Color Systems and Color Image Enhancement Methods

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ABSTRACT

There are many color systems. Some systems are correspond to the human visual system, such as the Munsell color system. Other systems are formulated to ease data processing in machines, such as RGB color space. At first, Munsell color system is introduced in this paper. Next, RGB color system and hue-saturation-intensity (HSI) color system which is derived from RGB color systems are reviewed. HSI color system is important, because HSI color system is closely related to Munsell color system. We introduce the advantage and drawbacks of the conventional HSI color space. Furthermore, the improved HSI color system is introduced. The second half of this paper, we introduce a lot of color image enhancement methods based on the histogram equalization or the differential histogram equalization. Since hue preserving is necessary for color image processing, intensity processing methods by using both intensity and saturation in HSI color space are reviewed. Finally, hue preserving color image enhancement methods in RGB color system are explained.

Keywords: Munsell Color System, RGB Color System, HSI Color System, Histogram Equalization, Differential Histogram Equalization, Color Image Enhancement, Hue-preserving Processing

1. INTRODUCTION

Color signal can be expressed in many different ways, each with its advantage and drawbacks. Some representations are formulated to help humans select colors, such as the Munsell color system. This kind of color systems is called the color appearance system. And others are formulated to ease data making and processing in machines, such as RGB color system. This kind of color systems is called the additive color system.

In this paper, we first explain about the Munsell color system in order to clarify the prosperity of the human visual system.

Secondary, we refer the RGB color system (CIERGB) which was the utmost additive color system which created by the International Commission on Illumination (CIE). We can derive various color systems which are belonged to the additive color system by the color system conversion such as CIEXYZ and CIELAB. The hue-saturation-intensity (HSI) color system [1] and the hue- saturation-value (HSV) color system [2] are included in such color systems. HSI and HSV color systems are important, since the HSI or HSV color system is close to human being's perception to color and is closely related to Munsell color system. The HSI color system is explained and the problem of the color system is pointed out in this paper. This problem is called the gamut problem. Then, we introduce the improved HSI color system whose gamut is same of RGB color system [3]. This means that the gamut problem is solved.

The second half of this paper, we introduce a lot of color image enhancement methods based on the histogram equalization (HE) [1] or the differential histogram equalization (DHE) [4]. Since hue preserving is necessary for color image processing, intensity processing methods in HSI color system are reviewed [5],[6]. Next we show an intensity processing method while preserving hue in RGB color system which is proposed by Naik and Murthy [7]. In this method, intensity value can be controlled. However saturation value is decided depend on the processing of intensity. Saturation is always decreased by this method. Therefore the colorfulness of the output image is decreased compared to the input image. Next we show a new processing scheme in RGB color system which can preserve hue [8]. The method also only can control intensity value and saturation value cannot be controlled. Saturation value of the output is increased by this processing which is different from Naik's method. High contrast and high colorfulness image is can be obtained by this method.

2. MUNSELL COLOR SYSTEM -THE HUMAN VISUAL PERCEPTION OF COLOR

Albert Henry Munsell who was an American painter, teacher of art was the first to separate hue, value, and chroma into perceptually uniform and independent dimensions, and he was the first to systematically illustrate the colors in three-dimensional system which is depicted in the Munsell color tree (see in Fig.1). Three attributes of the Munsell color system is illustrated in Fig.2.

Munsell's system is based on rigorous measurements of human subjects' visual responses to color. Though several replacements for the Munsell system

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have been invented, building on Munsell's foundational ideas including the International Commission on Illumination's CIELAB (L*a*b*) , the Munsell system has outlasted its contemporary color models.

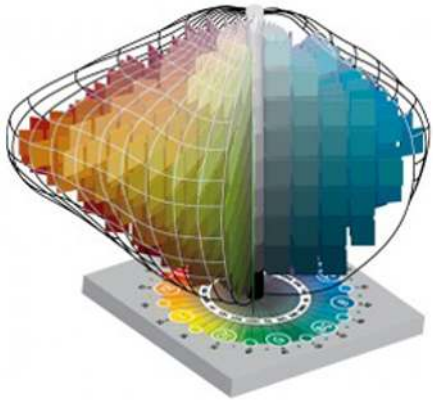


Fig.1: *Munsell color tree [9].*

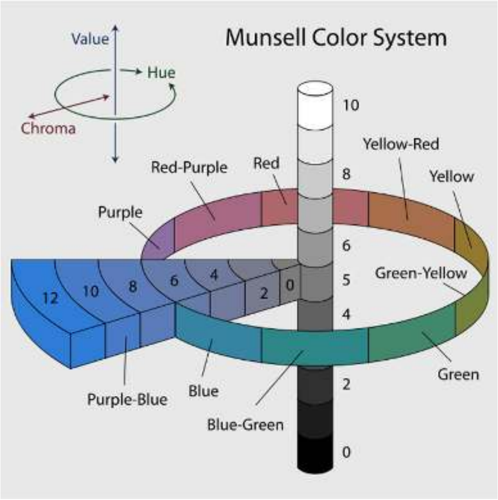


Fig.2: *Munsell color system [10].*

2.1 Munsell hue

Hue is that attribute of a color by which we distinguish red from green, blue from yellow, etc. Munsell hue circle is shown in Fig.3. Each horizontal circle Munsell divided into five principal hues: Red, Yellow, Green, Blue, and Purple, along with 5 intermediate hues (e.g., YR) halfway between adjacent principal hues. Each of these 10 steps, with the named hue given number 5, is then broken into 10 sub-steps, so that 100 hues are given integer values (see in Fig.3).

Two colors of equal Munsell value and Munsell chroma, on opposite sides of a hue circle, are complementary colors, and mix additively to the neutral gray of the same value.

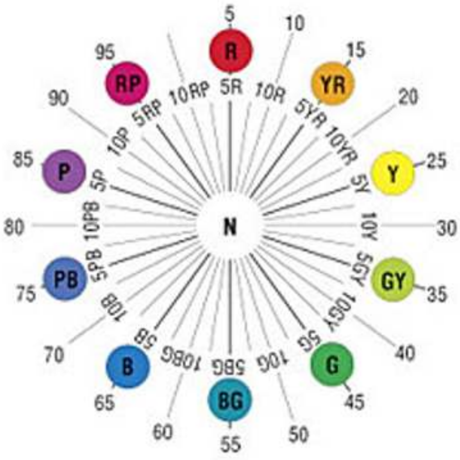


Fig.3: *Munsell hue [11].*

2.2 Munsell value

Munsell value varies vertically along the color solid, from black (value 0) at the bottom, to white (value 10) at the top and neutral grays lie along the vertical axis between black and white shown as Fig.2.

2.3 Munsell chroma

Munsell chroma shows the quality of a color's purity or saturation. For example, a gray color is an extreme low chroma. On the other hand, Fire-engine red may be a high-chroma red.

Note that there is no intrinsic upper limit to chroma. Different areas of the color system have different maximal chroma coordinates. For example, maximal chroma is 4 in the case of hue 5Y and value 3. On the other hand maximal chroma is 12 in the case of hue 5PB and value 6. This property makes the unique shape of the Munsell tree.

2.4 Munsell color system limit

The Munsell color system is the appeared color system. Therefore the color of color materials is described precisely in the Munsell color system. However, we cannot process the color image in the Munsell color system. Furthermore, the color cannot be evaluated in the Munsell color system.

In order to process the color image take the human visual system into account, the HSI system is used as a substitute for Munsell color system. The HSI color system will be explained later. On the other hand CIELAB is used as a substitute for Munsell color system in ordered to evaluate the color.

3. RGB COLOR SYSTEM AND COLOR SYSTEMS TRANSFORMED BY RGB COLOR SYSTEM

3.1 RGB color system -the additive color model

The RGB color model is an additive color model in which red, green and blue light are added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors, red, green and blue.

The main purpose of the RGB color model is for the sensing, representation and display of images in electronic systems, such as televisions and computers, though it has also been used in conventional photography. Before the electronic age, the RGB color model already had a solid theory behind it, based in human sensing system by three cone cells of the human retina.

The values of RGB are assumed to be in the range of [0,1] or in some cases in the range of [0-255] (i.e., 8bit). This way black is represented as (0, 0, 0), white is represented as (1, 1, 1) or (255, 255, 255). These black and the white colors are represented by 2 of the opposite corner of the cube that can be defined by the R, G, B axes of the Cartesian coordinate systems shown in Fig.4. Other corners of the cube represent the red, green, blue, cyan, magenta and yellow colors. Grayscale colors are represented with identical R, G, B components. Because the RGB color system is widely used in monitors, digital cameras, it is the most important color system in image processing.

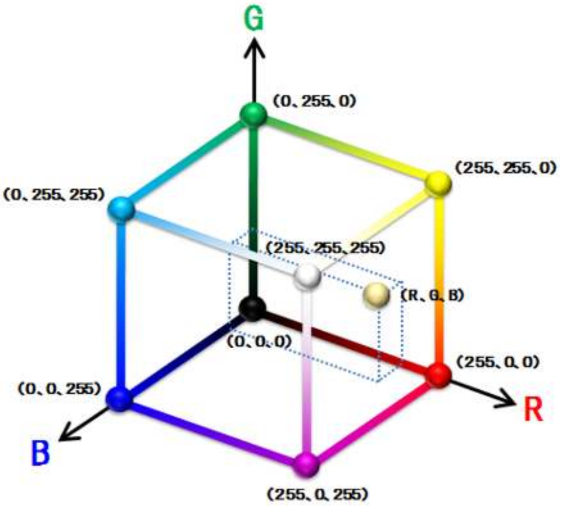


Fig.4: *RGB color system [12].*

3.2 Ideal HSI color system

The HSI color system is very important and attractive color system for image processing and its applications because it represents colors similarly how the human eye senses colors. The HSI color model represents every color with three components: hue (H), saturation (S), intensity (I). Figure 5 shows the ideal shape of the HSI color system.

The HSI color system is closely related to the Munsell color system. Hue, saturation and intensity correspond to Munsell hue, Munsell chroma and Munsell value, respectively. Three attributes of the HSI color system are same as those of the Munsell color system. However, the HSI color system is not a perceptually uniform color system unlike the Munsell color system.

The hue circle is shown in Fig.6. Three primary colors (i.e., red, green and blue) are located 120° intervals. The complementary color is also defined in the HSI hue. The complementary colors of red, green and blue are cyan, magenta and yellow, respectively. The location of three primary colors of HSI hue is different from the location of those of Munsell hue (see in Fig.3).

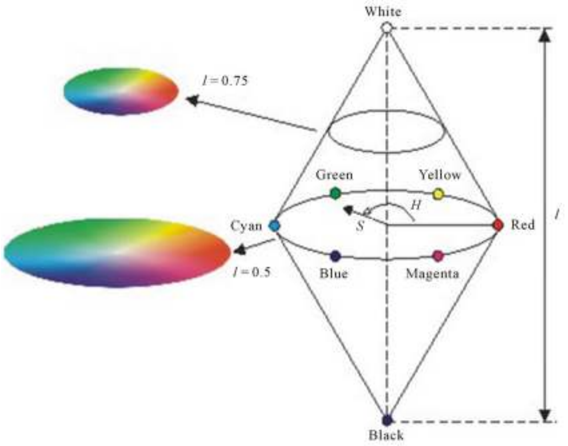


Fig.5: *Ideal HSI color system [1].*

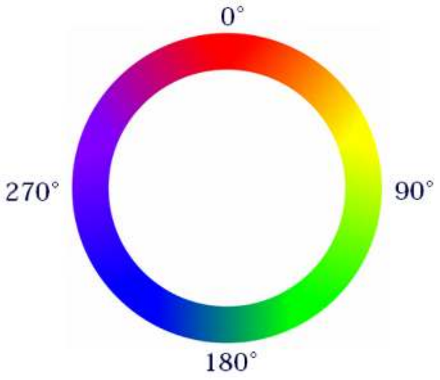


Fig.6: *HSI hue circle.*

3.3 HSI color system

Real HSI color system will be introduced. A lot of HSI color systems have been proposed [1], [2]. In this paper, we adopt the HSI color system which is defined in Ref. [1], since the definition of hue and intensity is appropriate. Furthermore, this system is regarded as the most common HSI color system which is employed in many researches [13]-[16]. We show the conversion formula between the RGB color system and the HSI color system.

(1) From RGB color system to HSI color system

It is assumed that the RGB values have been normalized to the range [0,1]. Intensity I is defined as

$$I = \frac{1}{3}(R + G + B) \tag{1}$$

The range of the intensity is [0,1]. The hue component is obtained as

$$H = \begin{cases} \theta & if\ B \leq G \\ 360 - \theta & if\ B > G \end{cases} \tag{2}$$

where

$$\theta = \cos^{-1}\left[\frac{\{(R-G)+(R-B)\}/2}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right]$$

The saturation component is given by

$$S = 1 - \frac{3}{(R+G+B)}\{\min(R,G,B)\} \tag{3}$$

The range of saturation is also from 0 to 1. In the case of (R,G,B)=(0,0,0), the denominator of second term of Eq.(3) becomes 0. Thus, we cannot calculate the equation. We define the saturation S as 0 in this case.

(2) From HSI color system to RGB color system

C_1, C_2 and C_3 are defined as shown in Table 1, then, the conversion formula from HSI color system to RGB color system is given as follows:

$$C_1 = I(1 - S) \tag{4}$$

$$C_2 = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right] \tag{5}$$

$$C_3 = 3I - (C_1 + C_2) \tag{6}$$

Table 1: *Conversion from HSI color system to RGB color system.*

H	0°-120°	120°-240°	240°-360°
	$H = H$	$H = H - 120$	$H = H - 240$
C_1	B	R	G
C_2	R	G	B
C_3	G	B	R

3.4 Relationship between the RGB color system and the HSI color system

The RGB and HSI color systems are shown in Fig.7. The diagonal which links point (1,1,1) to point (0,0,0) of the RGB color system is equivalent to the intensity (I) axis of the HSI color system. Seeing from point (1,1,1) (i.e., white) to (0,0,0) (i.e., black) the RGB color system, the RGB color system is shown as the regular hexagon such as Fig.8. The center point of the regular hexagon corresponds to the diagonal line from (1,1,1) to (0,0,0). The hue is defined as Fig.8. That is, red corresponds to 0° and green and blue correspond to 120° and 240°, respectively.

The SI planes of $H = 0°, 30°$ and 60° are illustrated in Fig.9. The SI plane of H= 0° is also drawn in Fig.7. A black triangle in Fig.9 shows a cross-section with the RGB color system. From Fig.9(a), we understood that the gamut of SI color plane of H= 0° is larger than that of RGB color system. Only in the condition of $I \leq 1/3$, the HSI gamut and the RGB gamut is same each other. In $I > 1/3$, only R (i.e., C_2) component is larger than 1. Next, we study in the case of H=30°. Figure 9(b) shows the relationship between HSI and RGB color systems when H=30°. The common area of two color systems with H=30° get larger compared to the case of H=0°. In the condition of $I \leq 1/2$, the gamut of HSI and RGB color systems is same each other. In $I > 1/2$, only R (i.e., C_2) component is larger than 1 same as the case of H=0°. Figure 9(c) shows the relationship between HSI and RGB color systems when H=60°. In this case, the common area of two color systems becomes maximum. In the condition of $I \leq 2/3$, the gamut of two color systems is same each other. In the condition $I > 2/3$, both R (i.e., C_2) and G (i.e., C_3) are larger than 1.

The shape of common region of two color systems when H=90° is same as that when H=30°. Furthermore, the shape of common region of two color systems when H=120° is same as that when H=0°.

Next, we would like to make study about the volume of two color systems. The RGB color system is the cube whose length of a side is 1. Thus, the volume of the RGB color system is 1. On the other hand, the HSI color system is the triangular pyramid. The area of the bottom face is $9\sqrt{3}/2$ and the height is $\sqrt{3}$. The volume of the HSI color system is 9/2 and 4.5-times of the volume of the RGB color system.

From the study mentioned above, the width of common gamut of two color systems depends on hue value. The boundary condition that two color systems become common for intensity is shown in Fig.10

4. HSI COLOR SYSTEM WITH SAME GAMUT OF RGB COLOR SYSTEM [3]

We studied the relationship between RGB gamut and HSI gamut. The shape of HSI color system is a triangular pyramid and the HSI gamut is larger

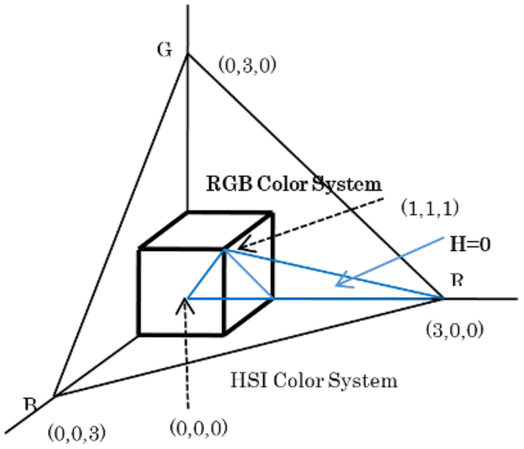


Fig.7: *RGB color system and HSI color system.*

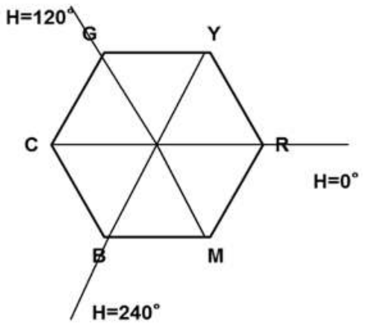
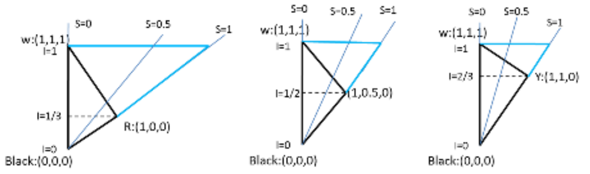


Fig.8: *Seeing the RGB color system from (1,1,1) to (0,0,0).*



(a) $H=0^\circ$ (b) $H=30^\circ$ (c) $H=60^\circ$

Fig.9: *SI planes of HSI color system with $H = 0^\circ$, 30° and 60°.*

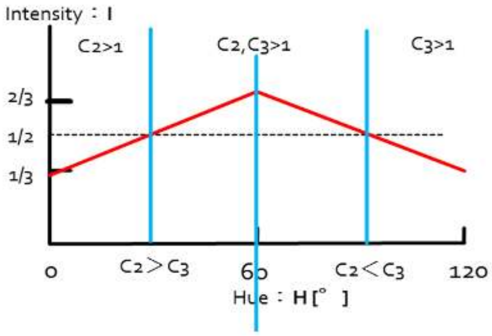


Fig.10: *The condition that two color systems become common.*

than the RGB gamut were made clear. Furthermore, we showed that the relationship between the gamut of two color systems is changed depend on the hue value. Then, the condition of intensity value that two color systems become common was also illustrated in Fig.10. In this chapter, a novel HSI system with same gamut of RGB color system is shown.

In order to introduce the novel conversion method, we utilize the CMY color system. We can also clarify the relations of the CMY color system and the HSI color system. The relationship between the CMY color system and the HSI color system is shown in Fig.11.

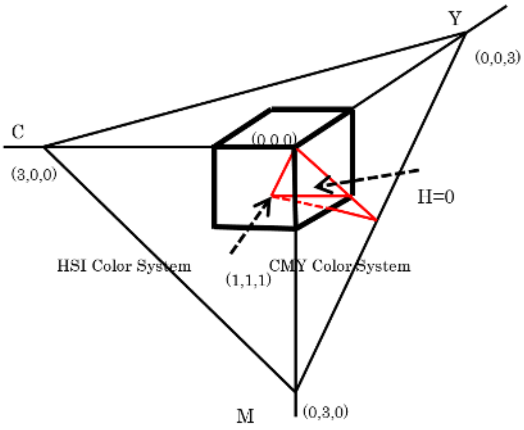


Fig.11: *CMY color system and HSI color system.*

The SI plane with $H = 0^\circ$ which is converted from CMY color system is drawn by red line in Fig.11 and Fig.12. A blue triangle in Fig.12 is the SI plane which is converted from RGB color system. If we use the conversion rule between RGB color system and HSI color system in the condition $0 \leq I \leq 1/3$ and use the conversion rule between CMY color system and HSI color system in the condition $1/3 < I \leq 1$, HSI gamut become same as the RGB gamut. The switching value of intensity is changed depend on the hue value. The red line which is described in Fig.10 shows the switching value.

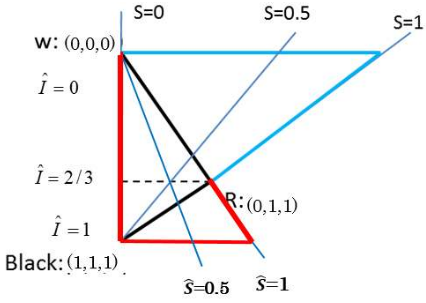


Fig.12: *SI planes of HSI color system with $H=0^\circ$ and cross-sections RGB and CMY systems (CMY coordinate system).*

A new conversion formula between RGB color system and HSI color system with same gamut of RGB color system is shown as follows.

(1) Conversion color systems from RGB to HSI

Given an image in RGB color format, the intensity component is given by Eq. (1) same as the conventional conversion formula.

We divide intensity range into two parts. First part is from 0 to the value on red line in Fig.10, and second part is from the value on red line to 1.

$$\text{(A)}\ \begin{array}{l} 0 \leq I \leq \left(\frac{\theta}{180} + \frac{1}{3}\right) : 0^\circ \leq \theta < 60^\circ \\ 0 \leq I \leq \left(-\frac{\theta}{180} + 1\right) : 60^\circ \leq \theta < 120^\circ \end{array}$$

The hue and saturation components are obtained by Eq.(2) and (3), respectively. These conversion rules are same as the conventional rules.

$$\text{(B)}\ \begin{array}{l} \left(\frac{\theta}{180} + \frac{1}{3}\right) < I \leq 1 : 0^\circ \leq \theta < 60^\circ \\ \left(-\frac{\theta}{180} + 1\right) < I \leq 1 : 60^\circ \leq \theta < 120^\circ \end{array}$$

The hue component is same as the case (A), thus, given by Eq. (2).

The saturation component is derived by using CMY components ($C = 1 - R, M = 1 - G, Y = 1 - B$) as follow:

$$S = \hat{S} \tag{7}$$

where

$$\hat{S} = 1 - \frac{3}{(C + M + Y)}\{\min(C, M, Y)\}$$

The range of saturation is also from 0 to 1. In the case of (C,M,Y)=(0,0,0) (i.e., (R,G,B)=(1,1,1)), the denominator of second term of the above equation becomes 0. Thus, we define the saturation $\hat{S}$ as 0 in this case.

In our method, out-of-gamut problem is resolved since we give a new conversion method in the intensity condition (B).

(2) Conversion color systems from HSI to RGB

We show the conversion formula from the proposed HSI color system to RGB color system.

$$\text{(A)}\ \begin{array}{l} 0 \leq I \leq \left(\frac{\theta}{180} + \frac{1}{3}\right) : 0^\circ \leq \theta < 60^\circ \\ 0 \leq I \leq \left(-\frac{\theta}{180} + 1\right) : 60^\circ \leq \theta < 120^\circ \end{array}$$

In this case, the RGB components are given by the equations which are same as the conventional HSI color system (i.e., Eq. (4)-(6)).

$$\text{(B)}\ \begin{array}{l} \left(\frac{\theta}{180} + \frac{1}{3}\right) < I \leq 1 : 0^\circ \leq \theta < 60^\circ \\ \left(-\frac{\theta}{180} + 1\right) < I \leq 1 : 60^\circ \leq \theta < 120^\circ \end{array}$$

In the case of (B), we consider CMY color system instead of RGB color system. Thus, the hue is shifting 180° as follow:

$$\hat{H} = \left\{ \begin{array}{ll} H + 180^\circ & if\ 0 \leq \theta < 180^\circ \\ H - 180^\circ & if\ 180 \leq \theta < 360^\circ \end{array} \right. \tag{8}$$

We define the $\hat{S}$ and $\hat{I}$ as follows:

$$\hat{S} = S \tag{9}$$

$$\hat{I} = 1 - I \tag{10}$$

The relationship between RGB and CMY is shown as: $C = 1 - R, M = 1 - G, Y = 1 - B$. C_1, C_2 and C_3 are derived by using $\hat{H}, \hat{S}$ and $\hat{I}$ as follows:

$$C_1 = 1 - \hat{I}(1 - \hat{S}) \tag{11}$$

$$C_2 = 1 - \hat{I}\left[1 + \frac{\hat{S}\cos\hat{H}}{\cos(60^\circ - \hat{H})}\right] \tag{12}$$

$$C_3 = 3I - (C_1 + C_2) \tag{13}$$

where the definition of C_1, C_2 and C_3 are same as Table 1.

5. COLOR IMAGE ENHANCEMENT IN THE HSI COLOR SYSTEM

Hue, saturation and intensity are the attributes of color. Hue is that attribute of a color which decides what kind color it is, i.e., a red or an orange. Saturation shows the vividness of color and has effect on the impression of the image. For the purpose of enhancing a color images, it is to be seen that hue value should not change for any pixel. If hue value is changed, thereby distorting the image. For general hue-preserving color image processing, the original RGB image is usually transformed to another color system such as HSI or HSV, then, the intensity /saturation components is processed, but the hue component remains unchanged. We would like to introduce color image enhancement methods in HSI color system in this chapter.

5.1 Saturation Correction Algorithm for solving the gamut problem

In 3.4, we showed the RGB gamut and the HSI gamut is different. Therefore, there is a risk that the processed pixel is located outside of the gamut of RGB color system. According to the relationship between two color systems discussed 3.4, we can see that the processed pixel is located whether outside or inside of RGB color system without converting from HSI color system to RGB color system. New conversion formula from HSI color system to RGB color system with preserving hue and intensity is introduced.

In the processed pixel is located outside of RGB color system, saturation correction is carried out in order to move the pixel inside RGB color system.

5.1.1 New conversion formula from HSI color system to RGB color system [17]

We show the conversion procedure from HSI color system to RGB color system with the saturation correction algorithm as follows:

[Case 1] $0° \leq H < 60°$

C_2 is calculated by Eq. (5).

(1-a) $C_2 \leq 1$

C_1 and C_3 are also smaller than 1. Thus, C_1 is given by Eq.(4) and C_3 is given by Eq.(6).

(1-b) $C_2 > 1$

In this case, the pixel is located outside RGB color system and saturation correction is necessary. Saturation value is revised to make the value of $C_2 = 1$. From Eq.(5), the corrected saturation is given by

$$\hat{S} = \frac{(1-I)\cdot\cos(60° - H)}{I \cdot \cos H} \tag{14}$$

C_1 and C_3 are derived by using the corrected saturation value.

$$C_1 = I(1-\hat{S}) \tag{15}$$

$$C_3 = I\left[1 + \frac{\hat{S}(\cos(60° - H) - \cos H)}{\cos(60° - H)}\right] \tag{16}$$

[Case 2] $60° \leq H < 120°$

C_3 is calculated by Eq. (6).

(2-a) $C_3 \leq 1$

C_1 and C_2 are also smaller than 1. Thus, C_1 is given by Eq.(4) and C_2 is given by Eq.(5).

(2-b) $C_3 > 1$

In this case, saturation correction is necessary. Saturation value is revised to make the value of $C_3 = 1$. From Eq.(6), the corrected saturation is given by

$$\hat{S} = \frac{(1-I)\cdot\cos(60° - H)}{I \cdot \cos(60° - H) - \cos H} \tag{17}$$

C_1 and C_2 are derived by using the corrected saturation value.

$$C_1 = I(1-\hat{S}) \tag{18}$$

$$C_2 = I\left[1 + \frac{\hat{S}\cos H}{\cos(60° - H)}\right] \tag{19}$$

5.1.2 Experimental Results

We apply the HE to intensity component and saturation component independently for color image enhancement. We compare the transformation from HSI color space to RGB color space with saturation correction to without saturation correction. In the case of the transformation without saturation correction, the clipping operation is applied to transformed pixels which are located outside of the RGB gamut. The clipping causes the hue shifting.

Two images are prepared for enhancement and these images are shown in Fig.13. These images are 8-bit for each component.

Enhancement results without saturation correction are shown in Fig.14. On the other hand, enhancement results with saturation correction are shown in Fig.15.

First we give a qualitative analysis on enhancement results of "old town". We can easily distinguish that the most different section among these images is the house located at right side. Obviously, there is a great hue distortion in Fig.14(b). On contrast, Fig.15(b) is the result of proposed algorithm which has a perfect hue matching the original image (i.e., Fig.13(b)) and the intensity and saturation is properly enhanced. From Fig.14(a), we understand that the hue of the skin becomes red. The proposed saturation correction method is effective for color image processing in HSI color space.

Next, we perform the numerical evaluation. There are 24% pixels of "couple" is necessary for saturation correction. There are 27% pixels of "old town" need to be modified. In the case of color image enhancement in HSI color space, the gamut problem is often occurred and the correction algorithm is necessary for preserve hue components.

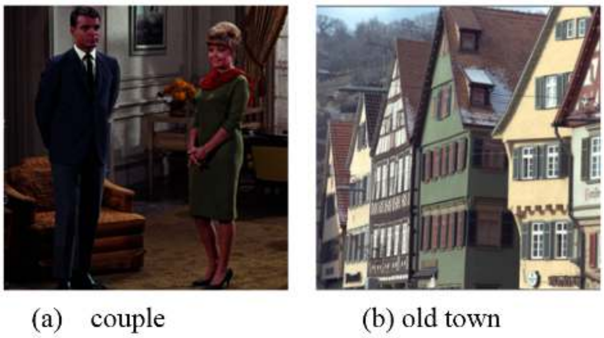


Fig.13: *Test images (1).*

5.2 Differential histogram equalization (DHE) for color images

5.2.1 DHE for gray-scale images

Histogram equalization is the most famous image enhancement method. On the other hand DHE which is a modified method of HE is not popular. Therefore the DHE is explained briefly as follow.

Consider an input image $f(i, j)$, which is a the


(a) couple (b) old town

Fig.14: *Enhancement results without saturation correction.*


(a) couple (b) old town

Fig.15: *Enhancement results with saturation correction.*

total number of N pixels with gray-levels in the range $[0, L-1]$. We calculate the differential gray-levels of the input image as follows:

$$d(i,j) = \text{int}\left\{\sqrt{d_H(i,j)^2 + d_V(i,j)^2}\right\} \tag{20}$$

where

$$d_H(i,j) = \{f(i+1,j+1)+2\cdot f(i+1,j)+f(i+1,j-1)\} - \{f(i-1,j+1)+2\cdot f(i-1,j)+f(i-1,j-1)\}$$

$$d_V(i,j) = \{f(i+1,j+1)+2\cdot f(i,j+1)+f(i-1,j+1)\} - \{f(i+1,j-1)+2\cdot f(i,j-1)+f(i-1,j-1)\}$$

int{} in Eq.(1) represents the integer transform processing.

The differential gray-level histogram (DH) $h_d(r)$ is given by

$$h_d(r) = \sum_{(i,j)\in D_r} d(i,j) \tag{21}$$

where D_r is a region composed of pixels whose value is r. Thus, the horizontal axis of DH is gray-level r and the vertical axis is the total differential gray-levels of (i,j) points which meet the condition $f(i,j) = r$.

The DHE will map an input gray-level r into an output gray level s using the following transformation function $T(r)$.

$$s = T(r) = (L-1)\cdot c(r) \tag{22}$$

where

$$c(r) = \frac{\sum_{k=0}^{r} h_d(k)}{\sum_{k=0}^{L-1} h_d(k)}$$

5.2.2 Intensity DHE (IDHE) for color images

First, the input image which is described RGB color system transforms to HSI color system. $I(i,j)$ is assumed to be the L-level intensity component of the input color image. The output of IDHE $O_I(I(i,j))$ is given from Eq.(20) to Eq.(22) by replacing $f(i,j)$ with $I(i,j)$.

5.2.3 Saturation DHE (SDHE) for color images

In color images another differential histogram which is the saturation differential histogram (SDH) can be defined. $S(i,j)$ is assumed the saturation component of input color image. $S(i,j)$ is expanded to L-level.

The differential of saturation $d_s(i,j)$ is derived by using Eq.(20) by replacing $f(i,j)$ with $S(i,j)$. The SDH is given by

$$h_d^{S(i,j)}(r) = \sum_{(i,j)\in D_r^{I_{i,j}}} \{|\rho(i,j)|\cdot d_s(i,j)\} \tag{23}$$

where

$$\rho(i,j) = \frac{\sum_{k=-2}^{2}\sum_{l=2}^{2}[I\{(i+k,j+l)-\bar{I}(i,j)\}\{S(i+k,j+l)-\bar{S}(i,j)\}]}{\sqrt{\sum_{k=-2}^{2}\sum_{l=2}^{2}\{I(i+k,j+l)-\bar{I}(i,j)\}^2}\sqrt{\sum_{k=2}^{2}\sum_{l=2}^{2}\{S(i+k,j+l)-\bar{S}(i,j)\}^2}}$$

D_r is a region composed of pixels whose intensity value is r (i.e., $I(i,j) = r$). In the case of SDHE, we also emphasize the intensity component of color images by using saturation information. The saturation information is generally not appropriate at locations where the component images do not have same basic image structure. Thus, we introduce $\rho(i,j)$ which is local correlation of intensity and saturation data, in order to measure the structural similarity. The magnitude of $\rho(i,j)$ determines how appropriate the saturation data is at a given location. In uncorrelated regions, since $|\rho(i,j)| \cdot d_s(i,j)$ shows small value, it does not contribute to the Eq.(23). $\bar{I}(i,j)$ and $\bar{S}(i,j)$ are local mean of intensity and local mean of saturation, respectively. We set 5×5 window for calculating the local mean in this paper.

The output of SDHE $O_S(I(i,j))$ is given by Eq.(22) by replacing $h_d(r)$ with $h_d^{S_{i,j}}(r)$.

5.2.4 The combination of IDHE and SDHE

The output $O(I(i,j))$ of the combination of two DHEs is derived easily as follow.

$$O(I(i,j)) = \alpha \cdot O_s(I(i,j)) + (1-\alpha) \cdot O_I(I(i,j)) \quad (24)$$

where $0 \leq \alpha \leq 1$. The output of the combination method with $\alpha = 0$ and $\alpha = 1$ are equivalent to IDHE and SDHE, respectively.

5.2.5 Experimental Results

We prepare two test images with RGB 24-bit shown in Fig.16. We demonstrate how the results of the combination method changed, when parameter α is changed. Enhancement results with $\alpha = 0$, 0.2, 0.4, 0.6 0.8 and 1 of two test images are shown in Fig.17 and Fig.18.

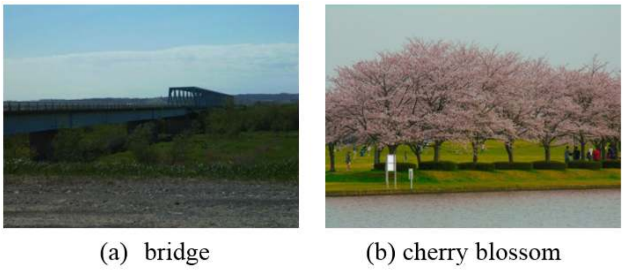

(a) bridge (b) cherry blossom

Fig.16: *Test images (2).*

Subjective evaluation is performed by 20 men and women in its twenties. Subjects choose their favorite one enhancement image from 11 enhancement images with from 0 to 1 at 0.1 intervals. The result is shown in Table 2. In the case of “bridge”, the average value of is 0.435. In the other hand, the average of is 0.525 in “cherry blossom”. The average values of two images are different each other. It is necessary to give a decision guideline of depend on the original image which is agree in human sense.

Table 2: *Subjective evaluation (Number of persons).*

α	0.3	0.4	0.5	0.6	0.7
bridge	2	10	7	1	0
cherry	0	3	10	6	1

In order to evaluate the contrast and colorfulness of images, we introduce two variance-based indexes in CIELAB color system. The contrast of color images corresponds to the width of $L*$ axial color signal distribution. Thus, the contrast is quantified by the variance value of $L*$ component of color signals which is the first index of the color image quality evaluation. The colorfulness can be evaluated by the value based on signal variance on $a*b*$ plane. M1 [17] is introduced as the second index to evaluate the colorfulness of the color image as follow.

$$M1 = \sigma_{ab} + 0.37\mu_{ab} \quad (25)$$

where σ_{ab} and μ_{ab} are the standard deviation and average of the color image on $a*b*$ plane, respectively.

We plot of two indexes vs. α in Fig.19. Two straight lines in each graph show the index value of the original test image. In the case of “bridge”, $M1$ of all enhancement results is larger than that of original “bridge” image. On the other hand, L* variance of enhancement results with α from 0 to 0.5 is larger than that of original image. It is preferable for two indexes of enhancement result to be larger than those of the original image. From these points of view, it is preferable for α to set smaller than 0.5. We study about “cherry blossom” in the same way, it is preferable for α to set larger than 0.3.

From Table 2, 95% of subjects chose α smaller than 0.5 for “bridge” and 100% of subjects chose α larger than 0.3 for ”cherry blossom”.

We come to see that parameter can be decided by the following guideline.

(1) Deciding α to meet the condition that two indexes of the enhancement result are larger than those of original image.

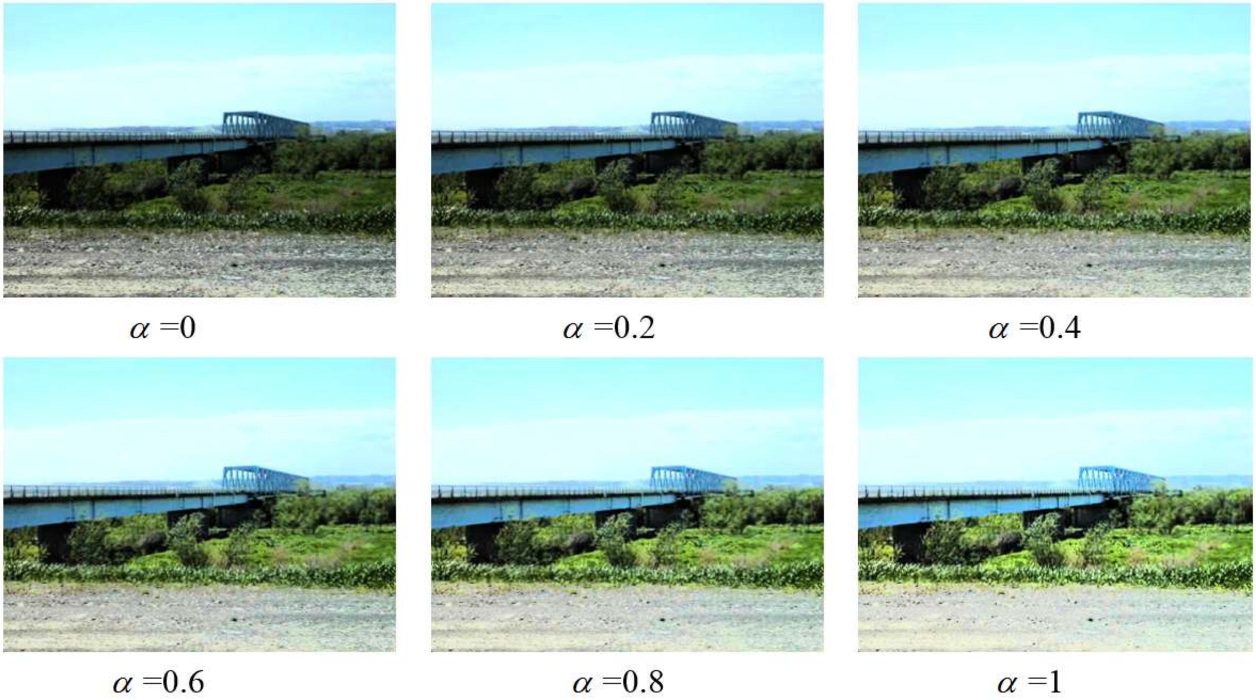
(2) It is preferable to decide around 0.5, in order to use two DHEs effectively.

6. COLOR IMAGE ENHANCEMENT IN THE RGB COLOR SYSTEM

It is necessary to preserve the hue before/after the color image enhancement. The color image is captured by RGB color system. Therefore, it is preferable to process the color image in RGB color system. However, if thought simply, it is considered that hue preserving processing is difficult in RGB color system. Nevertheless two processing schemes in the RGB color system which can be preserved hue are shown.

6.1 Hue-preserving processing scheme proposed by Naik and Murthy.

Naik and Murthy proposed a scheme to generalize any gray-scale contrast enhancement techniques to color images with hue preserving in RGB color system. Therefore this scheme frees from the gamut problem.



α =0 α =0.2 α =0.4

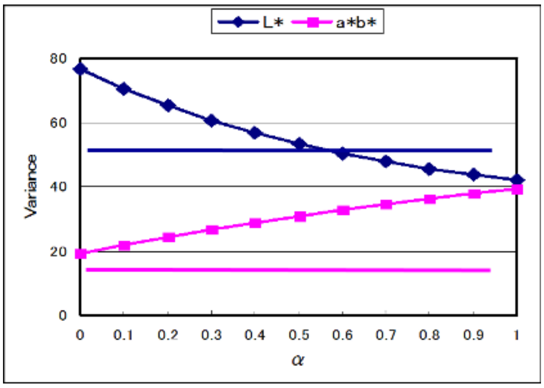
α =0.6 α =0.8 α =1

Fig.17: *Enhancement results (bridge).*

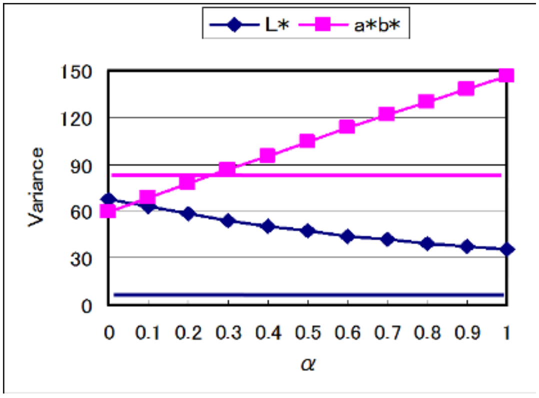
α =0 α =0.2 α =0.4

α =0.6 α =0.8 α =1

Fig.18: *Enhancement results (cherry blossom).*



(a) bridge



(b) cherry blossom

Fig.19: *Two indexes variances vs.α (L∗: L∗ variance, a ∗ b∗ : M1).*

Let the RGB element of the original input image be (R_{in}, G_{in}, B_{in}) and the RGB element of enhancement image be $(R_{out}, G_{out}, B_{out})$. The RGB element is assumed to be normalized. And we define l_{in} as

$$l_{in} = (R_{in} + G_{in} + B_{in})/3 \tag{26}$$

Let "f" denote the arbitrary gray-scale transfer function. This will be deal with in two separate cases. [Case 1] $\alpha(l_{in}) = f(l_{in})/l_{in} \le 1$

$$\mathrm{R}_{out}{=}\alpha(l_{in}) \cdot R_{in},\ \ G_{out}{=}\alpha(l_{in}) \cdot G_{in},\ \ B_{out}{=}\alpha(l_{in}) \cdot B_{in} \tag{27}$$

[Case 2] $\alpha(l_{in}) > 1$

In this case, first transform the RGB color element (R_{in}, G_{in}, B_{in}) to CMY color element (C_{in}, M_{in}, Y_{in})

$$C_{in} = 1 - R_{in}, M_{in} = 1 - G_{in}, Y_{in} = 1 - B_{in} \tag{28}$$

We define l_{in}^{CMY} as

$$l_{in}^{CMY} = (C_{in} + M_{in} + Y_{in})/3 = 1 - l_{in} \tag{29}$$

The output is given by

$$\mathrm{C}_{out}{=}\beta(l_{in}^{CMY}){\cdot}C_{in}, M_{out}{=}\beta(l_{IN}^{CMY}){\cdot}M_{in}Y_{out}{=}\beta(l_{in}^{CMY}) \cdot Y_{in} \tag{30}$$

where

$$\beta(l_{in}^{CMY}) = g(l_{in}^{CMY})/l_{in}^{CMY}$$

$$g(l_{in}^{CMY}) = 1 - f(l_{in})$$

Finally, we transform the output signal from CMY color system to RGB color system.

In this scheme, when the condition $\alpha(l_{in}) > 1$ is satisfied, the color signals of RGB space is transformed to CMY space. Therefore, each element of resulting images (i.e., $R_{out}, G_{out}, B_{out}$) should not exceed 1. However, the saturation value of enhancement images is always decreased.

6.2 Hue-Preserving Processing Scheme with rich saturation

We propose a novel scheme to generalize any gray-scale image processing to color images, which is the extended version of the Naik's scheme.

[Case 1]

$$(1{-}a)\ \alpha(l_{in}) \le 1 \ \mathit{and}\ \beta(l_{in}^{CMY}) \le 1/\max\{C_{in}, M_{in}, Y_{in}\}$$

Enhancement processing is carried out in CMY color system.

$$C_{out}{=}\beta(l_{in}^{CMY}) \cdot C_{in},\ \ M_{out}{=}\beta(l_{in}^{CMY}) \cdot M_{in},\ \ Y_{out}{=}\beta(l_{in}^{CMY}) \cdot Y_{in} \tag{31}$$

Next CMY elements are converted into RGB elements.

$$(1{-}b)\ \alpha(l_{in}) \le 1 \ \mathit{and}\ \beta(l_{in}^{CMY}) > 1/\max\{C_{in}, M_{in}, Y_{in}\}$$

In this case, the output signal is derived by two steps.

Step 1)

$$\hat{C}_{in} = \gamma(l_{in}^{CMY}) \cdot C_{in},\ \ \hat{M}_{in} = \gamma(l_{in}^{CMY}) \cdot M_{in},\ \ \hat{Y}_{in} = \gamma(l_{in}^{CMY}) \cdot Y_{in} \tag{32}$$

where

$$\gamma(l_{in}^{CMY}) = 1/\max\{C_{in}, M_{in}, Y_{in}\}$$

$$\hat{R}_{in} = 1 - \hat{C}_{in},\ \ \hat{G}_{in} = 1 - \hat{M}_{in},\ \ \hat{B}_{in} = 1 - \hat{Y}_{in}$$

Step 2)

$$\hat{l}_{in} = (\hat{R}_{in} + \hat{G}_{in} + \hat{B}_{in})/3$$

$$R_{out} = \hat{\alpha}(l_{in}) \cdot \hat{R}_{in}, G_{out} = \hat{\alpha}(l_{in}) \cdot \hat{G}_{in}, B_{out} = \hat{\alpha}(l_{in}) \cdot \hat{B}_{in} \tag{33}$$

where

$$\hat{\alpha}(l_{in}) = f(l_{in})/\hat{l}_{in}$$

[Case 2]

$$(2-a)\ \ \alpha(l_{in}) > 1 \textit{ and } \alpha(l_{in}) \leq 1/\max\{R_{in}, G_{in}, B_{in}\}$$

$$R_{out}=\alpha(l_{in}) \cdot R_{in},\ \ G_{out}=\alpha(l_{in}) \cdot G_{in},\ \ B_{out}=\alpha(l_{in}) \cdot B_{in} \tag{34}$$

$$(2-b)\ \alpha(l_{in}) > 1 \textit{ and } \alpha(l_{in}) > 1/\max\{R_{in}, G_{in}, B_{in}\}$$

Step 1)

$$\hat{R}_{in}=\delta(l_{in}) \cdot R_{in},\ \ \hat{G}_{in}=\delta(l_{in}) \cdot G_{in},\ \ \hat{B}_{in}=\delta(l_{in}) \cdot B_{in} \tag{35}$$

where

$$\delta(l_{in}) = 1/\max\{R_{in}, G_{in}, B_{in}\}$$

Step 2)

$$\hat{C}_{in} = 1 - \hat{R}_{in},\ \ \ \hat{M}_{in} = 1 - \hat{G}_{in},\ \ \ \hat{Y}_{in} = 1 - \hat{B}_{in}$$

$$\hat{l}_{in}^{CMY} = (\hat{C}_{in} + \hat{M}_{in} + \hat{Y}_{in})/3$$

$$C_{out} = \hat{\beta}(l_{in}^{CMY}) \cdot \hat{C}_{in},\ \ M_{out} = \hat{\beta}(l_{in}^{CNY}) \cdot \hat{M}_{in},\ \ Y_{out} = \hat{\beta}(l_{in}^{CMY}) \cdot \hat{Y}_{in} \tag{36}$$

where

$$\hat{\beta}(l_{in}^{CMY}) = g(l_{in}^{CMY})/\hat{l}_{in}^{CMY}$$

The output signal transformed into RGB color system.

$$R_{out} = 1 - C_{out},\ \ \ G_{out} = 1 - M_{out},\ \ \ B_{out} = 1 - Y_{out}$$

We illustrate the principle of the proposed scheme based on comparisons with the scheme which is proposed by Naik and Murthy. In order to explain clearly, we take a SI plane (i.e., equal hue plane) for example.

We show an example of [Case 2](2-b). The line which is connected (0,0,0) and (1,1,1) is intensity axis. Therefore, the saturation gets larger as the distance from intensity axis. Points "A" shown in Fig.20 is the input signal. Points "B" and "C" shown in Fig.20 mean the result of Naik's scheme and the proposed scheme, respectively. In the scheme of Naik and Murthy, the output signal is located on the line which connected input signal and (1,1,1). Thus, the saturation of the output signal is decreased. On the other hand, in our scheme, first, the input signal is translated to the boundary of the RGB color system, next, translated on the line which connected the boundary point signal and (1,1,1). The saturation of output signal is always higher than that of the output of Naik's scheme. Furthermore, the output signal of our scheme is also always located inside of the RGB system as is the case of the Naik's scheme.

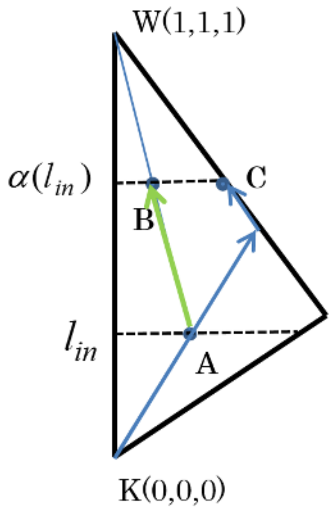


Fig.20: *Our scheme compared to Naik's scheme in the case of [Case 2](2-b) (A: Input B: Naik's result C: Our result)).*

6.3 Experimental Results

Two color images, "balloon" and "airplane" are used for simulation. HE is used as the transformation function $f()$. We compare our method to Naik's method.

Fig.21 and Fig.22 show the original image and the output images of 2 methods on "balloon" and "airplane", respectively. Two methods can preserve the hue component. Since HE is applied the contrast is improved efficiently by both methods. The intensity of both output images is same. However, the colorfulness of two outputs is different. Because of the saturation of the proposed method is larger than that of Naik's method for all pixels. The enhancement results of the proposed scheme show more colorful than those of Naik's method.

7. CONCLUSIONS

First half of this paper color systems are reviewed. Color systems are divided into two categories. One is the color appearance system and the other is the

(a) Original (b) Naik's method (c) Our method

Fig.21: *Enhancement results (balloon).*

(a) Original (b) Naik's method (c) Our method

Fig.22: *Enhancement results (airplane).*

additive color system. Munsell color system which is belonged to the color appearance system and RGB and HSI color systems which are belonged to the additive color system are reviewed. Munsell color system is constructed based on the human visual system. It is important point that HSI color system is closely related to Munsell color system. However the conventional HSI color system has the gamut problem. Therefore HSI color system with same gamut of RGB color system is introduced.

The second part of this paper color image enhancement methods are reviewed. It is necessary to preserve the hue before/after the color image enhancement. Enhancement in HSI color system is effective to preserve hue. We introduce high quality enhancement methods in HSI color system. Finally we show two processing schemes in RGB color system which can preserve the hue. These schemes to generalize any gray-scale contrast enhancement techniques to color images. These methods cannot control the saturation value, however, free from the gamut problem.

References

[1] R.C. Gonzalez and R.E. Woods, *Digital Image Processing* 3rd ed., Pearson Education, Inc., 2008.

[2] https://en.wikipedia.org/wiki/HSL_and_HSV

[3] M. Kamiyama and A. Taguchi, "HSI color space with same gamut of RGB color space," *IEICE Trans. on Fundamentals of Electronics, Communications and Computer Sciences*, Vol.E100-A, No.1, 2007 (to be appeared).

[4] F. Saitoh, "Image contrast improvement based on differential gray-levels histogram," *IEEJ Trans. EIS*, vol.126, no.2, pp.228-236, Feb. 2006 (in Japanese).

[5] K. Nakai, Y.Hoshi and A. Taguchi, "Color image contrast enhacement method based on differential intensity/saturation gray-levels histograms," *Proc. of 2013 International Symposium on Intelligent Signal Processing and Communications Systems (ISPACS)*, pp. 445 - 449, Nov. 2013.

[6] N. Nakajima and, A. Taguchi, "Intensity/Saturation enhancement based on differential gray-levels histogram equalization," *Proc. 2014 IEEE Asia Pacific Conference on Circuits and Systems*, pp. 527-530, 2014.

[7] S.K. Naik and C.A. Murthy, "Hue-preserving color image enhancement without gamut problem," *IEEE Trans. on Image processing*, vol.12, no.12, pp.1591-1598, December 2003.

[8] K. Murahira and A. Taguchi "Hue-preserving color image enhancement in RGB color space

with rich saturation," *Proc. of 2012 International Symposium on Intelligent Signal Processing and Communication Systems*, pp.266-269 (2012).

[9] https://notanothergardeningblog.com/tag/munsell-colour-system/

[10] https://en.wikipedia.org/wiki/Munsell_color_system#/media/File:Munsell-system.svg

[11] https://jp.pinterest.com/ythomasetyparis/the-munsell-color-system/

[12] http://imagingsolution.blog107.fc2.com/blog-entry-247.html

[13] L. Gao and X. Ling, "Color edge detection based on mathematical morphology in HSI space," *Proc. of 2010 International Conference on Computer and Information Application (ICCIA)*, pp.5-8, 2010.

[14] L.J. Ubong, S.T. Chee, and W.N. Giap, "A comparison of RGB and HSI color segmentation in real - time video images: A preliminary study on road sign detection," *Proc. of International Symposium on Information Technology (ITSim 2008)*, vol.4, pp.1-6, 2008.

[15] J. Zengwei, C. Jiazhong and Z. Jingli, "Image segmentation based on the HSI color space and an improved mean shift," *Proc. of International Conference on Information and Communications Technologies (IETICT 2013)*, pp.135-140, 2013.

[16] D. Yu, L-H. Ma and H-Q. Lu, "Normalized SI correction for hue-preserving color image enhancement," *Proc. of the Sixth International Conference on Machine Learning and Cybernetics*, pp.1498-1503, August 2007.

[17] A. Taguchi and Y. Hoshi, "Color image enhancement in HSI color space without gamut problem," *IEICE Trans. on Fundamentals of Electronics, Communications and Computer Sciences*, vol.E98-A, no.2, pp.792-795, 2015.

[18] D. Hasler and S. Susstrunk, "Measuring colourfulness in natural images," *Proceedings of SPIE*, Vol 5007, pp.87-95, jun. 2003.

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