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Color Image Enhancement Based on Luminance and Saturation Components

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Abstract

A new color image enhancement method is proposed based on the luminance component and the saturation component in the CIEXYZ color space. Hue is kept unchanged in order to avoid color distorting or shifting. According to the tricolor in the display system, saturation component is stretched to get rich color and obvious color differences. Luminance component is adaptive enhanced based on the saturation feedback to sharpen the edges and improve the image contrast. Experimental results show that the enhanced color image has more rich color, more clear details and better visual effect.

1. Introduction

Most technologies for digital image enhancement are applicable to gray images. The objective of image enhancement is to process an image to enhance its contrast and the definition. Nowadays the research of color image enhancement is becoming an increasingly important research area with the widespread use of color images. Compared with the gray level image, color image contains more rich color information. Color image enhancement is to process the luminance information and the color information to make the image has sharp details, rich color and better visual effect with no color distorting or shifting [1]. We obtain the transform matrix between the RGB color space and the CIEXYZ color space, and define the saturation according to the display system tricolor. Saturation is stretched and luminance is adaptively improved based on the saturation without changing the hue component. Experiment results show that the enhanced color image has more rich color, more clear details and better visual effect.

2. Color space conversions

Our algorithm operates on the representation of colors in the CIEXYZ chromaticity diagram and the first thing is to realize the converse between RGB and CIEXYZ. Without considering the display system tricolor constraints, the resultant colors of the algorithms in the CIEXYZ might not be correctly displayed on any monitor [2, 3]. The color space transform principle shows that the conversion matrix is varied with the tricolor coordinates [4]. The tricolor coordinates of the display adopted in our algorithm are R(x_r=0.6245,yr=0.3165), G(x_g=0.2952, y_g=0.5977), B(x_b=0.1468,y_b=0.087), and the write point is located at W(x_w=0.3132,y_w=0.3213). According to the conversions principle, we get the conversions matrix between RGB and XYZ:

$$T = \begin{pmatrix} 0.46494 & 0.32275 & 0.1871 \\ 0.23563 & 0.65348 & 0.11088 \\ 0.043925 & 0.1171 & 0.97655 \end{pmatrix}$$

And the transformations between the RGB and CIEXYZ color spaces are given by:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = T \begin{pmatrix} R \\ G \\ B \end{pmatrix} \qquad (1)$$

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$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = T^{-1} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = T^{-1} \frac{Y}{y} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \tag{2}$$

Where, T^{-1} is the inverse matrix of T and $x = \frac{X}{X+Y+Z}$, $y = \frac{Y}{X+Y+Z}$, $z = \frac{Z}{X+Y+Z}$.

3. Saturation enhancement

In order to avoid color shifting or distorting, we must keep the hue component unchanged to enhance a color image by processing its luminance and saturation components. Generally, we improve the colorful degree of an image by enhancing the saturation component with non-linear stretching to improve the saturated degree and then obtain higher saturated color image. In this paper, we first calculate the maximum saturation coordinate of every pixel with the saturation definition in the CIEXYZ chromaticity diagram. Stretch its saturation and then get the final coordinate by a transfer function.

3.1. Calculate the most saturated color coordinates

Fig. 1 illustrates how to calculate the most saturation color coordinates. R, G and B construct the gamut triangle and W is the white point of the display. The four points identify three sub-triangles, namely, RGW, GBW and RBW. The lines GR、GB、BR、RW、GW and BW can classify $C = (x_c, y_c, Y_c)$ in one of the three triangles. Specifying C in one of three kinds of triangle can identify which line intersects, namely, RG, BG or RB. Take C in the triangle RWG for example to express the process of saturating C to the most saturation $C_2 = (x_{C_2}, y_{C_2}, Y_{C_2})$. Stretch the line between the white point W and the point C to the line RG, and the intersection C_2 is the most saturation of color C. x_{C2} and y_{C2} represents the maximally saturated version of C with respect to the adopted color gamut. Since the point C_2 is on the line CW, the color C_2 and C have the same hue. Since the operation affects only the chromatic component of C, the saturated color C_2 is associated with the same brightness Yc and then can be represented as $C_2 = \left(x_{C_2}, y_{C_2}, Y_c\right)$.

The method to calculate the most saturation color coordinate expressed above is easy to realized, keeps the brightness and hue without changing and voids the color shifting or distorting.

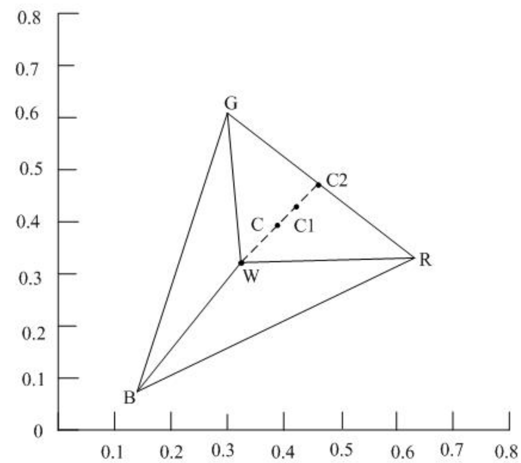


Fig. 1 Calculate the most saturation color coordinates

3.2. Saturation enhancement

The saturation in the CIEXYZ chromaticity diagram is defined as [4]:

$$S = \frac{\overline{CW}}{\overline{C_2W}} \tag{3}$$

Where, C_2 is the saturated color obtained above. $\overline{CW}$ and $\overline{C_2W}$ represent the distance between C and W, and the distance between C_2 and W. Obviously S is between 0 and 1. Colors which are less saturated have saturation S close to zero. Meanwhile, colors which are almost saturated have saturation S very close to one. Hence, the saturation of a color is altered by tuning its saturation. By increasing the saturation S, the color becomes more saturated.

We adopt exponent function to enhance the saturation and stretch its dynamic range. The expression is as :

$$f = S^{\alpha} \tag{4}$$

Where, α is a constant which reflects the degree of the saturation enhancement. The enhanced color coordinates $C_1 = (x_1, y_1, Y_1)$ are obtained as follows [5]:

$$\begin{pmatrix} x_1 \\ y_1 \end{pmatrix} = f \begin{pmatrix} x_{C_2} \\ y_{C_2} \end{pmatrix} + (1-f) \begin{pmatrix} x_w \\ y_w \end{pmatrix} \tag{5}$$

Expression (5) shows that C_1 is on the line CW, which promises the hue unchanged and without color shifting and distorting. The image after saturation processing looks more colorful. In order to get clear details and high contrast, luminance must be enhanced either to reach the anticipated goal.

4. Luminance enhancement based on the saturation feedback

Typical color image luminance enhancement algorithms such as histogram equalization haven't make use of the saturation component of a color image. Numbers of experiments indicate that the luminance and the saturation of a color image are related [6]. Strickland proposed a luminance enhancement algorithm bases on the saturation feedback taking account of the local relation between luminance component and the saturation component in [6]. And its algorithm can be expressed as:

$$\mathrm{Y_1 = Y + k1\left(Y - \overline{Y}\right) + k2\left(S - \overline{S}\right)}\rho \tag{6}$$

Where Y and S separately represent the luminance and the saturation component of the original image and Y_1 is the luminance component of the enhanced image. k1 and k2 are real numbers. ρ(x,y) is the local correlation coefficient of Y and S, and it is defined as:

$$\rho(x,y) = \frac{\sum_{(i,j)\in w} \left[\mathrm{Y(i,j)} - \overline{\mathrm{Y}}_w\right]\left[\mathrm{S(i,j)} - \overline{\mathrm{S}}_w\right]}{\sqrt{\sigma_Y^2(x,y)\sigma_S^2(x,y)}} \tag{7}$$

Window w effects on Y and S simultaneously, the local mean $\overline{Y}_{\varpi}$ and the local variance $\sigma_Y^2(x,y)$ can be defined as (8) and (9). The definition of $\overline{\mathrm{S}}_{\varpi}$ and $\sigma_S^2(x,y)$ is similar to (8) and (9):

$$\overline{Y}_w = \frac{1}{\mathrm{mn}} \sum_{(i,j)\in w} Y(i,j) \tag{8}$$

$$\sigma_Y^2(x,y) = \sum_{(i,j)\in w} \left[\mathrm{Y(i,j)} - \overline{\mathrm{Y}}_w\right]^2 \tag{9}$$

This algorithm makes the best of the local correlativity of the luminance component and the saturation. It adjusts the luminance component adaptively and makes some effects. When k1<1, it sharpens the image details not too obviously; whereas when k1>1, it can sharpen the details obviously but the noise be enhanced contemporarily. This suggests that this algorithm is sensitive to the image noise.

According to the fact that the human vision is more sensitive to the noise of the smooth parts in an image than to the noise in the detail parts, this paper enhances the local contrast more in the edges and less in the smooth area. So we present an improved algorithm expressed as:

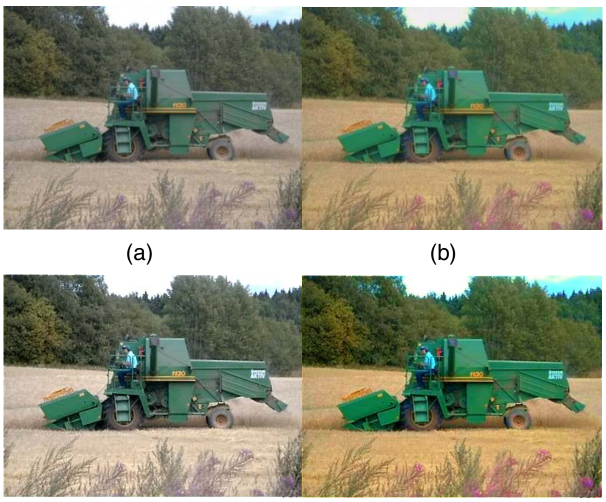
$$\mathrm{Y_1 = Y + K\left(Y - \overline{Y}\right) + k2\left(S - \overline{S}\right)}\rho \tag{10}$$

Where $K = k1 \times \frac{|\nabla Y|}{Max(\nabla Y)}$, ∇Y is the Sobel operator result and denote $Max(\nabla Y)$ is the max of $|\nabla Y|$. The reason to choose the Sobel operator is that it can smooth the noise and emphasize the details of edge [1]. K(x,y) guarantees the more enhancement of image details and less enhancement of noises. k1 and k2 are real numbers.

The color coordinate after saturation and luminance enhancement is $C_1 = (x_1, y_1, Y_1)$. And then transfer the color pixel back to the RGB color space. The R, G and B transform for CIEXYZ must be set in the range of 0 and 1 due to the dynamic range that the adopted display can display.

5. Experimental results

The improved saturation and luminance enhancement algorithm are applied to the color image. The experiment proves that the color image enhanced by the algorithm proposed in this paper can arrive at a good effect. Fig. 2 shows the experiment results.



(a) (b)

(c) (d)

Fig. 2 Experimental results

Fig.2 (a) is the original image. Fig.2 (b) is the enhanced image by only saturation process to the saturation component in the CIEXYZ chromaticity diagram. Compared with the original image, Fig.2 (b) looks more colorful and the color contrast is improved much with little improvement of the image details. Fig.2 (c) shows the processing result of enhancement only to the luminance component. Obviously, the picture looks clearer and gets more sharp edge than Fig.2 (a) and Fig.2 (b) with less change of color. Fig.2 (d) shows the effect of combining the saturation and the luminance enhancement. The value of the proportional coefficient K is greater on the image edge and the details are enhanced distinctly. The value of K in the smooth parts is smaller and the noise is effectively inhibited. The algorithm proposed in this paper can adaptively modulate image luminance components by appending the proportional coefficients K(x,y), and the saturation component by stretching algorithm. It looks much colorful with the saturation enhancement and more details with the luminance processing.

6. Conclusions

On the premise of keeping the hue unchanged, we propose a new color image enhancement algorithm based on the saturation and the luminance component in the CIEXYZ chromatic diagram. Experimentations prove that the enhanced image is clearer, more vivid and brilliant. Due to considering the display tricolor, the color shifting and distorting are avoided in this paper. With the widespread use of color image, a best enhancement algorithm for color image is needed to make the colors of the enhanced images more rich and the details clearer without noise either artifact. It is also the future research direction to the color image enhancement.

7. References

[1] R.C.Gonzales and E.Woods, Digital Image Processing, Addison-Wesley, Reading, MA, 1992.

[2] L. Lucchese, S. K. Mitra, and J. Mukherjee, “A New Algorithm Based on Saturation and De-saturation in the xy Chromaticity Diagram for Enhancement and Re-rendition of Color Images”, in Proc. Int. Conf. Image Processing, 2001, Vol. 2, pp. 1077–1080.

[3] S.-C. Pei, Y.-C. Zeng, and C.-H. Chang, “Virtual Restoration of Ancient Chinese Paintings using Color Contrast Enhancement and Lacuna Texture Synthesis”, IEEE Trans. Image Processing, Vol. 13, No. 3, Mar. 2004, pp. 416–429.

[4] Steve Fisk, Coloring theories, American Mathematical Society, 1989.

[5] Soo-Chang Pei and Yi-Mei Chiu, “Background Adjustment and Saturation Enhancement in Ancient Chinese Paintings”, IEEE Trans. Image Processing, Vol. 15, NO.10, Oct. 2006, pp.3230-3234

[6] B.A. Thomas, R.N.Strickland and Heffrey J, “Color Image Enhancement using Spatially Adaptive Saturation Feedback”, IEEE International Conference on Image Processing, Oct.26-29,1997.Vol.3, pp.30-33