NORMALIZED SI CORRECTION FOR HUE-PRESERVING COLOR IMAGE ENHANCEMENT

DONG YU [1], LI-HONG MA[1, 2], HAN-QING LU[2]

[1] GD Key Lab. of Computer Network, Dept. of Electronic Engineering, South China University of Technology, Guangzhou, China 510641

[2] National Lab. of Pattern Recognition, Inst. of Automation, Chinese Academy Of Sciences, Beijing, China 100080

E-MAIL: comet_1984@hotmail.com, eelhma@scut.edu.cn, luhq@nlpr.ia.ac.cn

Abstract:

We examine the issue of color distortion after enhancement in this study and proposed an algorithm named normalized SI correction to correct intensity and saturation components based on their relationship. Unlike previous research, this paper wants to emphasize on a general correction method suitable for different kind of enhancement. We start with a general introduction to the HSV color space. Next, we go deep into the relationship between intensity and saturation. Based on the relationship we conclude, we propose our algorithm in detail and test the algorithm with different kind of images. Experimental results demonstrate that the proposed algorithm can correct the color distortion caused by the enhancement without reducing the visual effect and it is especially useful for images with rich colors and local high component values.

Keywords:

Visual information processing; Color image enhancement; Saturation correction; Intensity correction; Normalization; Hue preserving; HSV color space

1. Introduction

With the rapid development of color image applications in different fields, effective approaches to address color compensation and high contrast correction before further using are inspired, especially for exposure replacement, image matching and retrieval and occasions of transmission distortion. Several algorithms are available for contrast enhancement in grey scale images, which change the grey values of pixels depending on the criteria for enhancement, such as histogram equalization, linear and nonlinear modification. The generalization of these techniques to color images is not a straight forward, because unlike grey scale images, there are some factors in color images like hue which need to be properly taken care of. For the purpose of color image enhancement, it is to be seen that hue should not change for any pixel. If hue is changed then the color gets cooled or warmed, sometime even alter the object appearance. One needs to improve the visual quality of an image without distorting its color. For example, the commonly used coordinate systems HSV is not perceptually orthogonal; that is, intensity and saturation modification can cause perceptual shifts in the hue.

Several different techniques for color contrast enhancement are proposed in [1,2] using 3-D histogram of colored images. Bockstein et al. [3] proposed a color equalization method based on both saturation and intensity of the image. Weeks et al. [4] proposed a hue preserving color image enhancement technique which modifies the saturation and intensity components in color difference (C-Y) color space. To take care of the R, G, and B values exceeding the bounds, Weeks et al. suggested normalizing each component after enhancement. Yang et al. [5] proposed two hue preserving techniques, namely, scaling and shifting, for the processing of luminance and saturation components. To implement these techniques one does not need to do the color coordinate transformation. Murtaza et al. [6] proposed an efficient generalized hue preserving technique avoiding the gamut problem. These algorithms perform differently depending on the content of the image. Unfortunately, none of the mentioned papers proposed a general correction method suitable for different kind of enhancement and few of them go deep into the relationship between saturation and intensity, especially in HSV color space which is widely used in color image processing.

In this article we have suggested a novel and effective way of hue-preserving correction algorithm named normalized SI correction. It takes full advantage of the relationship between intensity and saturation in HSV space to implement saturation and intensity correction before HSV to RGB transformation, which is followed by a normalization step. The normalization and correction are just like a dual fail-safe to keep the hue of the original image intact.

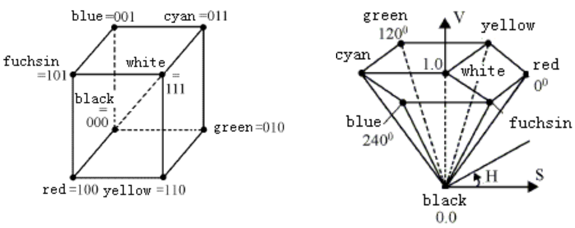
1-4244-0973-X/07/$25.00 ©2007 IEEE

Experimental results demonstrate that the proposed algorithm can correct the color distortion caused by the enhancement without reducing the visual effect. Using different kind of images for contrast, it is shown that the normalized SI correction performs differently depending on the hue, intensity and saturation of the image.

2. Intensity and saturation in HSV color space

2.1. A brief introduction to HSV color space

HSV color space, often used by artists, is based on the psychological feelings of human eyes about colors. The phrase HSV stands for the attributes of color: hue, saturation, and value [7]. Hue denotes what kind of color it is, i.e., a red or an orange. In the spectrum each color is at the maximum purity (or richness) that the eye can appreciate, and the spectrum of color is described as fully saturated. If a saturated color is diluted by being mixed with other colors or with white light, its richness or saturation is decreased. On the other hand, the value component of the HSV space is a measure of its intensity, so we call it intensity afterwards. By the way, we have to mention that the HSV color space is normalized.



(a) RGB color space (b) HSV color space

Figure 1. RGB & HSV color space

Figure 1 shows a line drawing of HSV space in the form of a hexcone. At the vertices of each cross section are the colors red, yellow, green, cyan, blue, and fuchsine. A color in HSV space is specified by stating a hue angle, a saturation level, and an intensity level. The hue angle increases in a counterclockwise direction. For example, angle 0° stands for red, angle 120° stands for green, angle 240° stands for blue. Complementary colors are 180° apart. By comparison of RGB and HSV color space, we can see that V axis in HSV is corresponding to the main diagonal in RGB.

2.2. Discussion of relationship between intensity and saturation

The mathematical relationship between HSV and RGB components is as follows:

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

$$S = 1 - \frac{3}{R+G+B} * \min(R,G,B) \tag{2}$$

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

Approved by many experiments, HSV color space is a good choice for color image enhancement. There is only a weak correlation between HSV components, which indicates that a modification to one component will only slightly change another. Unfortunately, in some situation, the slightly change in HSV will result in great color distortion.

For detail discussion of the relationship between saturation and intensity, we can derive formula (4) from formula (2) and (3), that is:

$$S = 1 - \frac{\min(R,G,B)}{I} \tag{4}$$

Then we can find out the range of S component under a constant *I*. Only when *R*=*G*=*B*=*I*, $\min(R,G,B)$ gets its maximal value as follows:

$$\max_I \{\min(R,G,B)\} = I \tag{5}$$

By substituting part of formula (4) with (5), we can see that no matter what the value of *I* is, $S_{\min} = 0$. In other word, there is no value constraint of minimal saturation. But does a maximal value constraint of saturation exist? For pixels with $I \le \frac{2}{3}$, we can easily set one of the RGB components to zero so that *S* component can reach its maximal value. But for pixels with $I > \frac{2}{3}$ (or *R*+*G*+*B*>*2*), we can not set any of the RGB components to zero, which means we have to find another way to solve the problem. Let's assume that the reachable largest component of RGB is $I'_{\max}$ when *I* component takes a definite value. The third component gets its reachable minimal value when the other two components reach I'_{max} . We can express it in the following formula:

$$\min_I\{\min(R,G,B)\} = 3*I - 2*I'_{max} \qquad (6)$$

From formula (4) we know that when $\min(R,G,B)$ gets its minimal value, S component gets its maximal value. So we could get the relationship as:

$$S_{max} = 1 - \frac{\min(R,G,B)}{I} = 1 - \frac{3*I - 2*I'_{max}}{I} = 2(\frac{I'_{max}}{I} - 1) \qquad (7)$$

We assume that I component is normalized, then the range of $\frac{I'_{max}}{I}$ could be solved as:

$$\frac{I'_{max}}{I} = \begin{cases} \frac{1}{I} & \frac{2}{3} < I \le 1 \\ \frac{3}{2} & 0 < I \le \frac{2}{3} \end{cases} \qquad (8)$$

Finally, by conducting formula (8) into (7), we get the constraint relationship between intensity and saturation as follows:

$$S_{max} = \begin{cases} 2(\frac{1}{I} - 1) & \frac{2}{3} < I \le 1 \\ 1 & 0 < I \le \frac{2}{3} \end{cases} \qquad (9)$$

3. The normalized SI correction algorithm

3.1. Correction of saturation

According to the relationship between intensity and saturation discussed in section 2.2, especially from formula (9), we can see that for pixels with $I \le \frac{2}{3}$, there is no need to implement the correction of saturation, but for pixels with $I > \frac{2}{3}$, the correction of saturation after enhancement is a necessary procedure. If the saturation after enhancement exceeds S_{max} , it must be set to S_{max} to avoid possible hue distortion after HSV->RGB transformation.

3.2. Correction of intensity

From formula (4) and (9) we can also get the range of I component under the condition that S component takes a definite value. According to formula (9), for pixels with $I > \frac{2}{3}$:

$$I_{min} = \frac{2}{S_{max} + 2} \qquad (10)$$

Formula (10) means that I component have a minimal value according to certain S_{max} , so the correction of intensity is also necessary for pixels with $I > \frac{2}{3}$ to prevent the possible hue distortion after HSV->RGB transformation. The correction steps are: Step 1, assume the intensity after modification is I' , and then bring I' into formula (9) to calculate S'_{max} . Step 3, if $S > S'_{max}$, replace S'_{max} with S in formula (10) to calculate a new value of intensity I'' as the final intensity value.

3.3. Normalization of RGB components

Even after correction of intensity and saturation (We call it SI correction for short), the RGB values transformed from HSV may also be beyond the bounds. Thus to guarantee the fidelity, normalization step must be carefully implemented to take care of these components instead of just cutting the exceeding part. We assume that *Max_RGB* presents for the maximal value of RGB components and *scale* is set to modify the RGB components synchronously. We can express the steps of normalization by a flow chart:

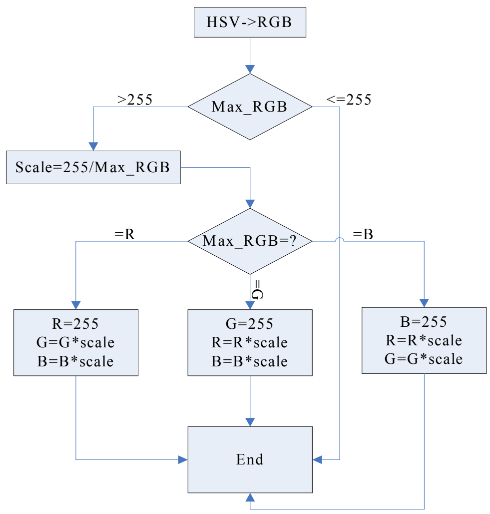


Figure 2. Steps of normalization

3.4. Algorithm description

By combining the methods of saturation correction, intensity correction and normalization described in section 3.1-3 orderly, we get the whole normalized SI correction procedures here. The whole algorithm can be illustrated as follows:

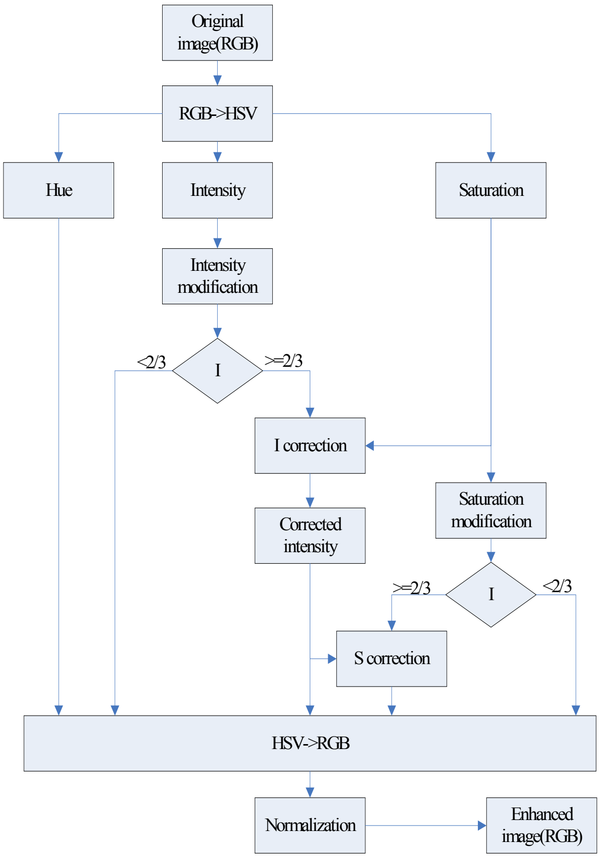


Figure 3. Flow chart of the proposed algorithm

From the above flow chart we can get to know that another advantage of this proposed algorithm is its independency from intensity and saturation modification. We can adjust the modification method from linear (nonlinear) stretching to multi-scale enhancement methods to fit different applicative requirement.

4. Results and comparisons

In this section, the proposed algorithm is tested with Murtaza et al. [6] algorithm in intensity component and a linear stretching in saturation component. We choose WERBLIN's nonlinear histogram modification method proposed in [8] as the gray function used in Murtaza et al. [6] algorithm. First we will give visual contrast and data comparison of different correction methods to verify the effectiveness and necessity of the normalized SI correction algorithm. Second we will implement our proposed algorithm to different kind of images to verify its adaptive capacity.

4.1. Comparison of different correction methods

A real life image of buildings with rich colors and local high component values is considered for showing the results by implementation of different correction methods. The visual contrast is as follows:

(a) Original image (b)Without normalization and correction (c)Only normalized

(d) Normalized I correction (e) Normalized S correction (f) Normalized SI correction

Figure 4. Comparison of different methods

First we give a qualitative analysis on these images. We can easily distinguish that the most different place among these images is the house located at right side. Obviously, there is a great hue distortion in Figure 4(b). The hue of Figure 4(c) and (d) seems not to be changed, but obviously, the saturation is too high. Although the hue of the house is corrected in Figure 4(e), there are still a little white spots within the house, and a big white spot appears in the sky on top left corner of the image. On contrast, Figure 4(f) with our proposed algorithm has a perfect hue matching the original image and the intensity and saturation is properly enhanced.

We choose a feature point (286,197) on the house mentioned above to view deeply in a quantitative way. The component data is shown in Table 1:

Table 1. Component data of feature point (286,197)

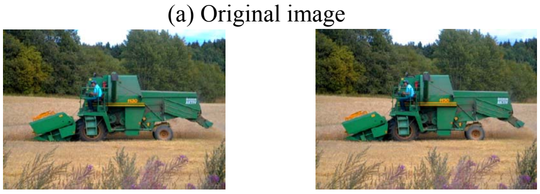
	R	G	B	H	S	I
Figure 4(a)	253	233	182	44.1°	0.183	0.873
Figure 4(b)	255	255	78	60.0°	0.602	0.769
Figure 4(c)	255	200	58	44.0°	0.660	0.670
Figure 4(d)	255	199	58	44.0°	0.660	0.670
Figure 4(e)	255	233	228	43.2°	0.063	0.954
Figure 4(f)	255	234	179	43.7°	0.195	0.876

Hue of Figure 4(b), corresponds to a modification without normalization and correction, is changed from 44.1° to 60.0° . The large angel shift is the reason why the unacceptable hue distortion occurs. Figure 4(c) and (d) almost have the same data and the hue is only modified by 0.1° , but the saturation increases greatly from 0.183 to 0.660. Therefore, the house looks so dense. Comparing the effect of the intensity correction, we can get a conclusion from Figure 4(e) that if we just implement saturation correction to the image, the saturation of this point decrease dramatically. This is why the white spot appears, and a lot more cases are in the top left corner of the image. Fully implemented with the normalized SI correction, Figure 4(f) has satisfied data, which means the saturation and the intensity are enhanced properly and the hue is only modified by 0.4° , this slight change of hue is imperceptible. We can get a conclusion that because R and G component of the house is almost at its maximal value, the normalized SI correction is a necessary operation after enhancement.

4.2. Implementation in different kind of images

Not all images are like the image used in section 4.1, which has rich colors and local high component values. So we have to implement our algorithm to an image with both low saturation and intensity for contrast.

(a) Original image



(b) Without normalization and correction (c) Normalized SI correction

Figure 5. Another example

Hardly can we see the difference between Figure 5(b) and (c) except the sky to the top right, so we have to calculate the proportion of correction and normalization of Figure 4 and Figure 5 for data analysis:

Table 2. Proportion of correction and normalization

	Figure 4		Figure 5	
	Pixels	Proportion	Pixels	Proportion
Total pixels	169004	100%	120000	100%
S Correction	19922	11.8%	2217	1.85%
I Correction	5824	3.45%	2212	1.84%
SI Correction	20129	11.9%	2646	2.21%
Normalization	26257	15.5%	4015	3.35%
Total modified	26451	15.7%	4376	3.65%

From Table 2 we can see that the proportion of pixels modified in Figure 4 is almost four times of that of Figure 5. This is why we can see more different place in comparison of Figure 4 than that of Figure 5. We tested a lot more images and get a conclusion that for the images which have rich colors and local high component values, the implementation of our proposed algorithm is very necessary and effective, i.e., there are totally 15.7% pixels modified in Figure 4. Even for the low intensity and saturation pictures, there is still a certain proportion of pixels need correction and normalization, because we could not assure that a high light spot doesn't occur. For example, in Figure 5 there are still 3.65% pixels need to be modified (either normalized or corrected). Even if no pixel is modified (almost impossible), the implementation of this method will not do any harm to the mage and it is not time consuming.

5. Conclusions

For many reasons, the images are always need to be corrected after enhancement, a HSV color space based normalized SI correction algorithm is proposed to fulfill this task. The data from the experimental results shows that the proposed algorithm is necessary and effective, and it is especially useful for images with rich colors and local high component values. The other advantages of the algorithm are its independency from intensity and saturation modification methods and its adaptive capacity to different kind of images. Hence, the proposed algorithm is an effective and reliable choice for correction of intensity and saturation enhancement of colored images. From the above discussion and experimental results, we can also conclude that simple techniques developed using the basic principles related to a problems domain can bring surprising results with respect to the quality of the output produced.

Acknowledgements

We would like to acknowledge the supports of China NNSF of excellent Youth (60325310), NNSF (60472063) and GDNSF/GDCNLF (04020074/CN200402).

References

[1] P. E. Trahanias and A. N.Venetsanopoulos, "Color image enhancement through 3-D histogram equalization," in Proc. 15th IAPR Int. Conf. Pattern Recognition, vol. 1, 1992, pp. 545–548
[2] P. A. Mlsna, Q. Zhang, and J. J. Rodriguez, "3-D histogram modification of color images," Proc. IEEE Intl. Conf. Image Processing, vol. III, pp. 1015–1018, 1996.
[3] I. M. Bockstein, "Color equalization method and its application to color image processing," J. Opt. Soc. Amer., vol. 3, no. 5, pp. 735–737, 1986.
[4] A. R. Weeks, G. E. Hague, and H. R. Myler, "Histogram specification of 24-bit color images in the color difference (C-Y) color space," J. Electron. Imag., vol. 4, no. 1, pp. 15–22, 1995.
[5] C. C. Yang and J. J. Rodriguez, "Efficient luminance and saturation processing techniques for bypassing color coordinate transformations," in Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics, vol. 1, 1995,pp. 667–672
[6] S. M. Murtaza., J. Ahmad and U. Ali, "Efficient Generalized Colored image Enhancement", in Cybernetics and Intelligent Systems, 2006 IEEE Conference , June 2006, pp.1-5
[7] R. S. Berns, F. W. Billmeyer, and M. Saltzman, "Billmeyer and Saltzman's Principles of Color Technology", 3rd ed. New York: Wiley, 2000.
[8] Frank S. WERBLIN. Control of Retinal Sensitivity [J]. The Journal of General Physiology 1974, 63(1), 62-87