Color Correction of Faded Images using Multi-scale Gray World Algorithm

Wang-Jun Kyung, Dae-Chul Kim, Massimo Fierro, and Yeong-Ho Ha, School of Electronics Engineering, Kyungpook National University, Daegu, South Korea

Abstract

The enhancement of faded color on old pictures, printings, and paintings is one of important issue in color image processing. Several techniques have been introduced to enhance the faded images. Almost techniques are performed with global illuminant estimation algorithms such as the gray world assumption and white patch Retinex methods, since the phenomenon of color fading is regarded as an illuminant effect. However, fading effect is shown up differently according to the ink property, temperature, humidity, illuminants, and so on. Therefore simple global operators to eliminate the illuminant effects are not suitable for enhancing faded images. This paper presents a color enhancement algorithm based on multi-scale gray world algorithm for faded images. First, the proposed method adopts local process by using multi-scale mask. The coefficients for each multi-scale mask are obtained to apply the gray world algorithm. Then, integrating the coefficients with weights is performed to calculate correction ratio for red and blue channels in the gray world assumption. Finally, the enhanced image is obtained by applying the integrated coefficients to the gray world algorithm. In the experimental results, the proposed method reproduces better colors for both wholly and partially faded images compared with the previous methods.

Introduction

Recently, digital image processing techniques has been developed with the purpose of image enhancement, restoration, and so on. The field of digital color restoration of old pictures, printings, and paintings are interested in the recent years. The old media generally lose their original colors with various reasons. Therefore, restoration of faded image has been studied with various assumptions. Meanwhile, the phenomenon of color fading has been analyzed through various experiments, as the attempt to correct the faded images. For example, Franziska et al.[1] and Henry[2] investigated the effect of temperature, humidity, and illuminants on color fading, and found that the fading rate was differed according to the ink property, temperature, humidity, and illuminant. As a result, the color photo prints or documents are faded according to the illuminant, color, and area in the image.

Color constancy methods are normally applied to correct the color of faded images, as the phenomenon of color fading is regarded as an illuminant effect. Most color constancy methods assume that the perceptual color is a product of the reflectance and the illuminant. The reflectance of an object can be calculated from the perceptual color using an estimation of the illuminant. The most widely used color constancy methods are the gray world assumption and white patch Retinex methods[3]. The gray world assumption method estimates the illuminant using the average color of the pixels, whereas in the white patch Retinex method, if a bright patch in the image is a white patch in the scene, this patch then reflects the maximum light possible for each band. However, the assumption of the white patch Retinex algorithm is incorrect for the correction of faded images due to the change of dye property by illuminants. In other words, white area in color photo prints or documents has no dyes, which is very little change.

Meanwhile, a combination of these two methods has also been proposed, which uses a quadratic correction of two channels in order to simultaneously satisfy the gray world assumption and white patch Retinex[4]. Likewise, these methods are based on the global adaptation mechanism of human vision and work point-wise on the image data. These methods are simple and efficient, but they do not correct the partially faded images.

Recently, various Retinex methods have been widely used, due to their high local illuminant estimation and visibility improvement, even given the presence of artifacts like halo effects. Jobson 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[5,6]. Initially, the MSR method experienced problems related to appropriate values for the parameters, chromatic unbalance, color distortion, noise, and graying out. Thus, a lot of research has been dedicated to improve these issues. A multi-scale Retinex with color restoration attempted to overcome the graying-out phenomenon in large uniform areas of an image by adopting a color restoration function to control the saturation of final rendition[7]. 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[8]. In this case, a Gaussian pyramid decomposition is used to reduce the computational time for generating a large-scale surround, while an integrated surround value for the luminance is applied to each channel to preserve color balance in RGB color space. However, IMSR do not correct the faded images due to their preservation of the color balance in input image.

In this paper, we propose a multi-scale gray world algorithm to enhance the wholly or partially faded images. First, multi-scale masks such as average filter are used to estimate wholly or partially faded color. Next, to apply gray world algorithm, the coefficients are calculated for each pixel in each filtered image. The coefficient represents the correction ratio for red and blue channels based on green channel in the gray world assumption theory. After that, the integrated coefficient map is generated by using weighted sum of the calculated coefficients for each scale. Then, the enhancement image is obtained by applying the integrated coefficient map to gray world algorithm. It is shown in the experiments that the proposed method recovers the color not only on wholly faded image, but also on partially faded image.

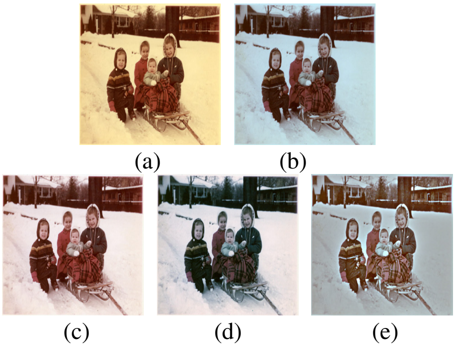

Figure 1. Result of GWA, WR, CGWR, and MSR. (a) is the original image, (b) is the resulting image by GWA, (c) is the resulting image by WR, (d) is the resulting image by CGWR, and (e) is the resulting image by MSR.

Related Work

Many color balance or color restoration algorithms are based on the theory of color image formation. The intensity I measured by camera sensor at position (x, y) can be modeled as

$$I(x, y) = E(x, y)\int R(\lambda, x, y)L(\lambda)S(\lambda)d\lambda \quad (1)$$

where $E(x, y)$ is the scaling factor resulting from the geometry of the patch at position (x, y), $R(, x, y)$ denotes the reflectance at position (x, y), $L( )$ is the radiance given off by the light source, and $S( )$ describes the sensitivity of the sensors.[9]

It is assumed that the response functions of the sensors have a very narrow-band, i.e. they can be approximated by a delta function. Let $_i$ with i•$\{r, g, b\}$ be the wavelengths to which the sensors respond. Under a nonuniform illuminant, the intensity measured by the sensor can be modeled as follows[3]:

$$I_i(x, y) = E(x, y)R_i(x, y)L_i(x, y) \quad (2)$$

where $E(x, y)$ is the factor that depends on the scene geometry, $R_i(x, y)$ is the reflectance for wavelength $_i$, and $L_i(x, y)$ is the irradiance at position (x, y) for wavelength $_i$.

Gray World Assumption Algorithm

The gray world assumption was proposed by Buchsbaum[10]. It estimates the illuminant by assuming that a certain standard spatial spectral average exists for total visual field. In terms of implementation, the image $I(x, y)$ have size $M\times N$, where x and y denote the indices of the pixel position. Furthermore, $I_R(x, y)$, $I_G(x, y)$, and $I_B(x, y)$ denote the red, green, and blue channels of the image respectively. The average values, R_{avg}, G_{avg}, and B_{avg}, are calculated as

$$R_{avg} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_r(x, y), \quad (3)$$

$$G_{avg} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_g(x, y), \quad (4)$$

$$B_{avg} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N} I_b(x, y). \quad (5)$$

The gray world assumption keeps the green channel unchanged, and defines the correction ratio for the red and blue channels as

$$\hat{\alpha} = \frac{G_{avg}}{R_{avg}}, \text{ and } \hat{\beta} = \frac{G_{avg}}{B_{avg}}. \quad (6)$$

Then, the red and blue pixels can be adjusted by

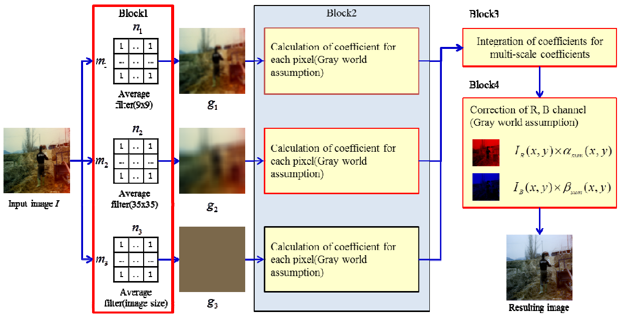

Figure 2. Procedure of the proposed color enhancement method.

$$\hat{I}_r(x, y) = \hat{\alpha} I_r(x, y), \quad (7)$$

$$\hat{I}_b(x, y) = \hat{\beta} I_b(x, y). \quad (8)$$

White Patch Retinex Algorithm

Under the Retinex theory, it is argued that the perceived white is associated with the maximum cone signals of the human visual system [11]. As such, the method for white balance should be to equalize the maximum values of the red, green, and blue channels. To avoid disturbances to the calculation caused by a few bright pixels, one can treat clusters of pixels or lowpass the image [12]. The maximum values, R_{max}, G_{max}, and B_{max}, are calculated as

$$R_{max} = \max_{x,y}\{I_r(x, y)\}, \quad (9)$$

$$G_{max} = \max_{x,y}\{I_g(x, y)\}, \quad (10)$$

$$B_{max} = \max_{x,y}\{I_b(x, y)\}, \quad (11)$$

As with the gray world assumption, the white patch Retinex keeps the green channel unchanged. This method define the gain for the red and blue channels as

$$\tilde{\alpha} = \frac{G_{max}}{R_{max}}, \text{ and } \tilde{\beta} = \frac{G_{max}}{B_{max}}. \quad (12)$$

Then, the adjusted red and blue channels are given by

$$\tilde{I}_r(x, y) = \tilde{\alpha} I_r(x, y), \quad (13)$$

$$\tilde{I}_b(x, y) = \tilde{\beta} I_b(x, y). \quad (14)$$

Combining Gray World and White Patch Retinex Algorithm

The combining gray world and white patch Retinex(CGWR) method proposed by Edmund method is based on the gray world assumption and the white patch Retinex algorithms for white balancing and color restoration[4]. The CGWR adopts a quadratic mapping of intensities and keep the green channel unchanged. The calculation of correction coefficients for red channel can be represented in a matrix form:

$$\begin{bmatrix} \sum_{x=1}^{M}\sum_{y=1}^{N} I_r^2(x, y) & \sum_{x=1}^{M}\sum_{y=1}^{N} I_r(x, y) \\ \max_{x,y}\{I_r^2(x, y)\} & \max_{x,y}\{I_r(x, y)\} \end{bmatrix} \begin{bmatrix} \mu \\ \nu \end{bmatrix} = \begin{bmatrix} \sum_{x=1}^{M}\sum_{y=1}^{N} I_g(x, y) \\ \max_{x,y}\{I_g(x, y)\} \end{bmatrix}, \quad (15)$$

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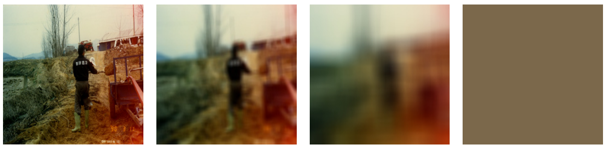


(a) (b) (c) (d)

Figure 3. Average filtered images. (a) is the original image, (b) is the resulting image by small scale filter, (c) is the resulting image by middle scale filter, and (d) is the resulting image by large scale filter.

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

Figure 4. Result of the proposed method. (a) is the wholly faded image, (b) is the resulting image for (a), (c) is the partially faded image, and (d) is the resulting image for (c).

where (μ, ν) are the parameters for white balance. In the Eq.(15), each column is represented for gray world assumption and white patch Retinex, respectively. Eq. (15) can be solved analytically, either with Gaussian elimination or using Cramer's rule. After that, the corrected image, $\tilde{I}_R(x,y)$, is calculated with (μ, ν) as

$$\tilde{I}_r(x,y) = \mu I_R^2(x,y) + \nu I_R(x,y). \quad (16)$$

The correction for the blue channel can be computed in an analogous manner. Figure 1(b), (c), and (d) shows the resulting images from the gray world assumption, white patch Retinex, and the CGWR algorithms. The CGWR shows better enhancement for white balance than other two methods. However, in the resulting image of white patch Retinex, faded colors are not corrected in snow region and the whole, since white region of old pictures and printings most little changes which is influenced the only paper without ink or dye by various effects. Therefore, the white patch Retinex is unsuitable for restoration of faded images.

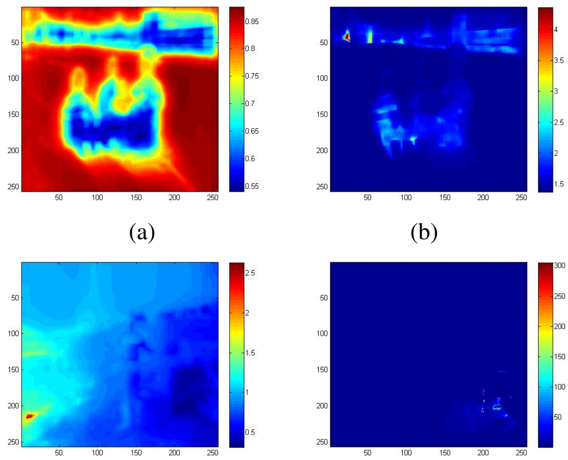
Multi-scale Retinex Algorithm

To consider local illumination effect, the multi-scale Retinex (MSR) used Gaussian filters based on the center/surround model[5,6]. The center/surround model simply estimates the luminance L around a pixel in consideration of averaging the image I with Gaussian filter. The MSR composes the integrating multiple SSRs with different scales and weights, so that the results for Gaussian filters with various scales are averaged with different weights using the following computation:

$$O_i(x,y) = \sum_{n=1}^{N} w_n \left\{ \log I_i(x,y) - \log\left\{ F_n(x,y) * I_i(x,y) \right\} \right\} \quad (17)$$

$$F_n(x,y) = Ke^{-(x^2+y^2)/\sigma_n^2} \quad \text{and} \quad \iint F_n(x,y)\,dxdy = 1 \quad (18)$$

where w_n represents the weight of the n-th scale. $F_n(x, y)$ is the Gaussian filter and $O_i(x, y)$ is the resulting image for each channel. 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



(a) (b)

(c) (d)

Figure 5. Integrated correction coefficients. (a) and (c) are the coefficient map for red channel, (b) and (d) are the coefficient map for blue channel.

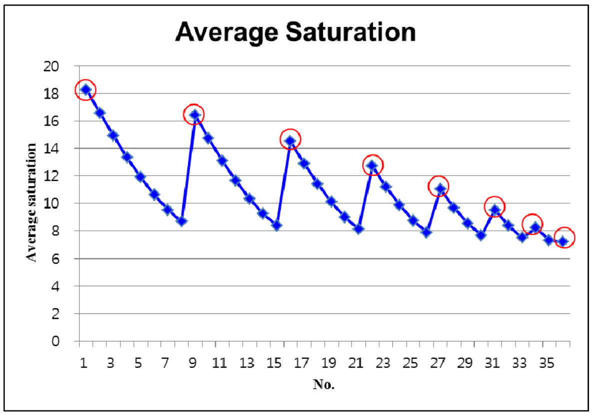


Figure 6. Change of average saturation for weights.

based on the weighted summation of these results. Figure 1 (e) shows the resulting image from the MSR. In the Fig. 1 (e), the whole faded image is corrected with local contrast enhancement. However, the MSR method produces the chromatic unbalance, i.e. color distortion.

The Proposed Multi-scale Gray World Algorithm

In this paper, we propose a multi-scale gray world algorithm to enhance wholly and partially faded images as shown in the Fig. 2. The proposed method is composed of four blocks. First, multi- scale average filter are used to estimate wholly or partially faded color. Next, to apply gray world algorithm, the coefficients are calculated for each pixel in multi-scale filtered images. The coefficient represents the correction ratio for red and blue channels based on green channel in the gray world assumption theory. After that, the integrated coefficient map is generated by using weighted sum of the calculated coefficients for each scale. Then, the correction image is obtained by applying the coefficient map to gray world algorithm.

Table I. Weight values for all cases.

No.	w_1	w_2	w_3	No.	w_1	w_2	w_3
1	0.1	0.1	0.8	19	0.3	0.4	0.3
2	0.1	0.2	0.7	20	0.3	0.5	0.2
3	0.1	0.3	0.6	21	0.3	0.6	0.1
4	0.1	0.4	0.5	22	0.4	0.1	0.5
5	0.1	0.5	0.4	23	0.4	0.2	0.4
6	0.1	0.6	0.3	24	0.4	0.3	0.3
7	0.1	0.7	0.2	25	0.4	0.4	0.2
8	0.1	0.8	0.1	26	0.4	0.5	0.1
9	0.2	0.1	0.7	27	0.5	0.1	0.4
10	0.2	0.2	0.6	28	0.5	0.2	0.3
11	0.2	0.3	0.5	29	0.5	0.3	0.2
12	0.2	0.4	0.4	30	0.5	0.4	0.1
13	0.2	0.5	0.3	31	0.6	0.1	0.3
14	0.2	0.6	0.2	32	0.6	0.2	0.2
15	0.2	0.7	0.1	33	0.6	0.3	0.1
16	0.3	0.1	0.6	34	0.7	0.1	0.2
17	0.3	0.2	0.5	35	0.7	0.2	0.1
18	0.3	0.3	0.4	36	0.8	0.1	0.1

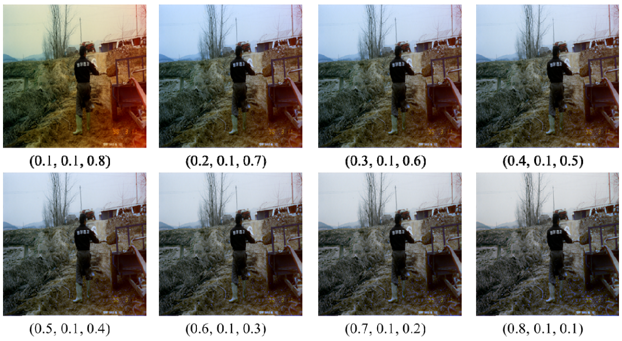


Figure 7. *Selected result using red circle in Fig. 6.*

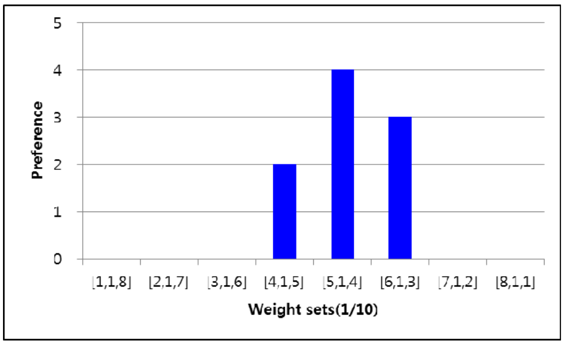


Figure 8. *Result of observer's preference test to define final result.*

Calculation of Multi-scale Correction Coefficients

The proposed method is based on the gray world algorithm to estimate illuminant, since its assumption is suitable for the faded image. In Eqs. (6), $\hat{\alpha}$ and $\hat{\beta}$ in the gray world algorithm are correction coefficients for global operation. These two coefficients are applied to red and blue channels as correction ratio, respectively. In the proposed method, to correct partially faded color, the multi-scale technique is used to calculate multi-scale correction coefficients. To obtain correction coefficients, the faded input image which have size $M \times N$, is first blurred using average filters as follows:

$$g_{i,k}(x,y) = \frac{1}{m_k n_k} \sum_{s=-a_k}^{a_k} \sum_{t=-b_k}^{b_k} I_i(x+s, y+t) \tag{19}$$

where the $g_{i,k}(x,y)$ is the average filtered images, k is scale number which used three scale, and i is the color channels such as R, G, B. The m_k and n_k are the sizes of average filters. In the proposed method, each filter kernel size used is 9×9, 35×35, and whole image, which means small, middle, and whole area to estimate partially faded color. Figure 3 shows the average filtered images for each scale. In the Fig. 3 (d), the resulting image by whole average filter is obtained by calculation of average value for each channel to reduce computational costs. Then, the pointwise correction coefficients for each scale are calculated by

$$\alpha_k(x,y) = \frac{g_{G,k}(x,y)}{g_{R,k}(x,y)}, \tag{20}$$

$$\beta_k(x,y) = \frac{g_{G,k}(x,y)}{g_{B,k}(x,y)}. \tag{21}$$

where $\alpha_k(x, y)$ and $\beta_k(x, y)$ are pointwise correction coefficients for each scale k. In Eqs. (20) and (21), calculation of coefficients is similar to Eq. (6) in the gray world assumption. The pointwise correction coefficients for each scale k are included the color correction ratio according to small, middle, and whole image area for red and blue channel. To apply the correction coefficients to the gray world assumption, these coefficients are integrated scales with weights as follows:

$$\alpha_{sum}(x,y) = \sum_{k=1}^{3} \alpha_k(x,y) \cdot w_k \tag{22}$$

$$\beta_{sum}(x,y) = \sum_{k=1}^{3} \beta_k(x,y) \cdot w_k \tag{23}$$

$$\sum_{k=1}^{3} w_k = 1 \tag{24}$$

where $\alpha_{sum}(x, y)$ and $\beta_{sum}(x, y)$ are the integrated correction coefficients, wk is weight for each scale k. The proposed method then adjusts the red and blue pixels using both $\alpha_{sum}(x, y)$ and $\beta_{sum}(x, y)$ as follows:

$$I'_R(x,y) = I_R(x,y) \cdot \alpha_{sum}(x,y) \tag{25}$$

$$I'_B(x,y) = I_B(x,y) \cdot \beta_{sum}(x,y) \tag{26}$$

where I' is a resulting image. Figures 4 (b) and (d) are shown the resulting images with w_1=0.4, w_2=0.3, and w_3=0.3 for Figs. 4 (a) and (c), which are wholly and partially faded input images, respectively. It is shown that the wholly and partially faded images are almost corrected, and especially, in Fig. 4 (d) the reddish color on the bottom of right is almost removed. In the Fig. 5, (c) and (d) are the integrated correction coefficients by Eqs. (22) and (23) for Fig. 4 (c). The $\alpha_{sum}(x, y)$ for red channel have ratio from 0.3 to 2.6 and the $\beta_{sum}(x, y)$ for blue channel have ratio from 1 to 305. In other words, the correction ratios of reddish region on the bottom of right in Fig. 4 (d) have small rate for reduction of the reddish color. On the other hand, the correction ratios of normal region on the left side in Fig. 4 (d) have similar rate to 1, which means preservation of the blue channel.

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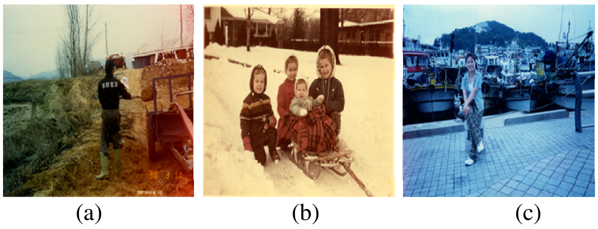

Figure 9. *Input images for experimentation.*

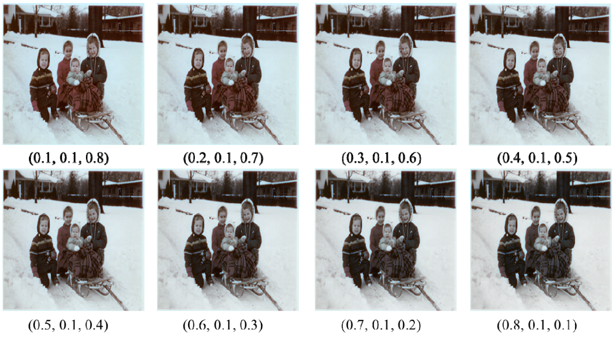

Figure 10. *Selected result using red circle for Fig. 9 (b).*

Figure 11. *Selected result using red circle for Fig. 9 (c).*

Experiments and results

In the experiments, first, we observed the influence according to the weights. Figure 6 shows average saturation in CIELAB color space for each weight such as Table 1. The average saturation of resulting images is reduced depending on the small weight which is w_1. In other words, w_1 is related to partially faded correction. Then, we select candidate images as the circle in Fig. 6 including high saturation image for each w_1. Figure 7 shows the selected candidate images. Then, we select the final resulting image using subjective preference test. The subjective preference test was performed involving 9 observers, aged 24-34. The observers were then asked to select the image according to the correction of faded image between the input image and the resulting images. Figure 8 shows the resulting subjective preference test for selected candidate images from Fig. 4 (c).

In the second experiments, we compared resulting images with three faded images. Figure 9 shows the input images, and Figs. 7, 10, and 11 are the calculated candidate images for each input image. Then, the final selected image is obtained by observer's preference test. The results from the proposed method were compared with those from the gray world assumption [3], white patch Retinex [3], CGWR [4], and

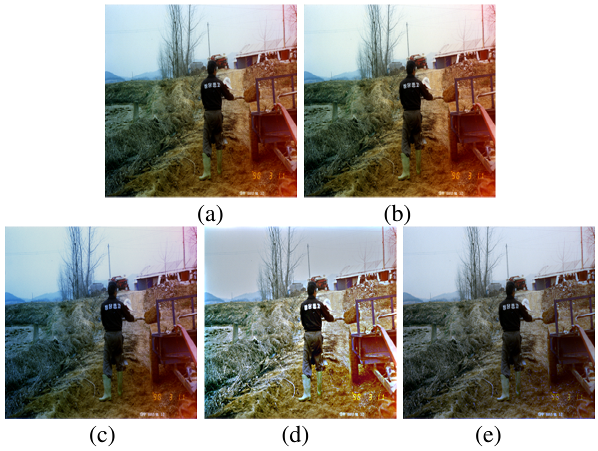

Figure 12. *Comparison of resulting images for Fig. 9 (a). (a) is the resulting image by GWA, (b) is the resulting image by WR, (c) is the resulting image by CGWR, (d) is the resulting image by MSR, and (e) is the resulting image by proposed method.*

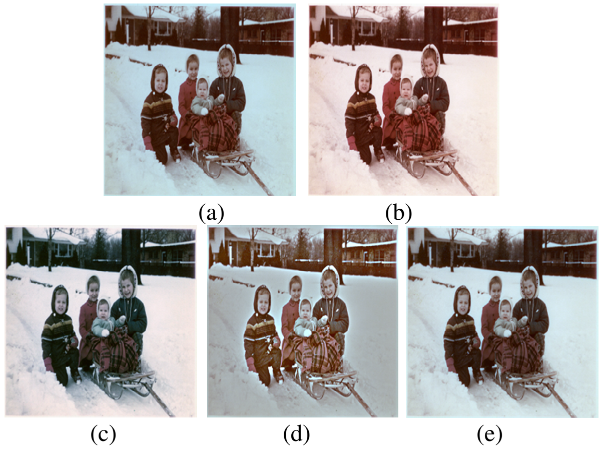

Figure 13. *Comparison of resulting images for Fig. 9 (b). (a) is the resulting image by GWA, (b) is the resulting image by WR, (c) is the resulting image by CGWR, (d) is the resulting image by MSR, and (e) is the resulting image by proposed method.*

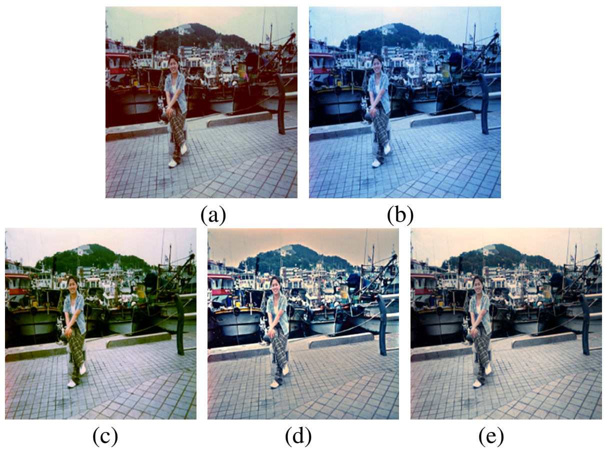

Figure 14. *Comparison of resulting images for Fig. 9 (c). (a) is the resulting image by GWA, (b) is the resulting image by WR, (c) is the resulting image by CGWR, (d) is the resulting image by MSR, and (e) is the resulting image by proposed method.*

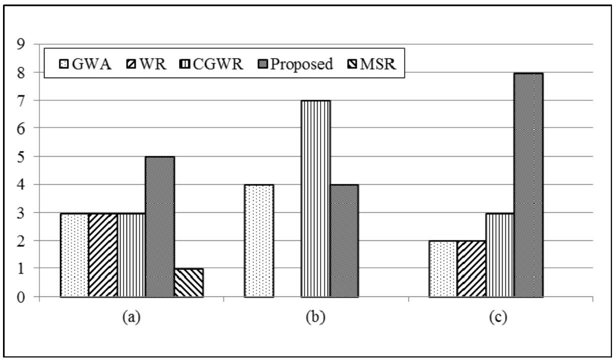

Figure 15. Result of preference test.

MSR[5-6]. The proposed method produced a better color enhancement for the partially faded images, comparing to the conventional method in the Figs. 12, 13, and 14.

As subjective evaluation, an observer's preference test was performed involving 15 observers, aged 25-34. The observers were asked to select the image according to criteria: enhancement of faded color between input and resulting images. As shown in Fig. 15, most observers selected the proposed method for the partially faded images.

Conclusion

We proposed a multi-scale gray world algorithm to enhance both wholly and partially faded images. To consider partially faded images, we integrated gray world assumption algorithm and multi-scale technique. First, we calculate multiple correction ratios to apply gray world algorithm. Then, the integrated coefficient map is generated by using weighted sum of the calculated coefficients for each scale. Finally, the integrated correction ratio is applied to each pixel of input red and blue channels based on the gray world assumption. In the experiments, the proposed method shows color correction in both globally and partially faded images. However, finding more robust and stable weights in a full automatic mode and enhancing the local contrast for faded images are left to future work to improve the proposed method.

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Author Biography

Wang-Jun Kyung received his B.S. in Dept. of Computer engineering from Andong National University, in 2007, and M.S in the School of Electrical Engineering and Computer Science from Kyungpook National University in 2010. He is also currently pursuing Ph.D student in the School of Electrical Engineering and Computer Science from Kyungpook National University. His research interests include color reproduction algorithm, color image enhancement, and image quality evaluation.

Yeong-Ho Ha received the B. S. and M. S. degrees in Electronic Engineering from Kyungpook National University, Taegu, Korea, in 1976 and 1978, respectively, and Ph. D. degree in Electrical and Computer Engineering from the University of Texas at Austin, Texas, 1985. In March 1986, he joined the Department of Electronics Engineering of Kyungpook National University and is currently a professor. He served as TPC chair, committee member, and organizing committee chair of many international conferences held in IEEE, SPIE, and IS&T and domestic conferences. He served as president and vice president in Korea Society for Imaging Science and Technology (KSIST), and vice president of the Institute of Electronics Engineering of Korea (IEEK). He is a senior member of IEEE, a member of Pattern Recognition Society and Society for IS&T and SPIE, and a fellow of IS&T. His main research interests are in color image processing, computer vision, and digital signal and image processing.

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