Classified Image Enhancement Method Based on Histogram Characteristics in YCbCr Color Space

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Abstract

Color image enhancement in YCbCr space is an important task since most of the color image signals captured from the embedded camera or the professional video device are YCbCr image signals. Prior classical color image enhancement methods like linear transforms such as binarization, piecewise-line transform, and gray-level slicing, or non-linear transforms such as logarithm transform, index transform, and power-law transform did not consider possible histogram characteristics, and thus their enhancement performance on different image types would be degraded in some cases. In this paper, a novel classified image enhancement method based on CbCr and Y histograms is proposed to address the aforementioned problem. First, captured images are divided into two types, document image and scene image, according to the normalized chrominance histogram characteristic. For the document image, a filter is applied in space domain to get a better foreground and background. For the scene image, three different types are divided by the normalized luminance histogram characteristics. Then, three different processing schemes are applied to the three types of scene images respectively. Experimental results on different images with a variety of variations verify the effectiveness and robustness of the proposed method.

Keywords: Image processing, Image enhancement, Characteristic classification, YCbCr color space, Normalized Histogram

1 Introduction

Over the last few years, more and more embedded devices with small cameras emerged in our daily life. The signals captured from the embedded cameras, also most of the professional video devices, are YCbCr image signals. Because of camera performance, shooting environment, human vision and other reasons, the quality of the image cannot satisfy the user very well sometimes. To get a better visual experience, the image needs to be processed by the enhancement method.

For example, we developed an intelligent reader, which can read the document image out and zoom in the captured image for sight impaired in Figure 1. The image signal from the embedded camera is the YCbCr signal. YCbCr image enhancement is a key step for the entire processing flow.

FIGURE 1 Intelligent reader developed by us

YCbCr image can be enhanced in RGB color space also. However, it is difficult for luminance and saturation control in RGB color space. Hence, direct enhancing the YCbCr image signals in its own YCbCr color space is a better choice. For enhancement method in YCbCr color space, some methods have been proposed.

Gwanggil J proposed a near infrared (NIR) image enhancing method with the help of a high resolution RGB image [1]. However, this method is effective mainly for the low resolution NIR image.

Yang S and Liu W proposed a color fusion method of low-level-light and infrared images to render multiband image to a comparative realistic color appearance in YCbCr color space [2]. However, this method is proposed to solve the problems of the low-level light image intensifiers and thermal infrared cameras.

Zolfaghari, Mohammad and Yazdi, Mehran offered an efficient edge-preserving algorithm for color contrast enhancement [3]. However, through comparisons, this method can get a better performance in CIE Lu'v' color space, not the YCbCr color space.

Wang J, Wang C, and Lee J proposed an image enhancing and processing method in YCbCr color space to remove the remaining background around the hand [4]. However, this method is mainly suitable for compact hand image.

Jiang D, Li M, and Mao J proposed an effective method of combining histogram manipulation and moving objects region enhancement for nighttime video enhancement [5]. However, this method enhances only the chrominance signal in YCbCr color space.

Chiang J, Hsia C, Peng H, Lien C, Li H proposed a saturation adjustment method based on human vision with YCbCr color model characteristic sand luminance changes [6]. However, this method is mainly for the scene image, not including the document image.

Zhang W, Wang Z, and Li Y proposed a method, which can enhance driver video image quality [7, 8]. However, this method enhanced only the Y component, not including the saturation.

Lee S, Kwak Y, Youn J Ki, SeHyeok P, Jaehyun K proposed a chroma enhancement algorithm using the YCbCr signals by predicting the amounts of lama change needed to compensate for the lightness change induced by chroma enhancement [9]. However, the image contrast is preserved unchanged.

Yin W, Lin X, and Sun Y described a novel framework for low-light color image enhancement and denoising [10]. However, only the noise reducing is processed in the YCbCr color space based on noise characteristics in low-light images.

Bonghyup K, Changwon J, David K H, Hanseok K proposed an Adaptive Height-Modified Histogram Equalization (AHMHE) algorithm as a compensation technique for backlight images [11]. However, the histogram equalization algorithm is not suitable for all kinds of images, especially the document images.

Some of these proposed methods are mainly for some special images, for example, the near infrared (NIR) image, the low-level light image, the thermal infrared image, and so on. Some of these proposed methods are mainly for some special applications, for example, the hand, the face, and so on. The other proposed methods did not consider the different types of the captured images.

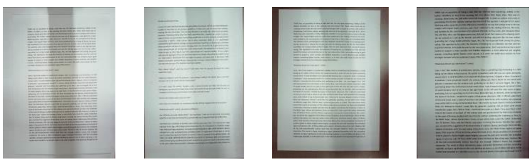
This paper proposes a classified enhancement method using histogram characteristics in YCbCr color space. First, the normalized chrominance histogram characteristic is used to distinguishthe document image and the scene image. Then for the document image, a spatial filtering is performed to eliminate possible shading and enhance the background and the foreground. For the scene document, some further different types are identified by the normalized luminance histogram characteristics and different enhancement schemes are applied to them.

2 Image classification based on normalized chrominance histogram characteristic

The signal Y of the YCbCr is the luminance signal. Its range is in [0, 255]. The signal Cb and Cr are the chrominance signals. Their ranges are both in [-128, 128]. The relationship between YCbCr and RGB can be represented as Equation (1).

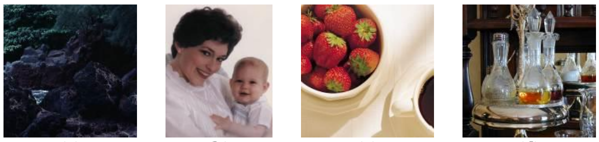
$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.2990 & 0.5870 & 0.1140 \\ -0.1687 & -0.3313 & 0.5000 \\ 0.5000 & -0.4187 & -0.0813 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

The main content of the document image is the text characters, for example, Figure 2. The main content of the scene image normally is portraits, objects, landscapes, and so on, for example, Figure 3.



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

FIGURE 2 Some examples of document images



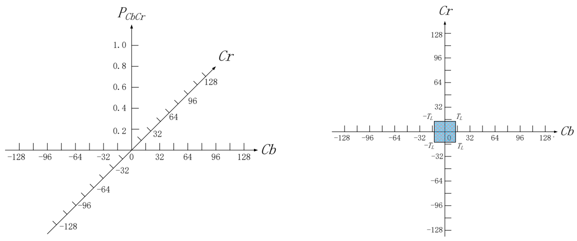
(a) (b) (c) (d)

FIGURE 3 Some examples of scene images

Normalized chrominance histogram is used to identify the document and scene images. The normalized chrominance histogram is a 2-dimension normalized histogram. The horizontal plane is composed by Cb and Cr axes. The vertical axis is P_{CbCr}, which is the probability of (Cb, Cr). The normalized chrominance histogram is shown in Figure 4(a). And the P_{CbCr} is calculated as Equation (2).

$$P_{CbCr} = \frac{N_{CbCr}}{H \times W}, \quad \begin{aligned} Cb &= -128, -127, \cdots, 0, \cdots, 127, 128 \\ Cr &= -128, -127, \cdots, 0, \cdots, 127, 128 \end{aligned} \tag{2}$$

Normally, most of pixels in the document image have lower saturation than the scene image. Hence, a threshold, T_L, for the value of Cb and Cr in the normalized chrominance histogram can be set, for example, 10% of the 128. The region, which the maximum value of Cb and Cr is less than the threshold is called threshold region. The threshold region is shown in Figure 4(b).



(a) (b)

FIGURE 4 (a) Normalized chrominance histogram; (b) Low saturation region

Normally, the possibility sum in the threshold region of the document image is very high. This normalized chrominance histogram characteristic can be used to identify the types of the image. For example, if the possibility sum in the threshold region, SP_{CbCr}, is more than 75%, the image can be identified as the document image. The SP_{CbCr} is calculated as Equation (3).

$$SP_{CbCr} = \sum_{Cr=-T_L}^{T_L} \sum_{Cb=-T_L}^{T_L} P_{CbCr} \tag{3}$$

In fact, the SP_{CbCr} of Figure 2(a)~(d) are 98.5%, 96.2%, 90.0%, and 94.0%. And the SP_{CbCr} of Figure 3(a)~(d) are 66.9%, 72.6%, 28.6%, and 65.9%.

3 Document image enhancement method based on spatial domain filtering

3.1 IMAGE FILTERING IN SPATIAL DOMAIN

Figure 5 is the normalized luminance histogram of Figure 2(a). The P_Y in the histogram is the possibility of the pixels which has luminance *Y*. P_Y is calculated as Equation (4).

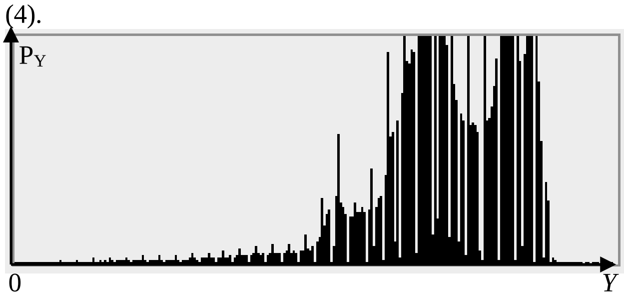


FIGURE 5 Luminance histogram of Figure 2(a)

$$P_Y = \frac{N_Y}{H \times W} \quad Y = 1, 2, ..., 255 \tag{4}$$

In order to degrade the shading in the document image, for the luminance value of pixel (x, y), i.e. $f(x, y)$, the spatial filtering is calculated as Equation (5).

$$h(x,y) = \begin{cases} e^{\ln 80 + \ln f(x,y) - LPF(\ln f(x,y))}, & e^{\ln 80 + \ln f(x,y) - LPF(\ln f(x,y))} \le 255 \\ 255, & e^{\ln 80 + \ln f(x,y) - LPF(\ln f(x,y))} > 255 \end{cases} \tag{5}$$

Here, $h(x, y)$ is the filtering result. The LPF is a low-pass filtering. The low-pass filtering is fulfilled by a convolution $f(x, y) * m(x, y)$. $m(x, y)$ is the convolution mask. For the position (x, y) in the mask, the mask coefficients are calculated by Equation (6).

$$T(tx, ty) = \frac{1}{2\pi\sigma^2} e^{-(tx^2 + ty^2)/(2\sigma^2)} \tag{6}$$

Figure 6 is the normalized luminance histogram of Figure 2(a) after spatial filtering.

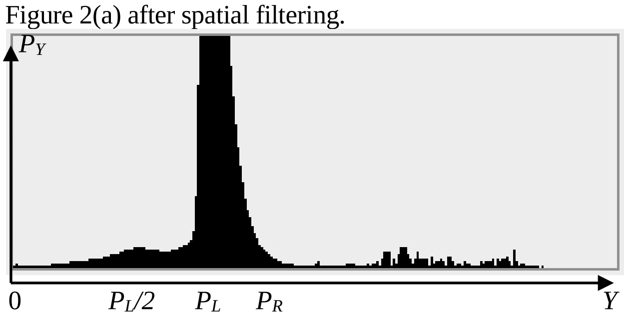


FIGURE 6 Luminance histogram after spatial filtering

3.2 LINEAR DYNAMIC RANGE ADJUSTMENT

After spatial filtering, most of the luminance values are relatively low. So a linear dynamic range adjustment is performed. Here, two variables in the luminance histogram after spatial filtering are defined. One is P_L, the first luminance value which probability is more than $\frac{1}{255}$. The other is P_R, the last luminance value which probability is more than $\frac{1}{255}$. For example, for the Figure 2(a), the P_L and P_R in Figure 6 are about 77 and 100.

Most of the background pixels should be in [P_L, P_R]. The pixels in the range [P_R, 255] then can be identified as 255. The pixels in the range [0, P_L] should be the foreground. For the robust reason, the pixels in the range [0, $\frac{P_R}{2}$] can be identified as 0.

For the pixels in the range [$\frac{P_R}{2}$, P_L], a linear function is applied to their luminance values as Equation (7). The histogram after the processing of Equation (7) is shown in Figure 7.

$$l(x,y) = \begin{cases} 0, & h(x,y) \le \frac{P_L}{2} \\ \frac{510h(x,y) - 255P_L}{2P_R - P_L}, & \frac{P_L}{2} < h(x,y) < P_R \\ 255, & h(x,y) \ge P_R \end{cases} \tag{7}$$

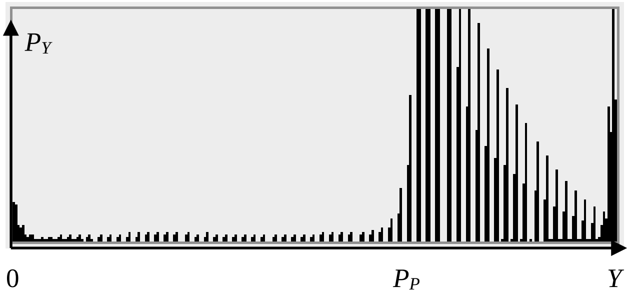


FIGURE 7 Luminance histogram after dynamic range adjustment

3.2 PEAK VALUE POSITION ADJUSTMENT

Considering most of the pixels in the document image should be the background pixels, the peak value position, for example 176 in Figure 7, then should be the back ground color. So the peak value position in the figure of the luminance histogram after dynamic range adjustment can be adjusted further to 255. Supposing the peak value position P_P, the pixels in the range [0, P_P] should be adjusted to [0, 255] also. The whole peak value position adjustment equation can be summarized in Equation (8).

$$p(x,y) = \begin{cases} \frac{255l(x,y)}{P_P}, & l(x,y) \le P_P \\ 255, & l(x,y) \ge P_P \end{cases} \tag{8}$$

After peak value position adjustment, the histogram in Figure 7 can be changed to Figure 8. From Figure 8, we can see that a lot of pixels are distributed in 0 or 255. The pixels in the range of (0, 255) also have a good distribution.

FIGURE 8 Luminance histogram after peak value position adjustment

4 Scene image enhancement method based on normalized luminance histogram characteristics

4.1 SCENE IMAGE CLASSIFICATION

For the P_L, the first luminance value which probability is more than $\frac{1}{255}$, and P_R, the last luminance value which probability is more than $\frac{1}{255}$, their average value, i.e. P_M, can be calculated as Equation (9).

$$P_M = \frac{P_L + P_R}{2} \tag{9}$$

Then the probability sum of the left side of the P_M, i.e. SP_L, and the probability sum of the right side of the P_M, i.e. SP_R, can be calculated as Equation (10) and Equation (11). At last, the absolute value of the SP_L and SP_R, i.e. ΔSP, is calculated as Equation (12).

$$SP_L = \sum_{Y=0}^{P_M} P_Y \tag{10}$$

$$SP_R = \sum_{Y=P_M}^{255} P_Y \tag{11}$$

$$\Delta SP = \left| SP_L - SP_R \right| \tag{12}$$

If the absolute value ΔSP is smaller than a threshold, for example, 15%, normally the distribution ratio of the foreground pixels and the background pixels are nearly balanced. The scene images belonging to this category are called class I scene image here. For the class I scene image, the luminance histogram equalization algorithm is performed.

On the contrary, if the absolute value ΔSP is bigger than the threshold, normally the distribution ratio of the foreground pixels and the background pixels are much different. One is for the scene image which probability sum of the left side in the luminance histogram is more than the right side. This kind of scene image is called class II scene image here. The other is for the scene image which probability sum of the right side in the luminance histogram is more than the left side. This kind of scene image is called class III scene image. Two non-linear transformations are used to enhance them.

4.2 SCENE IMAGE LUMINANCE ENHANCEMENT

For the class I scene image, the luminance histogram equalization algorithm is performed. For every luminance value in the luminance histogram, i.e. *Y*, and its probability, i.e. P_y, its probability sum, i.e. SP_y, is calculated as Equation (13).

$$SP_Y = \sum_{i=0}^{Y} P_i \tag{13}$$

Then, for the original luminance value, i.e. *Y*, the enhanced luminance value, i.e. *m(Y)* is calculated as Equation (14).

$$m(Y) = 255 SP_Y \tag{14}$$

Supposing the original luminance value is *l(x,y)* for every pixel which coordinates is (*x,y*) in the class II scene image, its enhanced luminance value, i.e., *P(x, y)* is calculated as Equation (15). Its transformation curve is presented in Figure 9(a).

$$p(x,y) = 255\sin\frac{\pi l(x,y)}{510} \tag{15}$$

Supposing the original luminance value is *l(x, y)* for every pixel which coordinates is *(x, y)* in the class III scene image, its enhanced luminance value, i.e. *p(x, y)*, is calculated as Equation (16). Its transformation curve is presented in Figure 9(b).

$$p(x,y) = 2l(x,y) - 255\sin\frac{\pi l(x,y)}{510} \tag{16}$$

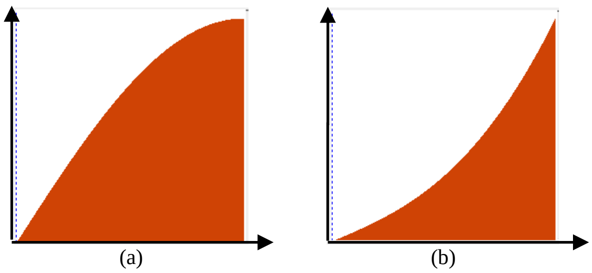


FIGURE 9 (a) Luminance enhancement curve for class II scene image; (b) Luminance enhancement curve for class III scene image

4.3 SCENE IMAGE SATURATION ENHANCEMENT

In order to enhance the color saturation under the condition of keeping the hue unchanged, normally the YCbCr color space should be transformed to RGB color space as Equation (17). Then the RGB color space can be transformed to HSI color space as Equations (18) ~ (21). The *S* value of HSI color space can be increased then. At last, the new HSI signals should be transformed back to RGB color space again. However, that scene image saturation enhancement method is a little bit complicated.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.403 \\ 1 & -0.344 & -0.714 \\ 1 & 1.773 & 0 \end{bmatrix} \begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix}, \tag{17}$$

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right], \tag{18}$$

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360-\theta & \text{if } B > G \end{cases}, \tag{19}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2 + (R-B)(G-B)\right]^{\frac{1}{2}}} \right\}, \tag{20}$$

$$I = \frac{1}{3}(R+G+B). \tag{21}$$

In order to enhance the scene image saturation with YCbCr color space signals directly, let us consider the condition of Equation (22). Here, both *Cb* and *Cr* are increased the same magnification, i.e. $\beta(\beta > 1)$. Then the new differences of *R, G* and *B* are also increased the same magnification, i.e. β, because of Equation (23) which is deduced from Equation (17).

$$\begin{cases} Cb' = \beta Cb \\ Cr' = \beta Cr \end{cases}, \tag{22}$$

$$\begin{cases} R\text{-}G = \quad 0.344Cb + 0.689Cr \\ R - B = -1.773Cb + 1.403Cr \\ G - B = -2.117Cb - 0.714Cr \end{cases}. \tag{23}$$

Hence the θ in Equation (20) can be kept unchanged because the new differences of *R, G* and *B* is increased the same magnification. That means the *H* is unchanged because of Equation (19). Also through some algebraical deductions, the scene image's saturation *S* in Equation (18) is increased under the condition Equation (22) when $\beta > 1$.

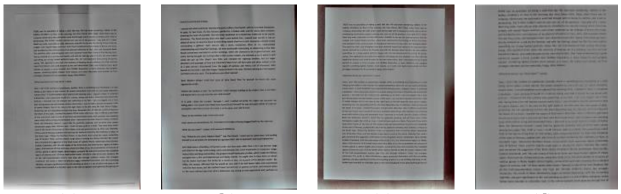
For every (*Cb, Cr*), the increasing magnification, i.e. β, is limited in a range because the *R, G* and *B* should be limited in the range of [0, 255] in Equation (17). Supposing the maximum increasing magnification is $\beta_{\max}$, the new adjusted value of (*Cb, Cr*), i.e. *Cb'*, *Cr'*, can be calculated as Equation (24). Here the α is a coefficient for saturation adjustment which range is [0, 1]. User can set the α according to his personal preferences for the saturation of the current scene image.

$$\begin{cases} Cb' = \alpha\beta_{\max} Cb \\ Cr' = \alpha\beta_{\max} Cr \end{cases} \tag{24}$$

5 Experimental results and analyses

We made the programs for the proposed method of this paper in Windows operating system in our personal computer. The programming environment is the Microsoft Visual C++ 2005. A lot of images' testing demonstrated that this method can effectively enhance not only the document image but also the scene image.

Figure 10 and Figure 11 shows the enhanced document images from Figure 2 processed by the SSR and MSR. The document images of Figure 2 come from the famous novel of "*Jane Eyre*" by English writer Charlotte Brontë [12]. Figs. 12 shows the enhanced images from Figure 2 processed by the proposed method.



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

FIGURE 10 Document images enhanced by the SSR method

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

FIGURE 11 Document images enhanced by the MSR method

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

FIGURE 12 Document images enhanced by the proposed method

The average of the chrominance, chrominance standard deviation, and chrominance contrast are counted in Table 1. The chrominance contrast is calculated by Equation (24) through the 8 neighbourhood method.

$$C = \frac{\sum_{y=1}^{H\text{-}2}\sum_{x=1}^{W\text{-}2} \begin{matrix} (f(x,y) - f(x\text{-}1,y\text{+}1))^2 + (f(x,y) - f(x,y\text{+}1))^2 + \\ (f(x,y) - f(x\text{+}1,y\text{+}1))^2 + (f(x,y) - f(x-1,y))^2 + \\ (f(x,y) - f(x\text{+}1,y))^2 + (f(x,y) - f(x-1,y\text{-}1))^2 + \\ (f(x,y) - f(x,y\text{-}1))^2 + (f(x,y) - f(x\text{+}1,y\text{-}1))^2 \end{matrix}}{(H\text{-}2)\times(W\text{-}2)}. \tag{24}$$

From Table 1, we can see that the chrominance average values, chrominance standard deviations, and chrominance contrast of the enhanced document images with the proposed method are 46%, 32%, and 70% higher than the SSR and MSR method on average.

Figure 13 and Figure 14 show the enhanced scene images from Figure 3 processed by the SSR and MSR. Figure 3 is selected from the book of "Digital Image Processing, 3rd ed." by Gonzalez and Woods [13]. Figure 15 shows the enhanced images processed by the proposed method. Here, the coefficient in Equation (24) is taken can be taken a less value to deduce the color saturations.

TABLE 1 Document image enhancement result comparison

Me ȅ thod	Name	Y Avg.	Y Std. Dev.	Contrast
Orig. Image	Fig. 2(a)	181.13	33.15	215.98
	Fig. 2(b)	188.97	31.39	206.46
	Fig. 2(c)	159.82	51.24	253.24
	Fig. 2(d)	155.14	49.43	767.02
	Average	171.27	41.30	360.68
SSR	Fig. 10(a)	128.95	30.61	282.56
	Fig. 10(b)	128.95	30.94	295.45
	Fig. 10(c)	127.97	38.52	279.50
	Fig. 10(d)	129.48	30.62	490.03
	Average	128.84	32.67	336.89
MSR	Fig. 11(a)	128.98	28.76	349.18
	Fig.11(b)	129.03	29.34	363.99
	Fig. 11(c)	128.24	36.27	390.64
	Fig. 11(d)	129.62	30.32	528.70
	Average	128.97	31.17	408.13
Proposed Method	Fig. 12(a)	242.05	43.67	1054.85
	Fig. 12(b)	240.58	41.81	954.10
	Fig. 12(c)	235.23	48.14	1167.53
	Fig. 12(d)	236.76	54.89	1930.10
	Average	238.66	47.13	1276.65

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

FIGURE 13 Scene images enhanced by the SSR method

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

FIGURE 14 Scene images enhanced by the MSR method

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

FIGURE 15 Scene images enhanced by the proposed method

The standard deviations of the RGB, chrominance contrast, and color saturation are counted in Table 2.

TABLE 2 Scene image enhancement result comparison

Method	Name	R. Std. Dev.	G. Std. Dev.	B. Std. Dev.	Con-trast	Sat.
Orig. Image	Fig. 3(a)	19.62	23.78	28.42	79.71	0.27
	Fig. 3(b)	66.66	67.52	68.36	14.35	0.07
	Fig. 3(c)	59.99	82.02	75.35	150.86	0.27
	Fig. 3(d)	61.83	64.85	68.14	197.62	0.21
	Average	52.03	59.54	60.07	110.64	0.21
SSR	Fig. 13(a)	40.39	39.73	46.41	229.78	0.08
	Fig. 13(b)	43.58	41.95	41.87	8.34	0.06
	Fig. 13(c)	37.27	44.96	37.95	127.90	0.13
	Fig. 13(d)	41.74	42.35	43.25	85.86	0.07
	Average	40.75	42.25	42.37	112.97	0.09
MSR	Fig. 14(a)	40.30	38.97	46.12	359.84	0.10
	Fig. 14(b)	43.42	41.97	41.92	15.07	0.06
	Fig. 14(c)	36.53	45.37	37.01	231.74	0.13
	Fig. 14(d)	41.11	41.94	43.71	150.38	0.08
	Average	40.34	42.06	42.19	189.26	0.09
Proposed Method	Fig. 13(a)	93.94	75.99	75.41	681.71	0.54
	Fig. 15(b)	88.38	88.17	100.97	25.64	0.55
	Fig. 15(c)	80.85	84.64	76.84	131.58	0.77
	Fig. 15(d)	85.05	85.89	105.08	223.44	0.63
	Average	87.06	83.67	89.58	265.59	0.62

The standard deviations of the RGB, chrominance contrast, and color saturation of the enhanced scene images with the proposed method are 53%, 50%, 53%, 43%, and 85% higher than the SSR and MSR method on average.

6 Conclusions

This paper proposes an image enhancement method based on image classification by histogram characteristics for YCbCr color space signals. Firstly, the images are divided into document image and scene image according to the normalized CbCr histogram characteristic. For the scene image, three types are identified by the normalized Y histogram characteristics. For different types of images, different enhancement scheme is applied. Experimental results showed that the proposed method can enhance not only the contrast for the document image, but also both the contrast and saturation for the scene image effectively.

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