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Color Image Enhancement with Saturation Adjustment Method

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Abstract

In the traditional color adjustment approach, people tried to separately adjust the luminance and saturation. This approach makes the color over-saturate very easily and makes the image look unnatural. In this study, we try to use the concept of exposure compensation to simulate the brightness changes and to find the relationship among luminance, saturation, and hue. The simulation indicates that saturation changes withthe change of luminance and the simulation also shows there are certain relationships between color variation model and YCbCr color model. Together with all these symptoms, we also include the human vision characteristics to propose a new saturation method to enhance the vision effect of an image. As results, the proposed approach can make the image have better vivid and contrast. Most important of all, unlike the over-saturation caused by the conventional approach, our approach prevents over-saturation and further makes the adjusted image look natural.

Key Words: Color Adjustment, Human Vision, Color Image Processing, YCbCr, Over-Saturation

1. Introduction

With the advanced development of technology, the image is digitized and the high quality requirement of the image becomes common. For the massive demand of high quality and bright color of the image for people, the bright color adjustment technique becomes more and more important. The color adjustment requirement is mostly due to the demand of the consumers, human vision (HV) characteristics, and color model characteristics. Since the adjusted images are viewed by people, the adjustment must both comply with the theory and fitting the sensation of HV. Most of the conventional color adjustment methods only adjust or enhance the color luminance and saturation to obtain more colorful and clearer images. However, these approaches very easily generate over-saturated images. An over-saturated image looks unnatural due to the loss of color details in high saturation area of the image.

Generally there are two categories of colorful image processing: 1) Processing the RGB color information directly, 2) Converting the RGB data to luminance, saturation, and hue data to process the color adjustment. In the first approach, people adjust the RGB information by increasing or decreasing the R, G, and B data. Because of the directly processing RGB data it can save the color conversion time. Capra et al. [1] proposed a method which can effectively adjust the shadow and luminance part of the image at the same time. However, by this method the contrast and brightness of the image make it look unnatural. Wu et al. [2] proposed to increase the contrast and saturation of the image. Their approach may cause over-exposure and over-saturation in the high brightness part of the image. Lee et al. [3] used the technique of Space-Vari-

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ant Luminance Map (SVLM) to enhance the brightness and saturation of an image. Due to the massive increasing of the brightness and saturation, it causes the color to be unbalanced and make the image look unnatural. Ding et al. [4] used the concept of Human Vision System (HVS) and the technique of adaptive filter to reduce the color distortion. However, the algorithm is too complicated to operate in real-time. Therefore, the approaches of the first category may effectively increase the contrast and saturation of an image and can adjust the color adaptively according to the HV. However, owing to enhancing the R, G, and B data directly, it is very easy to cause the color to over-saturate and make the image look unnatural.

On the other hand, the conversion of color information from RGB to luminance, saturation, and hue may cause the color adjustment to be more flexible and more reliable. In this category, people adjust the color by adjusting luminance, saturation, and hue separately. Shi et al. [5,6] used adaptive Gamma curve to adjust the luminance. It may weaken the color brightness and saturation, and further it very easily causes over-saturation. Ku et al. [7] adjusted color saturation adaptively according to luminance and hue. By this approach, luminance and hue are kept unchanged, and it enhances the color saturation. The color saturation becomes very strong, and it makes the image look unnatural. In [8] adjusted color by processing luminance and saturation separately. The continuity of the color becomes bad, and it makes the image look unnatural. Therefore the approaches of this category adjust the color by adjusting luminance, saturation, and hue separately without coordinating the information of luminance, saturation, and hue which cannot find an optimum result and it may easily cause color over-saturation.

A saturation adjustment method to prevent color over-saturation which coordinates HVS, YCbCr model, and luminance together in this study. The proposed approach is based on the HV using luminance as the main factor to adjust the color saturation. Our coloradjustment method can prevent over-saturation when adjusting color and make the adjusted image look natural.

2. Human Vision and Color Systems

2.1 Human Vision Model

It is an interesting research topic for the human eyes to sense color information through what kind of sensing systems or organic characteristics, and thus many theorems and doctrines were proposed. The physical structure of human eyes is very similar to that of a camera system. Among the components of the HVS, the most important color sensing component is the retina. The retina is composed of visual cells with photoreceptor functions. There are two kinds of visual cells, rod cells and cone cells. The rod cells can sense the brightness of light. On the other hand, the cone cells sense the color information under certain brightness environment. The total numbers of the rod cells and cone cells of one human eye are one hundred million and seven million, respectively, and according to the ratio number of these two cells luminance sensing is more significant for the human beings. Therefore for color adjustment, luminance is the major concern, and saturation and hue are for secondary concerns.

The relation energy responses of rod and cone cells for photoreceptors [1]; thecone cells and rod cells act on different luminance intensities. The rod cells act at very low luminance, however the cone cells start acting at certain scales of luminance. Therefore, the human eye senses luminance much better than senses color information. According to [1], when adjusting colors, the variation of luminance should dominate the variation of saturation. The spatial contrast sensitivity for luminance and chromatic contrast [9]; The luminance contrast is band pass in nature, and it illustrates that the luminance contrast sensitivity of the human eye concentrates on the detailed and high frequency parts of an image. Therefore, when processing the luminance of an image, we had better consider the detailed changes of the image. The chromatic contrast is low frequency in nature, and it indicates that the human eyes cannot sense the chrominance changes keenly. Therefore when adjusting the chrominance of an image, it must adjust it in general instead of details.

The Munsell color system [10] is the most typical color system for colorimetry. It is based on rigorous measurements of human subject visual responses to color, and puts it on a solid experimental scientific basis. The Munsell system specifies colors based on three color dimensions: hue, value (lightness), and chroma (color purity). Among the many color models, the concept of the YCbCr model can most represent the Munsellcolor system, and therefore we use the YCbCr model as the basis of our color saturation adjustment method in this study.

2.2 Color Space

Generally speaking, there are two categories of color processing: 1) Processing RGB data directly, 2) Converting RGB data to luminance, saturation, and hue and then processing the converted data. In the first category, people adjust the color by increasing or decreasing the R, G, and B data directly. Due to the directly processing of the R, G, and B data, it can save the data conversion time. However, directly increasing or decreasing the RGB data may not completely comply with the HVS. On the other hand, the second category of color processing is flexible and has a higher reliability. Besides, it is more suitable for the HVS.

For the color data adjustment by adjusting luminance, saturation, and hue, we always expect to effectively adjust the color luminance and saturation and keep hue unchanged. Most of the image capturing devices captures images in the RGB data format. It is very difficult to effectively adjust both luminance and saturation but keep hue to be unchanged for the RGB color space. Therefore, it is better to convert the image in RGB color space to some other color spaces, such as YUV, YCbCr, HSV, and HSL, to find the color information of luminance, saturation, and hue.

This work, we use YCbCr as the basis of our color model owing to the following reasons: 1) YCbCr is a linear transformation and it is easier for design and operation in the hardware implementation. 2) The current display devices for LCD-TV, digital TV, and HDTV all use the YCbCr color space model. 3) YCbCr is closer to the Munsell color system.The RGB color space model can be represented as a cube [11]. The YCbCr data are linear combinations of the RGB data and can be represented as a rectangular solid [11]. The YCbCr color space model is more suitable for the HV characteristics.The YCbCr is converted from RGB as shown in the following:

$$\begin{cases} Y = 0.2989 \times R + 0.5866 \times G + 0.1145 \times B \\ Cb = -0.1688 \times R - 0.3312 \times G + 0.5000 \times B \\ Cr = 0.5000 \times R - 0.4184 \times G - 0.0816 \times B \end{cases} \quad (1)$$

The value of Y is in between 0 1nd 255; the values of Cb and Cr are in between -128 and +127. Generally, Y represents luminance, and saturation and hue can be obtained from Cb and Cr by the following equations:

$$\begin{cases} Sat = \sqrt{Cb^2 + Cr^2} \\ Hue = \tan^{-1}(Cr / Cb) \end{cases} \quad (2)$$

For easier and more efficient color adjustment considerations, the color space can be divided into several regions in the Cb-Cr plane. Each region has its own characteristic and can provide more efficient color adjustment. The color space is projected into the Cb-Cr plane, and for convenience we divide the Cb-Cr plane into six regions. Each region corresponds to a vertex. The details are shown in Figure 1, where the six vertices: Red (R), Green (G), Blue (B), Yellow (Y), Cyan (C), and Magenta (M), respectively. In the Cb-Cr plane with 360° classification, the M region is between 22° and 80°; the R region is between 80° and138°; the Y region is between 138° and 202°; the G region is between 202° and 259°; the C regionis between 259° and 319°, and the B regionis between -41° and 22°.

3. Luminance Variation and Exposure Compensation

Currently most of the color adjustment methods adjust luminance, saturation, and hue separately to find the best performance of each item to finish the color adjustment. However, according to the HVS when the brightness of color changes, it does not simply change luminance, saturation, and hue, separately [12]. Actually the color changes by complying with the changes of luminance, saturation, and hue, and luminance, saturation, and hue must be associated with each other. In order to find the relationship of brightness variation according to chroma changing, we simulated the exposure compensation upon the theory of image capturing. We used the Lena image for the simulation. Since people are the most important objects, the skin color is the key issue in the image. The target of simulation of the exposure compen-

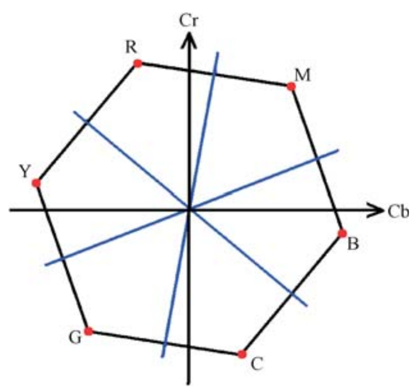


Figure 1. The color projection into the Cb-Cr plane.

sation in this study is based on the skin color.

Table 1 shows the simulation results. We used the results of exposure compensation values of ±2.0 EV, ±1.5 EV, ±1.0EV, and ±0.5 EV, respectively, to compare that with the original image without exposure compensation. We also plot the color histograms of saturation-brightness and hue-luminance for analyses. The vertical coordinate of the color histogram is luminance. According to the color histograms of saturation-luminance for +0.5 EV, +1.0 EV, +1.5 EV and +2.0 EV, and the original one,

Table 1. Color changes of the skin color of Lena with saturation-luminance histogram and hue-luminance histogram based on the simulation results of the exposure compensation

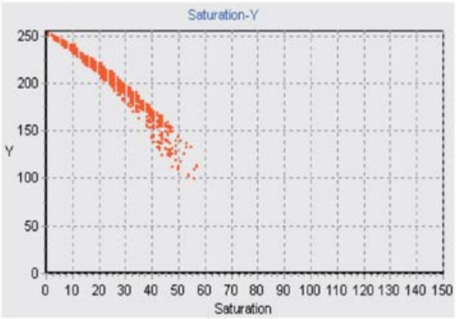
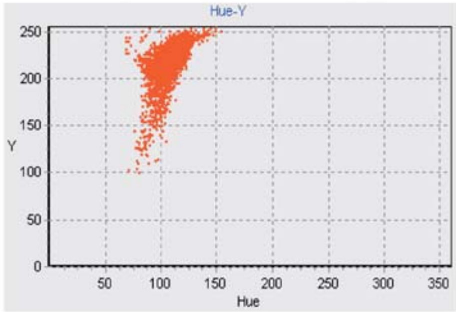
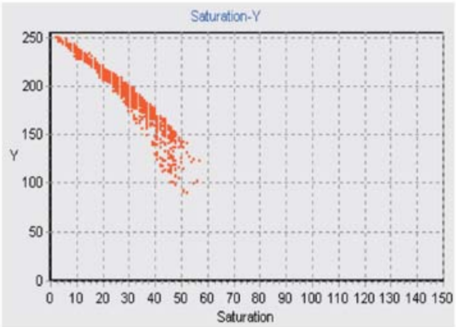
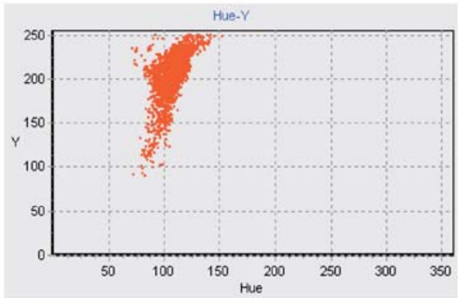
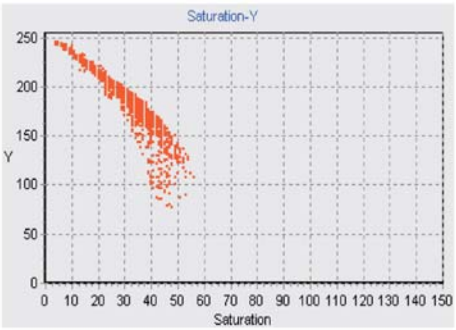
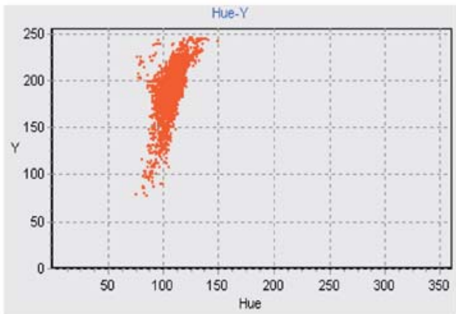
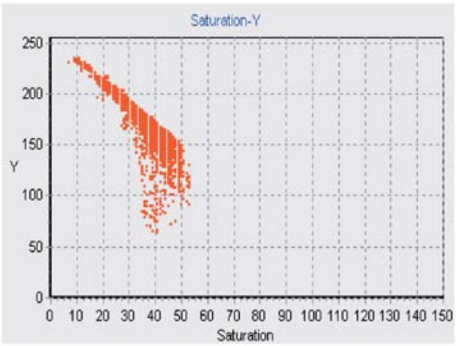
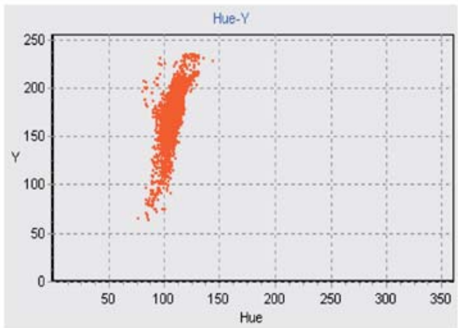
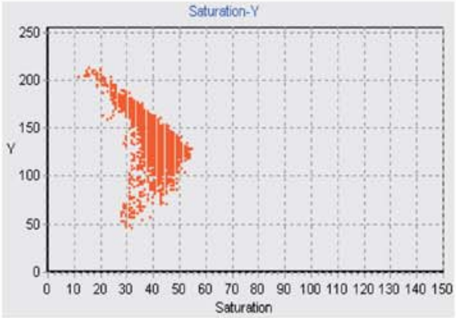
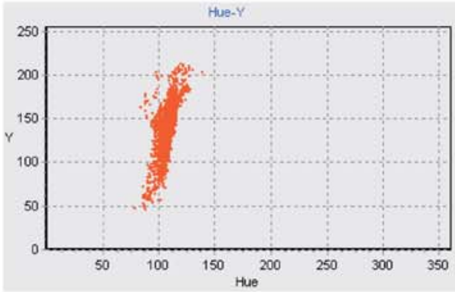
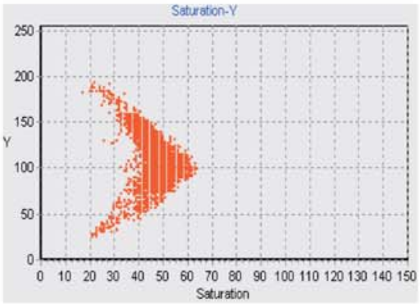
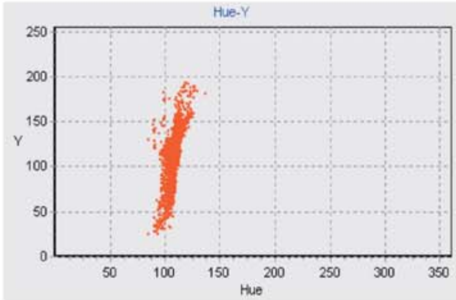
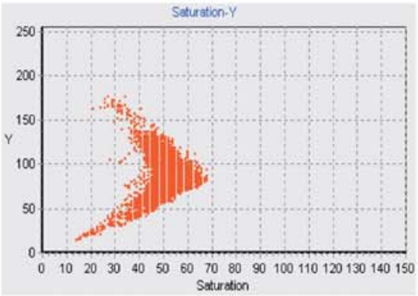
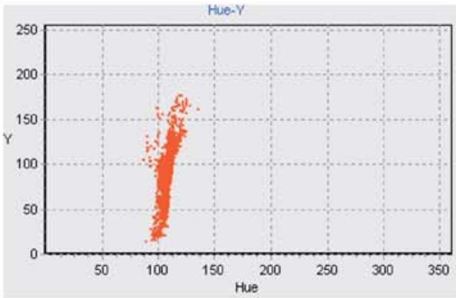
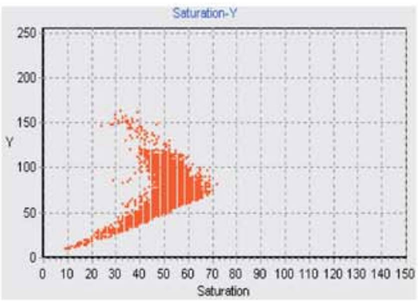
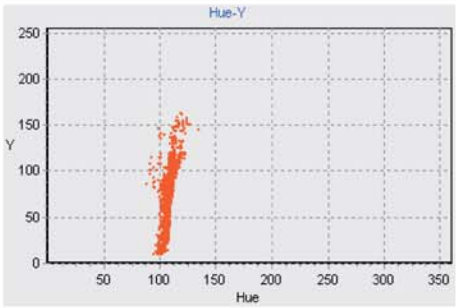
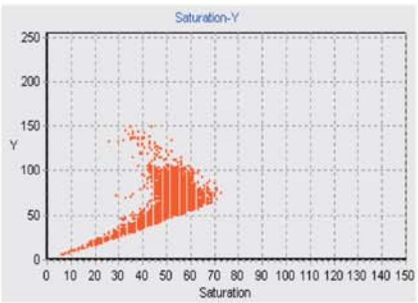
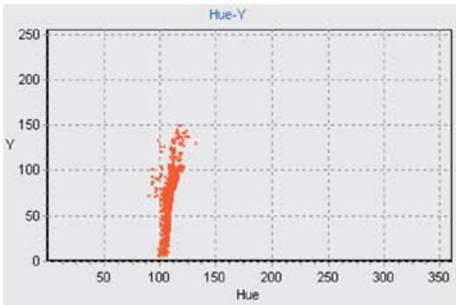
Simulation image	Saturation-luminance histogram	Hue-luminance histogram
 +2.0 EV		
 +1.5 EV		
 +1.0 EV		
 +0.5 EV		

Table 1. Continued

Simulation image	Saturation-luminance histogram	Hue-luminance histogram
 Original image		
 -0.5 EV		
 -1.0 EV		
 -1.5 EV		
 -2.0 EV		

when the luminance becomes brighter, the color distribution has the tendency to move toward the upper left direction. It is owing to having too much light to cause over-exposure and the results are similar to the over exposure of a camera. From the color histogram, when the luminance is increasing, the saturation is increasing but has some limit. When the luminance increases to a certain value, the saturation starts decreasing. Let us check the color histograms of saturation-luminance for -0.5 EV, -1.0 EV, -1.5 EV and -2.0 EV, and the original one. When the luminance becomes darker, the color distribution has the tendency to move toward the lower left direction. Most of the color saturation decreases according to the darker luminance. However, some of the color saturation increases contrarily according to the darker luminance. The symptoms that the color saturation does not change proportionally to the change of luminance are worth discussing. The reasons may be caused by some relationships of HVS and YCbCr model. We will propose a new model and approach to solve this issue in next section.

From the color histograms of hue-luminance, basically the hues do not change much upon the changes of luminance. However, when compared with the color histogram of +2.0 EV and the original one, the hue is diverged. It is owing to light over exposure. Over-exposure causes the color to tend to become white. In the YcbCr model, the data tends to (Y, Cb, Cr) = (255, 0, 0) and makes the color to deviate and diverge. This paper will focus on the saturations of over brightness and over darkness to find the best color adjustment solution.

From the simulation results discussed above, we find that color luminance, saturation, and hue are correlated with each other when luminance changes. It is different from the conventional concepts that the color saturation is proportional to the luminance. We will propose a new method for the color saturation adjustment according to the variation of light brightness.

4. Color Saturation Adjustment Method

In this section,we use the YCbCr model to construct a new color adjustment method. It associates with the correlation of light brightness and color saturation that was found by the simulation of light over exposure in the previous section. When the light brightness varies, the color saturation also changes accordingly. The changes of luminance and color saturation are corresponded to the YCbCr color model. Therefore, the proposed approach uses luminance as the major parameter to adjust the color saturation. This proposed method can prevent over-saturation and color discontinuity to make the image look natural. At last, this method will fine-tune to adjust the image according to the HVcharacteristics to obtain a better result.

4.1 Color Adjustment and Luminance Variation

The proposed method can effectively adjust the color saturation in corresponding to the luminance variation which is designed for the YCbCr model. In order to deal effectively with the light luminance and color saturation at the same time, we must analyze the YCbCr model first. The model is sectioned on the basis of 360 degrees of hue, and the profile is shown in Figure 2. The horizontal axis of this section profile is the saturation, and that of the vertical axis is the luminance. Because it sections the hue profile, for color adjustments we do not need to worry about the variation of hue. The cross-section is through hue of the YCbCr model, and therefore the 360 sections are all in triangular shape. The shapes of these triangles are slightly different due to different color characteristics in different hue. For example, the right side of Figure 2 is a cross section triangle at 0 degree. According to subsection 2.2, this one is belonged to the B region (blue color). Actually the blue color (B region) is belonged to the darker color part of the HVS, and the saturation is low. The characteristics of the color regions can thus be applied for the color saturation adjustment.

Each cross section triangle consists of three sides and three angles. According to the hue information, this study we define the left side of the cross section triangle

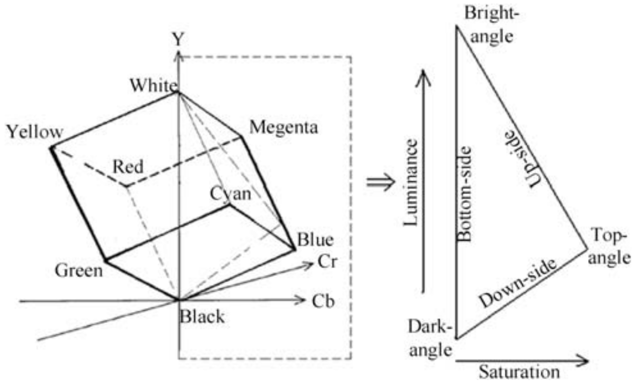


Figure 2. The cross section schematic of YCbCr model based on hue.

as the first side, and the length of the first side is set to 255. The color is in the grayscale format, and 255 means white color. The data close to this side means it has lower saturation. In this study, we also call this side as the bottom-side. The second side is the down-side of the cross section triangle. Due to different hues the lengths and slopes of these sides are different. This side reflects the characteristics of the lower brightness in a hue. The second side is also called down-side. The third side is the up-side of the cross section triangle. Owing to different hues, the lengths and slopes of these sides are different. This side (the third side is called up-side) reflects the characteristics of higher brightness in a hue. For the angles of the cross section triangle, we define the down-angle as the first angle.Because this angle means the smallest brightness part in a hue and is close to the black color, this angle is called dark-angle. The second angle is the up-angle of the cross section triangle. Since this angle is the highest brightness part in a hue and is close to the white color, the second angle is called bright-angle. The third angle is the right angle of the cross section triangle, the highest saturation part in a hue, and this angle is called top-angle and the intersection point is called vertex. The vertices are located in different luminance according to the different hues. For example, the vertex of the blue color is located in the lower brightness part, and the vertex of the yellow color is located in the higher brightness part.

The range of hue is from 0 degree to 360 degrees. The human eyes are not very sensitive to the details of color changes, and therefore it is not necessary to adjust color according to hue in each degree of the 360-degree range. Instead, we can simply adjust the color by the characteristic color range. In the previous section, we use the color characteristic and YCbCr color model to divide the hue into six regions: M (22°~80°), R (80°~138°), Y (138°~202°), G (202°~259°), C (259°~319°), and B (-41°~22°). We can try to summarize all the section triangles in each of the six regions and induce a new cross section triangle. Totally only six cross section triangles are obtained. Since it needs only six cross section triangles instead of 360 cross section triangles, it can be implemented much more easily.

When adjusting colors, the symptom of color over-saturation must be prevented. The color over-saturation causes color information to be lost and further it may reduce the details of an image. In order to prevent color over-saturation, we must find the largest boundary and range of each region of the six regions for color adjustment. This study summarizes the slopes of the up-side and down-side of all the cross section triangles in each color region as the constraint to avoid the light brightness and color saturation varying beyond the effective color adjustment range. Here let us take the M region as an example. The hue range of the M region is from 22°~80° and it has 59 cross section triangles. In order to induce a characteristic triangle to fit the color characteristics of the 59 cross section triangles we must find the maximum allowed boundary and range for color adjustment. Under this consideration, we have to find the minimum and maximum slopes of the up-side and down-side of the cross section triangles, respectively, among the 59 cross section triangles as the constraint. In the M region, the smallest slope of the up-side is -1.624160 and the largest slope of the down-side is 0.792559. It can use these two slopes together with the bottom-side to find the vertex $(x, y) = (105, 83)$ of the characteristic triangle by the following:

$$\begin{cases} x = \dfrac{255}{m_1 - m} \\ y = 255 \times \overline{m} \end{cases} \tag{3}$$

where m_1 denotes the largest slope of the down-side, m_2 the smallest slope of the up-side, and (x, y) the vertex of the characteristic triangle. In the same manner, it can find the vertices of the other five characteristic triangles for R, Y, G, C, and B color regions. Table 2 shows the characteristic triangles of the six color regions. For the coordinate, the vertical axis is the luminance and the horizontal axis is the color saturation. The characteristic triangles are very different, because they have different color characteristics depending on the six color regions. In order to better fit the HVS, the six characteristic triangles will be modified according to the HV model for color adjustment in next subsection.

4.2 Characteristic Triangles and Human Vision Systems

In the HVS, cone and rod cells in the retina of human eyes are very different. The number of rod cells is much greater than that of cone cells, and the light intensities of cone and rod cells have different stimulus thresholds. Therefore the luminance sensitivity of human eyesis much greater than that of the saturation sensitivity. In order to have a better fit for the HVS, the characteristic triangles described in the previous subsection should be modified.

The color adjustment is achieved by using the ratio, i.e. slope, of luminance and saturation to enhance or reduce the saturation. From Table 2, we find that the slopes of the down-side of the characteristic triangles in the M and B color regions are greater than 1. The slope of the up-side of the characteristic triangles in the Y and G color regions are smaller than -1. These situations show that the saturation changes greater than the luminance, and it is not reasonable for HVS. Therefore the characteristic triangles shown in Table 2 must be modified. The slope values of the down-side of the characteristic triangles for M and B color regions are adjusted to 1, and the slope values of the up-side of the characteristic triangles of the Y and G color regions are adjusted to -1. The modifications can improve the problems of saturation changing greater than that of luminance to prevent over-saturation. Table 3 shows the revised characteristic triangles for the six color regions. The vertices have moved slightly to the bottom-side. Although the modifications affect the saturation a little bit, it is still acceptable. The color characteristics are still maintained. Most important of all, the new characteristic triangles can fit both the color characteristic and human visual system.

4.3 Color Adjustment by Using Characteristic Triangles

The proposed color adjustment method adjusts the color saturation based on the luminance changes. In order to prevent over-saturation and unnatural image looking, we use the six characteristic triangles discussed in section 4.2 to adjust colors within the allowed range. Generally human eyes are more sensitive to the luminance but less sensitive to the color saturation. Therefore the luminance becomes the main factor and color satura-

Table 2. The characteristic triangles of the six color regions

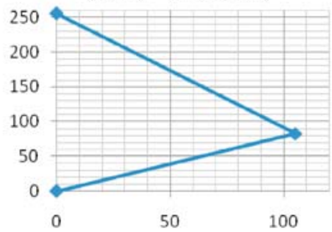
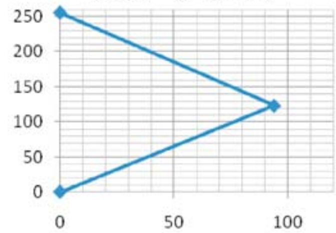
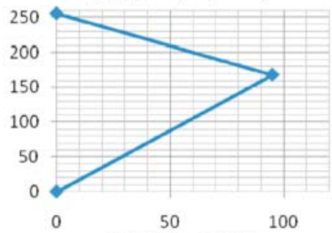
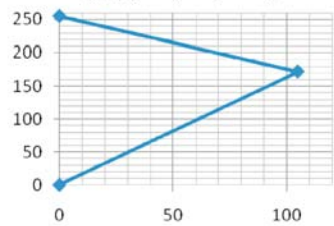
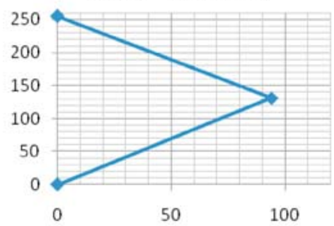
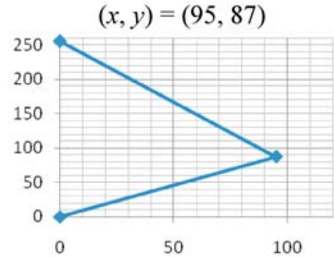
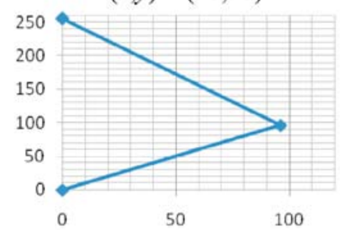
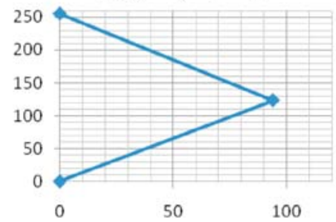
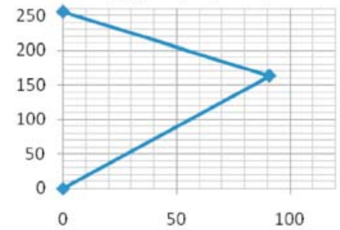
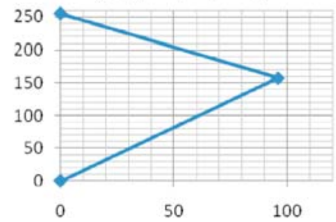
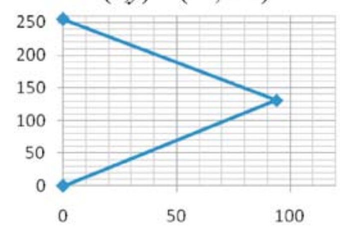
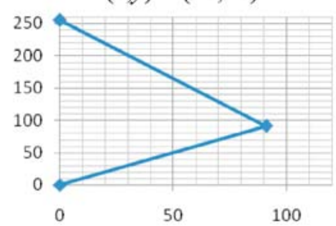
	M (22°~80°)	R (80°~138°)
Locations of vertices	$(x, y) = (105, 83)$	$(x, y) = (94, 123)$
Characteristic triangles		
	Y (138°~202°)	G (202°~259°)
Locations of vertices	$(x, y) = (95, 168)$	$(x, y) = (105, 172)$
Characteristic triangles		
	C (259°~319°)	B (-41°~22°)
Locations of vertices	$(x, y) = (94, 131)$	$(x, y) = (95, 87)$
Characteristic triangles		

Table 3. The characteristic triangles of the six color regions correcting by human visual model in the six groups

Color regions	M (22°~80°)	R (80°~138°)
Locations of vertices	(*x*,*y*) = (96,96)	(*x*,*y*) = (94,123)
Characteristic triangles		
	Y (138°~202°)	G (202°~259°)
Locations of vertices	(*x*,*y*) = (91,163)	(*x*,*y*) = (96,158)
Characteristic triangles		
	C (259°~319°)	B (-41°~22°)
Locations of vertices	(*x*,*y*) = (94,131)	(*x*,*y*) = (91,91)
Characteristic triangles		

tion the secondary factor in color adjustment. We use the difference between the original and new luminance as the main coefficient to adjust the color saturation. The simulation in section 3 of this study finds that the luminance change of an image may cause the change of luminance and saturation bur hue keeps almost the same. From the saturation-luminance histogram we find the color variation from +2 EV to –2 EV has very strong relations with the cross section triangle. Therefore it can be used together with the slopes of the up-side and down-side of the characteristic triangles of the six color regions to adjust the color saturation. The color saturation adjustment algorithm is thus achieved by using the luminance variation to find the chrominance belonged to which region of the six color regions. Finally the slopes of the up-side and down-side edges of the specific characteristic triangle are used to adjust the color saturation. The color saturation adjustment procedures are illustrated as shown in the following:

$$\begin{cases} S_{before} = \dfrac{x}{y} \times Y, \ Y \le y \\ S_{before} = \dfrac{x}{y-255} \times (Y-255), \ Y > y \end{cases} \tag{4}$$

$$\begin{cases} S_{after} = \dfrac{x}{y} \times Y', \ Y \le y \\ S_{after} = \dfrac{x}{y-255} \times (Y'-255), \ Y > y \end{cases} \tag{5}$$

$$Sat' = Sat \times \frac{S_{after}}{S_{before}} \tag{6}$$

In Eqs. (4), (5), and (6), Y denotes the original luminance, Y' is the new luminance, (x, y) the vertex, S_{before} and S_{after} the computing parameters, and Sat' the computed saturation value. This algorithm mainly utilizes the linearization of a line segment to achieve the saturation adjustment. It is suitable for hardware implementation and also fits the linear characteristic of the YCbCr model. In Figure 3, we can use (4) and (5) to obtain S_{before} and S_{after}. Here shows the proportional relation of variations of luminance and saturation in the characteristic triangle. Finally, we can use (6) to amplify the original saturation in linear operation.

The proposed method can effectively adjust the color saturation accompanying with the variant luminance instead of separately adjusting the luminance and saturation. It is also consistent with the HV characteristics. By our approach, it can effectively avoid over-saturation and it makes the image look more natural. Besides, the proposed method has the characteristics of low complexity and can be widely and conveniently applied.

5. Experimental Results

We have proposed a color saturation adjustment method based on the brightness of the YCbCr model to fit for the HVS. When the luminance is known, it can use (4)–(6) to effectively adjust the color saturation. This work uses a digital camera to capture a variety of images with different colors to test the proposed method. We can adjust the exposure time and aperture value to capture a darker or lighter image. The extreme cases of animage such as too dark or too light were captured by the camera intentionally and then these pictures were processed by the proposed approach to become better quality pictures. The tested images were also processed by the techniques proposed in [2]. We have compared the original images, that processed by the proposed approach, and that by [2]. Our approach can prevent over-saturation, and the image processed by our approach looks more natural.

The natural images have colors, such as green of leaves, yellow, red and purple of petals, and blue of sky. On the other hand, the colors of the artificial objectsare very diverse, which include complexity and variability of colors. Figures 4, 5, and 6 show the tested images. Figure 4(a) is photographed in exposure time of 1/200 s, aperture of F/8, and ISO of 400. Then, we can observe the yellow and green color adjustment, and also observe the changes of color contrast. Figure 5(a) is photographed in exposure time of 1/100 s, aperture of F/6.3, and ISO of 100. In Figure 5 we can observe not only colors of green and red and blue sky in nature, but also artificial buildings. Figure 6(a) is photographed in exposure time of 1/200 s, aperture of F/3.5, and ISO of 100. In Figure 6 we can observe artificial objects.

It can be seen from Figures 4(b), 5(b), and 6(b) that only luminanceis adjusted unnaturally. The image of only luminance adjusted is not colorful enough, and the brightness and contrast enhancement in the whole image are very limited. Figures 4(c), 5(c), and 6(c) are adjusted by luminance and saturation with the proposed method at the same time. All the adjusted images of Figures 4(c), 5(c), and 6(c) look more natural than that of Figures 4(b),

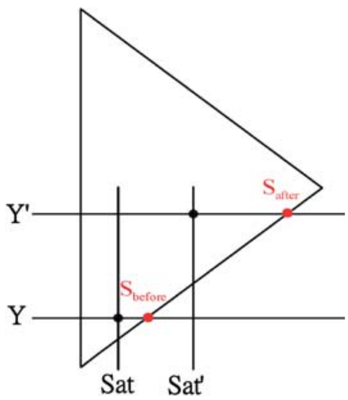


Figure 3. An example for the color saturation adjustment.

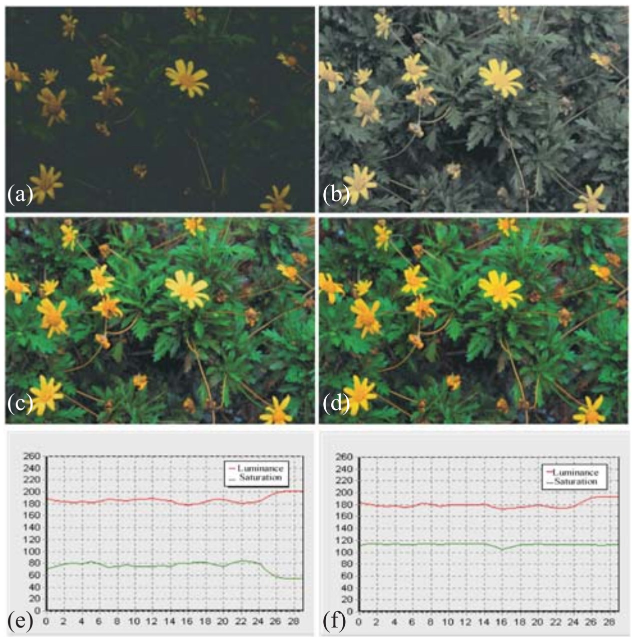


Figure 4. The image was photographed in exposure time of 1/200 s, aperture of F/8, and ISO of 400: (a) The original image. (b) The image after luminance adjustment with Gamma curve. (c) The image after luminance and the proposed method adjustment. (d) The image after luminance and the technique of [2] adjustment. (e) The detailed analysis of (c). (f) The detailed analysis of (d).

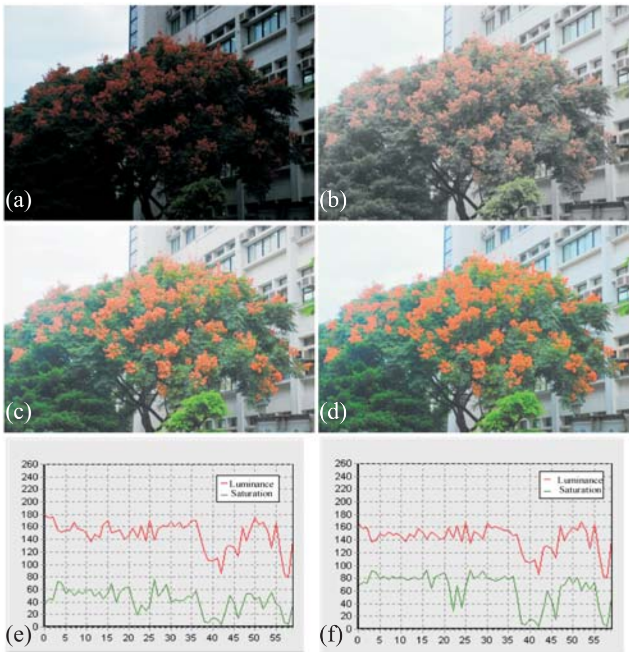


Figure 5. The image was photographed in exposure time of 1/100 s, aperture of F/6.3, and ISO of100: (a) The original image. (b) The image after luminance adjustment with Gamma curve. (c) The image after luminance and the proposed method adjustment. (d) The image after luminance and the technique of [2] adjustment. (e) The detailed analysis of (c). (f) The detailed analysis of (d).

5(b), and 6(b). Besides, the brightness and contrast of the images in Figures 4(c), 5(c), and 6(c) are much more enhanced than that of Figures 4(b), 5(b), and 6(b). Because color saturation is also parts of the brightness of color, it is necessary to adjust the luminance and saturation at the same time when the brightness is changed.

Let us compare parts of (c) and (d) of Figures 4, 5, and 6. The yellow color of Figures 4(c) and (d) changes very much but the green color only changes a little bit. The yellow color is located in the high luminance part. Figure 4(d) is the adjusted result by using directly adjusting the RGB values. When it adjusts the luminance, it changes the color saturation proportionally and it is very easily over-saturated. On the other hand, the proposed approach uses the characteristic of YCbCr model. When the luminance reaches a certain high value, the color saturation will be reduced to avoid over-saturation. Figure 4(f) indicates the results of over-saturation correction and we can find the luminance curve and saturation curve approaching smooth. The smoothness of both curves means data lost due to over-saturation. Since no

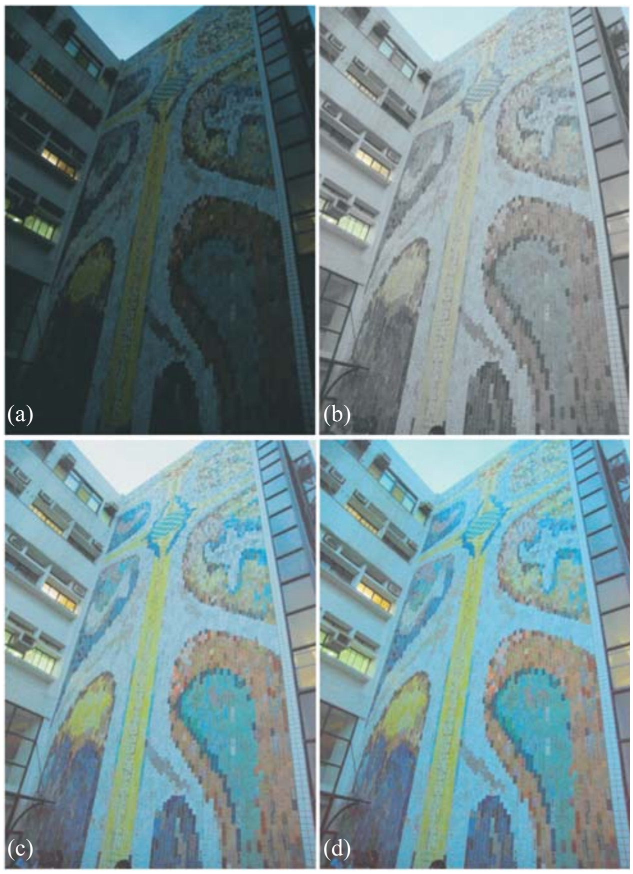


Figure 6. The image was photographed in exposure time of 1/200 s, aperture of F/3.5, and ISO of100: (a) The original image. (b) The image after luminance adjustment with Gamma curve. (c) The image after luminance and the proposed method adjustment. (d) The image after luminance and the technique of [2] adjustment.

over-saturation occurs, Figure 6(a) has no data lost. Let us check Figures 5(c) and (d), and the image shown in Figure 5(d) looks more unnatural. It is because there are a lot of over-saturations and color shifts. When processing color adjustments, Figure 5(f) indicates that the real flower is over-saturated. Let us look at Figures 6(c) and (d), and we can find that Figure 6(d) looks more unnatural (a little bit bluish). It is because the direct RGB adjustment makes the white color shift and over-saturate. However, Figure 6(c) looks more natural.

6. Conclusions

This study proposes a new color saturation adjustment method for color adjustment which can effectively prevent color over-saturation and make the image look natural. Similar to the operation of a camera, the exposure compensation to simulating changes of brightness indicates that the color saturation has certain regularity relations with the brightness. The proposed color saturation adjustment method adjusts the color saturation with the variation of luminance and also fit the HVS. As a result, the color saturation adjustment method outperforms the existed methods in the colorful quality without over-saturation. This method can prevent color over-saturation and make the image look more natural, it can be applied to the popular multimedia devices, such as HDTV and LCD TV.

References

[1] Capra, A., Castrorina, A., Corchs, S., Gasparini, F. and Schettini, R., "Dynamic Range Optimization by Local Contrast Correction and Histogram Image Analysis," *IEEE International Conference on Consumer Electronics*, pp. 309−310 (2006). doi: 10.1109/ICCE.2006.1598434

[2] Wu, Y., Liu, Z., Han, Y. and Zhang, H., "An Image Illumination Correction Algorithm Based on Tone Mapping," *IEEE International Congress on Image and Signal Processing*, Vol. 2, pp. 645−648 (2010). doi: 10.1109/CISP.2010.5647231

[3] Lee, S., Kwon, H., Han, H., Lee, G. and Kang, B., "A Space-Variant Luminance Map Based Color Image Enhancement," *IEEE Transactions on Consumer Electronic*, Vol. 56, No. 4, pp. 2636−2643 (2010). doi: 10.1109/TCE.2010.5681151

[4] Ding, X., Wang, X. and Xiao, Q., "Color Image Enhancement with a Human Visual System Based Adaptive Filter," *IEEE International Conference on Image Analysis and Signal Processing*, pp. 79−82 (2010). doi: 10.1109/IASP.2010.5476159

[5] Shi, Y., Yang, J. and Wu, R., "Reducing Illumination Based on Nonlinear Gamma Correction," *IEEE International Conference on Image Processing*, Vol. 1, pp. I-529−I-532 (2007). doi: 10.1109/ICIP.2007.4379008

[6] Shi, Y., "Adaptive Illumination Correction Considering Ordinal Characteristics," *IEEE International Conference on Wireless Communications Networking and Mobile Computing*, pp. 1−4 (2010). doi: 10.1109/WIMOB.2010.5645051

[7] Ku, C.-C. and Wang, T.-M., "Luminance-Based Adaptive Color Saturation Adjustment," *IEEE Transactions on Consumer Electronics*, Vol. 51, No. 3, pp. 939−946 (2005). doi: 10.1109/TCE.2005.1510507

[8] Zeng, Y.-C. and Liao, H.-Y., "Video Enhancement Based on Saturation Adjustment and Contrast Enhancement," *IEEE International Symposium on Circuits and Systems*, pp. 3550−3553 (2008). doi: 10.1109/ISCAS.2008.4542226

[9] Fairchild, M. D., *Color Appearance Models*, 2nd Edition, John Wiley & Sons, Inc., NY, November (2004). doi: 10.1049/iet-ipr.2012.0657

[10] Lee, K.-Y., Park, R.-H. and Lee, S.-W., "Colour Matching for Soft Proofing Using a Camera," *IET Image Processing*, Vol. 6, No. 3, pp. 292−300 (2012). doi: 10.1002/9781118653128

[11] Xu, T., Wang, Y. and Zhang, Z., "Pixel-Wise Skin Colour Detection Based on Flexible Neural Tree," *IET Image Processing*, Vol. 7, No. 8, pp. 751−761 (2013).

[12] Chang, S.-H., Hsia, C.-H., Chang, W.-H. and Chiang, J.-S., "Self-Localization Based on Monocular Vision for Humanoid Robot," *Journal of Applied Science and Engineering*, Vol. 14, No. 4, pp. 323−332 (2011). doi: 10.1049/iet-ipr.2011.0046

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