An Improved Adaptive Correction Algorithm For Non-uniform Illumination Panoramic Image

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***Abstract*—An adaptive non-uniform illumination panoramic image enhancement algorithm was proposed, which can improve the visual effect of panoramic images captured under non-uniform illumination. Firstly, according to the illuminance-reflection imaging model, we adopt a bilateral filtering method to decompose the brightness into illuminance component and reflection component. Secondly, an adaptive gamma correction function is constructed, which can dynamically adjust the illuminance component. In the reflection component processing, an improved morphological operation is proposed to denoise and enhance the image details. Finally, we combine the illumination component with the reflection component to get the enhanced panoramic image. The experimental results show that the proposed algorithm can improve the effect of non-uniform illumination on the panoramic image, and can obtain better image contrast, detail information and visual effect.**

***Keywords*—non-uniform illumination correction; bilateral filter; panoramic image; adaptive gamma function; morphological operation .**

I. Introduction

With the rapid development of science and technology, panoramic imaging technology has been widely used in many research hotspots such as manless driving, robots, virtual reality and so on. Owing to the influence of weather, illumination and reflective characteristics of object surface, the illumination distribution in the obtained panoramic image is not uniform. It not only seriously affects the visual effects of panoramic image, but also make it difficult for subsequent panoramic image processing operations such as image segmentation, feature extraction, target tracking and recognition. Therefore, reducing the influence of illumination inhomogeneity on the quality of panoramic images and improving the visual quality of panoramic images is particularly important to the future information technology society[1].

At present, the existing image processing algorithms for non-uniform illumination mainly include histogram equalization[2,3],wavelet transform[4], gamma correction[5-7], and retinex algorithm[8-12]. Retinex-based algorithms decompose the image into illumination and reflection components, and output adjusted reflection components as enhanced results. This kind of algorithm has better enhancement effect for non-uniform illumination image, but its complexity is a bit high and it is easy to produce a halo phenomenon. To solve this problem, an improved adaptive non-uniform illumination panoramic image correction algorithm is proposed in this paper. Firstly, the illumination component of the image is extracted quickly and effectively by using bilateral filtering. Next, an adaptive gamma correction function is constructed to correct illumination information by relying on the characteristics of illumination distribution. Finally, an improved morphology operation is proposed to process the reflected component, which can remove the image noise and enhance the image details. The proposed algorithm can remove image noise and enhance image contrast, which provides avaluable reference for the research of processing of non-uniform illumination panoramic image.

Other chapters of the paper are arranged as follows. In Section II, the proposed adaptive non-uniform illumination panoramic image enhancement algorithm is explained in details. Section III uses subjective evaluation and objective analysis to evaluate the proposed algorithm, and Section VI concludes this paper.

II. Proposed Method

A. Illuminance-Reflection Imaging Model

According to the illumination-reflection imaging model[5], if a two-dimensional function $S(x,y)$ is used to represent an image, the corresponding function value of each (x,y) is the brightness value of the image at that point. The model $S(x,y)$ is composed of the product of the illumination component $I(x,y)$ illuminated to the scene and the reflection component $R(x,y)$ reflected from the surface of the object. The expression of the model is as follows:

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

According to the theory of illumination-reflection imaging model, the illumination component mainly determines the dynamic range of the pixels for a digital image. It corresponds to the low-frequency component of the image and reflects the global characteristics of the image and the details of the image edge. The reflection component represents the intrinsic characteristics of the image corresponding to the intrinsic characteristics of the image. The high-frequency component reflects most of the local detail information of the image and all the noise.

B. Illumination Extraction using Bilateral Filter

In order to improve the image quality of non-uniform illumination panoramic image, it is particularly important to extract the illumination information of image accurately. At present, the use-widely illumination information extraction algorithms mainly include Gauss filter algorithm[5], bilateral filter algorithm[11], and retinex algorithm of avariational framework[12]. The extraction algorithm based on Gauss filter is likely to cause blurred image edges and poor details.

Retinex algorithm based on variational framework is not ideal for extracting illumination information from images with illumination changes. In this paper, a bilateral filtering algorithm with edge preservation characteristics is used to extract the illumination information of panoramic image, which can keep the edge information of image well and suppress image noise.

Bilateral filter is a kind of filter with edge preserving function. It consists of two kernel functions: spatial domain and intensity domain. The output value of bilateral filtering is related to the spatial position of the neighborhood spatial pixels and the brightness difference of the surrounding pixels. Its specific form is defined as follows:

$$F_s = \frac{1}{k(s)} \sum_{p\in\Omega} f(p-s) g(I_p - I_s) I_p \tag{2}$$

$$k(s) = \sum_{p\in\Omega} f(p-s) g(I_p - I_s) \tag{3}$$

where I_s is the input image, F_s is the output image, $k(s)$ is a standardization factor, Ω represents the neighborhood window, f and g are two Gaussian kernels which are used to calculate the weight contribution of p in the spatial domain and intensity domain respectively, and I_p represents the brightness value of p.

The two Gauss kernel functions are defined as follows:

$$f = e^{-\frac{1}{2}\left(\frac{d(p,b)}{\sigma_d}\right)^2} \tag{4}$$

$$g = e^{-\frac{1}{2}\left(\frac{\delta(I_p, I_b)}{\sigma_r}\right)^2} \tag{5}$$

where $d(p,s)$ represents the Euclidean distance between two pixels, $\delta(I_p, I_b)$ represents the gray difference between two pixels, δ_d and δ_r represent the standard deviation in the spatial domain and the luminance domain, respectively.

Multi-scale Gaussian function[5] scale usually uses the size of 15, 80, 250. For Guided filter[6], filtering radius is 16 and adjustment parameter is 0.01. And for bilateral filtering[13] , space domain weight δ_d is 16, the intensity domain weight δ_r is 0.1, and the filter radius is r =21. The illumination component of the color panoramic image is extracted. The result is shown in Fig.1.

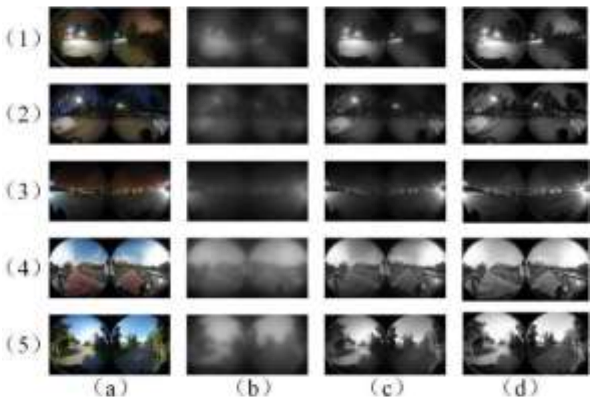

Fig. 1. The results of illumination extraction. (a) the original panoramic image, (b) results of multi-scale gaussian filter method, (c) results of guided filter method, (d) results of the proposed method

C. Illumination Estimation

To improve the quality of non-uniform illumination panoramic image, an adaptive gamma correction function based on illumination distribution characteristics is constructed. It reduces the excessive light region of the illumination component value and enhances the brightness of the area of low illumination. Illumination value of non-uniform illumination of panorama image is corrected adaptively. For input panoramic image $S(x,y)$, assuming that the illumination component extracted by bilateral filtering is $I(x,y)$, a new adaptive Gamma correction function is constructed on the basis of reference[5]. The expression is as follows:

$$I_{corrected}(x,y) = I(x,y)^{\gamma(x,y)} \tag{6}$$

where $I(x,y)$ is the illumination component of panoramic image extracted by bilateral filtering, and $\gamma(x,y)$ is the correction parameter of Gamma correction which directly determines the correction effect of illumination component.

The existing Gamma correction algorithms generally take the empirical value as the value. When $\gamma(x,y) < 1$, the brightness of the panoramic image will be enhanced. When $\gamma(x,y) = 1$, the brightness of the image will remain unchanged. And when $\gamma(x,y) > 1$, the brightness of the whole image will be weakened. However, the actual panoramic image contains the whole over-bright area of illumination intensity and the over-dark area of illumination intensity. There are even multiple light sources in the panoramic image. Therefore, we propose an adaptive selection strategy $\gamma(x,y)$, which adaptively adjusts Gamma function to obtain correction parameters by using the light distribution characteristics of each pixel. The calculation of $\gamma(x,y)$ is shown in Formulas 7 and 8.

$$r(x,y) = \frac{(I(x,y) + a)}{1+a} \tag{7}$$

$$a = 1 - \frac{1}{m*n} \sum_{x=1}^{m} \sum_{y=1}^{n} I(x,y) \tag{8}$$

Adaptive Gamma correction can improve the brightness of the image, enrich the details of dark areas, inhibit the enhancement of brighter areas in the original image, and prevent over-enhancement.

The illumination components of panoramic images with different scenes extracted by bilateral filtering are processed by the adaptive Gamma correction algorithm proposed in this paper. The experimental results are shown in Fig. 2.

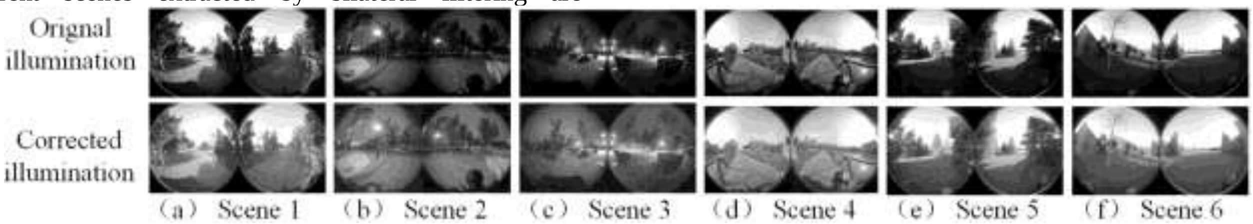

Fig. 2. Processed results in different illumination scene

D.Reflection Component Enhancement

The reflection layer of the image is obtained by the value component divided by the illumination layer, which contains most details and the noise of the image. A morphological operation method is proposed to process the reflection layer, and the image noise can be removed while enhancing the image detail information.

Due to the influence of the light environment and imaging technology, there is a certain amount of noise in the reflection layer of the panoramic image. The reflection component is obtained by dividing the brightness of the panoramic image by the illumination component of the image, which contains the noise of the panoramic image and most of the detailed information. An improved morphological operation is proposed to rich detail information and denoise the reflected component of the panoramic image. The processing steps are as follows:

(1) A detail enhancement algorithm based on morphological operation is proposed to denoise and enhance the details of the reflected components. Firstly, a 5 * 5 linear structure element H is chosen to expand the reflection component, and then the 5*5 structure element H^c perpendicular to H is selected to corrode the reflection component after expansion. The calculation equation is as follows:

$$R_{denoise} = (R \oplus H) \ominus H^{c} \quad (9)$$

(2) We propose an improved combined operation of cap and cap based on morphological operation to process the reflected component after denoising, so as to achieve the effect of image detail enhancement. The function is defined as follows:

$$R_{enhanced} = R_{denoise} * \{1 - \{R_{denoise} + [R_{denoise} - (R_{denoise} \circ b)]\} * \left[(R_{denoise} \bullet b) - R_{denoise}\right]\} \quad (10)$$

where b is a disc-shaped structural element of $3*3$.

Because the image noise in the reflection component is random noise, we cannot estimate the type of noise accurately. We add multiplicative noise (noise density is equal to 0.05), Gauss noise (noise density is equal to 0.1), Poisson noise and salt and pepper noise (noise density is equal to 0.02) to the image, and the noise densityof the proposed algorithm is 0.02. The improved morphological operations are processed to verify the denoising and detail enhancement performance of the proposed algorithm. The experimental results are shown in Fig. 3.

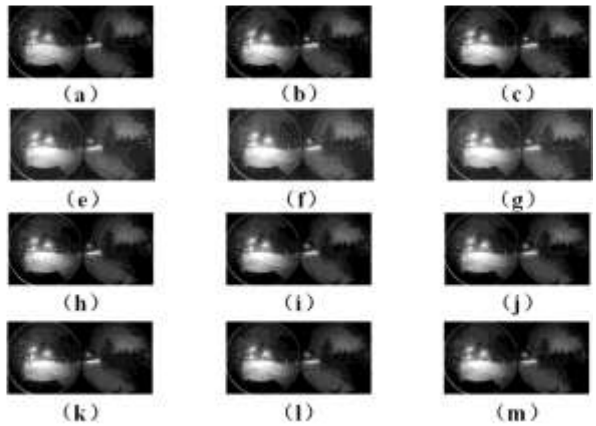

Fig. 3. Processing results of the reflection components:(a) image with multiply noise; (b) denoising algorithm proposed in this paper; (c) detail enhancement algorithm proposed in this paper. (d) image with Gaussian noise; (e) denoising algorithm proposed in this paper; (f) detail enhancement algorithm proposed in this paper; (g) image with poisson noise; (h) denoising algorithm proposed in this paper ; (i) detail enhancement algorithm proposed in this paper; (j) image with salt-and-pepper noise; (l) denoising algorithm proposed in this paper; (m) detail enhancement algorithm proposed in this paper.

III. EXPERIMENTS

In order to better verify the effectiveness of the proposed algorithm, eight panoramic images full of different scenes and different illumination intensity are selected. We choose MSRCR algorithm[9], ACANU algorithm[5], NLUCR algorithm[11] and SRVRM algorithm[12] to conduct experiments. The experimental results are shown in Fig.4.

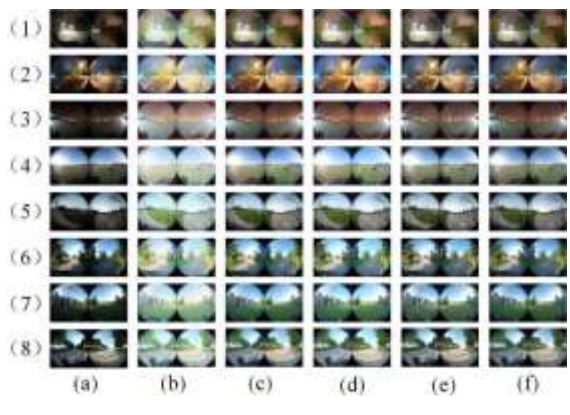

Fig. 4. The corrected results by different methods on non-uniform illumination panoramic images: (a) the input non-uniform illumination image, (b) the result of MSRCR method, (c) the result of ACANU method, (d) the result of NLUCR method, (e) the result of SRVRM method, (f) the result of the proposed method.

As can be seen from Fig. 4, the above five kinds of non-uniform illumination correction algorithms have greatly improved the correction effect of the panoramic images affected by different illumination effects in eight different scenes compared with the original image. The MSRCR method can better improve the brightness of the panoramic image and enhance the color information of the image, but it will cause the loss of detail information and enlarge the image noise. The ACANU method can improve the brightness of the dark area in the panoramic image and improve the contrast of the image. However, the image detail information is not clear enough, and there is an over-enhancement phenomenon. The NLUCR method improves the overall brightness of the image and highlights the image detail information effectively, but the over-enhancement phenomenon occurs at the light source, and there is a "halo" phenomenon. The SRVRM method improves the image brightness and enhances the color information in the image. The enhanced image has a better visual effect, but the image edge has been over-enhanced. The proposed algorithm enhances the image in two aspects: illumination and reflection. The overall brightness of the panoramic image is improved, and the edge information of the image is kept good. And the noise of image is well removed, the image details are highlighted, and the halo phenomenon is avoided. So the image quality is significantly improved.

In order to evaluate the correction effect of different algorithms more objectively and fairly, we use Peak Signal-to-Noise Ratio (PSNR)[13] and Structural Similarity (SSIM)[13]. The evaluation index is used to quantitatively analyze the correction effect of different algorithms on the non-uniform illumination image. The larger the peak signal-to-noise ratio is, the better the anti-noise performance of the image is. The structural similarity is an important evaluation index to measure the loss of distortion of the image structure. The larger the value, the higher the similarity between the image and the image is. The degree of distortion is weaker. The calibration effects of the above algorithms for different algorithms are shown in Fig. 5 and Fig. 6.

Fig.5 and Fig. 6 show that several algorithms have good enhance effects for non-uniform illumination images of different scenes. But the method that we proposed has a better correct effect than others, which can better remove image noise, enhance image contrast and improve image visual quality.

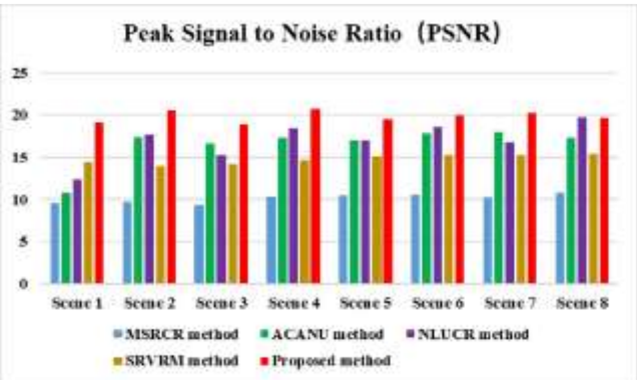

Fig. 5. Peak Signal-to-Noise Ratio(PSNR) of different algorithms

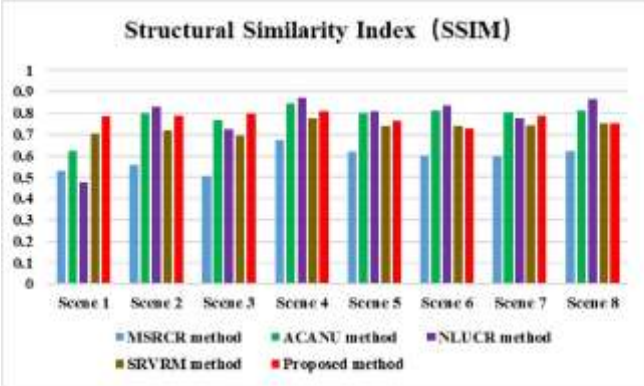

Fig. 6. Structural Similarity (SSIM) of different algorithms

IV. CONCLUSION

This paper proposes an improved adaptive non-uniform illumination panoramic image correction algorithm for image degradation caused by non-uniform illumination. Firstly, we present an improved adaptive gamma function, which can dynamically adjust the illuminance component by the local distribution characteristics. Secondly, an improved morphological operation is usedto denoise and enrich image details. Finally, extensive experiments showed that the proposed algorithm performed better than state-of-the-art algorithms in both subjective analysis and objective evaluation. In the future, wewill focus on faster and more efficient algorithms of illumination information extraction to improve the visual quality of panoramic images.

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