Pseudo-Linearly Modified IHS Color Model and its Application to Color Image Enhancement

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Abstract

Color image enhancement is a technique which makes an image more vivid for human vision. Most affecting color elements for the image are intensity, contrast and saturation. In handling these color elements with the conventional coordinates, their geometric form is important in view of valid gamut. Of them, IHS coordinate appropriately represents human color perception and it is easy to manipulate hue, intensity and saturation of the image. The geometric form of this coordinate is, however, nonlinear, so that it is difficult to control the element values since they may

exceed the valid gamut. In this paper, a modified IHS coordinate system is proposed to remedy the nonlinearity of IHS system. The proposed coordinate is derived to linearize the relationship between the saturation and intensity. To improve the image quality, contrast is increased by maximizing the dynamic range of intensity, and saturation is normalized in full range of the intensity because the ratio between the changed saturation values should be maintained the same ratio as between original values. Hue is preserved to keep the characteristic property of the color image. This coordinate system is easy to enhance color images and avoid the gamut-overflow problem.

1. Introduction

Image enhancement is the technique of making an image more vivid for human vision. Since color has more information than black and white and most natural images are color, the technique of color image enhancement is required to meet the increasing demands for applications. Thus the color becomes more useful in recent image processing.

Most influential color elements for an image are intensity, contrast and saturation.[1] Brightness is the global luminosity of an image. Contrast is the relative ratio between luminosity values. Saturation implies the purity of a color and gives vividness to an image. In handling these color elements with conventional color coordinate systems,[2-5] their geometric form is important in image enhancement in view of gamut validity problem.

RGB coordinate system is suited to the hardware of image processing devices. It is, however, difficult to manipulate color elements in this coordinate because its variables do not directly describe human color perception. YIQ coordinate system has a shortcoming which requires the constant ratio between I and Q in controlling saturation. XYZ coordinate system is generally accepted and used, but data manipulation is difficult due to its nonlinearity. IHS coordinate system appropriately represents human color perception and it is easy to manipulate hue, intensity and saturation of an image. The geometric form of this coordinate system is, however, nonlinear, so that it is also difficult to decide the validity of the controlled parameter values.

In this paper, a modified IHS coordinate system is proposed to remedy the nonlinearity of IHS system. Generally, hue value is presented in angle from 0 to 2π radian, and the distribution of hue values in the proposed coordinate system is uniform with respect to angle. Saturation has regular pattern along the hue angles, and intensity is the average of three primaries. In this coordinate system, saturation and hue can be calculated from the analysis of RGB's three primary vectors. And the global form of the proposed coordinate system is double cone. To improve image quality, contrast is increased by maximizing the dynamic range of intensity[4, 6-8] and saturation is normalized in full range of intensity values because the ratio between controlled saturation values should be maintained the same ratio as between original saturation values. Hue is preserved because it is the characteristic property of an image. The form of the proposed coordinate system is pseudo linear, and the compensation is needed for normalization in practical processing.

2. Pseudo-Linearly Modified IHS Coordinate System

Since the geometric form of the conventional coordinate systems is nonuniform, it is difficult to control color in image enhancement. To improve controllability problem, linear geometric form of coordinate system is preferred. The IHS coordinate system has nonlinear form for the intensity values since the given weights to R, G, and B are not equal. The locus which connects maximum saturation points of all hue is not perpendicular to the intensity axis. It means the coordinate system is nonlinear in the geometric form. To improve this, it needs to give equal weights to R, G, and B. Any arbitrary chromaticity $\vec{C}$ can be expressed by the proper combination of three primary vectors R, G and B as

$$\vec{C} = r \angle 0 + g \angle (2\pi/3) + b \angle (4\pi/3)$$
$$= \frac{2r-g-b}{2} + j\frac{\sqrt{3}\,(g-b)}{2}$$
$$= S_p \angle H_p. \qquad (1)$$

where r, g and b are the magnitudes of three primary color vectors. S_p means the magnitude of the color in complex domain, and H_p, the phase angle. The proposed color coordinate system is presented in Fig. l and expressed by using r, g and b as

$$\begin{cases} I_P = \frac{1}{3}(r+g+b), & 0 \le I_P \le 255 \\ H_p = \operatorname{atan2}(\sqrt{3}(g-b), 2r-g-b), & \pi \le H_p \le \pi \\ S_p = \sqrt{r(r-g)+g(g-b)+b(b-r)}, & 0 \le S_p \le 255 \end{cases}$$

(2)

The I_p-S_p cross-section for a certain hue is shown in Fig. 2(a), and normalized S_p for the maximum value in a certain I_p is shown in Fig. 2(b). In controlling the intensity, the problem that the controlled value can exceed the valid gamut can be solved by normalization. Thus the controlled saturation value also can be preserved in the same ratio between the original value and maximum value of the saturation in a certain hue. The method to find both S_m and I_m, the reference points in the normalization of S_p, is as follows: S_m is the maximum value of saturation in a certain hue as expressed in (3). I_m is the intensity value when the saturation value is S_m for a certain hue, H_p and H_d is the value of H_p in degree.

$$S_m = \frac{255 \times \cos(30^\circ)}{\cos(H_d - 30 - 60 \times k)}, \quad k = H_d/60 \qquad (3)$$

where k is integer.

The relation of transformation from Fig. 2(a) to Fig. 2(b) is presented as

$$S_{p'} = \begin{cases} S_p \times \frac{255 - I_m}{255 - I_p}, & I_m \le I_p < 255 \\ S_p \times \frac{I_m}{I_p}, & 0 < I_p < I_m \end{cases} \qquad (4)$$

If the intensity is 0 or 255, it is not considered in saturation processing because it means black or white. The inverse transform of the coordinate system is expressed as the transformation from $I_pH_d'S_p'$ through $I_pH_pS_p$ to RGB using I_m and S_m. At this point, the inverse transform and parameter values, V_1, V_2 and V_3, are expressed as

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & 0 & 1 \\ -\frac{1}{3} & \frac{1}{\sqrt{3}} & 1 \\ -\frac{1}{3} & -\frac{1}{\sqrt{3}} & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V2 \\ V_3 \end{bmatrix} \tag{5}$$

$$V_1 = S_p \times \cos H_p,$$
$$V_2 = S_p \times \sin H_p, \tag{6}$$
$$V_3 = I_p$$

3. Image Enhancement Using Pseudo-Linearly Modified IHS Coordinate System

The flowchart of color image enhancement is shown in Fig. 3 and the sequence of coordinate system conversion is as follows:

$$RGB \rightarrow I_pH_pS_p \rightarrow I_pH_dS_p \rightarrow I_pH_d'S_p' \rightarrow I_pH_pS_p \rightarrow RGB$$

3.1 Intensity processing

To increase the continuity of an image and extend dynamic range, histogram stretching and adaptive smoothing with 3 × 3 mask were used.

3.1.1 Adaptive smoothing

Edge values were calculated by Sobel operator and quantized into 32 levels to be used as the weight of center pixel in 3 × 3 mask. I_{pN} is the sum of neighboring intensities, and I_p' is smoothed intensity value with weighted center pixel as

$$V_{sob} = |G_x| + |G_y|, \tag{7}$$

$$W = V_{sob} / 8, \tag{8}$$

$$I_{pN}(i, j) = (\sum_{k=-1}^{1} \sum_{l=-1}^{1} I_p(i+k, j+1)) - I_p(i, j), \tag{9}$$

$$I_{p'}(i, j) = \frac{W \times I_p + I_{PN}(i, j)}{W + 8} \tag{10}$$

3.1.2 Histogram stretching

Intensity values are manipulated by using I_{min} and I_{max} as the reference point. I_p"; is the normalized value of intensity.

$$I_{p''}(i, j) = 255 \times \frac{(I_p'(i, j) - I_{min}}{(I_{max} - I_{min})} \tag{11}$$

3.2 Hue processing

Hue is the characteristic property of an image and should be preserved as much as possible. The averaging with 5 × 5 mask may be used to increase the continuity of an image, if it is no harmful to original hue values.

3.3 Saturation processing

Saturation is also smoothed with 5 × 5 mask and shifted to the maximum value in the normalized gamut after compressing its dynamic range to l/N. Higher saturation values can be obtained by shifting the saturation values after compressing them instead of scaling them merely. The new saturation S_p' can be calculated by using mean and maximum values of the original saturation, and the shift is calculated by

$$S_c = \frac{S_{p'} + (N-1) \times \text{mean}}{N}, \tag{12}$$

$$d = 255 - \frac{\max + (N-1) \times \text{mean}}{N}, \tag{13}$$

$$S_p'' = S_c + d. \tag{14}$$

The value of N is proportional to the saturation of an image. If the value of N is, however, excessive, it degrades image quality.

4. Experimental Results

The indoor and outdoor images were used in the experiment. In Fig. 4, (a) is the image captured under a fluorescent lamp, (b) is the result of linear processing without smoothing, and (c) is the result with edge-preserving smoothing of intensity. The value of N, which determines saturation scaling, is 1 in all cases. Fig. 4(d) is the result of N = 2 and shows the image quality degraded somewhat because the saturation is excessively increased. Since this method can increase the saturation very much, the image quality can be improved by adjusting N when the saturation of the original image is very low. Fig. 5(a) is the image of printed material captured under fluorescent lamp and (b) is the result when N is 1. Since there is a limit in increasing the contrast using linear stretching of intensity histogram, a new algorithm should be suggested through further study.

5. Conclusion

Image enhancement consists of a collection of techniques that seek to improve the visual appearance of an image, or to convert the image to a form better suited for analysis by a human or a machine. Most natural images are color and the technique of color image enhancement is required to meet the increasing demands for applications.

Since the conventional IHS color coordinate system is geometrically nonlinear, it is difficult to use it directly in image enhancement because it requires gamut validity in every data manipulation process. The proposed coordinate system is comparatively linear and can be used effectively in enhancement process without checking the validity of controlled data. The new coordinate system is based on human color perception and has the merit that it can be used in the color image enhancement easily. Another algorithms such as smoothing, stretching of histogram can be used in the intensity processing which improves the image quality without any adjustment of them. The value of N, which is related to the saturation, should be appropriately determined with the characteristic property of an image in further study.

6. References

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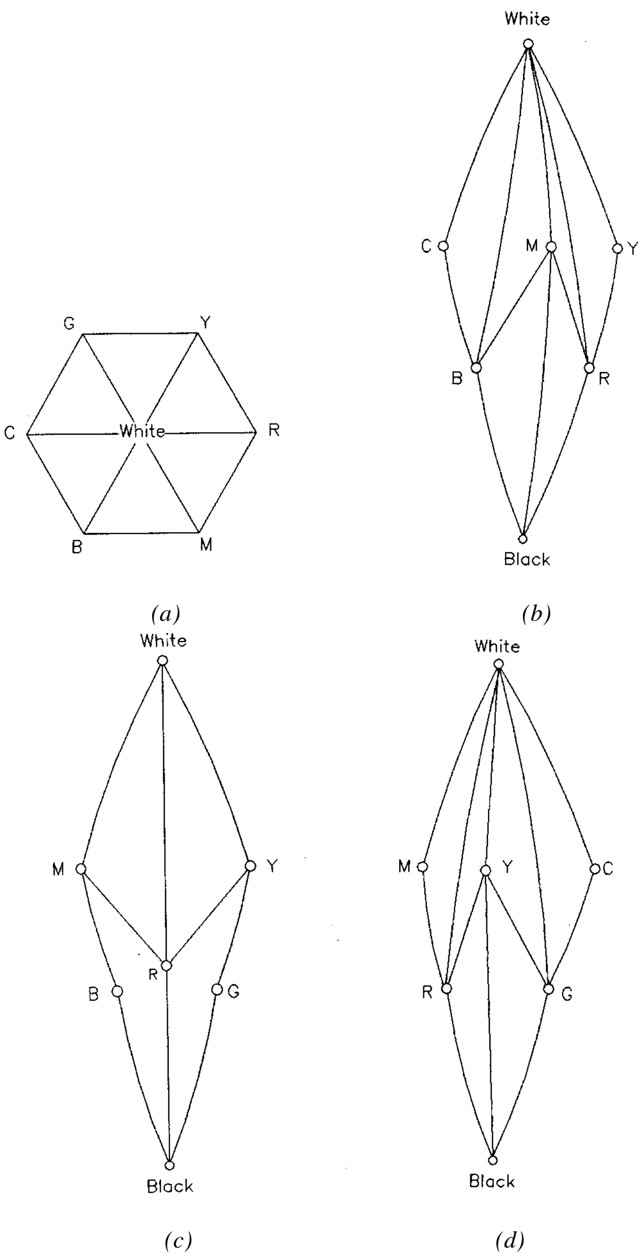


Figure 1. The proposed coordinate system
(a) plane view (b) side view (left)
(c) front view (d) side view (right)

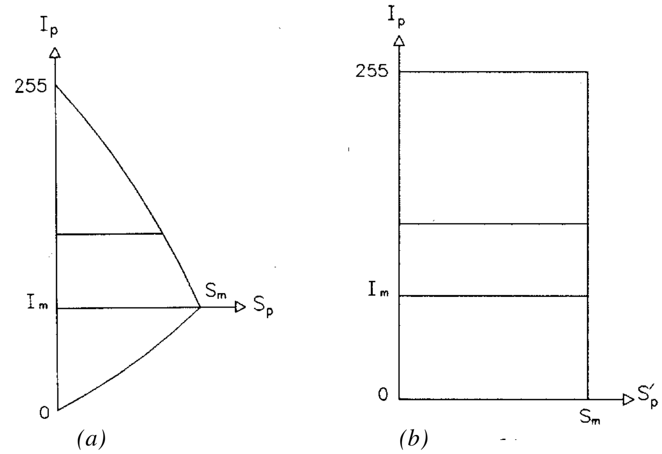


Figure 2. A cross section of the proposed coordinate system
(a) original (b) normalized

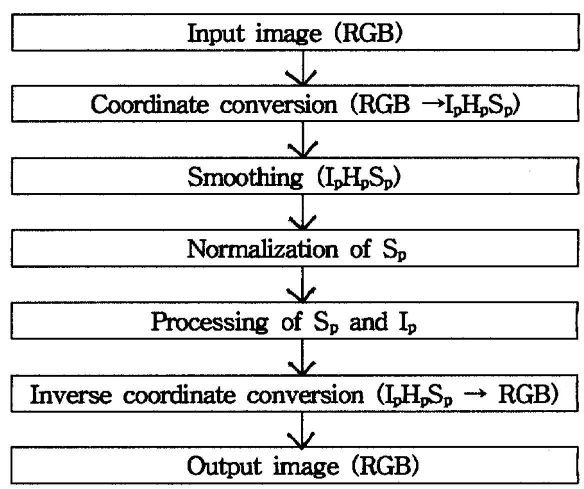
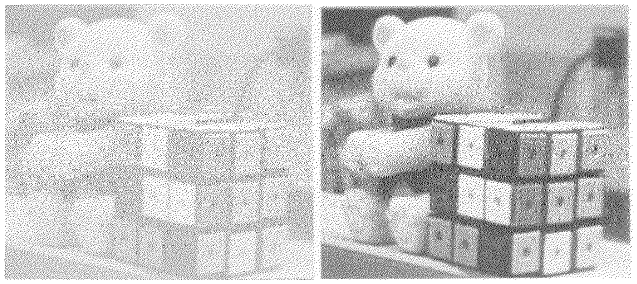
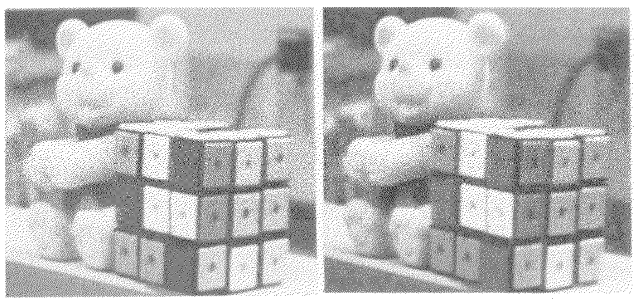


Figure 3. Flowchart of the processing



(a) (b)



(c) (d)

Figure 4. The bear and cube image.
(a) original image *(b) after linear operation*
(c) result with intensity smoothing *(d) in case of N=2*

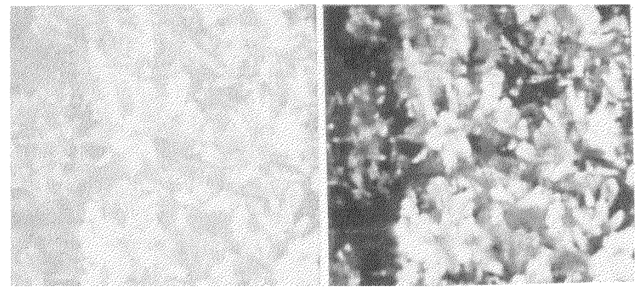


Figure 5. The flower image
(a) original image *(b) result with intensity smoothing*