An Improved Image Enhancement Approach Using Retinex

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Abstract: Aiming at the halo artifacts and over-enhancement of low-illumination image enhancement by Retinex algorithm, this paper introduced an improved low-illumination image enhancement algorithm based on Retinex theory. Convert the original image to the HSV color space and select the V channel as input. Use tone mapping to globally enhance the luminance channel to obtain detailed information of the image in the shadow. Select guided filter with edge preservation for filtering operations to reduce halo artifacts. Experimental results indicate that the proposed algorithm can effectively improve the overall luminance of low-illumination images, reduce the effects of halo artifacts, and solve the problem of image distortion.

1. Introduction

Due to insufficient light and severe light scattering, color shift and image detail loss often occur when pre-processing low illumination images. Therefore, the processing of low-illuminance images has been an urgent problem and has very important theoretical significance and application value.

To date, several illumination enhancement algorithms can be roughly divided into two categories, which are global-based operations and non-global operations. The global operations on images mainly include logarithmic compression, gamma correction, Histogram equalization (HE), and linear stretching. Veluchamy [1] uses adaptive gamma correction combined with histogram equalization to enhance low-light image enhancement. Compared with the traditional HE algorithm, there is some improvement in the enhancement and color distortion, but it will cause a loss of image detail. The global operation only selects a single function to process the image, and the run time is fast, but the processing of details is ignored. The non-global operations need to consider the current pixel and its neighborhood pixels. The most common operation is the convolution on the image. Among them, Retinex-based image enhancement can balance dynamic compression, edge enhancement, and color constancy. The center-surround function greatly reduces the computational cost of Retinex for image processing, which is used to enhance low-illumination images [2-4]. According to its constant color characteristics, the enhancement of low illumination images can be achieved only by using the Retinex algorithm for the luminance channel. Xiao and Peng [5] select the luminance channel in the color space as the input of the image by projecting the original RGB color space into the HSV color space. According to the orthogonality of PCA, the image is reduced in dimension to obtain the main information of the image, that is, the luminance component [6-7]. In the image mapping, Lin [8] uses the sigmoid function to replace the logarithmic calculation in the convolution process to reduce image information loss and introduces the noise suppression factor and the highlight retention factor adaptive to adjust the enhanced nighttime image.

The rest of this paper is organized as follows: Section 2, introduce the Retinex theory; Section3 describe the principle of the proposed algorithm; Section 4 compares and analyzes the image quality after enhancement, and a conclusion is obtained. Section 5 summarizes the whole paper and looks forward to the future.

2. Theory of Retinex

Edwin H. Land [9] experimentally demonstrated that the color observed by the Human Visual System (HVS) is determined by the ability of objects to reflect long (red), medium (green), and short (blue) waves. The original image is further divided into the environmental illumination component reflecting the overall change of the image and the reflection component with the essential properties of the image. The single-scale Retinex (SSR) is given by

$$
\begin{aligned}
R_i(x,y) &= \log\left(\frac{I_i(x,y)}{L_i(x,y)}\right) \\
&= \log(I_i(x,y)) - \log(I_i(x,y) * F(x,y))
\end{aligned} \tag{1}
$$

where $R_i(\mathrm{x},\mathrm{y}), i \in (\mathrm{R},\mathrm{G},\mathrm{B})$ represents the output of the Retinex algorithm in R, G, and B channels, mark * is the convolution operator, F(x, y) is a center-surround function that is typically using Gaussian filter,

$$
F(x,y) = \lambda \exp\left(-\frac{x^2+y^2}{\sigma^2}\right) \tag{2}
$$

where λ is the normalized parameter, in order to satisfy $\iint F(x,y)dxdy = 1$ .And σ is the Gaussian surround space scales constant.

When the value σ is small, the image has high contrast and a clear representation of details, while σ too small will lead to color distortion and excessive enhancement. On the contrary, when the value σ is large, More original image color information can be retained, but the contrast of the image will decrease. To ensure the ideal effect of the enhanced image, an appropriate scale parameter should be selected.

There are several problems in the enhancement of low-illumination image by original MSR: 1) Retinex algorithm estimates the reflection components of the three channels respectively, which destroys the proportional relationship among channels R, G, and B, resulting in image distortion. 2) Gaussian filtering ignores the brightness difference between pixels, resulting in enhanced edge blur, halo artifact, etc., which affects the detection of the lane line. 3) Enhance low-illumination images by changing the mapping relationship between images, and the noise will be amplified along with the enhancement.

3. Proposed Method

In order to solve the above problem, an improved Retinex image enhancement method is proposed. Firstly, the image is converted from RGB space to HSV space to obtain the v channel. Secondly, the image illuminance component is globally enhanced to improve the overall luminance. Then, the enhanced illuminance image is locally enhanced using Retinex with guided filter improvement. Improve image contrast by reducing over-enhancement and protecting the edges of details. Finally, the enhanced illuminance component is converted into an RGB color space to obtain an enhanced color image.

3.1. Luminance Channel Processing

According to the theory of Retinex, the color of objects is not affected by the non-uniformity of light and has the characteristic of constant color. Hue Saturation Value (HSV) is an intuitive color model that is widely used in digital image processing. Select V channel in HSV color space as input and the equation can be written as

$$L_w(x,y)=\max\{R,G,B\} \tag{3}$$

where max{R,G,B} represents the maximum pixel value at the pixel point (x, y) in the R, G and B channel.

After obtaining the luminance channel, use tone mapping to stretch the distribution of low-value pixels to a range more consistent with the HVS. The global luminance output can be expressed as

$$L_g(x,y)=\frac{\log(L_w(x,y)/\bar{L}_w+1)}{\log(L_{w\max}/\bar{L}_w+1)} \tag{4}$$

where $L_{w\max}$ denotes the maximum value of the luminance channel $L_w(x,y)$; $\bar{L}_w$ is the background luminance, which is obtained via log-average of the luminance channel. The equation is expressed as follows

$$\bar{L}_w=\exp\left(\frac{1}{m\times n}\sum_{x,y}\log(\delta+L_w(x,y))\right) \tag{5}$$

where $m\times n$ is the size of the image, and δ is a constant term which can avoid numeric overflow during the logarithm calculation. The tone mapping proposed in this paper redistributes pixels to a new range, stretches the distribution of low-value pixels, and the other pixel values increase smoothly. The algorithm ignores the protection of details in the process of increasing the brightness. After the enhancement, some high-contrast content is lost.

3.2. Reflection Component Processing

Gaussian filtering is a process of weighting individual pixels in a window without considering the effects of brightness. In the edge part with large luminance difference, halo artifact will appear after filtering. As an improvement, filter with edge protection is selected to process the input image, such as bilateral filter [10], guide filter [11,12], etc.. The bilateral filter algorithm has a high time complexity, so that it is difficult to achieve real-time performance.

Therefore, this paper introduced the guide filter to replace the Gaussian filter in Retinex. The guided filter uses the Euclidean distance and the brightness difference as the weight reference, and it is linear in the calculation process, independent of the size of the core. It should be noted that the guided filter can suppress the gradient inversion and protect its edge texture. The improved algorithm is described as follow

$$R_l(x,y)=\log\left(\frac{L_g(x,y)}{f(L_g(x,y))}\right) \tag{6}$$

where $R_l(x,y)$ is the reflectance component of the Retinex output; f (•) represent the guided filter function. The guied filter is given as

$$f(L_g(x,y))=\frac{1}{|\omega|}\sum_{k\in\omega_k}(a_kL_g(x,y)+b_k) \tag{7}$$

where the linear coefficient a_k, b_k is obtained by solving the optimization problem by the least square method

$$a_k = \frac{\frac{1}{|\omega|}\sum_{i\in\omega_k} I_i p_i - \mu_k \overline{p}_k}{\sigma_k^2 + \delta} \tag{8}$$

$$b_k = \overline{p}_k - a_k \mu_k \tag{9}$$

where μ_k and σ_k^2 represent the mean and variance of the guide image in the window ω_k, respectively. The dynamic range of the output is related the radius of the filter window r. $|\omega|$ represents the number of pixels in the window. $\overline{p}_k$ represents the average pixel value of input image P in the window. δ is the regularization parameter, which prevents the value of a_k out of the range. To simplify the calculation process, select the global luminance output as guide image and the input image of guide filter.

After obtaining the illuminance component, the output image is adjusted using linear stretch. Linear stretch can selectively stretch the image channel to the maximum allowable range to maximize the overall luminance. The stretched reflection component is given as

$$\tilde{R}(x,y) = \frac{R(\mathrm{x},\mathrm{y}) - \min\{R(\mathrm{x},\mathrm{y})\}}{\max\{R(\mathrm{x},\mathrm{y})\} - \min\{R(\mathrm{x},\mathrm{y})\}} \tag{10}$$

where min{ • } and max{ • } represent the largest and smallest pixels in the image, respectively. After stretching, the enhanced reflection component is combined with the H and S channels in the HSV color space and converted into RGB color channels.

3.3. Algorithm Architecture

The basic algorithm steps are described as follows in Table 1.

Table 1: Proposed Algorithm Steps.

Algorithm architecture
Input: Original image Step 1: Calculate the luminance channel of HSV. Step 2: Convert RGB color space to HSV color space, then extract V channel Step 3: Use guided filter to obtain the illuminance component and adaptively adjust the output by linear stretch. Step 4: Convert HSV color space to RGB color space Output: Enhanced color image

4. Experimental Results and Discussion

To verify the effectiveness of the proposed algorithm for the image enhancement, the results of the proposed algorithm is compared with SSR and BBHE[13] algorithms. The experimental parameters are consistent with the original article, programming language is Matlab 2018a.

4.1. Image Quality Evaluation

In this section, image with low overall illumination and uneven illumination images are selected as references to verify the effectiveness of the proposed algorithm. Figure 2 and Figure 3 display the enhancement outputs of SSR, BBHE and the proposed method. Figure 4 is a comparison of local details under uneven illumination conditions.

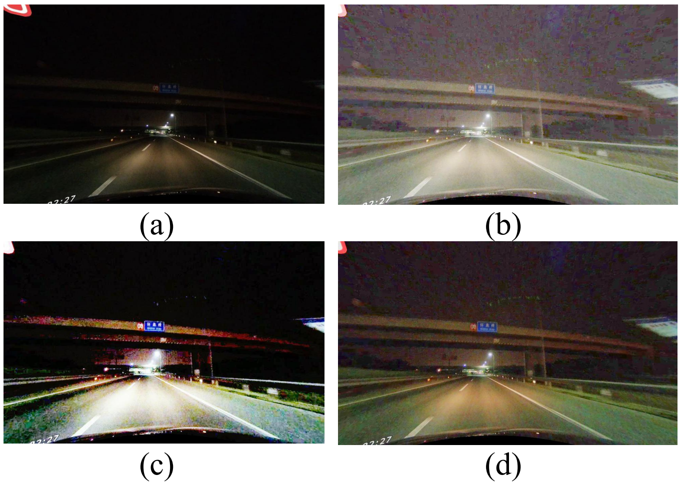

Figure 2: Original images and results from different algorithms under low overall illumination conditions. (a)Original image, (b)SSR, (c)BBHE and (d)Proposed method.

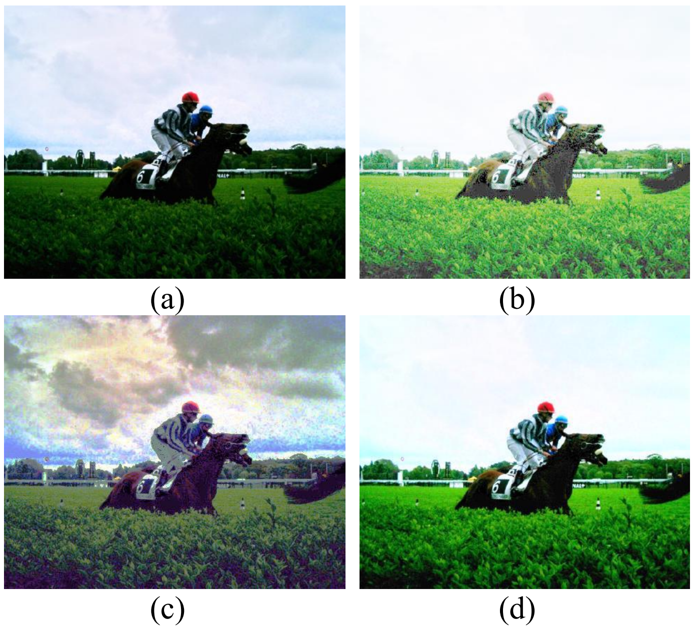

Figure 3: Original images and results from different algorithms under uneven illumination conditions (a)Original image, (b)SSR, (c)BBHE and (d)Proposed method.

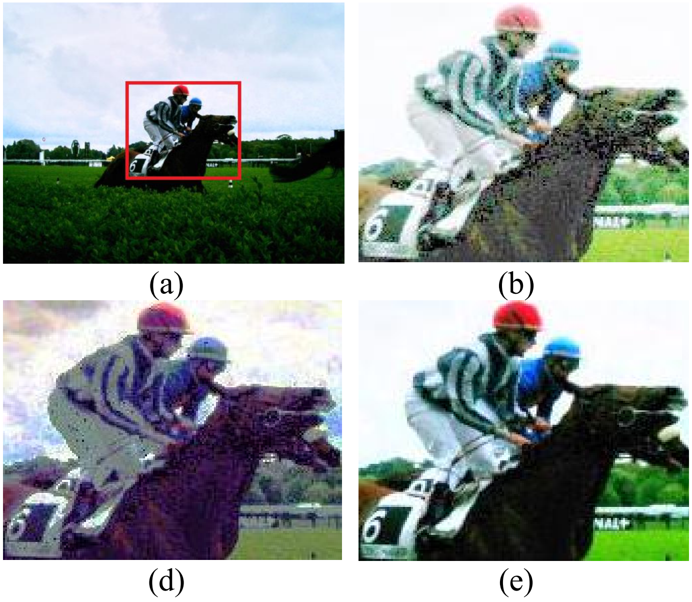

Figure 4: Comparison of details under uneven lighting conditions
(a)Original image, (b)SSR, (c)BBHE and (d)Proposed method.

Figure 2(b) and Figure 3(b) shows that the entire image is white and bright after SSR algorithm enhancement. In Figure 4 (b), the image is over-enhanced and the noise is amplified. In Figure. 2(c), BBHE has insufficient processing capabilities for dark areas. Meanwhile, in Figure 3(c) and Figure 4(c), the enhancement of uneven brightness images easily leads to color distortion. It can be seen in Figure 3(d) that the proposed algorithm improves the color saturation and makes the grass part look greener. Enlarging the details can find that the algorithm in this paper can protect the color from distortion, restore the details of the shadow area, and effectively suppress the noise in this area.

The color restoration and edge protection of the resulting image are especially enhanced compared with other algorithms. The proposed algorithm effectively reduces the effect of halo artifacts and prevents the image from over-enhancement.

5. Conclusions

This study proposes a low-illuminance image enhancement technology based on Retinex, which processes the luminance channel from both global and local aspects. Experiments show that the proposed method achieves good results in image noise suppression and contrast preservation. At the same time, the chroma of the image has been improved without distortion. In the future, the algorithm of this paper will be extended to wider fields, such as low-illuminance lane detection and vehicle detection. It is necessary to improve the fastness and stability of the algorithm for different scenes to ensure the success rate of the detection algorithm under low light conditions.

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