GAMUT-ADAPTIVE CORRECTION IN COLOR IMAGE PROCESSING

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ABSTRACT

In color image processing, an image is usually processed in a color space consisting of luminance and chrominance components. The processed result is then converted to the RGB color space for display. However, a straightforward color space conversion can cause color distortion due to gamut difference between the two color spaces. In order to alleviate this gamut problem, we propose two gamut-adaptive correction schemes. For the chrominance component processing, we propose the gamut-adaptive clipping scheme to effectively solve the out-of-gamut problem. For the luminance component processing of a color image, we propose the gamut-adaptive scaling scheme to alleviate both the out-of-gamut and under-saturation problems. The proposed methods can be applied for image processing in any color space since the proposed correction is performed in the RGB color space. Experimental results show that the proposed methods can preserve the luminance and hue values and provide rich colors by adaptively controlling the saturation value according to the luminance component value.

Index Terms**—** Color image processing, out-of-gamut problem, under-saturation problem, saturation clipping and scaling, hue-preserving

1. INTRODUCTION

The RGB color space is usually employed for color image display. However, it does not correspond to human perception. Therefore, color image processing is usually performed in color spaces such as HSI and YUV where the color is decomposed into luminance and chrominance components. Those color spaces are known to well correspond to perceptual attributes of the human visual system (HVS). After the processing, we need to convert the result to the RGB space again for display. During this conversion, the gamut difference between the color space which is adopted for the processing and the RGB color space can cause the out-of-gamut [1] and under-saturation problems. Therefore, those problems need to be alleviated before the display with RGB components.

In order to solve the out-of-gamut problem, we usually perform simple RGB clipping if their values are outside the range of [0, 1]. The problem can also be solved by decreasing the luminance value. However, those approaches can distort the hue and luminance values or decrease the contrast. To alleviate those degradations, a saturation clipping method was proposed so as to preserve the hue and luminance values [1]. Even though the method outperforms the two approaches mentioned above, it did not consider the pixels where R, G, or B value is less than 0. That problem was handled by changing the saturation values of those pixels to zero [2], even though the result was not satisfactory.

Meanwhile, luminance component processing in a color image can cause the under-saturation problem as well as the out-of-gamut problem. To solve those problems, several techniques have been proposed [3-5]. A principle was developed for hue-preserving contrast enhancement transformations [3]. Murtaza *et al.* proposed an efficient generalized hue-preserving technique to avoid the gamut problem [4]. A color image histogram equalization approach was also proposed by exploiting the correlation between color components [5]. However, most of those methods focus only on the out-of-gamut problem and neglect the under-saturation problem that makes the color fade. Moreover, none of those is suitable for various luminance component processing schemes.

In this paper, we first propose the gamut-adaptive clipping method for the chrominance component processing such as colorization and color transfer. This can effectively solve the out-of-gamut problem based on saturation clipping. We also propose the gamut-adaptive scaling method for the luminance component processing. This method can alleviate both out-of-gamut and under-saturation problems through the saturation compensation.

The paper is organized as follows. In section 2, we briefly review the HSI and YUV color spaces. The proposed methods are described in section 3. In section 4, we show some experimental results to demonstrate the performance of the proposed methods. Finally, we conclude the paper in section 5.

2. HSI AND YUV COLOR SPACES

There are many color spaces that decompose the color into the luminance and chrominance components. Among them, we will consider the HSI-type and YUV color spaces which are popularly used. The HSI-type includes the HSI [7], HSV

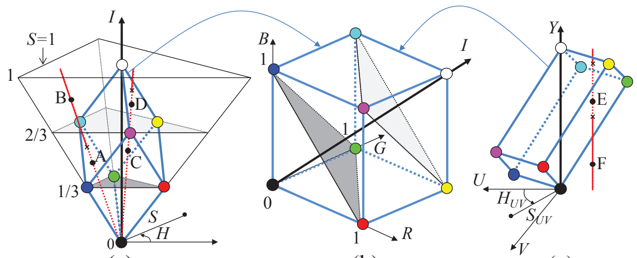

Fig. 1. Relation between color spaces and RGB cube. (a) HSI, (b) RGB cube, and (c) YUV.

[6], and HSL [6]. Among those, the HSI is considered conventional and provides accurate hue values [6]. In addition, luminance components of HSL and HSV are not appropriate for the HVS. Therefore, we consider the HSI as the representative of HSI-type color spaces.

In Fig. 1(a), the relation between the HSI color space and the RGB cube is described. Note in the figure that the boundary of the HSI space for a given value of I is a triangle shape and the saturation value on the boundary is always one. Let us now consider the case when the value of I changes due to the luminance component processing. If we change the value of I of a certain point while keeping its values of H and S unchanged, the point moves along a red line shown in Fig. 1(a). If a point moves from A to B on the red line, the out-of-gamut problem occurs. In this case, the color can be distorted and appears oversaturated if we apply the simple RGB clipping. Meanwhile, under-saturation occurs when the corresponding 2-D gamut boundary of the RGB cube increases as the value of I decreases. For example, the movement of a point from D to C can under-saturate the color or make it fade even if it does not produce the out-of-gamut problem.

Meanwhile, the change of Y with fixed U and V values in the YUV color space makes a point move along the red line as shown in Fig. 1(c). Similarly to the HSI, the color of the point can be under-saturated if the 2-D gamut boundary of the RGB cube, that is determined at a fixed value of Y, increases. In addition, this movement frequently causes the out-of-gamut problem such as the point movement from E to F as shown in the Fig. 1(c).

The color conversion from the RGB to YUV spaces can be written as [6],

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}. \tag{1}$$

Also, the H and S can be approximated by using the values of U and V as [6]

$$H_{UV}(=\alpha) = \tan^{-1}(V/U), \tag{2}$$

$$S_{UV} = \sqrt{U^2 + V^2}. \tag{3}$$

Here, H_{UV} corresponds to the hue value H and is not affected by changing of Y. It is known that H_{UV} has an offset from H. Meanwhile, S_{UV} is a scaled version of S and its scale factor varies according to the value of Y.

Based on (2) and (3), we can change the color while preserving H as well as Y by using

$$U' = \tau \cdot U, \; V' = \tau \cdot V, \tag{4}$$

where τ is a non-negative parameter. We can notice in (4) that only the value of S is varied in the color change. Meanwhile, the YUV to RGB conversion can be written as

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1.140 \\ 1 & -0.395 & -0.581 \\ 1 & 2.032 & 0 \end{pmatrix} \begin{pmatrix} Y \\ U \\ V \end{pmatrix}. \tag{5}$$

Therefore, the same process above can be done in the RGB space by applying (4) to (5) [2], namely,

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} \tau Y + 1.140\tau V + (1-\tau)Y \\ \tau Y - 0.395\tau U - 0.581\tau V + (1-\tau)Y \\ \tau Y + 2.032\tau U + (1-\tau)Y \end{pmatrix}, \tag{6}$$

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \tau \begin{pmatrix} R \\ G \\ B \end{pmatrix} + (1-\tau) \begin{pmatrix} Y \\ Y \\ Y \end{pmatrix}. \tag{7}$$

According to (7), the saturation change of the color while preserving its hue and luminance can also be achieved in the RGB space by properly choosing a value of τ.

3. PROPOSED METHODS

We now consider the gamut-adaptive correction problem in the RGB space on the basis of (7). Following subsections describe two methods to automatically determine a proper value of τ for color image processing. In both methods, we set the values of R, G, and B to 0 if Y is less than 0 and to 1 if Y is greater than 1.

3.1. Gamut-adaptive clipping (GAC)

In the color image processing only with chrominance components, we usually want to preserve the processed hue and original luminance values, H and Y, when we fix the out-of-gamut problem. This can be achieved by clipping the saturation value of the out-of-gamut colors as shown in Fig. 2. Therefore, in the proposed gamut-adaptive clipping (GAC) method, we move the pixels outside the allowable range of U and V (ARUV) to the boundary of gamut that varies along the Y axis. The value of parameter τ corresponding to this movement can be obtained by using the condition of

$$0 \le R', G', B' \le 1. \tag{8}$$

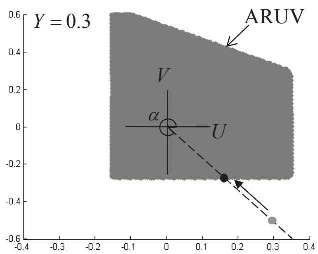

Fig. 2. Proposed gamut-adaptive clipping (GAC). Here, all points on the dashed line have the same value of α (or the same hue).

Table I.
Results of the GAC for several points on the dashed line in Fig. 2.

	Before clipping (α is the same.)			After simple RGB clipping			After Yang and Kwok's clipping [2]			After the proposed GAC		
	Y	U	V	Y	H	S	Y	H	S	Y	H	S
Inside ARUV	0.30	0.05	-0.09	0.30	200°	0.35	0.30	200°	0.35	0.30	200°	0.35
	0.30	0.10	-0.17	0.30	200°	0.68	0.30	200°	0.68	0.30	200°	0.68
	0.30	0.15	-0.26	0.30	200°	0.99	0.30	200°	0.99	0.30	200°	0.99
Outside ARUV	0.30	0.20	-0.35	0.33	204°	1.00	0.30	0°	0	0.30	200°	1.00
	0.30	0.25	-0.43	0.36	206°	1.00	0.30	0°	0	0.30	200°	1.00
	0.30	0.30	-0.52	0.39	208°	1.00	0.30	0°	0	0.30	200°	1.00
	0.30	0.35	-0.61	0.42	209°	1.00	0.30	0°	0	0.30	200°	1.00

By applying (7) to (8),

$$\begin{aligned} -Y &\le \tau(R-Y) \le (1-Y), \\ -Y &\le \tau(G-Y) \le (1-Y), \\ -Y &\le \tau(B-Y) \le (1-Y). \end{aligned} \tag{9}$$

Since the value of τ is non-negative and it should not exceed one in this processing,

$$0 \le \tau \le 1. \tag{10}$$

Using (9) and (10), τ can be obtained as

$$\tau = \tau_C = \min\big(1, \gamma(R,Y), \gamma(G,Y), \gamma(B,Y)\big), \tag{11}$$

where

$$\gamma(C,Y) = \max\left(\frac{1-Y}{C-Y}, \frac{-Y}{C-Y}\right), \tag{12}$$

and C indicates R, G, or B component. According to (7), (11), and (12), we can use the proposed method in any color space other than the YUV color space, once the values of R, G, B and Y are determined.

3.2. Gamut-adaptive scaling (GAS)

In the color image processing only with luminance components, the processed luminance values are considered more meaningful than the chrominance components. Therefore, the modification of chrominance components is preferable to solve the gamut problem. Meanwhile, the chrominance components consist of hue and saturation values, and hue is more important than saturation in the viewpoint of HVS. Hence, it is more desirable to adjust the

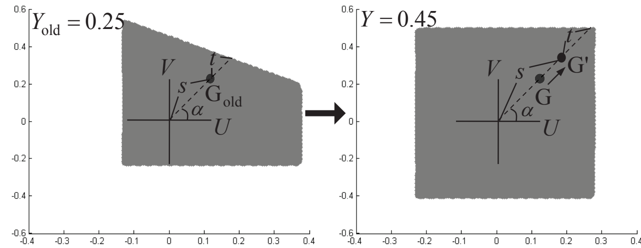

Fig. 3. Proposed gamut-adaptive scaling (GAS). Here, all points on the dashed line have the same value of α (or the same hue).

saturation value than the luminance or hue value. Accordingly, (7) can also be used in this case.

We may use the GAC for the saturation adjustment. However, the GAC cannot prevent the under-saturation of colors although it can solve the out-of-gamut problem. Therefore, we need a new method to handle both the out-of-gamut and under-saturation problems arising in the color image processing only with luminance components.

The proposed gamut-adaptive scaling (GAS) method is as described in Fig. 3. Let us assume that luminance Y_{old} is changed to Y due to the luminance processing. Here, suffix 'old' denotes the original values before applying the color image processing. Then, point G_{old} moves to point G in the ARUV newly defined by the processed value of Y. However, the color of point G becomes under-saturated since the ARUV is enlarged. To overcome this problem, point G needs to be modified properly based on saturation adjustment. Hence, the GAS repositions point G to G' while maintaining the ratio of s to t. Here, s and t denote the distances from point G_{old} to the origin of (U, V) and from G_{old} to the boundary of ARUV, respectively. By using (9), the value of τ to move point G to G' can be obtained as

$$\tau_S = \begin{cases} 0, & \text{if } R = G = B, \\ \dfrac{\min\big(\gamma(R,Y), \gamma(G,Y), \gamma(B,Y)\big)}{\min\big(\gamma(R_{\text{old}},Y_{\text{old}}), \gamma(G_{\text{old}},Y_{\text{old}}), \gamma(B_{\text{old}},Y_{\text{old}})\big)}, & \text{otherwise}. \end{cases} \tag{13}$$

The GAS can also prevent the out-of-gamut problem.

4. EXPERIMENTAL RESULTS

In order to evaluate the performance of the proposed GAC method, we compare it with the simple RGB clipping and the Yang and Kwok's clipping [2] in Table I. In the table, if pixels locate outside ARUV, the simple RGB clipping produces distortions in Y and H values. Also, the Yang and Kwok's clipping cannot effectively perform saturation clipping when processed R, G, or B value is less than 0. However, the proposed algorithm perfectly preserves the Y and H values while keeping the maximum saturation value.

Meanwhile, the performance of the proposed GAS method is evaluated by comparing with the Yang and Kwok's clipping that can be also applicable to various color images processing in the HSI and YUV color spaces [2].

Fig. 4. (a), (d) Original images and the results of (b), (e) Yang and Kwok's clipping and (c), (f) the proposed GAS after the luminance component processing. (a)-(c) are for the "park" image and (d)-(f) for the "toy" images [9].

The experimental results for the "park" image are given in Figs. 4(a)-(c). These results are obtained by using the subband decomposed multiscale retinex (SDMSR) [8] as a luminance component processing scheme in the YUV color space because SDMSR is effective for both over-exposed and under-exposed images. We can note in Fig. 4(b) that colors are under-saturated in the enhanced dark regions because the ARUV boundary is enlarged with the fixed values of U and V when the Y value increases. Moreover, the enlarged part shows that Yang and Kwok's clipping makes some yellow colors having the out-of-gamut problem gray. In Fig. 4(c), however, the proposed GAS can successfully provide rich colors and solve the out-of-gamut problem. Figs. 4(d)-(f) shows the results obtained by using the histogram equalization as luminance component processing in the HSI color space. In Fig. 4(e), color fading is noticed. This fading occurs because the decrease of I value in the HSI color space frequently under-saturates colors (for example, the movement of point D to C in Fig. 1(a)). However, the proposed GAS can successfully provide good colors by avoiding under-saturation problem via adaptively scaling of the saturation values (see Fig. 4(f)).

5. CONCLUSION

In color image processing, we found that the out-of-gamut and under-saturation problems can cause unwanted color distortions. In this paper, we propose the two gamut-adaptive correction schemes to alleviate those gamut problems. For the chrominance component processing, we propose the GAC to solve the out-of-gamut problem while preserving the processed hue and original luminance values. The GAC is useful for the applications such as colorization and color transfer where only the chrominance components are processed. For the luminance component processing, we propose the GAS so that we can preserve the processed luminance and original hue values and obtain richer colors. This is possible because the GAS can alleviate the under-saturation problem by properly controlling the saturation value according to the luminance change. Moreover, the out-of-gamut problem is naturally solved in this method. The GAS can be applied to the grayscale-based color image processing such as image enhancement, super-resolution, and deblurring. Both proposed methods are applicable for the processing in any color space since the colors are corrected in the RGB space where the image is displayed. Experimental results show that the proposed algorithms efficiently alleviate the gamut problems.

6. ACKNOWLEDGEMENTS

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