IMAGE ENHANCEMENT BASED ON RETINEX AND LIGHTNESS DECOMPOSITION

Bo Li, Shuhang Wang, Yanbing Geng

Digital Multimedia Laboratory, Computer Science and Engineering, Beihang University, Beijing 100191

ABSTRACT

In this paper, an efficient image enhancement method based on Retinex and lightness decomposition is proposed, which enhances details and preserves the naturalness simultaneously. The quality of an enhanced image is determined by two factors, details and naturalness. Accordingly, the lightness is proposed to be decomposed into reflex lightness and ambience illumination. The reflex lightness is utilized to extract details based on Retinex, and the ambience illumination is utilized to maintain the naturalness of scenes. Moreover, a coarse evaluation that keeps the corresponding order of ambience illumination is proposed to substitute the absolute amount of ambience illumination, which may not be necessary to preserve the naturalness. The experimental results demonstrate that the proposed method can efficiently improve the perceptual quality of images by not only enhancing the details of the images, but also keeping the naturalness of scenes.

***Index Terms*—** Image Enhancement, Naturalness, Retinex, Decomposition

1. INTRODUCTION

As a hot research topic, image enhancement is important for image analysis, diagnosis and display. However, image quality is related to human visual system (HVS) and it is difficult to enhance details and preserve the naturalness simultaneously.

Retinex theory is one of the most appealing approaches for image enhancement. Based on the work of Land et al. [11], many methods have been proposed and widely utilized in medical diagnostics and aerospace photography. However, these conventional methods usually aim at obtaining the reflectance of scenes [3, 4, 10]. Although these algorithms can efficiently extract the details of images, they are prone to destroy the naturalness. The naturalness is first defined by Chen et al. [4] as follows: the ambience of the image should not be changed greatly after enhancement, and no 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. It is unreasonable taking the reflectance as the enhanced image and disregarding the effect of illumination, which determines the naturalness.

Therefore, we propose an efficient image enhancement method aiming at enhancing details and preserving the naturalness simultaneously. We suppose that the captured light is composed of reflex lightness (the lightness observed when illumination is uniform) and ambience illumination (the lightness observed when reflectance is uniform). The reflex lightness determines the details and the ambience illumination has an import impact on the naturalness. Moreover, we found that the absolute value of ambience illumination is not necessary to preserve the naturalness; the coarse evaluation keeping the intensity order of ambience illumination is enough. The proposed method decomposes lightness into reflex lightness and ambience illumination. A modified Retinex method is adopted to extract details from reflex lightness. To adapt to HSV, ambience illumination is mapped to preserve the naturalness.

The remainder of this paper is organized as follows. In section 2, we present the related work. In section 3, the flowchart of the proposed method is presented and the technical details are described. In section 4, comparison experiments are conducted against some state of the art methods. In section 5, we draw the conclusions.

2. RELATED WORK

Many image enhancement methods based on Retinex have been proposed in the literature. Here, some notable works are reviewed as follows due to page limitation.

A. Single-Scale Retinex (SSR) Algorithm

The Single-Scale Retinex (SSR) Algorithm is a conventional center/surround Retinex algorithm proposed by Land et al. [8] and it can be summarized as follows.

$$R_i(x,y) = \log L_i(x,y) - \log[F(x,y) * L_i(x,y)] \quad (1)$$

where $R_i(x,y)$ denotes the output lightness of the ith channel, $i \in \{R,G,B\}$, $L_i(x,y)$ is the image distribution in the ith spectral band, "$*$" denotes the convolution operation, $F(x,y)$ is the normalized surround function.

Although SSR is widely utilized, it usually causes over-enhancement [2]. Based on SSR, lots of the center/surround Retinex algorithms, such as MSR [5, 6] and MSRC [7] are proposed. However, all the algorithms can not preserve the naturalness either.

B. Natural Enhancement of Color Image (NECI)

The Natural Enhancement of Color Image (NECI) method was proposed by Chen et al. [1] aiming at enhancing the

978-1-4577-1302-6/11/$26.00 ©2011 IEEE

images while preserving the naturalness. Although NECI can preserve the naturalness of the images, it usually loses many details.

The comparison of some state of the art methods is shown in Figure 1. From Figure 1 (b) and (c), it can be observed that both SSR and MSR enhance image details efficiently, but they tend to destroy the naturalness of the image. As shown in Figure 1 (d), NECI preserves the naturalness well, but it loses many details.

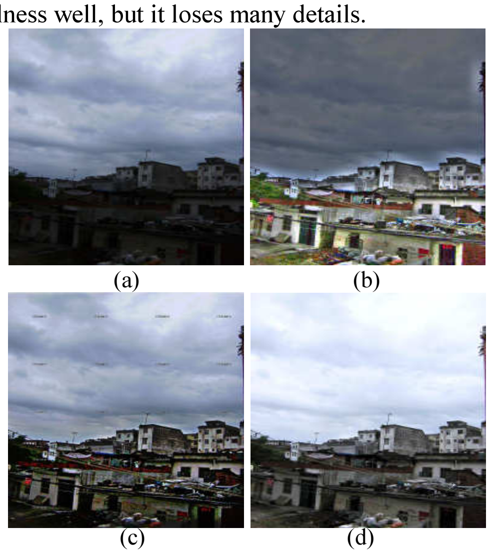

Figure 1 (a) Original image. (b) Image enhanced by SSR. (c) Image enhanced by MSR. (d) Image enhanced by NECI.

3. THE PROPOSED METHOD

The proposed method consists of four steps as shown in Figure 2. Firstly, the image is decomposed into reflex lightness and ambience illumination. Secondly, a modified Retinex filter is applied to the reflex lightness to extract the information of details. Thirdly, the ambience illumination is smoothed regarding its original order. Finally, the modified ambience illumination and information of details are composed to get the enhanced image.

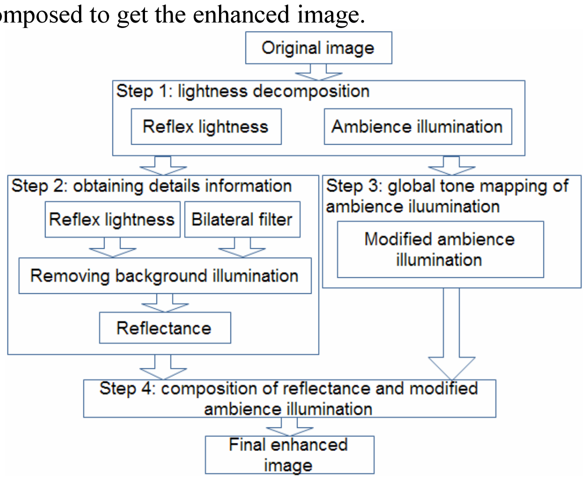

Figure 2 The flowchart of our algorithm

Part1: Image Decomposition

As mentioned above, we assume that the quality of an image is determined by two factors, details and naturalness, which are related to reflex lightness and ambience illumination, respectively. The image is firstly decomposed into two parts by the following equations.

$$L_i(x,y) = RL_i(x,y) + AI_i(x,y) \tag{2}$$

$$AI_i(x,y) = \alpha \cdot L_i(x,y) \tag{3}$$

$$RL_i(x,y) = (1-\alpha) \cdot L_i(x,y) \tag{4}$$

where $L_i(x,y)$ is the ith color spectral band, $RL_i(x,y)$ is the associated reflex lightness, $AI_i(x,y)$ is the associated ambience illumination, α is a weighting factors, which will be discussed in details in Part5.

Part2: Modified Retinex Filter to Reflex Lightness

Retinex theory assumes that the lightness is the product of the reflectance and the illumination. However, the natural scene usually is very complicated and it is hard to estimate the illumination exactly. Therefore, the proposed method dose not apply Retinex theory to the image $L(x,y)$ but to the reflex lightness $RL(x,y)$, which is described as follows:

$$RL_i(x,y) = R_i(x,y) \cdot F(x,y) \tag{5}$$

where $RL_i(x,y)$ is the reflex lightness of the ith color spectral band, $R_i(x,y)$ is the associated reflectance. $F(x,y)$ is the background illumination. We assume that the three color channels have the same $F(x,y)$.

In this paper, $F(x,y)$ is obtained by the convolution of bilateral filtering which is a non-linear technique and can blur an image while preserving the contours [9].The bilateral filter $BF[\cdot]$ is defined as follows.

$$BF[L]_p = \frac{1}{W_p}\sum_{q\in S} G_{\sigma_s}(\|p-q\|_2) G_{\sigma_r}(|I_p - I_q|_1) I_q \tag{6}$$

where q is the center of a local area S, $\|p-q\|_2$ is the Euclidean distance between pixel p and q, $|I_p - I_q|_1$ is the intensity difference between I_p and I_q, W_p is the normalized factor and can be calculated as follows.

$$W_p = \sum_{q\in S} G_{\sigma_s}(\|p-q\|_2) G_{\sigma_r}(|I_p - I_q|_1) \tag{7}$$

where $G_\sigma(x)$ denotes the 2D Gaussian kernel:

$$G_\sigma(x) = \frac{1}{2\pi\sigma^2}\exp(-\frac{x^2}{2\sigma^2}) \tag{8}$$

The lightness F can be obtained through the following equations.

$$F = L_{\max} * BF \tag{9}$$

$$L_i(x,y) = \max_{i\in\{r,g,b\}} (RL_i(x,y)) \tag{10}$$

where $L_{\max}$ is the maximum of three color channels. Finally, the reflectance $R(x,y)$ can be obtained as follows:

$$R_i(x,y) = \frac{RL_i(x,y)}{F(x,y)} \tag{11}$$

Part3: Global Tone Mapping of Ambience Illumination

Most Retinex-based algorithms take the reflectance as the enhanced image. However, different illuminations result in different senses and the reflectance looks over-enhanced disregarding illumination conditions. However, the actual illumination is difficult to evaluate and the ambience illumination $AI(x,y)$ is utilized to substitute it.

The ambience illumination that we get in Part1 usually varies a lot and is not fit to HSV. In order to make it smoother and to maintain its shape, the ambience illumination $AI(x,y)$ is further adjusted as follows.

$$MA(x,y) = \log(AI(x,y) + \varepsilon) \tag{12}$$

where ε is a small positive constant.

Part4: Composition of Details and Naturalness

According to Retinex theory, the amount of visible light reaching the eye depends on the product of reflectance and illumination. Therefore, we integrate $R(x,y)$ and $MD(x,y)$ together by multiplication to get the enhanced image $EI(x,y)$:

$$EI_i(x,y) = R_i(x,y) \times MA(x,y) \tag{13}$$

Part5: The Estimation of Proportion α

The proportion α is important in terms of the final result and it should be appropriately estimated. Most of the previous methods try to eliminate the effect of illumination, such as SSR. Taking Figure 3 as an example, if we simply remove the illumination, it may result in an unnaturally sharpened image and the light conditions may become confused. So the illumination is important for images. However, it is hard to get the ambience illumination exactly.

(a) (b)

Figure 3 Enhanced image by SSR. (a) Input image. (b) Enhanced image after removing illumination.

To preserve the naturalness, we found the absolute amount of intensity is not necessary and a coarse evaluation keeping the corresponding order is enough. The estimation should satisfy the following formulas. (a) The ambience illumination of the bright area is brighter than the dark area. (b) After the ambience illumination is subtracted from an image, the left part keeps the original order of the intensity. Based on the formulas, α is evaluated as follows:

$$\alpha(x,y) = \frac{1}{2}\frac{L(x,y)}{L_{\max}} \tag{14}$$

where $L(x,y)$ is the observed lightness, $L_{\max}$ represents the maximum of the image $L(x,y)$. Based on the above equations, $AI_i(x,y)$ and $RL_i(x,y)$ can be calculated as follows. When L varies from 0 to 255, the mapping function is shown as Figure 4.

$$AI(x,y) = \frac{1}{2}\frac{L^2(x,y)}{\max\limits_{(x,y)\in A}(L(x,y))} \tag{15}$$

$$RL(x,y) = (1 - \frac{1}{2}\frac{L(x,y)}{\max\limits_{(x,y)\in A}(L(x,y))}) \cdot L(x,y) \tag{16}$$

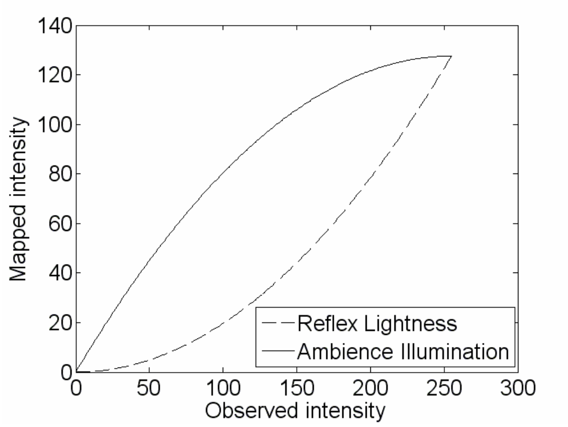

Figure 4 The mapping of reflex lightness and ambience illumination.

4. EXPERIMENTS

In this section, the proposed method is evaluated by comparing with SSR, MSR and NECI in term of two aspects, namely the details and the naturalness.

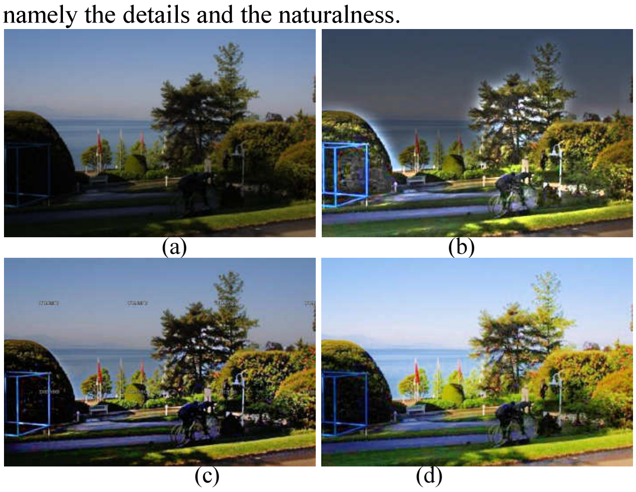

Figure 5 Comparison between SSR, MSR and the proposed method. (a) Input image. (b) The result of SSR. (c) The result of MSR. (d) Our result.

In the first experiment, we compare the proposed method with SSR and MSR. An example result is shown in Figure 5. As shown in (b) and (c), the contrast is significantly enhanced and many additional hidden details are unveiled. However, the halo effect is also observed at sharp edges in (b), and MSR can restrain the halo effect at the cost of missing many details. Moreover, both SSR and MSR lead to the change of light conditions.

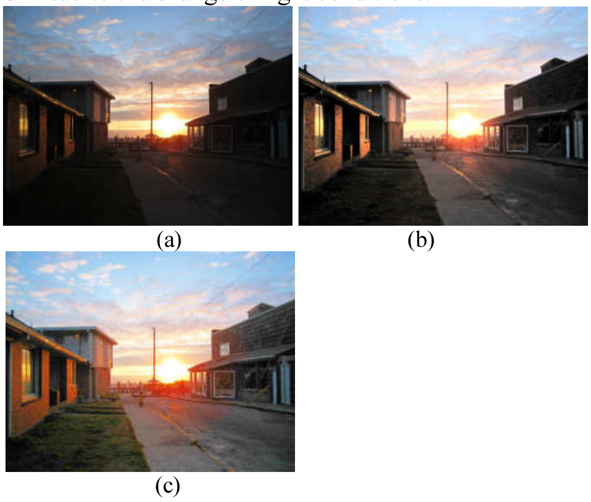

Figure 6 Comparison between our approach and NECI. (a) Input image. (b) Result of NECI. (c) Result of our method.

In the second experiment, we compare the proposed method with NECI. From Figure 6, it can be observed that both the methods can preserve the naturalness well. However, the details of Figure 6 (b) are not as clear as the proposed method as shown in Figure 6(c).

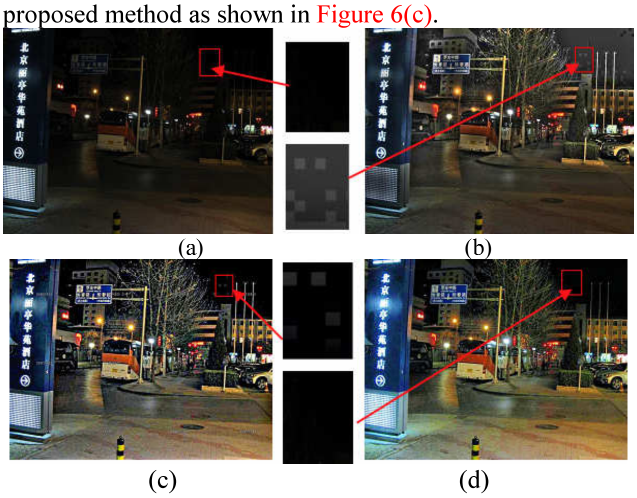

Figure 8 Comparison about artifacts. (a)Input image. (b) Result of SSR. (c) Result of MSR. (d) Result of our method.

In the third experiment, we evaluate the proposed method on the image with hidden blocks. As shown in Figure 8 (b) and (c), it can bee observed from the areas marked by blue rectangles that both SSR and MSR tend to amply the hidden blocks due to over-enhancement. In contrast, the proposed method can restrain noise and avoid artifacts (as shown in Figure 8 (d)).

According to the above experimental results, it is obvious that the proposed method outperforms SSR, MSR, and NECI. The proposed method not only enhances details effectively, but also preserves the naturalness well.

5. CONCLUSIONS

In this paper, we have presented an image enhancement method based on Retinex and lightness decomposition. The proposed method improves the quality of the image from two aspects, namely details enhancement and naturalness preservation. Extensive comparison experiments are conducted between the proposed method and some state of the art methods based on Retinex. The experimental results show that the proposed method is efficient in enhancing details and preserving the naturalness of image simultaneously. We believe that the proposed method delivers valuable information and provides an effective approach that facilitates image enhancement.

As future research, we plan to reduce the complexity of the proposed method for real-time application.

7. ACKNOWLEDGEMENTS

This work was partially supported by the 973 Program (Project No. 2010CB327900) and the Defense Industrial Technology Development Program (BXX2011XXX8).

6. REFERENCES

[1] S. Chen et al., “Natural rendering of color image based on Retinex,” Proceedings of the IEEE *ICIP*, Cairo Egypt, 2009.

[2] S. Chen et al., “Natural Enhancement of color image,” Journal on Image and Video Processing, 2010.

[3] Zia-ur Rahman et al., “Retinex Processing for Automatic Image Enhancement,” J. Electron Imaging, Vol. 13, 2004.

[4] A. Rizzi et al., “Unsupervised corrections of unknown chromatic dominants using a brownian-path-based Retinex algorithm,” Journal of Electronic Imaging 12(3), 431-440, 2003.

[5] M. Herscovitz et al., “A modified Multi Scale Retinex algorithm with an improved global impression of brightness for wide dynamic range pictures,” Machine Vision and Applications, 2004.

[6] D. J. Jobson et al., “A multiscale Retinex for bridging the gap between color images and the human observation of scenes,” IEEE Trans. on Image Processing, vol. 6, pp. 965-976, July 1997.

[7] S. S. Agaian et al., “A new measure of image enhancement,” the IASTED Int. Conf., Marbella, Spain, Sep.19–22, 2000.

[8] Z. Rahman et al., “A comparison of the Multiscale Retinex with other image enhancement techniques,” Special Issue on Color Processing, vol. 6, pp. 451-462, Mar. 1996.

[9] S. Pairis et al., “Bilateral Filtering: Theory and Applications,” Computer Graphics and Vision Vol.4, No. 1 (2008) 1-73

[10] Brian Funt et al., "Retinex in Matlab," Proceedings of the IS&T/SID Eighth Color Imaging Conference: Color Science, Systems and Applications, pp 112-121, 2000.

[11] Edwin H. Land et al., “Lightness and Retinex Theory,” Journal of the Optical Society of America, Vol. 61, 1971.