COLOR IMAGE ENHANCEMENT AND EVALUATION ALGORITHM BASED ON HUMAN VISUAL SYSTEM

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ABSTRACT

We propose a novel color image enhancement method, Human visual system Controlled Color Image Enhancement and Evaluation (HCCIEE) algorithm, and applied to color image by considering natural image quality metrics. This HCCIEE algorithm is based on multiscale representation of pattern, luminance and color processing in the human visual system. Experiments illustrated the HCCIEE algorithm can produce distinguished details while avoids artifacts, which often occur in conventional multiscale enhancement methods, as well as the production of images that appear as similar as possible to the viewer's perception of actual scenes.

1. INTRODUCTION

The goals of image enhancement can be differently stated depending on the particular application [1]. For natural color image, very often, human visual system gives the final evaluation of the processed image. There are two major problems should be solved for natural color image enhancement: 1) more distinguished texture details, and 2) color and brightness of the processed image are perceptually better.

There exist a number of techniques for color enhancement, mostly working in color spaces which transform the red, green and blue monochromatic planes to the perceptually based hue, saturation and intensity space. The techniques such as simple global saturation stretching [2], hue dependent saturation histogram equalization [3] and intensity edge enhancement based on saturation [4]have been attempted in this space. Among others, there are methods based on Land' s retinex theory [5] and nonlinear filtering technique in the xy chromaticity diagram [6].

In this paper, a novel image enhancement algorithm, Human visual system Controlled Color Image Enhancement and Evaluation (HCCIEE) algorithm, is presented considering the human visual characteristics [13, 17]. The method for color image enhancement is based on multiscale representation of pattern, luminance and color processing in the human visual system. First, wavelet based enhancement method with contrast sensitive functions (CSFs) are used to enhance R, G, B components respectively. Secondly, the colors of image are adjusted according to natural image quality metrics [7, 9] by a suitable manipulation of the color naturalness index (CNI) and color colorfulness index (CCI). Our technique proves to be useful to produce the nearly best looking image similar to Pappas and Pitas for digital color restoration of old painting [8] because it considers the human visual system. Finally we shall also give the evaluation of processed image quality from two aspects: naturalness and colorfulness.

This paper has four sections. Section 2 presents the HCCIEE algorithm for color enhancement. Section 3 discusses some experimental results. Section 4 concludes the experiments and algorithm.

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2. THE HCCIEE ALGORITHM

The flow of HCCIEE algorithm is depicted in Fig.1. Our algorithm consists of two stages: 1) Enhancing the texture details and avoiding artifacts such as ringing or halo. 2) Rendering the image colors according to natural image quality metrics. We show that the combination of these two operations is effective in enhancing the quality of color image.

2.1. Wavelet based enhancement method with contrast sensitivity functions (CSFs)

The wavelet transform is a hierarchy of resolution information at several different scales and orientations. At each level, the wavelet transform can be reapplied to the low-resolution subband to further decompose the image. An image f may be characterized as:

$$A_j f = A_{j+1} f + D^1_{j+1} f + D^2_{j+1} f + D^3_{j+1} f, \qquad (1)$$

the enhanced image:

$$\begin{aligned}\widetilde{A}_j f \quad &= \quad \widetilde{A}_{j+1} f + [F^1_{j+1}(D^1_{j+1} f) + \\ &+ F^2_{j+1}(D^2_{j+1} f) + F^3_{j+1}(D^3_{j+1} f)]. \qquad (2)\end{aligned}$$

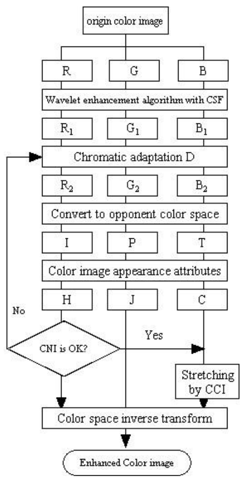

Fig. 1. the flow of HCCIEE algorithm

Signals $D^1_{j+1}f, D^2_{j+1}f, D^3_{j+1}f, j = 1, 2, \ldots, J$ are called the details, j indices the level, with J being the largest scale. $F^i_{j+1}(i = 1, 2, 3)$ is called oriented enhancement gain function or mapping function For the sake of simplicity, three oriented mapping functions are the same. The algorithms developed by Lu [10] have typically used non-mapping functions to process the wavelet coefficients. The ringing artifacts or halo artifacts might be present in these multiscale enhancement algorithms because of gain functions F^i_{j+1} [11, 12][1] In this paper we choose the gain functions as the cone's TVI-like functions [13] which represent thresholds of the cone system and the growth in response required to allow perceived contrast to increase with luminance level. The cones are called daylight vision, which adapt much more rapidly to changing light levels and color. The gain function for the cones is given as below :

$$G(I) = \frac{1}{0.55(I+1)^{0.85}}. \quad (3)$$

where I represents the cone signal that is used to set the level of adaptation. Equation (3) was derived to match available psychophysical TVI and brightness matching data [13]. In the wavelet inverse transform, the enhancement function (mapping function) of details can be defined as:

$$F_j(D_j f) = G(A_{j+1}f + F_{j+1}(\sum_{i=1}^{3} D^i_{j+1}f)), \quad (4)$$

where i indicates the wavelet orientation and the initial function is:

$$F_J = G(A_J f), \quad (5)$$

where $A_J f$ is the lowpass residual which contains much of the luminance distribution. In our algorithm the magnitude of these images is a function of luminance level as specified by the gain functions, which is necessary to allow prediction of luminance-dependent appearance effects.

[1]The $\grave{a}$ trous wavelet transform was often used to avoid the coherent ringing artifacts of it [16]. In this paper, we mainly used it for overcoming halo artifacts.

2.2. Color rendition according to natural image quality metrics

Running the first step of our algorithm will return an image which looks more distinguished but may unnatural or unvivid. A suitable color re-rendition operation is thus necessary. This is first carried out by simple chromatic adaptation model among enhanced R, G, B components. The chromatic adaptation model [15], given in (6)-(8), is a linear von Kries normalization of RGB image signals.

$$R_2 = \left[\left(L_1 \frac{D}{R_1}\right) + (1 - D)\right] R_1, \quad (6)$$

$$G_2 = \left[\left(L_1 \frac{D}{G_1}\right) + (1 - D)\right] G_1, \quad (7)$$

$$B_2 = \left[\left(L_1 \frac{D}{B_1}\right) + (1 - D)\right] B_1, \quad (8)$$

where L_1 is luminance which can be computed as a weighted sum of pixel in the $R_1G_1B_1$ components of the color image. The von Kries normalization is modulated with adegree-of-adaptation D that can vary from 0 for no adaptation to 1 for complete chromatic adaptation. In our algorithm, the factor D is chosen according to the color naturalness index (CNI)[7]. After hue adapts to natural scenes, the next stage is to enhance colorfulness. The image is converted from RGB signals to opponent-color signals (light-dark, red-green, and yellow-blue; analogous to higher-level encoding in the human visual system) that are necessary for constructing a uniform perceptual color space. The color space chosen is the IPT space published by Ebner [14], which is derived specifically to have a hue-angle component with good prediction of constant perceived hue. Once the IPT coordinates are computed, a simple coordinate transformation is applied to obtain image-wise predictors of lightness (J), chroma (C) and hue angle (H). Here we only simply stretch the chroma to enhance the image colorfulness according to color colorfulness index (CCI), which gives a more accurate metrics for colorfulness by fitting psychophysical experiments [9].

3. EXPERIMENTAL RESULTS

To verify the effectiveness of the proposed method, experiments were performed with a set of 24 bits color images. HCCIEE algorithm is tested in two ways.

First, the HCCIEE algorithm has been tested in comparison to some classic color image enhancement methods, namely histogram equalization of the intensity channel, and

MSRCR algorithm. The results are shown in Fig.2. Fig.2(a) is the origin image " Paris in night ", which is not good in local lightness, especially parterre is in poor visual condition. Fig.2(b) is the enhanced result of the HE only in intensity channel, where it is global enhanced to cause saturation of high illumination areas. Fig.2(c), the enhanced result of multiscale retinex with color restoration (MSRCR) algorithm, is better than that of Fig.2(a) in local scenes enhancement and color rendition because of considering Land' s retinex theory. In [5] the authors adopt a fix set of gain function scales [15,80,250], which causes halo artifacts, marked with white line, in shadow part of this image. The halo artifacts could be reduced by manipulating the gain function such as LCIS algorithm or Anisotropic diffusion [11]. Here we chose it according to HVS. Fig.2(d) is the result of our HCCIEE algorithm. We can see that the multiscale characteristics with CSFs make the parterre and other objects slightly more distinguished than Fig.2(c), but the halo artifacts in Fig.2(c) are reduced because of the gain functions chosen by HVS, The color effect is as good as Fig.2(c).

Secondly, the HCCIEE algorithm has been tested by human perceptual way: naturalness and colorfulness. The results are shown in Fig.3. Fig.3(a) is the origin image " hut and sheep ", which is faint and color shifts to green. Fig.3(b) is the result of naturalness processed in HCCIEE algorithm. The details are more clarity and the color shifting is corrected to natural scene, but the image is not enough vivid. Fig.3(c) is the result of colorfulness processed continued, which is more vivid than Fig.3(b). Fig.4(a) is another color-shifting image " fruit under sun " and Fig.4(b) is the result of naturalness processed, which is improved greatly. This is also can be testified by metrics in Table 1. For Fig.3, Fig.3(a) is bad in naturalness but good in colorfulness (15-20 is quite colorfulness by experiments [9], in Fig.3(b) the naturalness is improved but the colorfulness is not enough good, after both are processed, the image as Fig.3(c) is better. For Fig.4, Fig.4(a) is also bad in naturalness but good in colorfulness, after the naturalness processed, the Fig.4(b) achieves good in naturalness and colorfulness, so the colorfulness processed need not to be continued.

4. CONLUSIONS

We presented a novel algorithm for color image enhancement, which consists of wavelet based detail enhancement operation and the color rendition. We give a few examples that show the effectiveness of this technique in sharpening the texture details and rendering colors with an image thereby improving its appearance. We have also shown that the algorithm includes a subjective level in evaluating the result image, which proved to be more robust in achieving visually enhanced output images. This functionality may be useful in application concerned with image and video editing.

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Table 1. Measure naturalness and colorfulness

Fig. / Metr.	Fig.3 "hut and sheep"			Fig.4 " fruit"	
	(a)	(b)	(c)	(a)	(b)
CNI	0.6712 (bad)	0.9534 (good)	0.9578 (good)	0.5126 (bad)	0.9726 (good)
CCI	16.6033 (good)	9.3497 (bad)	15.9675 (good)	16.7568 (better)	19.5132 (good)

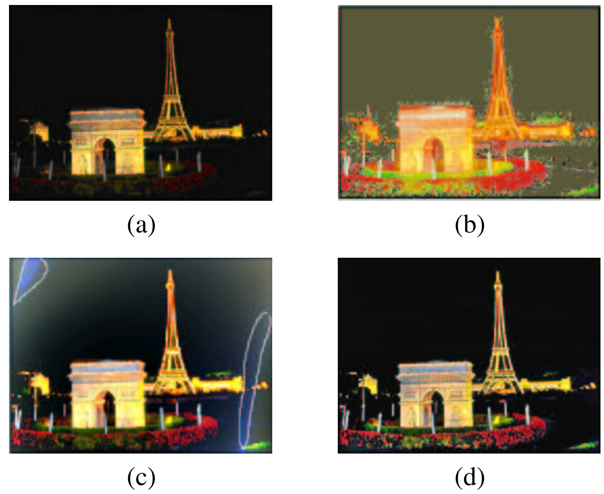

Fig. 2. Comparison of enhancement algorithms:(a) original color image. (b) histogram equalization (HE) in intensity channel. (c) the result of MSRCR algorithm. (d) the result of HCCIEE algorithm

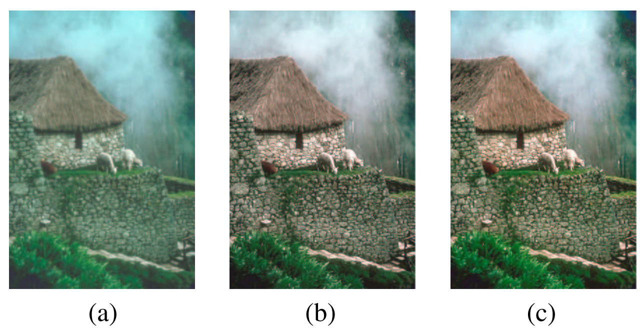

Fig. 3. Evaluation HCCIEE algorithm in human perceptual ways: (a) original color image. (b) naturalness processed result. (c) HCCIEE results (naturalness and colorfulness processed)

Fig. 4. Another example of evaluation HCCIEE algorithm in human perceptual ways. (b) Naturalness processed image.