NATURAL RENDERING OF COLOR IMAGE BASED ON RETINEX

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ABSTRACT

A new method for Natural Rendering of Color Image based on Retinex (**NRCIR**) is proposed. Here, the word "natural" means that the ambience of image (warm or cold color impression) should not be changed after enhancement. Furthermore, the treatment should not introduce any additional light sources and should not produce halo effect or amplify blocking effect. Inspired by Retinex theory and histogram rescaling techniques, the proposed method tries to realize natural rendering of image with respect to the constraints listed above. Extensive tests with different types of natural images have been performed. The obtained results clearly demonstrate the efficiency of the proposed method.

Index Terms— one-filter Retinex, enhancement, image rendering, tone mapping, histogram rescaling

1. INTRODUCTION

Retinex theory is one of the most appealing approaches for image enhancement and color constancy in digital imaging domain [1][2]. Wide applications in industrial scenario, medical diagnostics or aerospace photography can be found [3][4]. Many Retinex algorithms were proposed in the literature such as path version [5], iterative version [6] and center/surround version [7].

However, image enhancement is not detail retrieval or color constancy application. Therefore, these algorithms [6][7] cannot be *directly* applied into this domain because most of them will lead to several dramatic modifications such as light sources variations, color temperature changes, or additional artifacts introduced or amplified. These techniques often tend to extract as many details as possible while disregarding light conditions of scene which may result in an unnaturally sharpened image. Figure 1 shows a hiding cat whose body comes to be fully exposed to the light after image enhancement. It seems to have another light source projecting to the shelter which is *not* true. Such an alteration of light source leads to a confusing impression of the scene.

Dramatic color temperature change is another byproduct of general image enhancing techniques. Figure 2 shows a picture of sunset with burning flames of clouds. However, a color constancy algorithm often results in a bright blue sky due to unbalanced three-channel operation. This dramatic change of color temperature will certainly affect the design of the photographer.

Last but not least, most image enhancement algorithms work with image of good quality, that is, either on raw format or perceptually lossless compressed format. However, in practice most images are already compressed with loss, and most videos on Internet suffer from blocking and ringing effects and so does the video stream on television or PDA. Over-enhancement of these images often results in either visible halo effect or amplified blocking effect. For instance, the middle image in figure 3 shows a white halo in the lower part, and the middle image in figure 4 manifests blocking effect in dark zones.

We propose an algorithm of automatic Natural Rendering of Color Image based on Retinex (**NRCIR**) in this work. Since there is no universal qualitative definition available on "naturalness", we hereby define it as the following: the ambience of image (warm or cold color impression) should not be changed greatly after enhancement, and no additional light source should be introduced to the scene, and no halo effect should be added and no blocking effect should be amplified due to over-enhancement. Inspired by One-filter Retinex [8] and histogram rescaling techniques [9], we develop a natural rendering of image with respect to these constraints.

2. FLOWCHART OF NRCIR

The proposed method is divided into five steps as shown in figure 5. Step one is a global mapping operation serving as a pre-treatment of image rendering. The tone mapping curve is an arc of circle instead of a logarithm function because the latter tends to over-amplify dark zone which will emphasize blocking effect of images. Step two is inspired by One-filter Retinex [8], while an additional logarithm function is applied to image mask before taking ratio between the mapped luminance and the mask, which

Fig.1 Left: Original image; Middle: Image enhanced by NASA Retinex [7]; Right: Image enhanced by NRCIR (the proposed method)

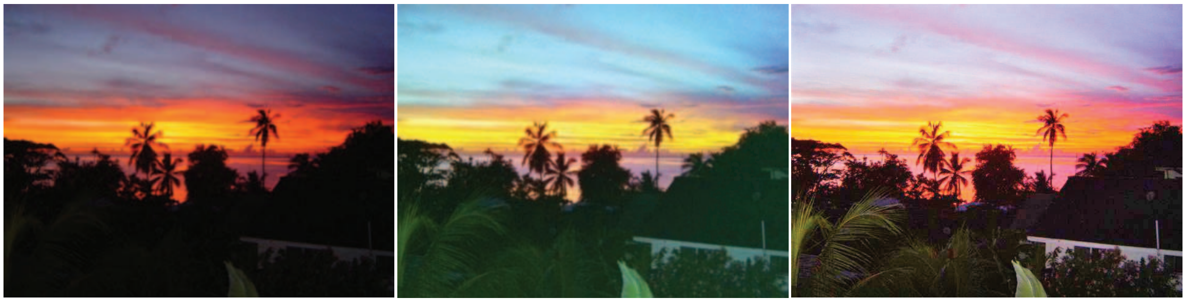

Fig.2 Left: Original image; Middle: Image enhanced by RGB 3-channel Retinex [6]; Right: Image enhanced by NRCIR

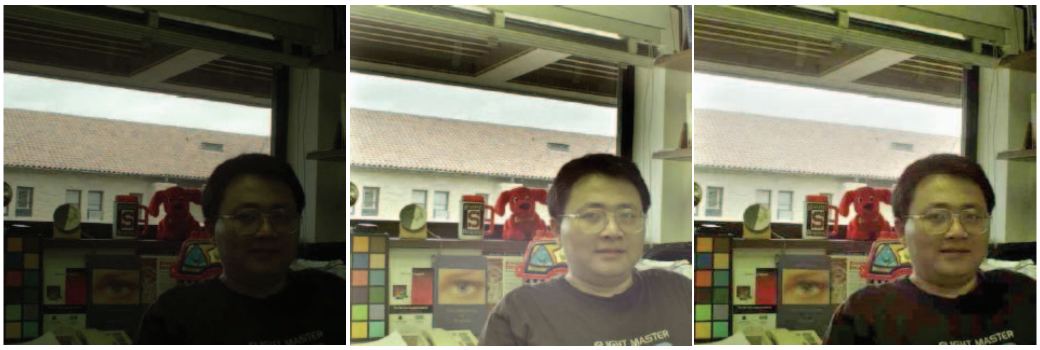

Fig.3 Left: Original image; Middle: Image enhanced by algorithm of [8]; Right: Image enhanced by NRCIR

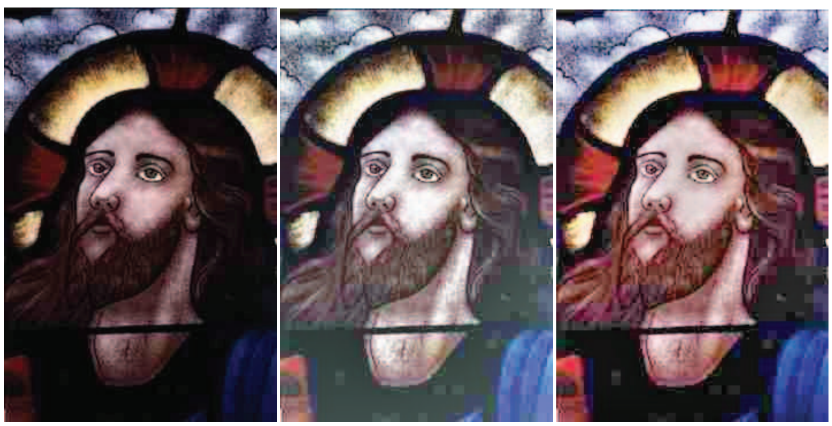

Fig.4 Left: Original image; Middle: Image enhanced by RGB 3-channel Retinex [6]; Right: Image enhanced by NRCIR

helps to reduce halo and blocking effect caused by over-enhancement. Only luminance channel is used in this step. Step three applies a histogram rescaling to luminance channel for white point correction. Only 99% of histogram is selected in order to remove influence of a few extreme bright pixels. Enhancement information obtained by the ratio between the enhanced luminance and its original version is used to create a reference map which weights RGB channels *simultaneously* to avoid isolated and unbalanced enhancement. Finally, another histogram rescaling step is applied to the final enhanced image which renders image into a more natural appearance.

3. NRCIR DETAILS AND TEST RESULTS

3.1 Global mapping function

To avoid over enhancement of blocking effect (Referred by red arrow in figure 6), a circle function is used as a mapping function. Indeed, it produces moderate gain (or attenuation) in dark zone compared to logarithm function. The radius is an empirical function of image key which is an index of dominating tone of image [9].

$$\mathrm{key} = \mathrm{e}^{\frac{\sum_x \sum_y \log(L(x,y))}{\mathrm{size}(I)}} \quad (1)$$

$$r = \begin{cases} 3 \times \log\left(\frac{\mathrm{key}}{10}\right) & \text{for key} \leq 50 \\ 3 \times \log\left(10 - \frac{\mathrm{key}}{10}\right) & \text{for key} \geq 60 \end{cases} \quad (2)$$

where r is the radius of circle, L(x,y) is the luminance of pixel (x,y) of image I. To avoid over-enhancement in dark zone, r is set to be no smaller than 1.4 (instead of 1 which is the smallest candidate). The mapping operation is performed as follows:

$$I_{gm} = \begin{cases} y_0 + \sqrt{r^2 - \left(I_{orig} - x_0\right)^2} & \text{for key} \leq 50 \\ y_0 - \sqrt{r^2 - \left(I_{orig} - x_0\right)^2} & \text{for key} \geq 60 \\ I_{orig} & \text{otherwise} \end{cases} \quad (3)$$

Where I_{orig} is the original image, I_{gm} is the mapped image, and (x_0,y_0) is the coordinate of the mapping circle center.

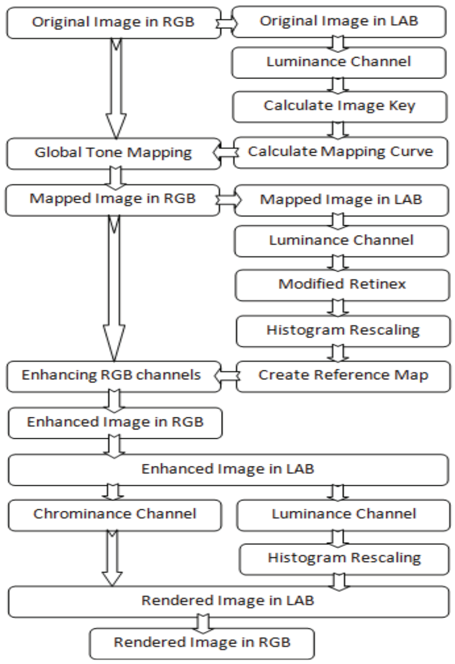

Fig.5 Flowchart of NRCIR

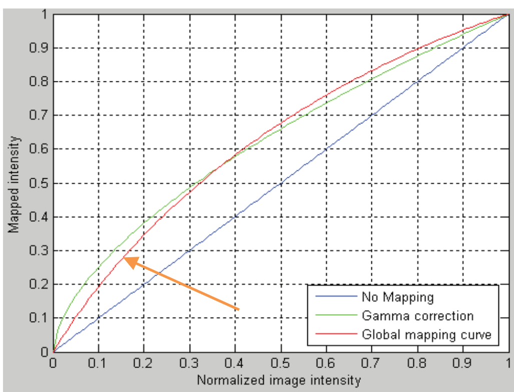

Fig.6 Global mapping curve using an arc of circle

It can be seen that when image key value is smaller than 50, the arc is on the left-hand of blue straight line (no mapping case) to amplify tone values of dark image. Whereas, when key value is larger than 60, the arc will be set on the right-hand side of the blue line to compress the global tone of over-exposed scene. For image with key value between 50 and 60, no global mapping is needed.

3.2 Modified One-filter version Retinex

The Retinex luminance in this work is defined as:

$$L_r = \frac{L_{gm}}{\log_{10}(I_m)} \tag{4}$$

where L_r and L_{gm} refers to Retinex luminance and mapped luminance respectively. I_m is an image mask obtained by a convolution between the mapped luminance and Retinex filter referring to formula (5) to (7) as defined in [8]. Note that the logarithm function applied to I_m is essential in the proposed method in preventing halo and blocking effect.

$$I_m = L_{gm} * F_r \tag{5}$$

$$F_r = \sum_{i=1}^{\lfloor \log2(K) \rfloor} e^{-\frac{(x^2+y^2)}{2^{2i}}} \tag{6}$$

$$K = \frac{\max(\text{size}(I))}{8} \tag{7}$$

where (x,y) is the coordinate of the image pixel varying from 1 to K. Figure 7 shows a profile of Retinex filter. The pointed shape enhances regional detail while the large base of filter reduces artifact introduced by enhancement.

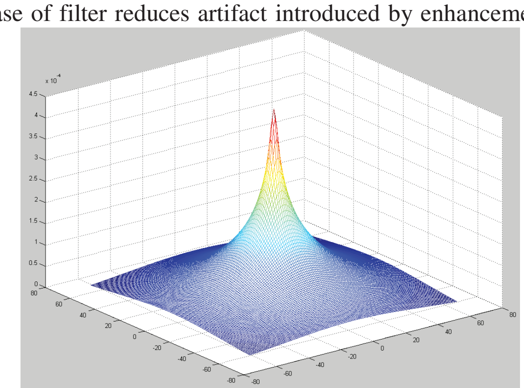

Fig.7 Retinex filter profile

3.3 Histogram Rescaling of Luminance Channel

The white point of the input image cannot be simply determined by the brightest pixel because it generally does not represent significantly the image content [9]. A group of bright pixels must be used which turns out to be a histogram-based white point correction. In the proposed method, only 99% of histogram is selected for further processing to avoid influence of a few extreme bright pixels. Therefore, the corrected white point is normalized to the intensity corresponding to 99% of image histogram.

3.4 Map-based Image Enhancement

Applying Retinex independently to RGB channels will generally result in false colors and hue-shift. Therefore, only luminance channel is used for modified Retinex enhancement. The ratio between the pixel values before and after enhancement will be used to create a reference map. All three color channels will be weighted *simultaneously* using this reference map defined by formula (8) and (9).

$$M_{ref} = \log_2\left(\frac{L_{enh}}{L_{orig}}\right) + 1 \tag{8}$$

$$I_{enh} = I_{gm} \times M_{ref} \quad \text{with } I = \{R, G, B\} \tag{9}$$

where M_{ref} refers to the reference map, and L_{enh} and L_{orig} refer to the enhanced and original luminance respectively. I_{enh} and I_{gm} in formula (9) represent each color channel of RGB for the enhanced and globally mapped image. The logarithm function in formula (8) controls over-enhancement of dark zones since the quotient could be considerably large for these zones after the ratio operation. If this ratio is directly applied to weight RGB channels, the dark zones will be over-enhanced and blocking effect will become consequently visible and annoying.

3.5 Histogram Rescaling Step

Finally, same as step 3, another histogram rescaling step is applied to the enhanced image for white point correction. Note that only luminance channel is used in this histogram rescaling and chromatic component remains unchanged. Some typical final results are shown in figure 8 and 9.

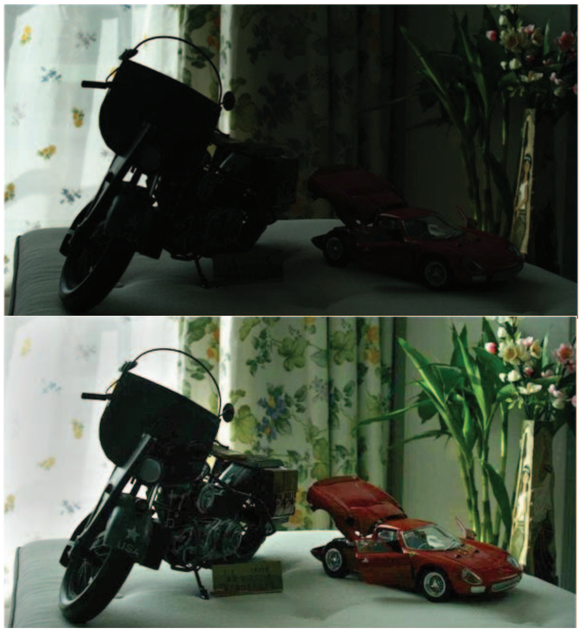

Fig.8 Up: Original; Down: Image enhanced by NRCIR

4. CONCLUSIONS AND LIMITATIONS

In order to naturally render color image appearance without modifying scene lighting conditions and introducing halo effect or amplifying blocking effect, the proposed method (**NRCIR**) applies five steps of image processing, namely global mapping using a circle function, luminance enhancement using modified one-filter Retinex, histogram rescaling for luminance channel, a map-based image enhancement and finally a histogram rescaling. Simultaneously weighing RGB channels with reference map prevents image from dramatic changes of color temperature, and logarithm function applied to image mask and reference map makes halo effect and blocking effect less visible. The integration of one-filter Retinex and histogram rescaling also improves natural appearance of image. Extensive tests with different types of image scenes have proved a stable performance of the proposed method. There are no parameters to be trained or modified for different image contents which is nevertheless crucial to some algorithms [6][10]. However, the proposed method works poorly with unnatural images (medical images, for example). Concerning over-exposed image rendering, it works well for high key image which is globally over-exposed (as shown in fig. 9), but is not equally sufficient in regionally over-exposed case. The empirical formulas of global mapping and the design of reference map also need to be improved for better performance. These limitations will be taken into concern of our future works.

6. REFERENCES

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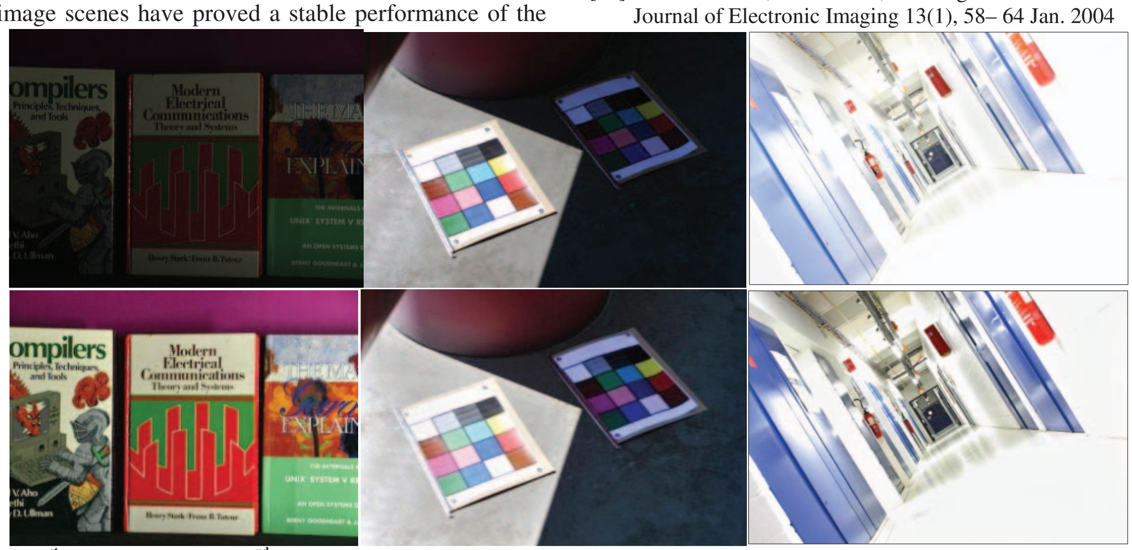

Fig.9: 1st row: original images. 2nd row: results from proposed NRCIR. (Left: Low key image, Middle: HDR image, Right: High key image)