A HUE-PRESERVING CONTRAST ENHANCEMENT METHOD USING HISTOGRAM SPECIFICATION FOR EACH RGB COMPONENT

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ABSTRACT

The image enhancement is one of the most important image processing techniques and is used to improve the quality of the image captured in various situations. In this study, we propose a novel hue preserving contrast enhancement method that realizes the chroma adjustment while suppressing over-enhancement. In the proposed method, firstly, the histogram of each RGB component of an original image is smoothed by a Gaussian filter. Then, the histogram specification method is performed using the smoothed histogram of each RGB component to spread the pixel distribution in RGB color space. The obtained RGB values are approximated by a linear equation of the input RGB values in order to satisfy Naik and Murthy's hue preserving condition. If out-of-gamut values occur after the approximation, they are corrected by rearranging them on the equi-hue plane in the RGB color space. In the experiments, the effectiveness of the proposed method is verified by qualitative and quantitative evaluations.

Index Terms— Contrast enhancement, Smoothed histogram, Hue preserving, Equi-hue plane, Chroma

1. INTRODUCTION

In recent years, with the spread of Social Networking Services (SNS), users are increasingly editing and sharing their own photos. The visibility of the photographs taken in some environments may be low. For these photos, enhancing its visibility through contrast enhancement is achieved commonly. Generally, for natural images, the contrast enhancement processing is applied to the lightness component of the image, and RGB values are adjusted based on the lightness before and after processing. In this process, the output RGB values are processed by clipping so that they do not exceed the displayable color gamut.

Histogram Equalization (HE) [1, 2] and Contrast Limited Adaptive Histogram Equalization (CLAHE) [3] are typical contrast enhancement methods. These method can enhance the overall contrast of the image. However they tend to cause over-enhancement. Naik and Murthy defined hue preservation conditions in the RGB color space and proposed a contrast enhancement method based on them [4]. In Naik and Murthy's method, the contrast is significantly enhanced by applying HE to the luminance component. Although it preserves hue and guarantees processing within the color gamut, this method has the disadvantage that the image becomes less vivid. Ueda et al. proposed a method which expands pixel distribution on the equi-hue plane in RGB color space constructed with white, black, and pure colors [5]. Ueda et al.'s method can enhance the lightness contrast and saturation of an image simultaneously. However, it is necessary to adjust the smoothing parameters depending on the image to be processed. Besides these methods, contrast enhancement methods [6–12] have been proposed for specific images such as low-light images and blurry images rather than natural images. Recently, learning-based contrast enhancement methods have also been proposed [13, 14]. Ni et al. proposed a method to enhance image contrast using GAN (Generative Adversarial Networks). Ni et al.'s method can effectively enhance image. However, it does not preserve the hue of the input image. Wang et al. proposed a method which enhances the image contrast by using local color distribution as prior information. Wang et al.'s method preserves the hue of the input image. However this method can not enhance the overall contrast of the image well. Ni et al. and Wang et al. methods have the problem that the contrast enhancement effects and chroma cannot be easily adjusted.

In this study, we propose a hue preserving contrast enhancement method that realizes the chroma adjustment while suppressing over-enhancement. The proposed method consists of 1) the contrast enhancement based on the histogram specification in each RGB component, 2) the output approximation by a linear equation of the input RGB values, and 3) the correction of out-of-gamut values. Experiments using various images are conducted to demonstrate the effectiveness of the proposed method.

2. PROPOSED METHOD

2.1. Hue preserving contrast enhancement method

The pixel value at the position (i, j) of the input image (24-bit full-color) is denoted as $\boldsymbol{I}(i, j) \in [0, 1]^3$. Naik and Murthy [4] defined the condition of the hue preservation in RGB color space as follows:

$$\boldsymbol{O}(i, j) = A(i, j)\boldsymbol{I}(i, j) + B(i, j)\boldsymbol{e}, \tag{1}$$

where $A(i,j)$ and $B(i,j)$ are parameters for scaling and shifting, respectively. In Eq. (1), $\boldsymbol{e}$ is $(1,1,1)$.

In the proposed method, a histogram of each RGB component of the input image is calculated as:

$$h^c(x) = \sum_{i=1}^{M}\sum_{j=1}^{N}\delta\big(x/255, I^c(i,j)\big), \quad \forall x \in [0,255], \tag{2}$$

$$\delta\big(x/255, I^c(i,j)\big) = \begin{cases} 1, & x/255 = I^c(i,j), \\ 0, & \text{otherwise}, \end{cases} \tag{3}$$

where $I^c(i,j)$ is the pixel value of c ($\in \{R,G,B\}$) component at position (i,j). $h^c(x)$ is the histogram of c component. A smoothed histogram of c component is obtained by:

$$h^c_\sigma(x) = \sum_{k=-r}^{r} g(k)h^c(x-k), \quad \forall x \in [0,255], \tag{4}$$

$$g(k) = \frac{\exp(-\frac{k^2}{2\sigma^2})}{\sum_{k'=-r}^{r}\exp(-\frac{k'^2}{2\sigma^2})}, \tag{5}$$

where $h^c_\sigma(x)$ is the smoothed histogram of c component. σ is the standard deviation of a Gaussian function. r is given as $\lceil 3\sigma \rceil$. $\lceil\cdot\rceil$ is a celling function. Also, the normalized cumulative histogram $H^c(x)$ of $h^c(x)$ is obtained by:

$$H^c(x) = \sum_{x'=0}^{x} h^c_{nor}(x'), \quad \forall x \in [0,255], \tag{6}$$

$$h^c_{nor}(x) = \frac{h^c(x)}{\sum_{x'=0}^{255} h^c(x')}, \quad \forall x \in [0,255]. \tag{7}$$

The normalized cumulative histogram $H^c_\sigma(x)$ of $h^c_\sigma(x)$ is obtained in the similar manner to Eqs. (6) and (7). Finally, the histogram specification method is achieved as follows:

$$J^c(i,j) = inf\big\{z/255 | H^c_\sigma(z) \geq H^c\big(255 I^c(i,j)\big)\big\}, \tag{8}$$

where $J^c(i,j)$ is an image obtained after the histogram specification. In this case, $\boldsymbol{J}(i,j)$ does not preserve the hue of the input image.

$\boldsymbol{J}(i,j)$ is approximated by Eq. (1) to adjust the chroma while preserving the hue of the input image. $A(i,j)$ and $B(i,j)$ are determined by solving the minimization problem whose cost function is given by:

$$\begin{aligned} E(i,j) = &\sum_{c\in\{R,G,B\}} \big\{J^c(i,j) - \big(A(i,j)I^c(i,j) + B(i,j)\big)\big\}^2 \\ &+ \lambda \sum_{(c',c'')\in\Omega} \Big\{A(i,j)\big(I^{c'}(i,j) - I^{c''}(i,j)\big)\Big\}^2, \end{aligned} \tag{9}$$

where Ω is $\{(R,G),(R,B),(G,B)\}$. λ is the chroma adjustment parameter. The second term of the right side of the equation is the term related to the chroma adjustment. When λ is positive, it approaches achromatic color, and when λ is negative, it moves away from the achromatic color. Figure 1 shows the resultant images when the parameters of the proposed method, (λ, σ) are changed from $(-0.1, 25)$ to $(0.1, 75)$. From Fig. 1, it can be seen that the contrast is enhanced as σ increases. Also, when $\lambda > 0$, it approaches achromatic color, and when $\lambda < 0$, it will be a highly saturated color. $A(i,j)$ and $B(i,j)$ are obtained by using the least-squares method as follows:

Fig. 1. Resultant images obtained by the proposed method with $(\lambda, \sigma) = (-0.1, 25) \sim (0.1, 75)$.

$$A(i,j) = \frac{s_{\boldsymbol{I},\boldsymbol{J}}(i,j)}{\sigma^2_{\boldsymbol{I}} + \frac{\lambda}{3}\sum_{(c',c'')\in\Omega}\big(I^{c'}(i,j) - I^{c''}(i,j)\big)^2}, \tag{10}$$

$$B(i,j) = \bar{J}(i,j) - A(i,j)\bar{I}(i,j), \tag{11}$$

$$s_{\boldsymbol{I},\boldsymbol{J}}(i,j) = \frac{1}{3}\sum_{c\in\{R,G,B\}} I^c(i,j)J^c(i,j) - \bar{J}(i,j)\bar{I}(i,j), \tag{12}$$

$$\sigma^2_{\boldsymbol{I}}(i,j) = \frac{1}{3}\sum_{c\in\{R,G,B\}}\big(I^c(i,j)\big)^2 - \bar{I}(i,j)^2, \tag{13}$$

$$\bar{I}(i,j) = \frac{1}{3}\sum_{c\in\{R,G,B\}} I^c(i,j), \tag{14}$$

$$\bar{J}(i,j) = \frac{1}{3}\sum_{c\in\{R,G,B\}} J^c(i,j), \tag{15}$$

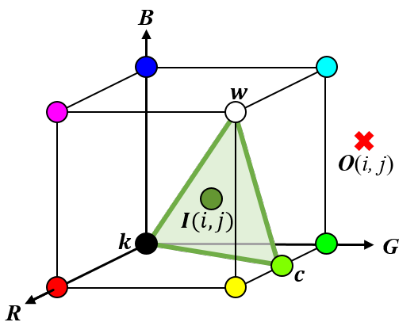

Fig. 2. Equi-hue plane in RGB color space.

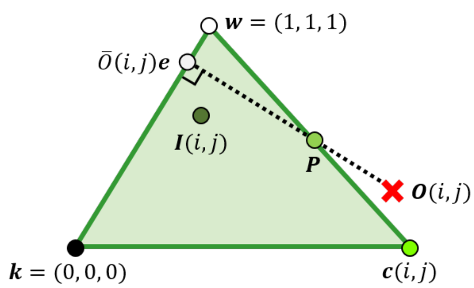

Fig. 3. Equi-hue plane of a $\boldsymbol{I}(i,j)$.

where $s_{\boldsymbol{I},\boldsymbol{J}}(i,j)$ is a covariance of RGB components of $\boldsymbol{I}(i,j)$ and $\boldsymbol{J}(i,j)$. $\sigma^2_{\boldsymbol{I}}(i,j)$ is a variance of RGB components of $\boldsymbol{I}(i,j)$. $\bar{I}(i,j)$ and $\bar{J}(i,j)$ are averages of RGB components of $\boldsymbol{I}(i,j)$ and $\boldsymbol{J}(i,j)$, respectively. Using the obtained $A(i,j)$ and $B(i,j)$, $\boldsymbol{O}(i,j)$ is obtained. When $\boldsymbol{O}(i,j)$ is out of the color gamut, it is rearranged on the equi-hue plane in RGB color space.

2.2. Correction of out-of-gamut pixels on equi-hue plane in RGB color space

An equi-hue plane in RGB color space is a triangular region whose vertices correspond to white, black and pure color. White and black are represented as 3-dimentional vectors $\boldsymbol{w} = (1,1,1)$ and $\boldsymbol{k} = (0,0,0)$, respectively. The pure color $\boldsymbol{c}$ [15] is most vivid color that has the same hue as the input pixel $\boldsymbol{I}(i,j)$. The pure color is calculated as:

$$\boldsymbol{c}(i,j) = \frac{\boldsymbol{I}(i,j) - \min_{c\in\{R,G,B\}}\big(I^c(i,j)\big)\boldsymbol{e}}{\max_{c\in\{R,G,B\}}\big(I^c(i,j)\big) - \min_{c\in\{R,G,B\}}\big(I^c(i,j)\big)}, \quad (16)$$

where $\max_{c\in\{R,G,B\}}\big(I^c(i,j)\big)$ and $\min_{c\in\{R,G,B\}}\big(I^c(i,j)\big)$ are the maximum and minimum among RGB components in the input $\boldsymbol{I}(i,j)$, respectively.

Figure 2 shows an example of the equi-hue plane in RGB color space when $\boldsymbol{O}(i,j)$ is out of color gamut. Figure 3 shows an example of processing when $\boldsymbol{O}(i,j)$ is out of the color gamut. In this case, $\boldsymbol{O}(i,j)$ is modified to a point on an line of the equi-hue plane while keeping the lightness value of $\boldsymbol{O}(i,j)$. Specifically, $\boldsymbol{O}(i,j)$ on the line segment $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$ is modified to the intersection with the line of equi-hue plane. Figure 3 shows an intersection $\boldsymbol{P}$ of the line segment $\boldsymbol{c}(i,j)\boldsymbol{w}$ and the line segment $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$. The points $\boldsymbol{P_{c,w}}$ on the line segment $\boldsymbol{c}(i,j)\boldsymbol{w}$ and $\boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}}$ on line segment $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$ are given as:

$$\boldsymbol{P_{c,w}} = \boldsymbol{c}(i,j) + s\big(\boldsymbol{w} - \boldsymbol{c}(i,j)\big), \quad (17)$$

$$\boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}} = \boldsymbol{O}(i,j) + t\big(\bar{O}(i,j)\boldsymbol{e} - \boldsymbol{O}(i,j)\big), \quad (18)$$

where the positional relationship between the coefficient s and the point $\boldsymbol{P_{c,w}}$ is as follows.

$$\begin{array}{ll} s < 0 & \text{Outside line } \boldsymbol{c}(i,j)\boldsymbol{w}\ (\boldsymbol{c}(i,j) \text{ side}) \\ s = 0 & \text{Point } \boldsymbol{c}(i,j) \\ 0 < s < 1 & \text{On the line } \boldsymbol{c}(i,j)\boldsymbol{w}. \\ s = 1 & \text{Point } \boldsymbol{w} \\ s > 1 & \text{Outside line } \boldsymbol{c}(i,j)\boldsymbol{w}\ (\boldsymbol{w} \text{ side}) \end{array} \quad (19)$$

Also, the positional relationship between the coefficient t and the point $\boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}}$ is the same as in Eq. (19). At the intersection $\boldsymbol{P}$, the following relationship is satisfied:

$$\boldsymbol{P}_{\boldsymbol{O},\bar{O}\boldsymbol{e}} = \boldsymbol{P_{c,w}}. \quad (20)$$

By calculations using inner and cross products for Eq. (20), s and t can be obtained [16] as follows:

$$t = \frac{\Big(\big(\boldsymbol{c}(i,j) - \boldsymbol{O}(i,j)\big) \times \boldsymbol{d}_2\Big) \cdot (\boldsymbol{d}_1 \times \boldsymbol{d}_2)}{(\boldsymbol{d}_1 \times \boldsymbol{d}_2) \cdot (\boldsymbol{d}_1 \times \boldsymbol{d}_2)}, \quad (21)$$

$$s = \frac{\Big(\big(\boldsymbol{O}(i,j) - \boldsymbol{c}(i,j)\big) \times \boldsymbol{d}_1\Big) \cdot (\boldsymbol{d}_2 \times \boldsymbol{d}_1)}{(\boldsymbol{d}_2 \times \boldsymbol{d}_1) \cdot (\boldsymbol{d}_2 \times \boldsymbol{d}_1)}, \quad (22)$$

where $\cdot$ and $\times$ are the inner and cross product operators, respectively. In the case where $0 \le s$ and $t \le 1$ are satisfied, the intersection is on the line segment $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$ and the line segment $\boldsymbol{c}(i,j)\boldsymbol{w}$. The final output value $\boldsymbol{O}'(i,j)$ is calculated as follows:

$$\boldsymbol{O}'(i,j) = \boldsymbol{O}(i,j) + t\big(\bar{O}(i,j)\boldsymbol{e} - \boldsymbol{O}(i,j)\big). \quad (23)$$

If $0 \le s$ and $t \le 1$ are not satisfied, the line segment $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$ is assumed to have an intersection with line segment $\boldsymbol{c}(i,j)\boldsymbol{k}$. In this case, $\boldsymbol{O}'(i,j)$ is calculated by using $\boldsymbol{O}(i,j)\bar{O}(i,j)\boldsymbol{e}$ and $\boldsymbol{c}(i,j)\boldsymbol{k}$ in the similar manner to Eq. (23). If $0 \le s$ and $t \le 1$ are still not satisfied, $\bar{O}(i,j)\boldsymbol{e}$ becomes $\boldsymbol{O}'(i,j)$.

3. EXPERIMENTS

3.1. Conditions

In experiments, 37 images (24-bit full color) from datasets SIDBA (12 images) [17] and Kodak (25 images) [18] were used. The proposed method was compared with HE [1], CLAHE [3], Naik et al.'s method [4], Ueda et al.'s method [5], Ni et al.'s method [13] and Wang et al.'s method [14]. HE was applied to each RGB component of the input image, and was also applied to I component of HSI color space. CLAHE was applied to I component of HSI color space. Parameters in the compared methods were set according to references. Parameters in the proposed method were set as follows: $\sigma = 50$, $\lambda = -0.1$. For quantitative evaluations, the standard deviation of L^* in the CIE$L^*a^*b^*$ color space, CIE1976ab average of chroma C^*, LOE (Lightness Order Error) [19] and Q value [20] were used. The standard deviation of L^* is a measure for intensity contrast. The average of C^* is a measure for vividness. LOE is a measure showing the change in the order relationship of lightness between the original and resultant images. Q value is an evaluation index of image quality.

3.2. Experimental results

Figure 4 shows an example of the enhancement result. As shown in Fig. 4(b), the over-enhancement is caused in the resultant image obtained by HE (RGB). As shown in Figs. 4(c)-4(f), the resultant images obtained by HE (I), CLAHE (I), Naik et al.'s method and Ueda et al.'s method are less vivid than the image obtained by the proposed method, respectively. As shown in Fig. 4(h), the contrast of the image obtained by Wang et al.'s method is very low. On the other hand, as shown in Fig. 4(g), the contrast of the image obtained by Ni et al.'s method is well-enhanced. However, the lightness contrast of the girl's clothing gives a weaker impression than the proposed method as shown in Figs. 4(g) and 4(i).

Figure 5 also shows an example of the enhancement result. As shown in Figs. 5(c), 5(f), 5(g) and 5(i), the images obtained by HE (I), Ueda et al.'s method and Ni et al.'s method are similar to the image obtained by the proposed method, respectively. However, in HE (I), the over-enhancement is caused in the sky clouds as shown in Fig. 5(l). From Figs. 5(o), 5(p) and 5(r), it is observed that the proposed method has the best visibility improvement for the mountain surface. On the other hand, HE (RGB), CLAHE (I), Naik et al.'s method and Wang et al.'s method enhance the contrast, but are far from the impression of the input image as shown in Figs. 5(b), 5(d), 5(e) and 5(h), respectively.

Table 1 shows the averages of the standard deviation of L^* and the average of C^*. The boldface shows the maximum which indicates the best performance. From Table 1, the standard deviation of L^* of the proposed method is inferior to those of HE (RGB), HE (I), CLAHE (I) and Naik et al.'s method, but it still indicates a relatively large value. From the above, it can be seen that the proposed method emphasizes lightness contrast. Also, the average of C^* of the proposed method shows the largest value. It can be seen that the proposed method is able to increase the vividness of the image well.

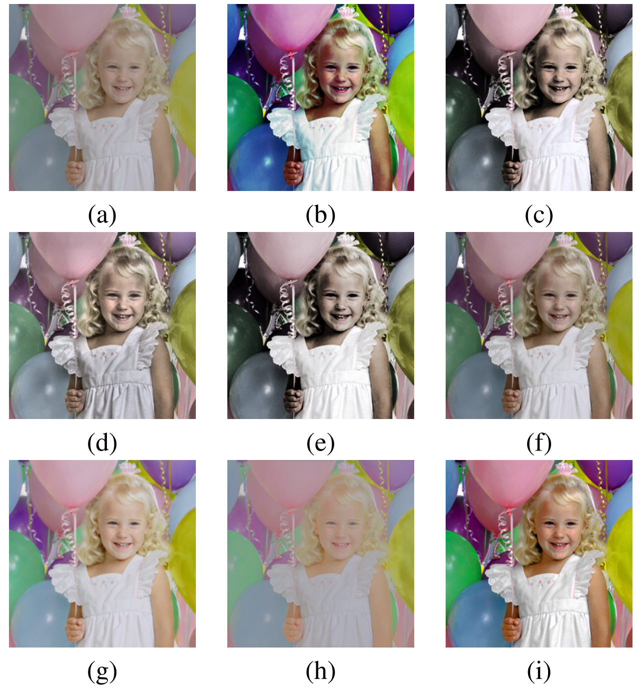

Fig. 4. The results for image1. (a) Original input image, (b) HE (RGB), (c) HE (I), (d) CLAHE (I), (e) Naik et al.'s method, (f) Ueda et al.'s method, (g) Ni et al.'s method, (h) Wang et al.'s method, (i) The proposed method.

Table 2 shows the average values of LOE. The boldface shows the minimum which indicates the best performance. The average of the proposed method is the second smallest value. From the above, it can be said that the proposed method does not disrupt the lightness order.

Table 3 shows the average values of Q, $\bar{I}$ and $\bar{\sigma}$. The boldface shows the maximum which shows the best performance. Q, $\bar{I}$ and $\bar{\sigma}$ of the proposed method are relatively high. It can be seen that the proposed method is an approach with a significant improvement in visibility.

4. CONCLUSIONS

In this paper, we proposed a hue preserving contrast enhancement method that realizes the adjustment of chroma without gamut problem in the RGB color space. In the proposed method, the pixel distribution in the RGB color space is spread through histogram specification method which is targeting the smoothed histograms of each RGB component

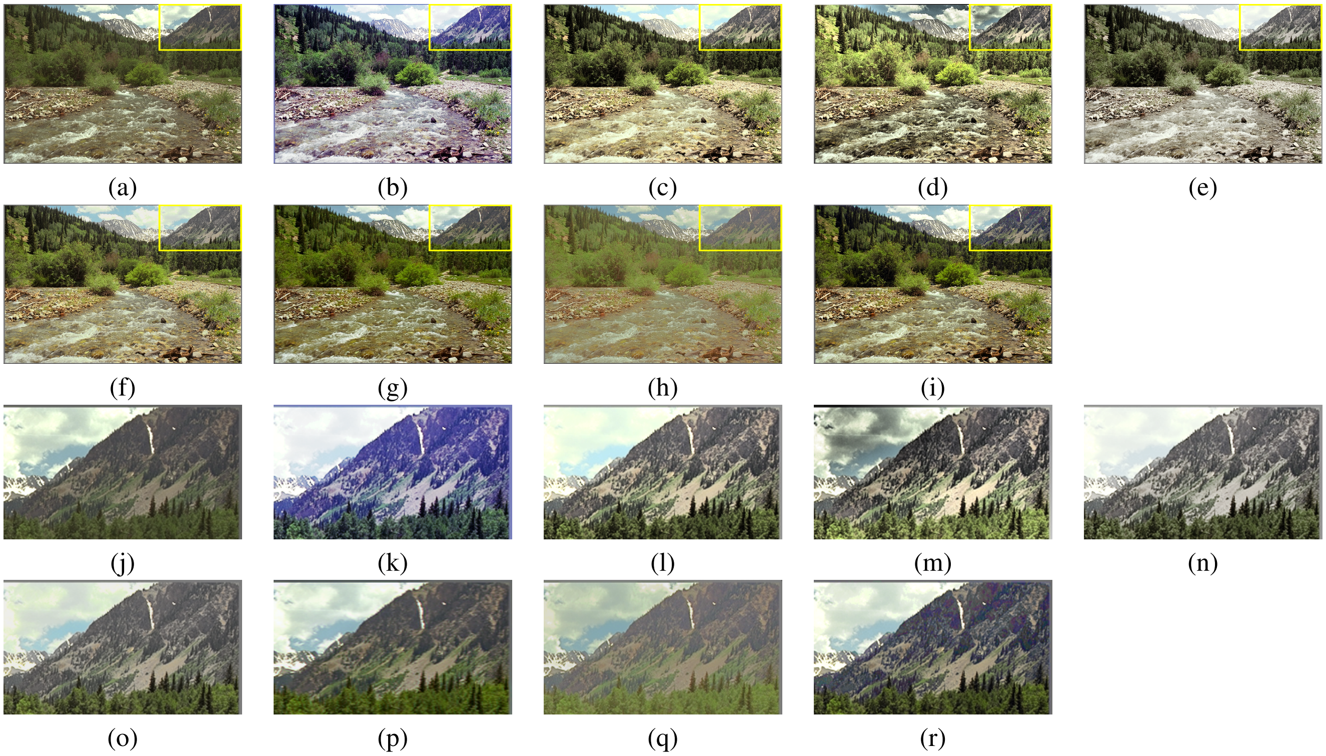

Fig. 5. The results for image2. (a) Original input image, (b) HE (RGB), (c) HE (I), (d) CLAHE (I), (e) Naik et al.'s method, (f) Ueda et al.'s method, (g) Ni et al.'s method, (h) Wang et al.'s method, (i) The proposed method. (j) to (r) are enlarged excerpts from (a) to (d), respectively.

Table 1. Standard deviation of L^*, Average of C^*.

	L^* (↑)	C^* (↑)
Orig.	18.61	19.44
HE (RGB)	28.11	18.62
HE (I)	**29.86**	20.36
CLAHE (I)	23.81	21.61
Naik et al.'s	29.59	11.99
Ueda et al.'s	21.70	20.41
Ni et al.'s	21.11	24.76
Wang et al.'s	13.19	24.80
Prop.	23.55	**24.83**

Table 2. LOE.

	LOE (↓)
HE (RGB)	925.82
HE (I)	864.36
CLAHE (I)	2503.09
Naik et al.'s	868.89
Ueda et al.'s	**442.53**
Ni et al.'s	565.30
Wang et al.'s	1536.45
Prop.	506.03

Table 3. Q value, $\bar{I}$, $\bar{\sigma}$.

	Q (↑)	$\bar{I}$ (↑)	$\bar{\sigma}$ (↑)
Orig.	3654.41	130.75	28.10
HE (RGB)	6700.59	150.91	44.51
HE (I)	7391.30	149.61	49.07
CLAHE (I)	**7516.91**	148.47	**50.88**
Naik et al.'s	6514.43	141.81	45.85
Ueda et al.'s	4790.37	140.26	34.36
Ni et al.'s	4457.57	144.19	31.62
Wang et al.'s	3095.64	**152.38**	20.41
Prop.	5417.37	140.42	38.65

of the input image. Furthermore, we preserved the hue and ensured color gamut by using Naik and Murthy's hue preserving condition and an equi-hue plane in RGB color space. And the regularization term was added to the second term of the cost function to realize the adjustment of chroma. In the experiments, the effectiveness of the proposed method is verified through qualitative and quantitative evaluations. Future work is the establishment of a method to determine the values of parameters automatically.

5. REFERENCES

[1] R. C. Gonzalez and R. E. Woods, *Digital image processing 2nd edition*, New Jersey, Prentice Hall, 2002.

[2] T. Acharya and A. K. Ray, *Image Processing - Principles and Applications*, Wiley-Interscience, USA, 2005.

[3] K. Zuiderveld, “Contrast limited adaptive histogram equalization,” *Graphics Gems IV*, pp. 474–485, Aug. 1994.

[4] S. K. Naik and C. A. Murthy, “Hue-preserving color image enhancement without gamut problem,” *IEEE Trans. Image Process.*, vol .12, no. 12, pp. 1591–1598, Dec. 2003.

[5] Y. Ueda et al., “Hue-preserving color contrast enhancement method without gamut problem by using histogram specification,” in *Proc. of 2018 IEEE Int. Conf. Image Process.*, pp. 1123–1127, 2018.

[6] M. Mukaida, Y. Ueda, and N. Suetake, “Low-light image enhancement method by using a modified gamma transform for convex combination coefficients,” in *Proc. of 2022 IEEE Int. Conf. Image Process.*, pp. 2866–2870, 2022.

[7] S. Kojima and N. Suetake, “Single image enhancement using gradient-norm-based tone curve for images captured in wide-dynamic-range scenes,” *IEEE Access*, vol. 12, pp. 1839–1851, Dec. 2023.

[8] M. Akai, Y. Ueda, T. Koga, and N. Suetake, “Low-artifact and fast backlit image enhancement method based on suppression of lightness order error,” *IEEE Access*, vol. 11, pp. 121231–121245, Oct. 2023.

[9] M. Mukaida, Y. Ueda, and N. Suetake, “Low-light image enhancement method using a modified gamma transform and gamma filtering-based histogram specification for convex combination coefficients,” *IEICE Trans. Fundamentals*, vol. E106-A, no. 11, pp. 1385–1394, Nov. 2023.

[10] M. Mukaida, S. Kojima, and N. Suetake, “Low-light image enhancement based on soft-closing-based illumination estimation and noise mitigation using correlation among RGB components,” *Optical Review*, vol. 29, no. 5, pp. 396–407, Sept. 2022.

[11] M. Akai, Y. Ueda, T. Koga, and N. Suetake, “A single backlit image enhancement method by image fusion with a weight map for improvement of dark area’s visibility,” *Optical Review*, vol. 29, no. 2, pp. 69–79, Mar. 2022.

[12] M. Akai, Y. Ueda, T. Koga, and N. Suetake, “A single backlit image enhancement method for improvement of visibility of dark part,” in *Proc. of 2021 IEEE Int. Conf. Image Process.*, pp. 1659–1663, 2021.

[13] Z. Ni et al., “Towards unsupervised deep image enhancement with generative adversarial network,” *IEEE Trans. Image Process.*, vol. 29, pp. 9140–9151, Sept. 2020.

[14] H. Wang, K. Xu, and R. Lau, “Local color distributions prior for image enhancement,” in *Proc. Computer Vision-ECCV*, pp. 343–359, 2022.

[15] Y. Tamagaki, M. Miyazaki, and Y. Ohara, “The affinity of HSV color model to the ostwald color system,” *Japanese Society for the Science of Design*, vol. 54, no. 3, pp. 9-18, Sept. 2007. (In Japanese)

[16] F. Dunn and I. Parberry, *3D Math Primer for Graphics and Game Development*, AK Peters/CRC Press, 2011.

[17] University of Southern California, The USC-SIPI Image Database., https://sipi.usc.edu/database/, Accesed Aug. 2022.

[18] E. Kodak Lossless True Color Image Suite., https://r0k.us/graphics/Kodak/, Accessed Aug. 2022.

[19] S. Wang, J. Zheng, H. M. Hu, and B. Li, “Naturalness preserved enhancement algorithm for non-uniform illumination images,” *IEEE Trans. Image Process.*, vol. 22, no. 9, pp. 3538–3548, May 2013.

[20] D. J. Jobson, Z. U. Rahman, and G. A. Woodell, “Statistics of visual representation,” *Visual Inf. Process. XI*, vol. 4736, pp. 25–35, Jul. 2002.