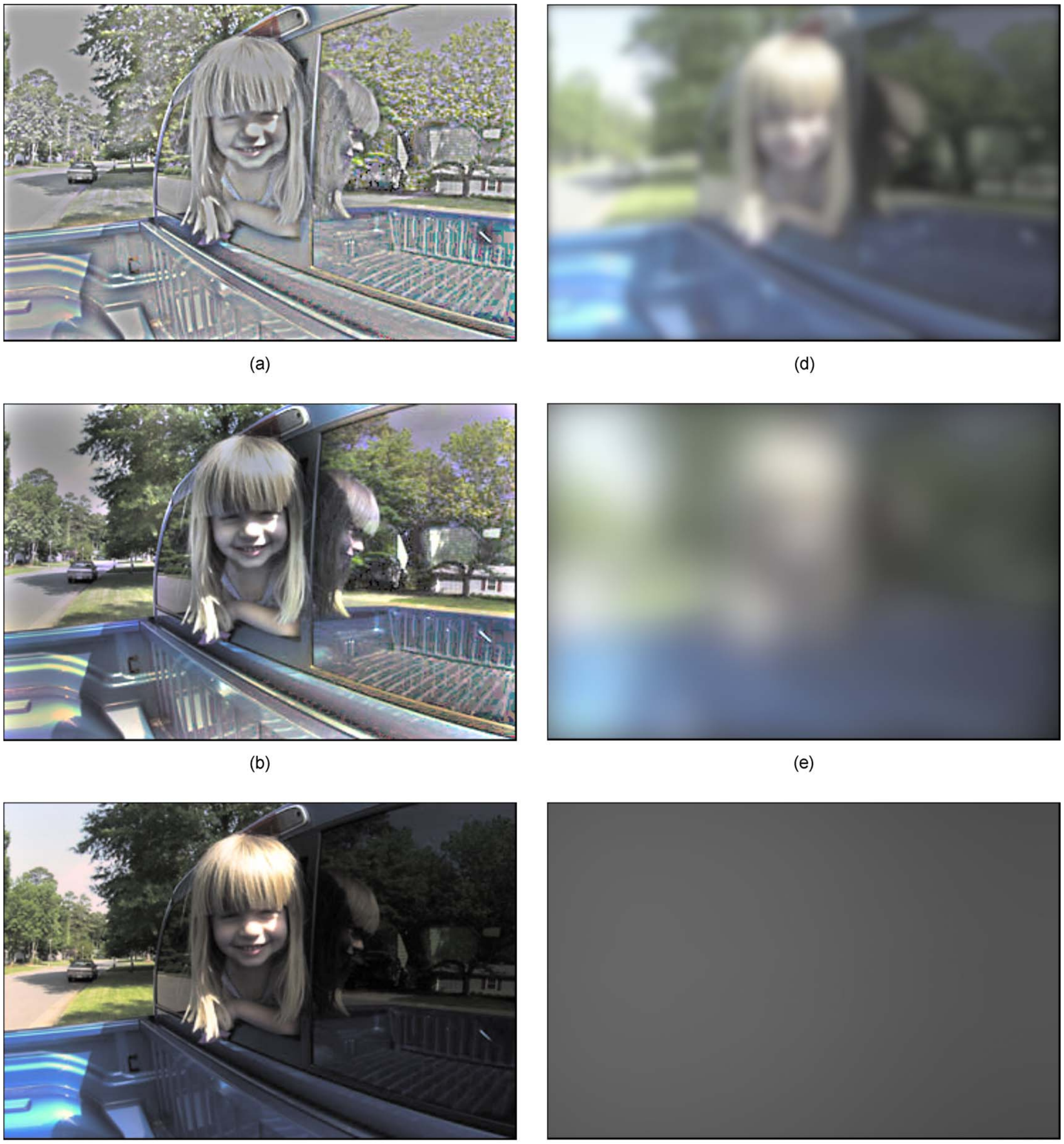
Figure 3. Flow chart for the proposed method.

PROPOSED MULTI-SCALED RETINEX ALGORITHM

Reverse gamma correction needs to be performed for conversion into linear color space as most images on color imaging devices, such as digital cameras, printers, monitors, and scanners, are stored in a format of standard RGB (sRGB) color space as shown in Figure 3. Then, to modify the local average image for the multi-scaled retinex algorithm, the chromaticity of the illumination is estimated using highlighted regions in the original image. Next, local average images are obtained by Gaussian filtering with several scales. These local average images are then modified using the estimated chromaticity of the illumination and average chromaticity of the original image considering the scale used for the Gaussian filter. The final output image is then computed based on a weighted sum of the difference images between the original image and the modified local average images. In addition, to compensate the saturation of the final output image, the chroma value for the output image is enhanced based on the chroma value of the original image in CIELAB space.

CORRECTION OF LOCAL AVERAGE IMAGES

The local illumination in a multi-scaled retinex process is regarded as the locally averaged luminance and chrominance values. Thus, the local illumination is estimated by low-pass filtering using Gaussian filters with various scales, as shown in Figure 4. However, if an original image has a dominant chromatic distribution for a certain chromaticity, the chromatic distribution of the difference images calculated between the original image and the local average images obtained from the Gaussian filtering with various scales become concentrated on the chromaticity complementary to



(a) (d) (b) (e) (c) (f)

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

the dominant chromaticity. An undesirable color distortion is thereby induced. In addition, when increasing the scale of the Gaussian filter, the chromaticity of the local average image becomes closer to the average chromaticity of the original image, thereby increasing the influence of the dominant chromaticity. Thus, the dominant chromaticity in the local average images needs to be removed to correct this undesirable color distortion. In general, the dominant chromaticity can be estimated based on the average chromaticity of the original image as follows:

$$a_i = \frac{1}{N}\sum_{y}\sum_{x} I_i(x,y). \tag{4}$$

However, the average chromaticity of the original image includes both the dominant chromaticity and the chromaticity of illumination. Therefore, if a local average image is directly divided by the average chromaticity, the chromaticity of the illumination is removed from the local average image. As such, the chromaticity of the illumination in the original image should be estimated in order to preserve the chromaticity of the illumination in a local average image.

In general, color constancy methods based on the gray world assumption are the best known algorithms, whereby the average reflectance in an image is assumed to be gray and can be considered as a random variable drawn from the range (0.1). Therefore, the chromaticity of the illumination is computed by averaging all the chromaticity values of the original image, which works well for an image with a sufficiently large number of different colors, i.e., the reflectances are uniformly distributed. However, if the chromatic distri-

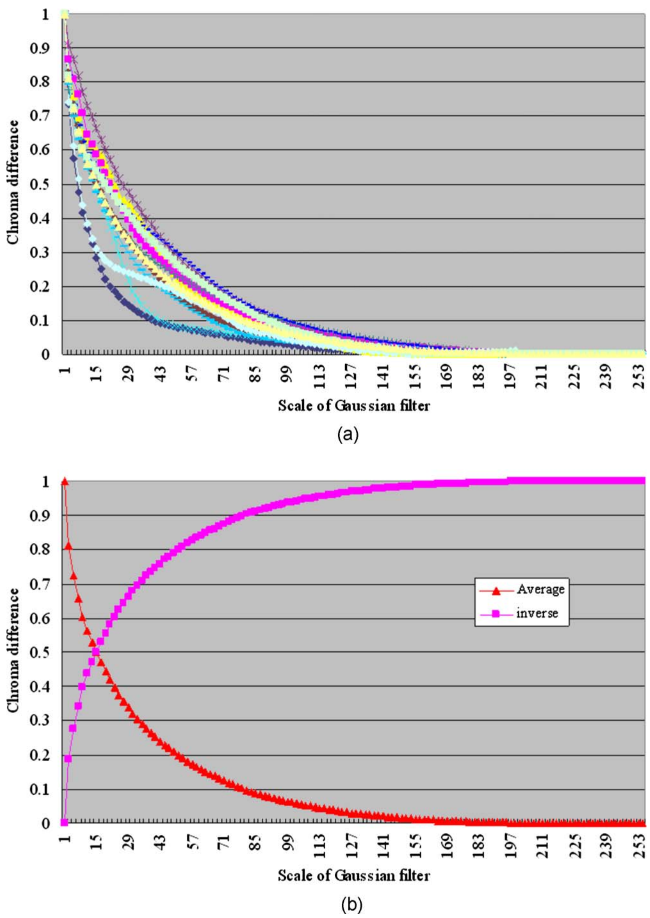


Figure 5. (a) Average and (b) its inverse for change in chroma difference with varying scale of Gaussian filter.

bution of an image is dominated by a certain chromaticity, the resulting image based on the gray world assumption becomes grayish even though the chromatic distribution of the image is not close to a gray color. Similarly, in the multi-scaled retinex algorithm, the illumination component of a certain region is decided by the average value of the neighboring illumination components even though the averaged area is not the whole image, thereby inducing an undesirable color distortion. In particular, the use of a larger scale Gaussian filter with the multi-scaled retinex algorithm induces more color distortion.

Accordingly, instead of averaging the chromaticity values to estimate the illumination component, the chromaticity of the illumination is simply estimated based on the averaged chromaticity value within a highlight region using the assumption that the image comprises specular reflections in the highlight regions. In addition, highlight regions are extracted from a small-scale Gaussian filtered image to reduce the noise. The histogram of a Gaussian filtered image is used to extract the highlighted regions from an image,[4] where the histogram for each channel is represented as follows:

$$H_i(k) = \mathrm{histo}\{F(x,y) * I_i(x,y)\}, \tag{5}$$

where i represents the RGB channels. The highlight regions in a histogram are extracted as follows:

$$Np \leq \sum_{k=1}^{b} H_i(k), \tag{6}$$

where N is the total number of image pixels, p is the predefined constant ratio for the highlight regions in the image and generally set at 0.01, and k indicates the bucket index for the histogram.[4] Based on the bth bucket, the highlight region is separated. After finding the highlight region for each channel, the common regions are extracted based on the final highlight region. The chromaticity of the illuminant is then estimated by the average chromaticity value in the highlight region for each channel as follows:

$$c_i = \frac{1}{N_h} \sum_{k=1}^{N_h} HR_i(k), \tag{7}$$

where HR is the intensity of the ith channel in the extracted final highlight region and N_h is the total number of pixels in the highlight region. Thus, the chromaticity of the illumination is estimated based on the average values of intensity for each channel in the extracted highlight region. To correct a locally averaged image, it is assumed that the averaged chromaticity value of the image includes the dominant chromaticity of the image and chromaticity of the illuminant. Thus, to remove the dominant chromaticity component from a locally averaged image, the average chromaticity is used as a divisor, while the chromaticity of the illuminant is used as a multiplier. By use of the estimated chromaticity of illumination, the local average image can then be corrected, while preserving the intensity of each channel as follows:

$$L_{\mathrm{red},s}(x,y) = \{F_s(x,y) * I_{\mathrm{red}}(x,y)\} \frac{a_{\mathrm{green}}}{a_{\mathrm{red}}} \frac{c_{\mathrm{red}}}{c_{\mathrm{green}}},$$

$$L_{\mathrm{green},s}(x,y) = \{F_s(x,y) * I_{\mathrm{green}}(x,y)\},$$

$$L_{\mathrm{blue},s}(x,y) = \{F_s(x,y) * I_{\mathrm{blue}}(x,y)\} \frac{a_{\mathrm{green}}}{a_{\mathrm{blue}}} \frac{c_{\mathrm{blue}}}{c_{\mathrm{green}}}, \tag{8}$$

where c represents the estimated chromaticity of the illumination and a indicates the average chromaticity value of the original image. The chromaticity of the illumination in the local average image is then preserved. However, the influence of the dominant chromaticity in locally averaged images differs according to the scale of the Gaussian filter. In particular, a locally averaged image resulting from use of a large-scale Gaussian filter is more influenced by the dominant chromaticity than is a locally averaged image resulting from use of a small-scale Gaussian filter. Thus, the correcting ratio for a local average image should be controlled by the scale of the Gaussian filter as follows:

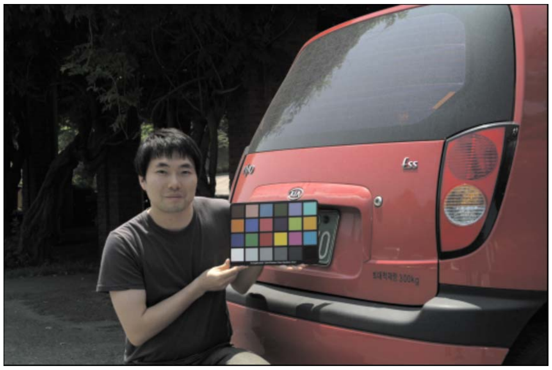


Figure 6. Test image for evaluation of color distortion.

$$L'_{\mathrm{red},s}(x,y) = (1-\gamma_s)\{F_s(x,y) * I_{\mathrm{red}}(x,y)\} + \gamma_s L_{\mathrm{red},s}(x,y),$$

$$L'_{\mathrm{green},s}(x,y) = L_{\mathrm{green},s}(x,y),$$

$$L'_{\mathrm{blue},s}(x,y) = (1-\gamma_s)\{F_s(x,y) * I_{\mathrm{blue}}(x,y)\} + \gamma_s L_{\mathrm{blue},s}(x,y), \tag{9}$$

where γ_s is the correcting ratio that is dependent on the scale of the Gaussian filter. The influence of the dominant chromaticity in a local average image is reduced by preserving the chromaticity of the illumination. Consequently, the image resulting from the multi-scaled retinex algorithm is obtained based on a weighted sum of the difference images between the original image and the corrected local average images in logarithmic space as follows:

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

CHROMA COMPENSATION

Although the undesirable color distortion is corrected by correcting the local average image, the saturation of the resulting image is still lower than that of the original image, as the output of the retinex when using a small-scale Gaussian filter has very low saturation.

A method for reproducing chroma and lightness in an enhanced image was recently proposed by McCann.[11] His approach preserved the color ratios between adjacent pixels and reproduces more original-like images. However, while this approach may be the best solution for the problem of color representation generated in an enhanced or mapped image, as color changes resulting from clipping or compression are minimized by preserving the ratio, this process is very complicated with a high computational cost. Thus, the proposed method preserves the chroma value of the original image instead of preserving the ratio. First, the color space is first converted into CIELAB space to consider the human visual system. Assuming that the color space is sRGB color space, the RGB values are converted into CIEXYZ stimulus space using a 3×3 conversion matrix for sRGB color space as follows:[12]

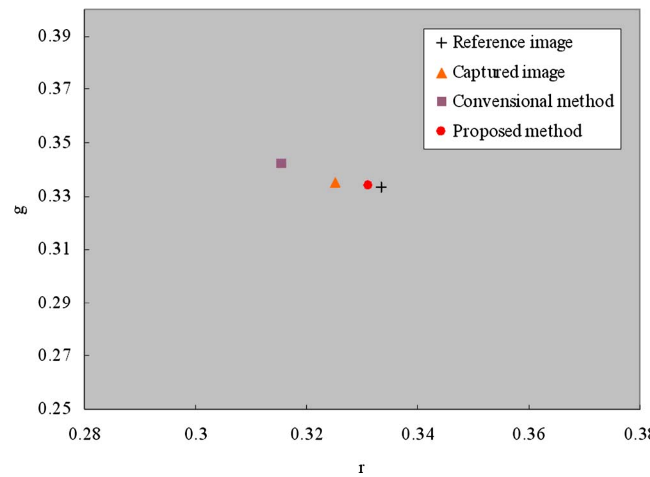


Figure 7. The chromaticity of white patches in *rg* space.

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

The XYZ values are then reconverted to CIELAB values as follows:

$$L^* = 116\left[f\left(\frac{Y}{Y_n}\right) - \frac{16}{116}\right],$$

$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right],$$

$$b^* = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right],$$

$$\text{where} \quad f(s) = \begin{cases} s^{1/3} & s > 0.008\,856 \\ 7.787s + 16/116 & \text{otherwise}, \end{cases} \tag{12}$$

where X_n, Y_n, and Z_n each represent the CIEXYZ value for the D65 illuminant. In CIELAB space, the chroma is given by

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

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

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

EXPERIMENT AND EVALUATIONS

As the results of a multi-scaled retinex are very sensitive to the scale parameters of the Gaussian filters, σ_n, and weight, ω_n, in Eq. (3), an evaluation criterion is needed for the re-

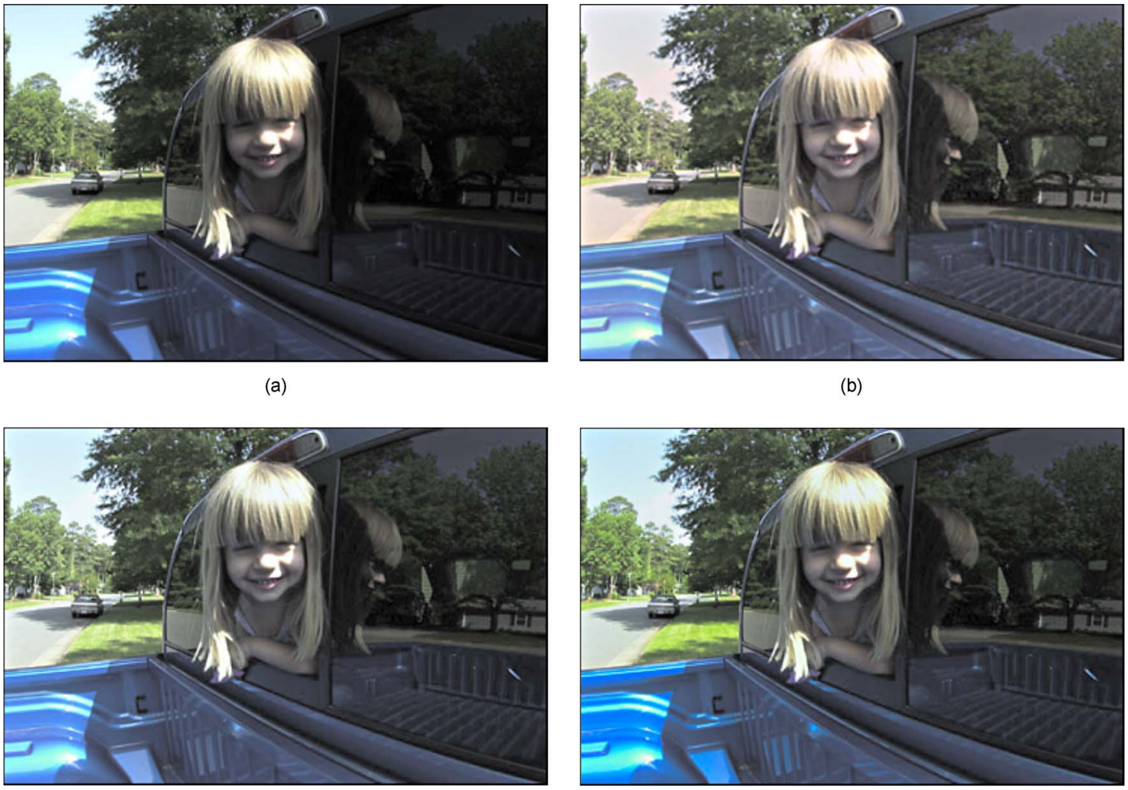
Table I. Comparison with chromaticity values of white patches.

White patch	Red	Green	Blue	*r*	*g*	Difference
Captured image	201	207	210	0.312	0.339	0.009453
Reference image	201	200	200	0.334	0.333	0
Resulting image by conventional method	234	254	254	0.315	0.342	0.021331
Resulting image by proposed method	251	253	254	0.331	0.334	0.003454

sulting image to optimize these parameters. However, since psychophysical experiments are generally used for evaluation, due to the absence of a reference image, the parameters must be determined empirically. The multi-scaled retinex proposed by Jobson[7] uses three Gaussian filters, small scale $\sigma=5$, middle scale $\sigma=20$, and large scale $\sigma=240$, with the weights uniformly applied as 1/3. The present study likewise used the same parameters $\sigma_n=(5,20,240)$ to create locally averaged images to stabilize and enhance the process results. However, use of equal weights for each scale increases halo artifacts in the resulting image. Accordingly the weights were empirically determined as $\omega_n=(0.3,0.1,0.6)$ to reduce the halos in the resulting images for good color rendition.

To determine the correction ratio, γ_s, for the local average image in Eq. (9), the chroma difference between the original image and the image processed with a single retinex algorithm was computed with variation in the scale of the Gaussian filter. The chroma difference was then normalized by the maximum chroma difference. Figure 5(a) shows the change in the chroma difference when varying the scale of the Gaussian filter for ten test images. Most of the chroma difference curves for the test images decreased exponentially. Figure 5(b) shows that the average curve for the test images decreased exponentially and converged to zero when the scale of the Gaussian filter was over 155. In other words, the image resulting from use of a small-scale Gaussian filter with a single-scale retinex had a smaller chroma component; thus the influence of the dominant chromaticity with a small-scale Gaussian filter was also lower than that with a large-scale Gaussian filter. Therefore, the correction ratios were determined as 0.1, 0.5, and 1.0 for the small-, middle-, and

Figure 8. "Red car with color chart" images with (a) reference image, (b) image resulting by multi-scaled retinex, (c) image resulting by proposed method without chroma compensation, and (d) image resulting by proposed method with chroma compensation.



(a) (b) (c) (d)

Figure 9. "Blue car" images with (a) original image, (b) image resulting by multi-scaled retinex, (c) image resulting by proposed method without chroma compensation, and (d) image resulting by proposed method with chroma compensation.

large-scale Gaussian filters based on the inverse curve in Fig. 5(b).

For a quantitative evaluation of the color distortion, as shown in Figure 6, the real scene test images were compared with a Macbeth color checker. The red color of the car became the dominant chromaticity of the test image. First, the chromaticity of a white patch in the captured image was extracted to estimate the chromaticity of the illumination in the real scene. The captured image was then divided by the average chromaticity of the white patch. An image with the chromaticity of the illumination removed was then obtained as a reference. Table I shows the chromaticity of the white patch in RGB and *rg* color space. When compared to the chromaticity of the white patch in the captured image, the chromaticity of the white patch in the reference image was close to gray. Thus, when compared with the reference image, the color difference, 0.02133, of the image resulting when using the conventional multi-scaled retinex was higher than the color difference (0.003 454) when using the proposed method. Figure 7 shows the distribution of the white patches in *rg* color space. The chromaticity of the white patch in the image resulting when using the proposed method was close to gray, while the chromaticity of the white patch in the image resulting when using the conventional multi-scaled retinex had a smaller r value than that of the reference.

The resulting images are compared in Figure 8. In the image resulting from use of the conventional multi-scaled retinex, shown in Fig. 8(b), a green color seemed to be added to the overall image, especially in the face region. In contrast, the image resulting using the proposed method, shown in Fig. 8(c), preserved the chromaticity of the reference image. In addition, the saturation of the image resulting was improved by the chroma compensation process, as shown in Fig. 8(d). Figures 9 and 10 show (a) the original image, (b) the images resulting after the multi-scaled retinex, (c) the proposed method without chroma compensation, and (d) the proposed method with chroma compensation process. The chromatic distribution of the original image [Fig. 9(a)] was dominated by blue and green. Thus, in Fig. 9(b), the image resulting with the multi-scaled retinex seemed to include a higher chromaticity value for magenta throughout although the detail was well represented in the window of the car. In particular, the color of the sky and load was shifted toward magenta. In contrast, for the image resulting with the proposed method without the chroma compensation process, shown in Fig. 9(c), the color of the sky and load was not shifted toward magenta, yet the detail in region of the car window was enhanced. For the image resulting with the proposed method including chroma compensation, shown in Fig. 9(d), the saturation preserving the lightness and hue was recovered. In contrast, in Fig. 10, the chromatic distribution of the original image shown in Fig. 10(a) was dominated by the red color. Therefore, in the image resulting with the multi-scaled retinex, shown in Fig. 10(b), the colors of the children's faces and white clothes

(a) (b) (c) (d)

Figure 10. "Wedding" images with (a) original image, (b) image resulting by multi-scaled retinex, (c) image resulting by proposed method without chroma compensation, and (d) image resulting by proposed method with chroma compensation.

became a bluish white color due to the dominant red color. However, in the image resulting with the proposed method, shown in Fig. 10(c), the colors of the children's faces and white clothes were preserved without any color distortion. In addition, in Fig. 10(d), the saturation of the resulting image was also restored when compared with the saturation of the original image.

To conduct a subjective evaluation, psychophysical experiments were performed. Ten observers with normal color vision participated in the test, and 30 test images were used to assess the image enhancement algorithms based on a multi-scaled retinex. Figure 11 shows some of the test images. The test images were classified into indoor scenes and outdoor scenes, where the 16 indoor test images were captured under an artificial illuminant and the 14 outdoor test images were captured at night or on an overcast day. Figure 12 shows the distribution of the average chromaticity for the test images in *rg* chromatic color space, which allowed the test images to be separated into four groups. The three test images with an average *r* chromaticity value over 5.5 were captured under a reddish illuminant or included a very reddish object in the scene. The test images with an average *r* chromaticity value between 0.4 and 0.5 were generally captured under an incandescent illuminant or included a reddish object in the scene. The test images with an average *r* chromaticity value between 0.3 and 0.4 were captured under a normal illuminant and included a grayish object. Finally, the two test images with an average *r* chromaticity value chromaticity below 0.3 included a bluish object, such as a car or the sky.

For the psychophysical experiments, a pair comparison method was used to assess the image resultings for each algorithm. The multi-scaled retinex proposed by Jobson,[7] the integrated multi-scaled retinex algorithm proposed by Wang,[2] and our proposed method were all compared. The parameters used for each algorithm were fixed based on the values suggested in the respective research papers. Each observer judged a pair of image resultings and assigned 1 to the selected image and 0 to the rejected image. In the case of a tie, 0.5 was assigned to each image. The scores were then totaled and converted to a *G*-score.[13]

Figure 13 and Table II show the *G*-scores of each algorithm for the 30 test images. The *G*-score values for our proposed method were generally higher than the *G*-score values for the other two methods, except for certain images. In particular, in the case of test images 2, 11, 15, 18, 20, 21, 25, and 26 that had an average *r* chromatcity value of more than 4.0, the images resulting from the proposed method were preferred. However, for images 3, 4, 12, 17, and 23, the image resultings from the integrated multi-scaled retinex method were preferred. The chroma and lightness of these original images were very low, thereby moving the observer preference to high saturation; the images resulting from the integrated multi-scaled retinex method generally had a

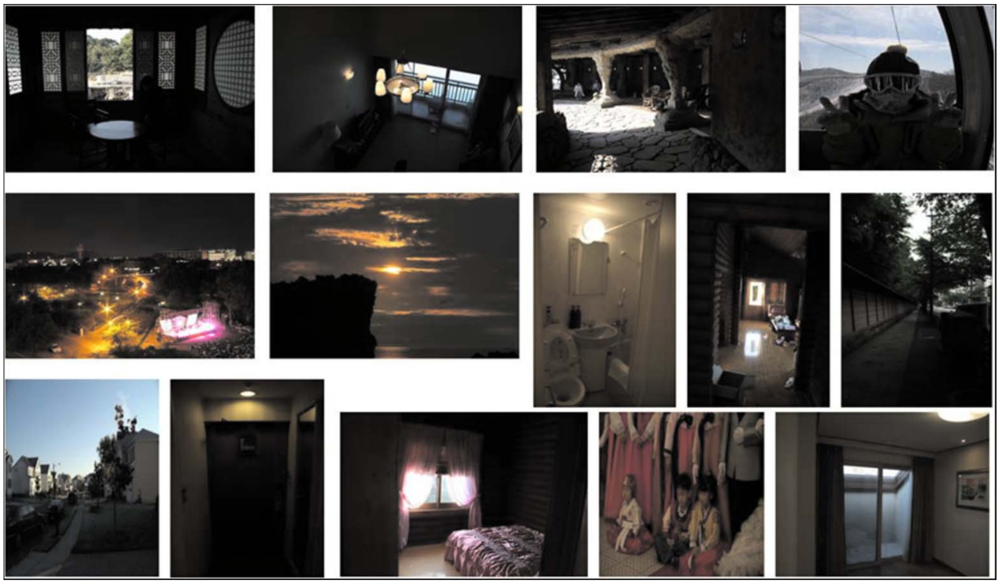


Figure 11. Test images for psychophysical experiment.

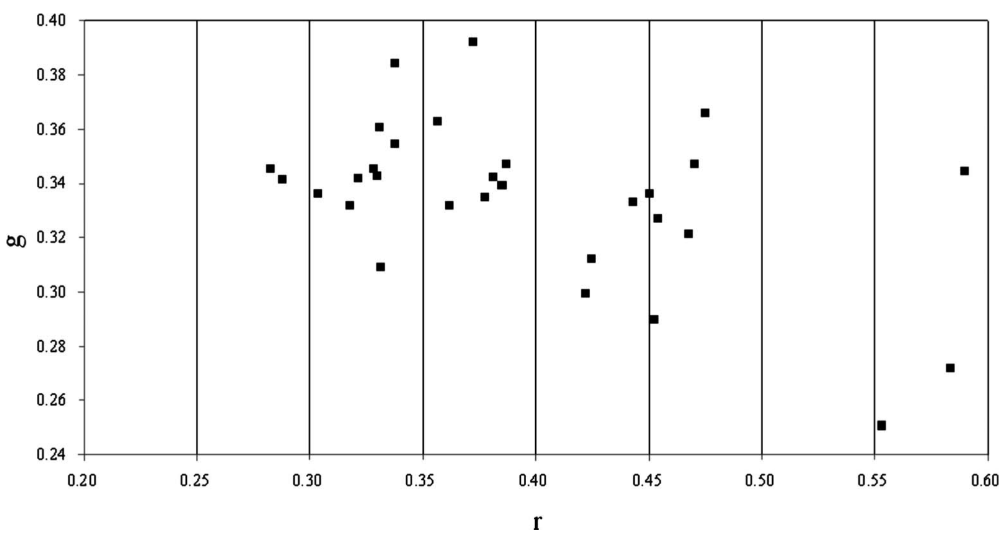


Figure 12. The average chromaticity values of test images in *rg* color space.

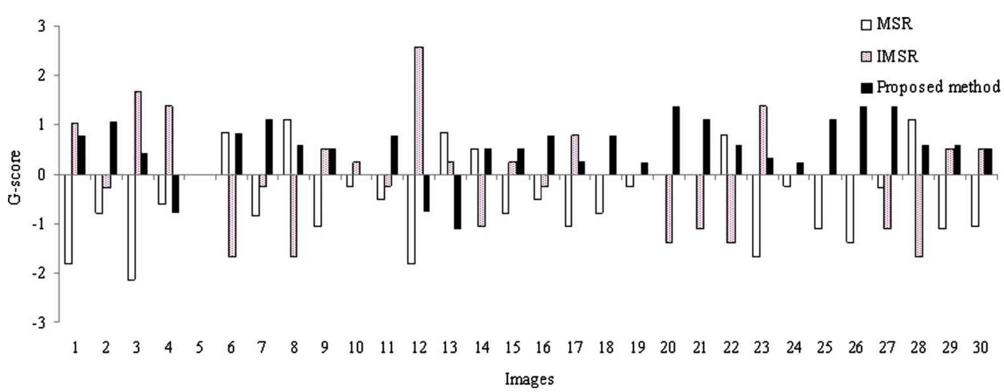


Figure 13. *G*-scores for 30 test images as a result of psychophysical experiment.

Table II. *G*-score for 30 images.

Image number	MSR	IMSR	Proposed method
1	−1.806	1.029	0.777
2	−0.777	−0.271	1.048
3	−2.124	1.684	0.44
4	−0.589	1.366	−0.777
5	0	0	0
6	0.842	−1.684	0.842
7	−0.842	−0.253	1.095
8	1.095	−1.684	0.589
9	−1.048	0.524	0.524
10	−0.253	0.253	0
11	−0.524	−0.253	0.777
12	−1.806	2.564	−0.758
13	0.842	0.253	−1.095
14	0.524	−1.048	0.524
15	−0.777	0.253	0.524
16	−0.524	−0.253	0.777
17	−1.048	0.777	0.271
18	−0.777	0	0.777
19	−0.253	0	0.253
20	0	−1.366	1.366
21	0	−1.095	1.095
22	0.777	−1.366	0.589
23	−1.684	1.366	0.318
24	−0.253	0	0.253
25	−1.095	0	1.095
26	−1.366	0	1.366
27	−0.271	−1.095	1.366
28	1.095	−1.684	0.589
29	−1.095	0.506	0.589
30	−1.048	0.524	0.524

higher chroma value than the images resulting from the other methods. In addition, test images 4, 12, and 13, which had negative *G*-scores for the proposed method, had lower lightness and chroma values.

CONCLUSIONS

The multi-scaled retinex algorithm improves the local contrast and image detail using the ratio of intensity for each channel between the original image and the local average image resulting from Gaussian filtering. When compared with conventional methods using a gamma curve or histogram, the multi-scaled retinex algorithm provides good performance, insofar as it considers the character of the spatially adaptive human visual system. However, if an original image has a chromatic distribution dominated by a particular chromaticity, the local average image obtained by Gaussian filtering includes that dominant chromaticity, thereby inducing color distortion. Therefore, the proposed method corrects the local average image using the average chromaticity and chromaticity of the illumination considering the scale of the Gaussian filter. Moreover, to improve the saturation of the resulting image, the chroma is compensated in CIELAB color space. As a result, the local contrast and image details are improved without any color distortion, and the saturation is restored using a chroma compensation process. Future studies will investigate a method for enhancing local contrast based on the lightness and chroma adaptation of the human visual system.

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