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Remote Sensing Image Enhancement Based on MSR and CLAHE

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Abstract. In view of the common problems of low contrast and color distortion in remote sensing images, this paper proposes a remote sensing image enhancement algorithm combining the improved contrast-limited adaptive histogram equalization (CLAHE) and multi-scale retinex (MSR) algorithms. First, the CLAHE algorithm is performed on remote sensing images for color distortion, and then a color recovery factor is introduced for color correction. Secondly, the multi-scale retinex algorithm is performed on the remotely sensed image in HSV color space to improve the image contrast as well as equalize the brightness. Finally, weighted fusion is performed according to certain image fusion rules. In this paper, the best fused image is obtained by image fusion, combined with the algorithm characteristics. Through subjective and objective comparison experiments with other traditional image enhancement algorithms, the results show that the algorithm proposed in this paper makes the image contrast enhanced, can restore the real color, greatly retain the image details, improve the image information entropy, greatly improve the image viewing experience, and lay a good foundation for the subsequent image processing.

Keywords: remote sensing image, image enhancement, MSR, CLAHE

1. Introduction

Remote sensing images are widely used and play an important role in meteorology, agriculture, topographic mapping and other fields. Due to the imaging reasons of remote sensing images, inadequate lighting conditions and other weather factors, the remote sensing images have problems such as low contrast, color unsaturation and distortion, which make it impossible to obtain accurate information from the images and give people a bad impression. Therefore, it is necessary to study remote sensing image enhancement technology.

Traditional image enhancement methods include histogram equalization algorithm based on the spatial domain, image enhancement algorithms based on retinex theory [1], and wavelet transform (WT) [2] based on the frequency domain.

The wavelet transform enhancement algorithm decomposes the image into different frequency images, and then enhances them to highlight the image details, but it is easy to enlarge the image noise and computationally expensive.

The histogram equalization (HE) algorithm [3] converts the probability density function of the gray level of an image into an approximate uniform distribution, so as to enhance the image contrast and improve the dynamic range of the image. However, the image is prone to over-enhancement, which distorts the image. Then someone proposed the contrast-limited adaptive histogram equalization (CLAHE) [4] algorithm to overcome the disadvantage of HE that is easy to be over-enhanced. In CLAHE, the image is divided into rectangular blocks of equal size, and the HE algorithm is carried out in each block. The CLAHE algorithm can improve the image contrast very well, but there will be color distortion. To solve this problem, a CLAHE algorithm with color recovery factor is presented, which can effectively solve the problem of color distortion.

The image enhancement algorithm based on retinex theory can improve the image visual effect to a certain extent, but the image contrast is not improved much, and the color restoration effect is not ideal, and color distortion is prone to occur. Retinex series algorithms have the advantages of dynamic compression and color constancy, but since retinex series algorithms process the RGB channels of images separately, this destroys the relationship between RGB channels. The most direct consequence is that the enhanced images have color bias. Based on this, this paper uses a method that converts the original image to HSV color space

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to estimate the illumination component of the V-channel image, acquires the reflection component image, and then converts it back to RGB color space to obtain the enhanced image, which can effectively solve the problem of color distortion and dark area over-enhancement after processing.

Because image fusion technology has been widely used in image enhancement [5], and has a good enhancement effect. Fusing different image enhancement algorithms together produces different algorithm features for image enhancement. In this paper, a fusion-based enhancement method for remote sensing images is presented.

2. Methodology

2.1. Improved Multi-scale Retinex Algorithm

The retinex theory is an image enhancement method proposed by Land based on the human color perception system. The theory believes that an image is composed of the product of its reflection component and brightness component , as follows

$$I(x,y) = R(x,y) * L(x,y) \tag{1}$$

where $I(x,y)$ is the original image. The reflection component of the image reflects the color characteristics of the object itself, corresponding to the high frequency part of the image; the brightness component of the image reflects the brightness of the environment, corresponding to the low frequency part of the image. The idea of retinex image enhancement is to remove the influence of environmental brightness from the original image and solve the color characteristics of the object itself, so as to achieve the purpose of image enhancement.

The multi-scale retinex (MSR) [6] calculates the value of the reflection component at different scales by setting different standard deviation values in the Gaussian function, and then performs a weighted average. The MSR algorithm formula is as follows

$$\lg R(x,y) = \sum_{n=1}^{N} W_n \{\lg I(x,y) - \lg[I(x,y) * F_n \quad x,y \quad]\} \tag{2}$$

among them, $F_n(x,y)$ represents the Gaussian wrapping function, W_n represents the weight coefficient; n represents the number of scales, where $N = 3$, represents the traditional RGB color image. A large number of experimental tests have shown that for most images, three scales of large, medium and small are selected. Generally, the larger scale is larger than 200, and the smaller scale is smaller than 20.

H, S, and V refer to the three basic image elements of Hue, Saturation and Value respectively, that is, the HSV color space is a way to express color through the three color components of hue, saturation and brightness [7]. The color space of an image is an object-oriented subjective color model space transformed from the RGB color model space. Because its color performance is more in line with the human visual perception than the RGB color space performance, it has received more extensive attention in recent years. And the single brightness component V operation does not affect other components. Therefore, first transform the image from the RGB color space to the HSV color space, and then use the retinex theory to solve the reflection component R of the V channel

$$\lg R_V(x,y) = \sum_{n=1}^{N} W_n \{\lg I_v(x,y) - \lg[I_v(x,y) * F_n \quad x,y \quad]\}. \tag{3}$$

Finally, through the antilog solution, the image is converted to the RGB color space, and the enhanced image with the improved MSR algorithm is obtained.

2.2. CLAHE with Color Restoration

The CLAHE algorithm divides the image into sub-blocks of the same size, and crops the gray-scale histogram of the sub-blocks by setting a threshold to achieve the purpose of limiting the contrast. Finally, the output value of each point of the image is calculated by bilinear interpolation to eliminate the boundary effect caused by the block.

Due to the image processed by the CLAHE algorithm, there will be color shifts. Therefore, the color restoration method is used to keep the original color of the image. In this paper, the color restoration factor is used to enhance the color of the image, and its expression is

$$C_i(x,y) = f\left[\frac{I_i(x,y)}{\sum_{j=1}^{N} I_j(x,y)}\right] = \beta\left\{\log\left[\alpha I_i(x,y)\right] - \log\left[\sum_{j=1}^{N} I_j(x,y)\right]\right\} \tag{4}$$

among them α is a constant that controls the intensity of nonlinearity, β is a gain constant. $f(\cdot)$ represents the mapping function of the color space. By introducing color factors to adjust the proportional relationship between the color channels in the original image, the color of the original image is restored to eliminate the defect of image color distortion.

Use the color restoration factor to adjust the RGB channels of the image, as follows

$$R' = C_R R \tag{5}$$

$$G' = C_G G \tag{6}$$

$$B' = C_B B \tag{7}$$

among them, R', G', B' are the values of the corresponding channel after the color is restored.

2.3. Image Fusion

The purpose of image fusion is to fuse an image with the information of images resulting from multiple different algorithms, so that the fused image has more information.

This article uses the idea of image fusion. First, the improved CLAHE and MSR algorithms are used to enhance the image respectively, and then the enhanced image is weighted and averaged according to a certain ratio to generate a new image, calculated as follows

$$F(x,y) = \lambda G(x,y) + (1-\lambda) H(x,y) \tag{8}$$

among them, $G(x,y)$ is the enhanced image generated by the improved MSR algorithm, $H(x,y)$ is the enhanced image generated by the improved CLAHE algorithm, and is the weighting coefficient.

Finally, bilateral filtering [8] is used to reduce image noise.

$$F(x,y) = \frac{\sum_{x,y} F(x,y)\, w(i,j,x,y)}{\sum_{x,y} w(i,j,x,y)} \tag{9}$$

among them, w is the weight coefficient, as shown in the following formula

$$w(i,j,x,y) = \exp\left(-\frac{(i-x)^2 + (j-y)^2}{2\delta_d^2} - \frac{\left\|F(i,j) - F(x,y)\right\|^2}{2\delta_r^2}\right) \tag{10}$$

among them, δ_d is the standard deviation of the spatial domain, and δ_r is the standard deviation of the value domain.

This article first performs the CLAHE algorithm with color recovery on the original image to restore the original color of the image and improve the image contrast. Then the original image is converted to HSV color space, its component V is enhanced by MSR algorithm, and then converted to RGB to further improve image contrast and balance light intensity. Finally, through weighted image fusion and image noise reduction, the final enhanced image is obtained. The algorithm flow is shown in Fig. 1.

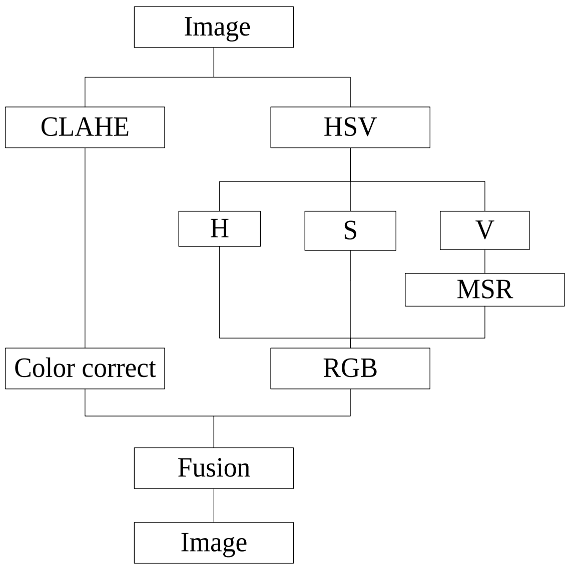

Fig. 1. Algorithm flowchart.

3. Experimental Results

This paper conducts comparative experiments with the traditional image enhancement algorithms of single-scale retinex (SSR) [9], MSR, multi-scale retinex with color restoration (MSRCR) [10], CLAHE and analyzes the results subjectively and objectively.

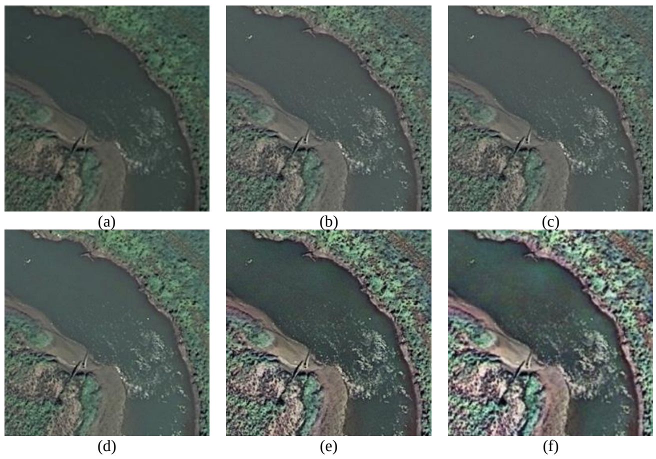

Fig. 2: Algorithm comparison results. (a) Original image, (b) SSR, (c) MSR, (d) MSRCR, (e) CLAHE, (f) Ours.

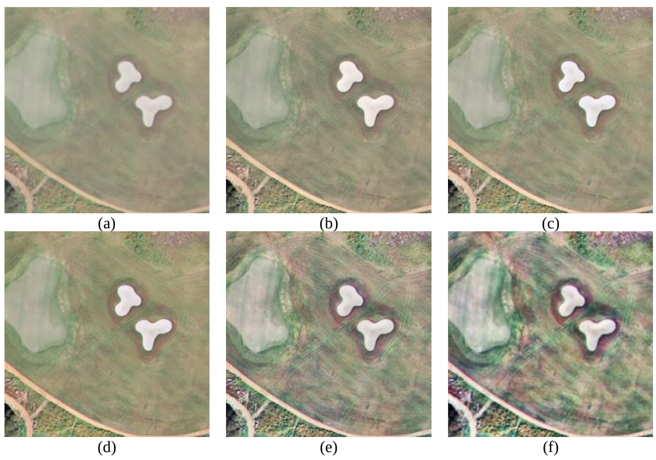

Fig. 3:Algorithm comparison results. (a) Original image, (b) SSR, (c) MSR, (d) MSRCR, (e) CLAHE, (f) Ours.

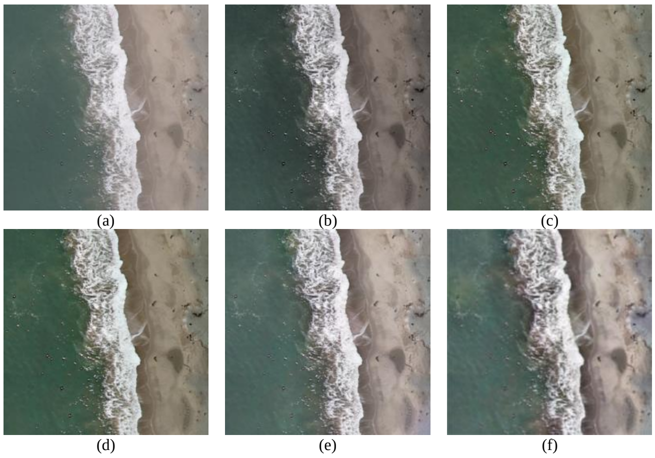

Fig. 4: Algorithm comparison results. (a) Original image, (b) SSR, (c) MSR, (d) MSRCR, (e) CLAHE, (f) Ours.

3.1. Subjective Analysis

Figs. 2-4 show the comparison between the proposed algorithm and other traditional image enhancement algorithms in remote sensing images of three different scenes, where (a) is the original image. It can be seen from Figs. 2-4(b) that the SSR algorithm reduces the highlight part of the image and appropriately enhances the contrast of the image, but there is obvious uneven illumination, darker edges of the image, and slight color deviation. It can be seen from Figs. 2-4(c) that the difference between MSR algorithm and SSR algorithm is not obvious. The details of the image are enhanced to a certain extent, but color distortion also appears. It can be seen from Figs. 2-4(d) that the MSRCR algorithm does not significantly improve the image contrast, the image color is not well restored, the color saturation is low, the edges of the image are blurry, and the details are not clear enough. It can be seen from Figs. 2-4(e) that the CLAHE algorithm improves the image contrast significantly, but the image color is distorted, and the edge details of the image are not clear enough. The algorithm proposed in this paper enhances the image contrast and also restores the image color well. The image details have also been enhanced to some extent.

3.2. Objective Analysis

This paper evaluates the image quality from five objective evaluation indexes: information entropy, mean, variance, the peak signal to noise ratio (PSNR) and the structural similarity index (SSIM). Information entropy represents the detail performance of the image, the mean value represents the change of the average brightness of the image, and the standard deviation represents the contrast of the image, as shown in Tables I-V. Show. It can be seen from Tables I-V that the results of the SSR, MSR, MSRCR algorithm are similar, but the difference is not big. The information entropy and variance of the original image are not improved much, resulting in the enhanced image, the contrast is still not high, and the difference from the original image is not obvious. Consistent with subjective evaluation. Compared with the SSR, MSR, MSRCR algorithm, the CLAHE algorithm has a very high increase in information entropy, and the image variance is also very well improved, so that the image contrast is well enhanced. In the PSNR and SSIM indicators, the methods mentioned in this paper have also achieved good results. Compared with other algorithms, the algorithm proposed in this paper is in objective indicators. Both have achieved good results, which can reasonably improve the image contrast, change the image brightness, and better improve the image information entropy.

Table 1: Evaluation Results of Information Entropy

	Orig.	SSR	MSR	MSRCR	CLAHE	Ours
golfcourse	5.853	6.184	6.173	6.213	6.822	7.511
river	5.736	6.026	6.011	6.025	6.906	7.411
beach	6.671	6.870	6.759	6.749	6.855	7.080

Table 2: Evaluation Results of Variance

	Orig.	SSR	MSR	MSRCR	CLAHE	Ours
golfcourse	17.527	22.773	21.959	22.727	28.866	44.736
river	16.041	18.147	18.934	19.046	34.918	48.311
beach	40.593	43.898	42.413	42.037	42.061	43.916

Table 3: Evaluation Results of Mean

	Orig.	SSR	MSR	MSRCR	CLAHE	Ours
golfcourse	151.793	149.520	149.190	152.682	148.838	143.502
river	71.313	89.751	92.867	93.195	92.090	103.132
beach	131.323	103.680	114.101	114.104	131.754	128.726

Table 4: Evaluation Results of PSNR

	SSR	MSR	MSRCR	CLAHE	Ours
golfcourse	30.708	30.966	31.943	24.953	26.676
river	21.033	21.033	20.915	18.782	19.162
beach	18.282	22.243	22.248	27.161	24.162

Table 5: Evaluation Results of SSIM

	SSR	MSR	MSRCR	CLAHE	Ours
golfcourse	0.937	0.945	0.952	0.827	0.886
river	0.921	0.921	0.921	0.705	0.753
beach	0.918	0.964	0.964	0.964	0.915

4. Conclusions

Aiming at the problems of low contrast, color distortion and blurry details of remote sensing images, a remote sensing image enhancement algorithm based on fusion is proposed. First, perform CLAHE algorithm and MSR algorithm respectively on the original remote sensing image, generate enhanced image results and then perform image fusion, combine the characteristics of multiple algorithms, and finally generate enhanced images. Experimental analysis shows that the algorithm proposed in this paper is superior to other traditional image enhancement algorithms. It can effectively enhance image contrast, restore true colors, enhance image details, improve image perception, and provide good help for further remote sensing image processing.

5. References

[1] E. H. Land and J. J. McCann, “Lightness and retinex theory,” *Josa*, vol. 61, no. 1, pp. 1–11, 1971.

[2] Antonini, M., and Barlaud, “Image coding using wavelet transform,” *IEEE Transactions on Image Processing*, vol. 1, no. 2, pp. 205–220, 1992.

[3] R. C. Gonzalez, R. E. Woods, and B. R. Masters, “Digital image processing, third edition,” *Journal of Biomedical Optics*, vol. 14, no. 2, p. 029901, 2009.

[4] Y. Chang, C. Jung, P. Ke, H. Song, and J. Hwang, “Automatic contrast-limited adaptive histogram equalization with dual gamma correction,” *IEEE Access*, vol. 6, pp. 11 782–11 792, 2018.

[5] K. Ma, H. Li, H. Yong, Z. Wang, D. Meng, and L. Zhang, “Robust multi-exposure image fusion: a structural patch decomposition approach,” *IEEE Transactions on Image Processing*, vol. 26, no. 5, pp. 2519–2532, 2017.

[6] Z.-u. Rahman, D. J. Jobson, and G. A. Woodell, “Multi-scale retinex for color image enhancement,” in *Proceedings of 3rd IEEE International Conference on Image Processing*, vol. 3. IEEE, 1996, pp. 1003–1006.

[7] P. Perona and J. Malik, “Scale-space and edge detection using anisotropic diffusion,” *IEEE Transactions on pattern analysis and machine intelligence*, vol. 12, no. 7, pp. 629–639, 1990.

[8] M. Zhang and B. K. Gunturk, “Multiresolution bilateral filtering for image denoising,” *IEEE Transactions on image processing*, vol. 17, no. 12, pp. 2324–2333, 2008.

[9] D. J. Jobson, Z.-u. Rahman, and G. A. Woodell, “Properties and performance of a center/surround retinex,” *IEEE transactions on image processing*, vol. 6, no. 3, pp. 451–462, 1997.

[10] D. J. Jobson, Z.-u. Rahman, and G. A. Woodell, “A multiscale retinex for bridging the gap between color images and the human observation of scenes,” *IEEE Transactions on Image processing*, vol. 6, no. 7, pp. 965–976, 1997.