Dual-Color Space Fusion Dehazing Algorithm Based on Retinex Theory

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Abstract

In order to solve the problem of haze weather affecting outdoor image quality, an image dehazing algorithm based on Retinex theory for dual-color space fusion is proposed in this paper. To achieve detail enhancement in the RGB color space, we use a small-scale bilateral filters to maximize image detail information; to achieve color retention in the HSV color space, we reflection component in the luminance channel, and enhancement with S-type function, while the saturation channel is stretched adaptively; finally, the processed image is weighted and fused in RGB color space to get the enhanced defogged image. Experiments show that compared with the traditional algorithm, the algorithm enhances the image detail information after dehazing, while avoiding color distortion and halo phenomenon.

Keywords

Dehazing; Retinex theory; Dual-color space.

1. Introduction

Fog and haze weather is a common natural phenomenon, which can lead to bad visibility, poor contrast and dim colors in outdoor images. While affecting visual effects, it also affects the efficacy of outdoor visual systems, such as security video surveillance, military investigation, remote sensing navigation and so on. Therefore, it is significant that research on image dehazing has an important practical significance.

Image dehazing can be divided into physical model and non-physical model. Physical model-based methods usually analyze the imaging process based on atmospheric scattering model, and then get the restored clear image through the inverse process. However, the computational complexity is high, which is not conducive to real-time processing[1]. Based on the non-physical model method, the visual effect can be improved by increasing contrast and highlighting image details[2].

The image dehazing algorithm based on non-physical model mainly includes histogram equalization algorithm[3], homomorphic filtering algorithm[4], wavelet transform algorithm[5] and Retinex algorithm[6]. The histogram equalization algorithm makes the histogram distribution uniform and restores the clear image by nonlinear transformation of the original image, but ignores the local information of the image and is prone to color deviation. The basic idea of homomorphic filtering method is to transform foggy image into frequency domain, and then use high-pass filtering to suppress fog effect in low frequency range. The basic idea of the wavelet change dehazing method is to get the different frequency characteristics of the image through the wavelet transform of the atomized image, and then enhance the detail information by enhancing the non-low frequency sub-blocks, and suppress the low frequency sub-blocks to remove the noise influence, and finally the clear image is obtained by the inverse wavelet transform.

Retinex theory is a model for describing color constancy, which was proposed by Land et al[7]. Its basic idea includes two aspects: the color of an object depends on its ability to reflect light of different wavelengths, but has nothing to do with the intensity of reflected light; the color of an object has constancy and is not affected by the non-uniformity of light. The theory explains that the human eye's acquisition of the target scene color is caused by the reflected light of the scene, and is independent of the surrounding ambient light[8]. The dehazing method based on Retinex theory separates the foggy image into the illumination component and the reflection component. The haze mainly affects the illumination component of the image, so the core of dehazing is to eliminate the influence of the illumination component.

In this chapter, the image dehazing algorithm based on Retinex theory is studied and analyzed. To overcome the shortcomings of traditional Retinex algorithm, a dual-color space image dehazing algorithm based on Retinex theory is proposed, and the radiation component is estimated by bilateral filtering. Finally, the two color space dehazing images are fused, and the effectiveness of the proposed algorithm is verified by subjective and objective experiments.

2. Image Dehazing Algorithm Based on Retinex Theory

Retinex theory is the theory of retinal cerebral cortex. The theory holds that the image S observed by human eyes is the product of the illumination image L and the object reflection image R, while R is the real and constant image[9]. The mathematical expressions of Retinex theory are as follows:

$$S(x,y)=R(x,y)\times L(x,y) \tag{1}$$

Where $S(x,y)$ represents the image captured by the imaging device, $R(x,y)$ represents the reflection component of the object carrying image details, and $L(x,y)$ represents the illumination component of the ambient light.

In order to facilitate the calculation, the equation (1) is usually processed logarithmically, and the result is as follows:

$$\log R(x,y)=\log S(x,y)-\log L(x,y) \tag{2}$$

The logarithmic processing not only reduces the computational complexity, but also conforms to the human eye's perception ability of the approximate brightness curve. The flow chart of fog removal algorithm based on Retinex theory is shown in Fig.1.

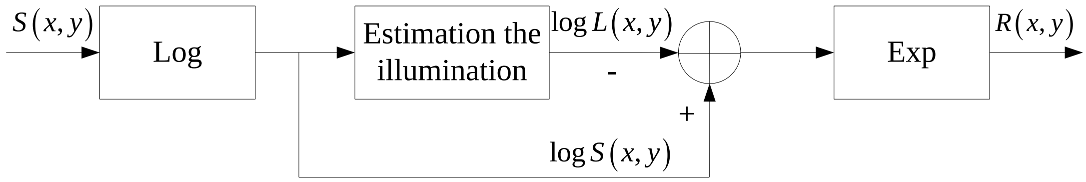


Fig.1 Flow chart based on Retinex theory dehazing algorithm

2.1 Single-Scale Retinex Algorithm

Single-Scale Retinex (SSR) algorithm is a kind of Retinex algorithm based on center surround. By constructing the Gauss surround function, the image R, G and B color channels are filtered separately to estimate the illumination component[10]. The illuminance component can be expressed as follows:

$$L(x,y)=S(x,y)*G(x,y) \tag{3}$$

Where $*$ represents convolution operation, $G(x,y)$ is Gauss surround function, and the mathematical expression of Gauss function is:

$$G(x,y)=\frac{1}{2\pi\sigma^2}\mathrm{e}^{-\frac{x^2+y^2}{2\sigma^2}} \tag{4}$$

Where σ is the center surround scale parameter. When σ is larger, the convolution kernel can act in a larger range, so the image is smoother and the color sense is better, but the dynamic compression ability is poor, and the detailed information of the image is easily lost; when σ is smaller, the detail information in the image is enhanced effectively, but it is easy to cause image color distortion.

The mathematical expression of the single-scale Retinex algorithm is:

$$r_{SSR}(x,y)=\log R_i(x,y)=\log S_i(x,y)-\log\left[S_i(x,y)*G(x,y)\right] \tag{5}$$

2.2 Multi-Scale Retinex Algorithm

In order to compensate for the deficiency of SSR algorithm in balancing dynamic range compression and color fidelity, Jobson et al. proposed Multi-Scale Retinex (MSR) algorithm[11]. The algorithm performs multiple scale SSR operations on a pair of images, and linearly superimposes the output results to improve the output. The formula of the MSR algorithm is as follows:

$$r_{MSR}=\log R_i=\sum_{k=1}^{N}\omega_k\left\{\log S_i(x,y)-\log\left\{S_i(x,y)*G_k(x,y)\right\}\right\} \tag{6}$$

Where k denotes the number of scale parameters. In order to avoid a large amount of computation, it usually takes a value of 3. When $k=1$, formula (6) is a single-scale Retinex algorithm. $G_k(x,y)$ represents the Gauss function in scale k. i represents the color channel, corresponding to R, G and B respectively.

MSR algorithm can better improve the shortcomings of SSR algorithm and highlight the details of the image. However, due to the change of the proportion between R, G and B components in the original image after enhancement, the color distortion still exists in the processed image.

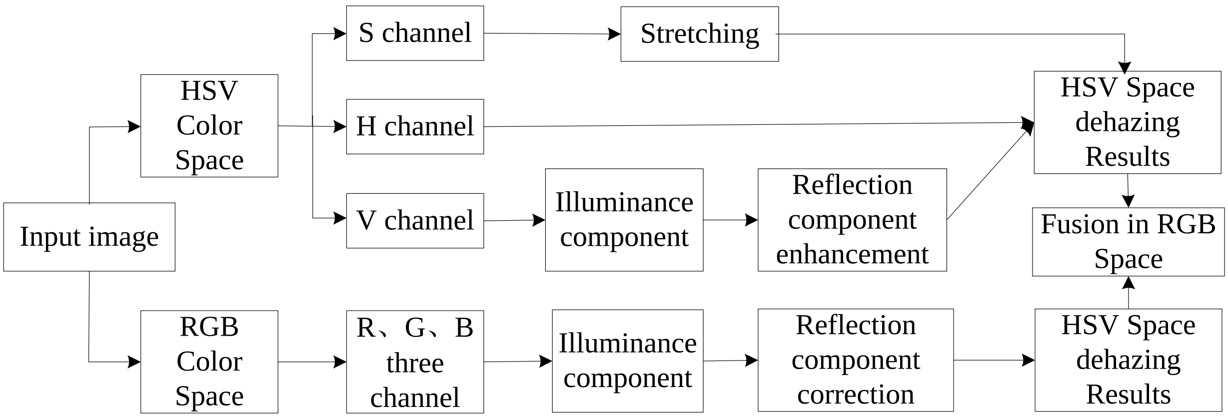


Fig.2 Flow chart based on dual-color space Retinex theory dehazing algorithm

3. Proposed Method

In view of the color distortion, lack of detail and the phenomenon of halo after dehazing of Retinex algorithm, this paper proposes a dual-color space image dehazing algorithm under Retinex model, which mainly includes the following four parts:

1) Improvement of the illuminance component estimation method. In this chapter, based on the characteristics of bilateral filtering with smooth image and maintaining edge information, it replaces the traditional Gaussian filter to estimate the illuminance component, in order to achieve better edge retention and eliminate the halo phenomenon at the depth of field change.

2) HSV color space color retention. In the HSV color space to maximize the color of the image, the higher-scale bilateral filtering is used to obtain the illuminance component in the luminance channel V and calculate the reflection component, and the reflection component is remapped using the S-type function. And according to the relationship between the V-S channels, stretch the S channel.

3) RGB color space detail enhancement. In the RGB color space, the image details are kept as much as possible. The lower-scale bilateral filtering is used to obtain the illuminance component in each color channel and calculate the reflection component. In order to avoid color distortion, the input image is introduced to correct the reflection component.

4) Dehazing image fusion. The image obtained by dehazing the HSV color space is converted into an RGB color space, and the two images are weighted and fused in the RGB space to obtain a final dehazing process result.

The proposed algorithm flow is shown in Fig.2.

3.1 Illumination Component Estimation Based on Bilateral Filtering

When the Gaussian function is used to estimate the illuminance component, since the Gaussian function does not have the edge-preserving property, the image after dehazing will produce a halo phenomenon at a large change in brightness and darkness. Bilateral filtering is a kind of filtering that combines the spatial proximity of an image with the similarity of pixel values. It smoothes the image while maintaining detailed information such as edges. The expression of the bilateral filtering is as follows:

$$u_{BF}\left(x,y\right)=\frac{1}{W_{BF}}\sum_{i,j\in\Omega}w_d\left(i,j\right)w_r\left(i,j\right)u\left(i,j\right) \tag{7}$$

Where $u_{BF}\left(x,y\right)$ is the filtered image; W_{BF} is the normalization factor, ensuring that the weight of the pixel is 1; Ω is the neighborhood centered on pixel $\left(x,y\right)$; $w_d\left(i,j\right)$ is the weight of the spatial domain, and $w_r\left(i,j\right)$ is the weight of the luminance domain; $u\left(i,j\right)$ is the input image. Among them:

$$u_{BF}\left(x,y\right)=\sum_{i,j\in\Omega}w_d\left(i,j\right)w_r\left(i,j\right) \tag{8}$$

$$w_d\left(i,j\right)=e^{-\frac{\left|i-x\right|^2+\left|j-y\right|^2}{2\sigma_d^2}} \tag{9}$$

$$w_r\left(i,j\right)=e^{-\frac{\left|u\left(i,j\right)-u\left(x,y\right)\right|^2}{2\sigma_r^2}} \tag{10}$$

Where $\left|i-x\right|^2+\left|j-y\right|^2$ is the square of the Euclidean distance between the pixel and the center point; $\left|u\left(i,j\right)-u\left(x,y\right)\right|^2$ is the square of the luminance difference between the pixel and the center point; σ_s and σ_r are the standard deviations in the Gaussian function, and the value is determined the performance of the bilateral filter.

3.2 HSV Color Space Color Retention

3.2.1 V Channel Illuminance Component Estimation

In order to improve image distortion, we change color image from RGB color space to HSV color space. Since the three components of HSV color space are independent of each other, the processing of V components will not change hue and saturation. Therefore, the illumination components obtained in HSV space are as follows:

$$L_V\left(x,y\right)=\frac{\sum_{(x',y')\in\Omega}w_d\left[\left(x,y\right),\left(i,j\right)\right]w_r\left[\left(x,y\right),\left(i,j\right)\right]V\left(i,j\right)}{\sum_{(x',y')\in\Omega}w_d\left[\left(x,y\right),\left(i,j\right)\right]w_r\left[\left(x,y\right),\left(i,j\right)\right]} \tag{11}$$

Where $V\left(i,j\right)$ is the image of V channel, $L_V\left(x,y\right)$ is the illumination component.

3.2.2 Reflection Component Enhancement

After calculating the reflection component by illuminance component, the reflection component can be further enhanced to obtain better details. In this chapter, we propose a method to enhance contrast by using S-type function. The regions at both ends of S-type function will be compressed, while the middle part will be stretched and enhanced. The details of the image are mostly in the areas with moderate brightness, so S-type function can be used to enhance the reflection component[12].

Sigmoid function is an S-shaped curve function, which can be used to re-map the reflection components. The function is defined as:

$$f\left(r\right)=\frac{1}{1+e^{-a*\left(2r-1\right)}} \tag{12}$$

Where r is the reflection component and a is the control parameter. The larger a is, the more obvious the enhancement effect is. The reflective component mapping is shown in Fig.3.

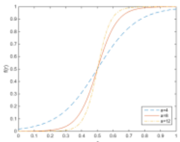


Fig.3 reflective component mapping

The reflection components of V-channel before and after enhancement by Sigmoid are shown in Fig.4. It can be seen from the figure that the contrast of the enhanced image is increased and the details of the scene are more obvious.

(a) Original reflection component (b) Enhanced reflection component

Fig.4 Contrast map of reflection components before and after enhancement

3.2.3 Saturation Component Stretching

In the process of image acquisition, due to the different external environment, the illumination of each image is also different, which requires stretching the saturation component S in different degrees in the process of image enhancement. Therefore, in order to make the saturation component S of the low illumination image achieve a better situation adaptively: in order to correct the saturation, we use adaptive Gamma correction, the formula is as follows:

$$S'=S^{(S+p)/(1+p)} \tag{13}$$

Where S' is the corrected saturation, S is the original image saturation, p is the adjusting factor, and the overall saturation can be increased by increasing p . The lower saturation part can be stretched by Gamma correction, and the higher saturation part can be reduced appropriately, which can improve the saturation and prevent the occurrence of supersaturation.

3.3 RGB Color Space Detail Enhancement

In RGB color space, the bilateral filtering with smaller σ_d value is used to estimate the illuminance component. On the basis of minimizing the relationship between R, G and B color channels, the details of the image are perfected to the greatest extent. Because of the small-scale bilateral filtering, the reflection component will inevitably produce some color deviations. In this paper, the original image is introduced to correct the reflection component. The expression is as follows:

$$R_i'(x,y) = R_i(x,y) \cdot \frac{3S_i(x,y)}{S_r(x,y)+S_g(x,y)+S_b(x,y)} \tag{14}$$

Where i is a color channel in RGB color space, $R_i(x,y)$ is the original reflection component, $R_i'(x,y)$ is the corrected reflection component, and $S_i(x,y)$ represents a color channel of the original image.

3.4 Dehazing Image Fusion

Finally, we will fuse the image in RGB color space to get the final output image. The formula is as follows:

$$\begin{cases} R'(x,y) = k \cdot R_1(x,y) + (1-k)R_2(x,y) \\ G'(x,y) = k \cdot G_1(x,y) + (1-k)G_2(x,y) \\ B'(x,y) = k \cdot B_1(x,y) + (1-k)B_2(x,y) \end{cases} \tag{15}$$

Where R_1, G_1 and B_1 are the corresponding values of each channel after the enhancement of RGB color space. R_2, G_2 and B_2 are the values of each channel after the HSV space is enhanced and converted to RGB space. R', G', and B' are the final output to enhance the RGB value of the image after dehazing, $0 < k < 1$.

4. Experiment and Analysis

In order to verify the effectiveness of the proposed algorithm, this paper uses MATLAB 2014B software platform to carry out experiments. The operating system is Windows 7, the main frequency of the processor is 3.2 GHz, and the system memory is 4 GB.

4.1 Illumination Component Estimation Based on Bilateral Filtering

In order to verify the effectiveness of the proposed algorithm, the algorithm is compared with SSR and MSR, the subjective comparison results are shown in Fig.1 and Fig.2. From the subjective experimental results, it can be seen that SSR algorithm will produce unreal color and obvious halo phenomenon after fog removal. MSR algorithm has no obvious effect on fog removal and halo still exists. The improved algorithm in this chapter can eliminate fog obviously without halo and color distortion, and the effect of fog removal is natural and real.

(a) The haze image

(b) The result of SSR algorithm

(c) The result of MSR algorithm

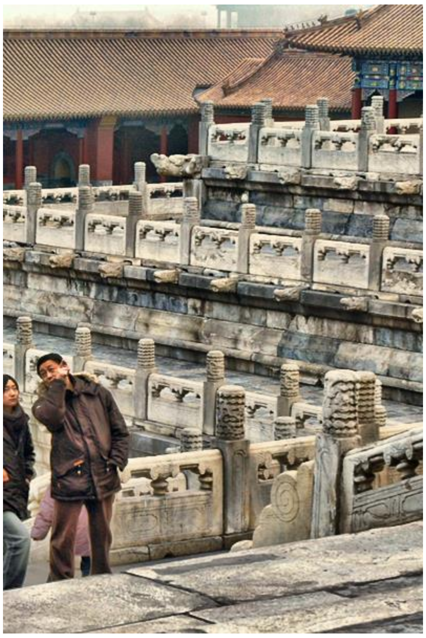
(d) The result of our algorithm

Fig.5 Comparing results of different algorithms

(a) The haze image

(b) The result of SSR algorithm

(c) The result of MSR algorithm



(d) The result of our algorithm

Fig.6 Comparing results of different algorithms

4.2 Illumination Component Estimation Based on Bilateral Filtering

Table 1 Contrast results of the Fig.5

Numble	Information entropy	Standard deviation	Average gradient
Original image	15.9786	47.4916	5.9147
SSR algorithm	15.9267	57.5087	13.6409
MSR algorithm	15.7764	58.2250	13.6015
Our algorithm	17.0821	57.9978	15.2000

Table 2 Contrast results of the Fig.6

Numble	Information entropy	Standard deviation	Average gradient
Original image	14.1040	44.8494	5.8928
SSR algorithm	14.5017	49.9495	8.2571
MSR algorithm	14.5927	49.5747	8.9947
Our algorithm	16.5966	63.1368	15.2420

In order to compare the experimental results more objectively and clearly, the image is evaluated objectively, the evaluation results are shown in Tables 1 and Tables 2. The information entropy represents the information content of the image, the standard deviation reflects the brightness of the image, and the average gradient reflects the details of the image. The higher the value of the three evaluation indexes, the better the dehazing effect. From the table, we can see that most of the indicators of the algorithm in this chapter are better than other algorithms, which objectively proves the effectiveness of the proposed algorithm.

5. Conclusion

In this paper, a dual-color space dehazing algorithm is proposed. The algorithm enhances the foggy image in RGB color space and HSV color space respectively, and uses weighted fusion to get the final enhanced image. The experimental results show that the final image enhancement effect obtained by this algorithm is superior to the traditional Retinex algorithm. The fog image enhancement effect is better, the details of the image are more obvious, and there is no color distortion.

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