A NOVEL RETINEX BASED APPROACH FOR IMAGE ENHANCEMENT WITH ILLUMINATION ADJUSTMENT

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ABSTRACT

Retinex based algorithms have been widely used among in image enhancement. Since many retinex based algorithms remove illumination and regard the reflectance as enhancement, over-enhancement and unnaturalness are inevitable. In this paper, a novel retinex based image enhancement using illumination adjustment is proposed. Different from existing variational retinex models, a new model without the logarithmic transformation is established and can well preserve the edge. A fast alternating direction optimization method is used to solve this problem. After the decomposition of illumination and reflectance, a simple and effective post-processing method for illumination adjustment is adopted for the enhancement to make the result more natural. The proposed method can deal with many kinds of image, such as high dynamic range (HDR) images and non-uniform illumination images. Experimental results illustrate that the naturalness can be preserved while details are enhanced by the presented new approach.

Index Terms— image enhancement, retinex, variational framework, illumination adjustment, alternating direction optimization

1. INTRODUCTION

Image enhancement is one of the basic content in image processing. The goal of image enhancement is to improve image quality for specific applications [1][2]. Image enhancement technology has permeated in many areas of science, engineering and civilian, such as biomedicine images, astrophotography, satellite pictures, computer vision, surveillance systems, civilian cameras, etc. Image enhancement algorithm has received stacks of studies in recent years, such as algorithms based on the histogram equalization [3][4][5][6], algorithms based on retinex method [7][8][9][10][11][12][13][14], algorithms based on haze removal method [15][16], etc.

Among these algorithms, retinex based algorithms have received more and more attentions. The retinex theory is first proposed by Land [17][18] to model the imaging process of the human visual system. This theory assumes that the scene in human's eyes is the product of reflectance and illumination [10][19]. Most retinex based enhancement algorithms use different ways to estimate the illumination and remove it to obtain the reflectance as the enhanced image. The details and textures can be enhanced by illumination removal [7][8][9]. While the enhanced results look over-enhanced and unnatural since the result does not meet with human vision system. As mentioned above, the scene in human eyes is a combined effect of reflectance and illumination. It is unreasonable to remove the illumination and only regard the reflectance as an improved result [10]. Other retinex based algorithms [20][21] firstly use logarithmic transformation to transform product into sum to reduce the computational cost [22], then employ a variational model for enhancement. Note that the logarithmic transformation stretches low values and compresses high values, increasing the contrast of low intensities and decreasing the contrast of high intensities. The resulting reflectance is usually smoothed and loses some details [21]. The histogram equalization algorithms [3][4][5][6] may have unsatisfactory results while dealing with some specific images, such as non-uniform illumination images. It is because the histogram redistribution may lead to inappropriate pixel values in some areas. Another kind of enhancement algorithms based on haze removal method [15][16] focuses on low light images. The algorithms may lead to a halo effect when the estimation of scene depth is wrong.

In this paper, a novel retinex based image enhancement approach using illumination adjustment is proposed. First, a new variational model based on retinex is established. Different from conventional variational models [20][21], the new model does not need the logarithmic transformation and is

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more appropriate for the decomposition because reflectance is constrained in image domain. Then a fast alternating direction optimization method is adopted to solve the proposed model, thus the reflectance and illumination can be computed and decomposed. Last, a simple and effective post-processing method of the decomposed illumination is used to make an adjustment for image enhancement. The enhanced image is obtained by combining the reflectance and the adjusted illumination. The naturalness of enhanced images can be preserved while details enhanced. Meanwhile, reflectance and illumination can be obtained as a by-product of the enhanced image. Experimental results demonstrate the good performance on naturalness preservation and detail enhancement due to the illumination adjustment and precise computed reflectance.

2. THE PROPOSED MODEL

The formula of retinex is $S = RL$, where $S \in [0, 255]$ is the observed image, $R \in [0, 1]$ is the reflectance and $L \in [0, 255]$ is illumination. It is an ill-posed problem to solve R and L by using one observed image S, so other assumptions should be used to constrain this problem. The following known information is used as the constraint of the proposed model: 1) illumination is spatially smooth; 2) the value of R is from 0 to 1, which means $L \geq S$; 3) the reflection contains high frequency part, i.e., edge and texture information.

While conventional models [20][21] may obtain a good enhanced result, the effect of logarithmic transformation in those models make it difficult to obtain a good reflectance. When the observed image affected by strong light or edges are in the region has high intensities, the effect is more obvious. The simulation of logarithmic transformation is shown in section 4. Base on the discussion above, a new variational retinex model without logarithmic transformation is proposed:

$$\arg\min_{R,L} \|RL - S\|_2^2 + \alpha \|DL\|_2^2 + \beta \|DR\|_2^2 + \gamma \|L - L_0\|_2^2 \quad s.t.\ S \leq L, 0 \leq R \leq 1 \qquad (1)$$

where α, β, and γ are free positive parameters, D is the difference operator at both in horizontal and vertical direction. The term $(\|RL - S\|_2^2)$ constrains proximity between RL and S. The term $(\|DL\|_2^2)$ and $(\|DR\|_2^2)$ constrain spatial smoothness on illumination and reflectance respectively. The term $(\|L - L_0\|_2^2)$ which weighted by γ, is used for a theoretical setting. L can be seen as a Gaussian distribution with mean of L_0. In this paper, we simply use the Gaussian low-pass filtering of S as L_0 to avoid illumination intensity is too small. Moreover, according to the prior, the value of R is from 0 to 1, the equation should subject to: $S \leq L$ and $0 \leq R \leq 1$.

The new model does not need the logarithmic transformation and the edge information of reflectance can be preserved. It is more appropriate compared to the existing variational retinex model. In the next section, a fast alternating direction optimization method is used to solve the proposed model. Meanwhile a simple and effective illumination adjustment is adopted to make the enhanced image more natural.

3. A NEW ALGORITHM FOR THE ENHANCEMENT BASED ON THE NEW RETINEX MODEL

Two approaches can be applied to solve (1) based on the new model. One approach is known as RGB (red, green and blue) retinex algorithm operating in each RGB-channel separately. Another is the HSV (hue, saturation and value) retinex algorithm, which transforms RGB space into HSV space. The algorithm only operates in value layer. After the processing, the data is transformed back to RGB domain. In this paper, HSV retinex is used for simplicity. Since there are two unknown variables in model (1), traditional gradient decent or other discrete optimization methods are not usable. To solve this problem, an alternating direction optimization algorithm is introduced to calculate R and L iteratively. The main idea of this algorithm is fixing one variables obtained from the previous iteration and updating another. The detail of the proposed new algorithm is as follows.

First, the observed image is transformed RGB space into HSV space. Then the image in V layer, denoted as S_V, is used as the image for processing.

Then we update R and L iteratively. It is natural to make an initialization for the alternating optimization. In this paper, the Gaussian low-pass filtered image of S_V is employed as the initialization of L. Given L, update R by using

$$R = \mathcal{F}^{-1}\left(\frac{\mathcal{F}(S_V/L)}{\mathcal{F}(1)+\beta(\mathcal{F}(D_x)^*\mathcal{F}(D_x) + \mathcal{F}(D_y)^*\mathcal{F}(D_y))}\right) \qquad (2)$$

where D_x and D_y are the difference operators in the horizontal and vertical directions, respectively, $\mathcal{F}$ is the Fast Fourier Transform (FFT) operator and $\mathcal{F}()^*$ is the complex conjugate. All calculations are component-wise operators. According to the prior knowledge: $0 \leq R \leq 1$, we simply make a correction of R after calculation: $R = \min(1, \max(R, 0))$.

Given R, update L by using

$$L = \mathcal{F}^{-1}\left(\frac{\mathcal{F}(\gamma L_0 + S_V/R)}{\mathcal{F}(1+\gamma)+\alpha(\mathcal{F}(\mathrm{D}_x)^*\mathcal{F}(D_x) + \mathcal{F}(D_y)^*\mathcal{F}(D_y))}\right) \qquad (3)$$

similar to the correction of R, L is corrected by $L = \max(L, S_V)$.

After computing R and L with a few iterations, an illumination adjustment is adopted to enhance the observed image and make the result more natural. Here are two steps of the adjustment. First, a sigmoid function is used to adjust the computed illumination $L_{adjusted}$,

$$L_{adjusted} = 2\arctan(aL)/\pi \qquad (4)$$

where a is the shrink parameter to control the shape of the arctan function. The effect of sigmoid function can lighten dark

Algorithm 1

Input: input observed color image $S_{RGB}^{original}$, parameters α, β, γ and compute L_0.

$S_V \leftarrow RGBtoHSV(S_{RGB}^{original})$.

Initialization: $L \leftarrow$ Gaussian filtering of S_V.

for iter =1:n.

given L update R in Eq. (2).

correct $R \leftarrow \min(1, \max(R, 0))$.

given R and L_0, update L in Eq. (3).

correct $L \leftarrow \max(L, S_V)$.

end.

$L_{adjusted} \leftarrow 2\arctan(aL)/\pi$, .

$L_{final} \leftarrow CLAHE(L_{adjusted})$.

$S_V^{final} \leftarrow RL_{final}$.

$S_{RGB}^{final} \leftarrow HSVtoRGB(S_{HSV}^{final})$.

Output: enhanced image S_{RGB}^{final}, illumination image L, reflectance image R.

areas to enhance details while compress intensities in bright areas to avoid over-enhancement. Second, the enhanced result may looks unnatural since equation (4) reduces global dynamic range of illumination. To solve this problem, contrast limited adaptive histogram equalization (CLAHE) as in [23] is used to make the final enhanced result more naturalness. A mapped illumination L_{final} is obtained after adjustment.

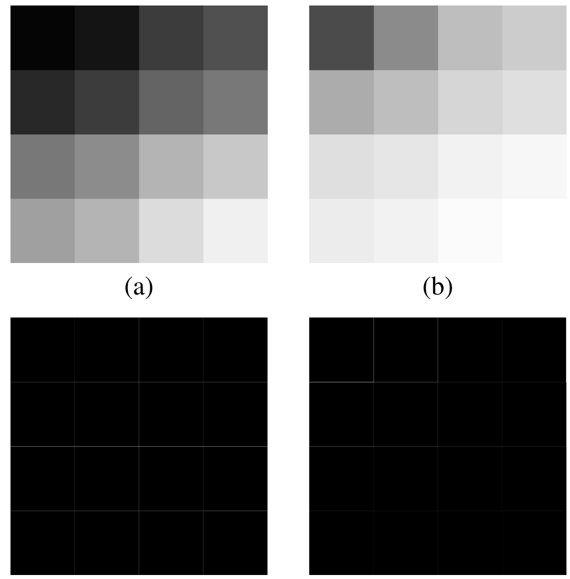
Finally, we combine R and L_{final} together to obtain the new value layer: $S_V^{final} = RL_{final}$. Then the new HSV image S_{HSV}^{final} is transformed into RGB to obtain the final enhanced color image S_{RGB}^{final}.

The proposed algorithm is shown in **Algorithm 1**. In the next section, some experimental results will be shown and compared with other methods.

4. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, first the simulation of logarithmic transformation is shown to express the disadvantage of conventional model. Then two different kinds of image, high dynamic range (HDR) image and non-uniform illumination image, are tested to demonstrate the effectiveness of proposed approach. The simulation tool is Matlab R2012a on a PC with a 2.60GHz Intel Pentium Dual Core Processor. α, β, γ and a are fixed as 10, 0.1, 10^{-3} and 10 respectively and 4-8 iterations are generally performed. Since all calculations are component-wise operators and FFT are used for speedup, the algorithm avoids very-large-matrix inversion and the computational time is satisfactory. It takes about 1.34 seconds to process one color image with size of 750×720.

Fig. 1 is a simulation of logarithmic transformation. As can be seen, edges in bright regions of Fig.1(b), which is the logarithmic transformation of Fig. 1(a), becomes fuzzier as the pixel values increase, i.e., the edge information is lost in the logarithmic domain. Fig. 1(c) and (d) are the difference operation of (a) and (b) to obtain the edge. As shown in Fig. 1(c), edges are preserved. In Fig. 1 (d), some edges in dark regions are enhanced while others in bright regions are weaken, especially in the bottom-right regions the edges almost disappear. This simulation illustrates the weakness of logarithmic transformation.



(a) (b) (c) (d)

Fig. 1. Simulation of logarithmic transformation. (a) the original image; (b) the logarithmic transformation of (a); (c) the difference operation of (a); (d) the difference operation of (b).

Fig. 2 shows the comparison with other two algorithms on HDR image. Since HDR image has a wide range that exceeds the display range of screen, it is required to compress the dynamic range to make it visible. As shown in Fig. 2(b), the result by multi-scale retinex for color image restoration (MSRCR) method [8] fails to process HDR image. This is because the MSRCR algorithm removes the estimated illumination and uses the reflectance as the enhanced image. It is unreasonable to use the reflectance as the enhanced result without illumination. Fig. 2(c) shows another HDR image enhancement algorithm using a model of retinal processing [24]. The result has a good visual quality but the details cannot be seen clearly since the illumination is not processed in the rendering steps. The zoomed-in parts in the red box are shown in Fig. 3. Fig. 2(d) shows the enhanced result by the proposed approach. Due to the illumination adjustment, the dynamic range is compressed to make the HDR image visible and more naturalness.

Fig. 3 shows the zoomed-in part of Fig. 2 in the red box. Both MSRCR [8] and [24] have over-enhancement and color

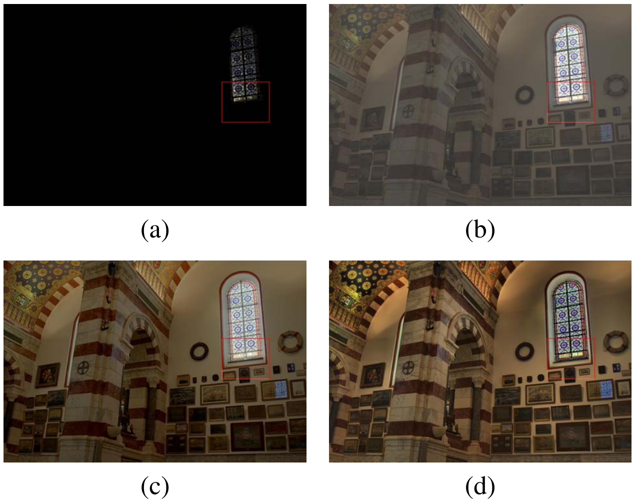


Fig. 2. (a) the original HDR image; (b) the enhanced image by MSRCR [8]; (c) the enhanced image by [24]; (d) the enhanced image by the proposed new approach.

distortion. Comparing with other two methods, details and textures in Fig. 3(d), which is the result by proposed method, can be enhanced meanwhile colors without distortion. This is due to the advantage of proposed model about reflectance which can preserved edge information well. Moreover, the effective illumination adjustment can avoid over-enhancement and reproduce color information.

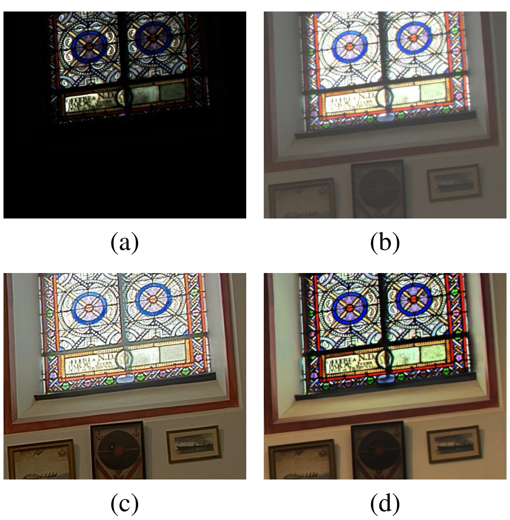


Fig. 3. (a)-(d): zoomed-in part of Fig. 2(a)-(d) in the red box.

Fig. 4 shows another experimental result of non-uniform illumination image. The non-uniform illumination image has the character of uneven brightness, the goal to process this kind of image is to lighten the dark areas to enhance details while avoiding over-enhancement in bright areas. In this test, two other algorithms are used for comparison: one is also M-SRCR [8] and another is a up-to-date algorithm which focuses on non-uniform illumination image [14]. The result by MSR-CR, as shown in Fig. 4(b), is over-enhancement since the algorithm does not consider the distribution of illumination and regards the reflectance as the enhanced image. Comparing with MSRCR algorithm, the results by [14] and the proposed method has similar and good visual effect. While in some areas, such as the shadow on the ground, the proposed approach has a better performance on local contrast comparing with [14]. Since [14] uses a bi-log transformation to map the global illumination, the local contrast is without processing. The proposed method achieves a balance between naturalness preservation and local contrast enhancement since the illumination adjustment processes both global dynamic range and local contrast.

Fig. 4. (a) the original observed image; (b) the enhanced image by MSRCR [8]; (c) the enhanced image by [14]; (d) the enhanced image by the proposed new approach.

5. CONCLUSIONS

In this paper, a novel approach for image enhancement is presented. First, a new variational retinex model without logarithmic transformation is presented. Comparing with conventional models, the proposed model can make the computation of reflectance more precise and well preserve edges. Then an effective and efficient alternating direction optimization algorithm is employed to decompose illumination and reflectance. Utilizing the decomposed illumination, a simple and effective illumination adjustment method is introduced to make enhanced images more natural. Two kinds of image, HDR image and non-uniform image, are processed by the proposed approach. Experimental results shows that both naturalness preservation and detail enhancement have good performances.

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