A New Algorithm Based on Saturation and Desaturation in the xy Chromaticity Diagram for Enhancement and Re-Rendition of Color Images

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ABSTRACT

This paper presents a new algorithm for color contrast enhancement which adopts the xy chromaticity diagram and consists of two steps. All the "chromatic" colors are £rst maximally saturated within a certain gamut; the opportune desaturation operation which follows is based on the *Center of Gravity Law for Color Mixture*. This prevents the introduction of unnatural colors and, in combination with a suitable manipulation of the brightness value, turns out to increase the image sharpness and to provide more appealing results. Our technique can also be applied to re-rendition of a color image since it can easily simulate the change of the illuminant(s) of the scene portrayed in the image; this could £nd useful applications in image and video editing. Some examples of the performance of the algorithm are reported and discussed.

1. INTRODUCTION

The objective of image enhancement is to process an image so that the result is more suitable than the original for a certain application [1]. Very often, this enhancement consists in improving the image contrast which is related to the sharpness of the details. In fact, textured details are more evident in images with high contrast which, in turn, implies a large range in intensity and color variations. Contrast ehnancement methods then aim at amplifying the local intensity or color variations within an image to increase the feature visibility [2].

There exist a number of techniques for color contrast enhancement, mostly working in color spaces which allow the separation of intensity and chromatic information, in agreement with the physiological models which describe the color processing of the human visual system [1, 2, 3, 4]. Among others, there are methods based on adaptive histogram equalization, unsharp masking, constant variance enhancement, homomorphic £ltering, highpass, and lowpass £ltering [2].

In this contribution, we present a truly original approach to color constrast enhancement which has been suggested by the new nonlinear £ltering technique proposed in [5]. It works in the xy chromaticity diagram associated with the CIE XYZ color space and consists of two steps. In the £rst step, all the "chromatic colors" are maximally saturated through shifting to the borders of a selected color gamut. In the second step, the colors are desaturated according to the *Center of Gravity Law for Color Mixture* [6] and by a suitable manipulation of the brightness level. If the desaturation operation is carried out towards the original white point, color enhancement is achieved. If instead a new white point with some chromatic bias is chosen, our technique proves to be useful for color re-rendition because it is possible to simulate the change of the illuminant(s) of the scene.

This paper has four sections. Section 2 presents the two-stage algorithm for color enhancement. Section 3 reports on some experimental results. Section 4, £nally, contains the conclusions.

2. ALGORITHM

Our algorithm consists of two stages: 1) transformation of each color pixel into its maximally saturated version with respect to a certain color gamut and 2) desaturation of this new color towards a new white point according to a proper color mixing rule. We show that the combination of these two operations is effective indeed in enhancing the contrast of color images.

2.1. Color space conversions

Our algorithm operates on the representation of colors in the xy chromaticity diagram which is derived as follows:
1) by converting the three RGB components into CIE XYZ coordinates according to the af£ne transformation [6]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.49000 & 0.31000 & 0.20000 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00000 & 0.01000 & 0.99000 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}, \tag{1}$$

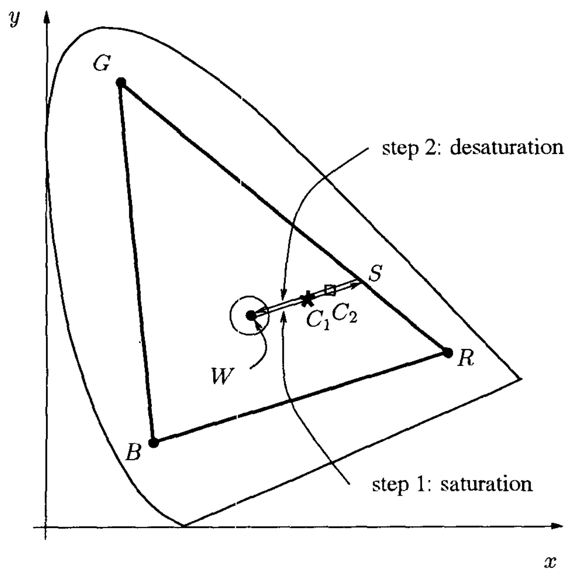

Fig. 1. xy chromaticity diagram: the outer solid line represents the spectral locus plus the line of purples; R, G, and B are the vertices of the color gamut; C_1 and C_2 are, respectively, the color before and after enhancement; W is the white point.

2) and by normalizing X and Y coordinates as

$$x = \frac{X}{X+Y+Z} \quad \text{and} \quad y = \frac{Y}{X+Y+Z}. \qquad (2)$$

A color C can then be uniquely represented as $C = (x, y, Y)$ where x and y carry the chromatic information whereas the CIE Y contains the brightness information.

Fig. 1 shows a sketch of the xy diagram: the outer solid line represents the spectral locus plus the line of purples; R ($x_R = 0.674, y_R = 0.326$), G ($x_G = 0.216, y_G = 0.716$), and B ($x_B = 0.162, y_R = 0.090$) are the vertices of the color gamut triangle for CRT monitors [7]; C is the color undergoing enhancement; W ($x_W = 0.310, y_W = 0.316$) is the *white point*. The small circle around the point W is the region of the diagram containing the achromatic colors for which no enhancement action is taken.

2.2. Step 1: Saturation

It is well-known that in any chromaticity diagram the blacks, the whites, and the grays are represented by a single point, the so-called *white point*. Since the saturation is zero for all these color families, and since the £rst step of our algorithm emphasizes the saturation component of each color, they cannot be included in the enhancement procedure in order to avoid meaningless results. For convenience, we have de£ned the region of achromatic colors to be a circle centered at W and typically having a radius of 0.1 (see Fig. 1).

Therefore, Step 1 applies only to any color $C_1 = (x_1, y_1, Y_1)$ lying outside this region according to the following procedure:

1) Find the intersection S of the line through points C_1 and W with the gamut triangle in such a way that C_1 lies between W and S (see Fig. 1); S, whose chromatic coordinates are x_S and y_S, represents the maximally saturated version of C_1 with respect to the adopted color gamut.

2) Since the saturation operation affects only the chromatic components of C_1, the saturated color S is associated with the same brightness Y_1 and can then be represented as $S = (x_S, y_S, Y_1)$.

It is interesting to note we can selectively saturate a chromatic pixel by considering its hue given by the angle with respect to a reference axis at the white point. In our case, we have considered the y-axis as the reference axis. The angular interval within which the pixels are processed is denoted by $[\theta_1, \theta_2]$, with $0 \le \theta_1 \le \theta_2 < 2\pi$.

2.3. Step 2: Desaturation

Step 1 returns an image which looks pretty unnatural since all the colors, except the achromatic ones, have been maximally saturated; a suitable desaturation operation is thus necessary. This is carried out by resorting to the well-known *Center of Gravity Law of Color Mixture* [6] which has recently been proposed by [5] for a new color £ltering technique.

Preliminarily, we compute the average luminance Y_{avg} of the color image as the mean of all the pixel luminances and we associate the white point W with a new luminance value $Y_W = \kappa Y_{avg}$, where κ is a factor chosen to control the illumination level: positive values of κ make the scene to appear brighter whereas negative values of κ make the scene to appear darker.

The *Center of Gravity Law* provides the resulting color $C_2 = (x_2, y_2, Y_2)$ of the mixture of the two colors $W = (x_W, y_W, |Y_W|)$ and $S = (x_S, y_S, Y_1)$ where

$$x_2 = \frac{x_W \frac{|Y_W|}{y_W} + x_S \frac{Y_1}{y_S}}{\frac{|Y_W|}{y_W} + \frac{Y_1}{y_S}}, \quad y_2 = \frac{|Y_W| + Y_1}{\frac{|Y_W|}{y_W} + \frac{Y_1}{y_S}}, \qquad (3)$$

and $Y_2 = Y_W + Y_1$. The value of κ has to be chosen in such a way that the luminance values of all pixels remain positive; negative luminance values are treated as zeroes in our implementation.

One may think of adding more ¤exibility to the rendering process by shifting the white point to any chromatic zone and simulating this way the addition of a certain color bias to the illuminant(s) of the scene.

One could also make use of the knowledge of the human visual system for getting better contrasts in the rendered images. According to *Weber's Law* in fact, the just noticeable difference (JND) in brightness is proportional to the average intensity of the surrounding pixels [8, 9]. This means that textured details are much more visible in the darker regions than in the brighter areas. Accordingly, Step 2 can be suitably modi£ed so as to selectively process the pixels based on their luminance value (Y); in our implementation, luminance values below a selected threshold $\mathcal{L}_{\min}$ do not undergo desaturation.

3. EXPERIMENTAL RESULTS

We have carried out experiments on various images and in this contribution we report on the results relative to one of them, *Alps*, which is shown in Fig. 2 (a). The maximally saturated image returned by Step 1 is shown in Fig. 2 (b): we may observe that the oversaturation of some of the colors makes the picture visually less appealing than the original.

The result of the desaturation operation carried out in Step 2 with $\kappa = 0.5$ is shown in Fig. 2 (c): the new image looks brighter than the original of Fig. 2 (a) and many of the details not visible in that image are now clearly visible in Fig. 2 (c). If we use a negative value for κ in Step 2, the image gets darker as shown in Fig. 2 (d) for $\kappa = -0.2$.

The desaturation process of Step 2 could also be applied directly to the original images without the preliminary saturation of Step 1. Fig. 2 (e) displays the result of such an operation with $\kappa = 0.5$. We have found that in some cases the application of only Step 2 returns results which are similar to those yielded in combination with Step 1 or even sharper.

Moreover, one can increase the contrast of the image by selectively desaturating the pixels based on their luminance value; an example is shown in Fig. 2 (f) where the pixels having a luminance below $\mathcal{L}_{\min} = 50$ (in a scale ranging from 0 to 255) are unchanged.

We have also experimented by moving the white point to a new point in the chromaticity diagram (within the triangle of the color gamut). In such cases, we have used a negative κ to produce the effect of dusk (by moving the white point towards the zone of the reds) and reduced light conditions. Some examples are shown in Figs. 2 (g) and (h), where the white point used in Step 2 has been set, respectively, to $(0.5, 0.2)$ and to $(0.2, 0.5)$. These two re-rendering operations seem to simulate different outdoor illuminations in correspondence to various moments of the day.

4. CONCLUSIONS

We have presented a new algorithm for color contrast enhancement which consists of a color saturation operation followed by a desaturation operation, both carried out in the xy chromaticity diagram. We have reported a few examples that show the effectiveness of this technique in sharpening the textured details within an image, thereby improving its appearance. Also, we have shown that color re-rendition is possible through a suitable modi£cation of the second step ot the algorithm. This functionality may be useful in applications concerned with image and video editing.

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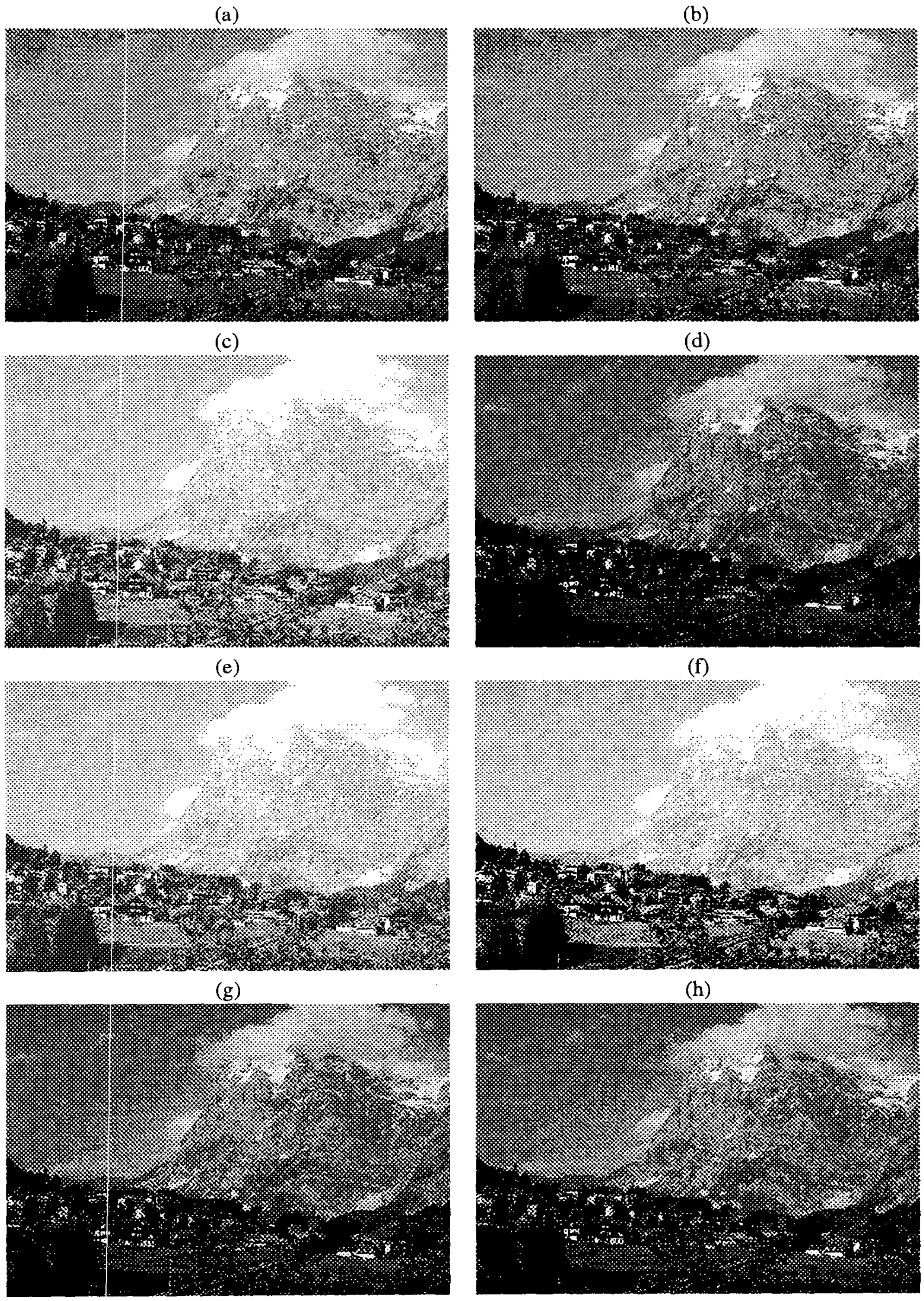

Fig. 2. a) Original image (*Alps*); b) Maximally saturated image (after Step 1); c) Desaturated image with $\kappa = 0.5$ (after Step 2); d) Desaturated image with $\kappa = -0.2$ (after Step 2); e) Desaturated image from original with $\kappa = 0.5$; f) Desaturated image from original with $\kappa = 0.5$ and $\mathcal{L}_{\min} = 50$; g) Desaturated image obtained by shifting the white point to $(0.5, 0.2)$; h) Desaturated image obtained by shifting the white point to $(0.2, 0.5)$.