An Aerial Remote Sensing Image's Mosaic Approach Using Multi-layer Wavelet Fusion Based on Structure Similarity

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ABSTRACT

In order to solve the problems that image's entropy of information decline obviously and boundary line phenomenon appear obviously in the processing of aerial remote sensing image's mosaic, an image mosaic approach is presented in this paper, which uses wavelet image fusion based on structure similarity and is capable of creating seamless mosaics in real-time. The approach consists of three steps. First, the overlapping area of two aerial images is extracted. Then, the two overlapping area images are fused adaptively by the method of multi-layer wavelet decomposition based on the structure similarity and appointed regulation. Finally, weighted average fusion is used again to avoid the visible boundary line for the both sides of the boundary of the above fusion image. Experimental results show the entropy of information, sharpness and standard deviation have been improved significantly, and the boundary line has been eliminated observably.

Keywords: Aerial remote sensing; Image's mosaic; Wavelet transform image fusion; Structure similarity; Weighted average fusion

1. INTRODUCTION

Image mosaic technology is to put two or more remote sensing images together into a whole image, which aims to increase visual perception by composing visual data obtained from separate images since a composite image provides richer description than individual images. Along with the rapid advance of the aerospace technology, the requirement of extensive and high definition remote sensing image is growing, especially for the aerial remote sensing image. The image mosaic technology is an important link of remote sensing image processing. About image mosaic approach, in 1994, Li applied wavelet transform to image fusion[1]; In 2001, Scheunders presented a multi-spectral image fusion based on multi-scale wavelet[2], and a new vector-valued image wavelet representation was presented and image edge information was made use of; In 2000, Liu and Yang proposed pixel-level operator[3], and this method improved the effect of image fusion on the detail; In 2002, Jin proposed multispectral image realistic fusion method[4], which emphasized retain original image's spectral signature; In 2004, Jiang adopted histogram matching to achieve color balance[5]; In 2010, in order to improve the entropy of information and avoided the obvious boundary line, Zhang and Pan adopted side-scan sonar to research remote sensing image mosaic[6]; In order to eliminate the intensity difference, Li proposed robust image mosaic by corner matching[7], and adopted weighted average fusion in the process of image mosaic.

In order to solve the problems that image's entropy of information decline obviously and apparent boundary line phenomenon in the processing of aerial remote sensing image's mosaic, a new image mosaic approach is presented in this paper, which uses wavelet image fusion based on structure similarity and is capable of creating seamless mosaics in real-time.

2. METHOD

The proposed approach consists of three steps. First, overlapping area of two aerial images is extracted using the software "ENVI" of processing remote sensing images, and edge of the two overlapping area are extracted further using the improved "Canny" operator[8]. Owing to intensity difference of two mosaic images obtained from different time, histogram matching is used to eliminate the intensity difference before first step[9]. Then, the two overlapping area

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images are decomposed by the method of multi-layer wavelet, and fused adaptively according to different fusion rule for low frequency component and high frequency component respectively. Image fusion for the low frequency component is

based on region energy. Image fusion for the high frequency component is based on variance and are served largest variance of pixels as the blending image's pixels for pixel points of the extracted edge, and for another pixel points, we judge the size of structural similarity and threshold value, and determine the fusion algorithm based on maximum value or weighted-average fusion that will be chose. Finally, weighted-average fusion is used again to avoid the visible boundary line for the both sides of the boundary of the above fusion image.

2.1 Wavelet-based image fusion

Two images of the overlapping area are decomposed into low frequency component and high frequency component by wavelet transform, in which the choice of wavelet function is to use the methods of designing filter bank, which match all the conditions and match wavelet basis criterion. The low frequency component denotes image's approximate component, and the high frequency component denotes image's detail component. The choice of fusion rule determines the quality of fusion image, and affects the result of image mosaic, then has an important influence for visual effect. The detail of the image always consist in high frequency component, so only chose appropriate fusion rule, can we perform image fusion effectively in the corresponding frequency component. The existing fusion rule divided into two types, one is based on pixel, which regards one pixel as one isolated point, and the other one is based on a window region, which reflects the characteristics of the image largely. This paper chooses fusion rule based on a region, and the size of window is 3×3.

(1) Fusion rule of the low frequency component

The wavelet fusion adopts three layer wavelet decomposition. This paper choose region energy as fusion rule for the low frequency component, and then obtain the low frequency coefficient.

First, calculating the sum of energy in the border-upon domain, which is centered on (i,j) and sized of 3×3 window, then calculating the weight of the wavelet coefficient of the fusion image. The formula is described as:

$$\mathrm{E}_1 = \frac{1}{9}\sum_{\mathrm{i,j}=-1}^{1} \omega(1+\mathrm{i}, 1+\mathrm{j}) \times [\mathrm{L}_1\,(\mathrm{x}+\mathrm{i}, \mathrm{y}+\mathrm{j})]^2 \tag{1}$$

$$\mathrm{E}_2 = \frac{1}{9}\sum_{\mathrm{i,j}=-1}^{1} \omega(1+\mathrm{i}, 1+\mathrm{j}) \times [\mathrm{L}_2\,(\mathrm{x}+\mathrm{i}, \mathrm{y}+\mathrm{j})]^2 \tag{2}$$

E_1 and E_2 denote the sum of region energy, L_1 and L_2 denote the low frequency coefficients of wavelet decomposition of two source images, ω denotes weight coefficient matrix, and described as:

$$\omega = \frac{1}{12}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 4 & 1 \\ 1 & 1 & 1 \end{bmatrix} \tag{3}$$

Then, L denotes the low frequency coefficient of the fusion image, and described as:

$$\mathrm{L}(\mathrm{i},\mathrm{j}) = \frac{\mathrm{E}_1}{\mathrm{E}_1+\mathrm{E}_2} \times \mathrm{L}_1(\mathrm{i},\mathrm{j}) + \frac{\mathrm{E}_2}{\mathrm{E}_1+\mathrm{E}_2} \times \mathrm{L}_2(\mathrm{i},\mathrm{j}) \tag{4}$$

(2) Fusion rule of the high frequency component

First, we choose a pixel from the edge region of the two overlapped images respectively, then choose a partial region around the chose pixel. The size of the partial region is 3×3, then the variance of the partial region is calculated[10], if the value is larger than other one, this image's wavelet coefficient serve as the wavelet coefficient of the fused image. The variance of the partial region can be given by:

$$\mathrm{D}_1 = \sum_{\mathrm{i,j}=-1}^{1} [\mathrm{W}_1(\mathrm{x}+\mathrm{i}, \mathrm{y}+\mathrm{j}) - \mathrm{Ave}_1]^2 \tag{5}$$

$$\mathrm{D}_2 = \sum_{\mathrm{i,j}=-1}^{1} [\mathrm{W}_2(\mathrm{x}+\mathrm{i}, \mathrm{y}+\mathrm{j}) - \mathrm{Ave}_2]^2 \tag{6}$$

D_1 and D_2 denote variance of the partial region, W_1 and W_2 denote high frequency coefficient of wavelet decomposition, Ave_1 and Ave_2 denote mean value of partial region wavelet coefficient, then the high frequency coefficient of fused image is defined as:

$$W(x,y)=\frac{D_1}{D_1+D_2}W_1(x,y)+\frac{D_2}{D_1+D_2}W_2(x,y) \tag{7}$$

Second, for another pixel points, the value of structural similarity (SSIM) is calculated. The SSIM quantifies visual quality with a similarity measure between two patches x and y as the product of three components: mean $m(x,y)$, variance $v(x,y)$, and cross-correlation $r(x,y)$. The two patches: x and y, correspond to the same spatial windows of the images X and Y , respectively. The SSIM value for the patches x and y is given as[11]:

$$SSIM(x,y)=m(x,y)^{\alpha}\times v(x,y)^{\beta}\times r(x,y)^{\gamma}=\left(\frac{2\mu_x\mu_y+C_1}{\mu_x^2+\mu_y^2+C_1}\right)^{\alpha}\times\left(\frac{2\sigma_x\sigma_y+C_2}{\sigma_x^2+\sigma_y^2+C_2}\right)^{\beta}\times\left(\frac{\sigma_{xy}+C_3}{\sigma_x\sigma_y+C_3}\right)^{\gamma}=m\times v\times r \tag{8}$$

Where μ_x denotes the mean of x, σ_x denote the standard deviation of x, σ_{xy} is the cross-correlation(inner product) of the mean shifted images $x-\mu_x$ and $y-\mu_y$, and the C_i for $i=1,2,3$ are small positive constants, these constants combat stability issues when either $\mu_x^2+\mu_y^2$ or $\sigma_x^2+\sigma_y^2$ is close to zero. The positive exponents α, β, and γ allow adjustments to the exponent's contribution to the overall SSIM value. The original specification for SSIM, set $C_3=\frac{C_2}{2}$ and $\alpha=\beta=\gamma=1$, which simplifies (8) to[11]:

$$SSIM(x,y)=\left(\frac{2\mu_x\mu_y+C_1}{\mu_x^2+\mu_y^2+C_1}\right)\times\left(\frac{2\sigma_{xy}+C_2}{\sigma_x^2+\sigma_y^2+C_2}\right)=(m)\times(v\times r) \tag{9}$$

The overall SSIM image quality index for images X and Y is computed by averaging the SSIM values computed for small patches of the two images. The SSIM value is computed with $\alpha=\beta=\gamma=1$ and after downsampling the images X and Y by (9) in both spatial direction.

With more tests and analyzes were proceed repeatedly, we calculated a threshold value ($T=0.9$). If the value of SSIM is larger than the threshold value, the component pixels should be adopted by weighted-average fusion[10], and the weighted-average operator is defined as:

$$F_{L_iL_j}=0.5A_{L_iL_j}+0.5B_{L_iL_j} \qquad i=1,2;\ j=1,2 \tag{10}$$

If the value of SSIM is larger than the threshold value, in order to ensure image's entropy of information don't decline, the image fusion algorithm based on maximum value[12], and we choose the maximum pixel value serve as the pixel value of the fusion image.

2.2 Elimination of visible boundary line

The two images obtained from different time led to the image intensity difference and appear the obvious boundary line. In order to eliminate the visible boundary, the pixel gray difference should be counted up on both sides of boundary line within certain limits, and the intensity difference is eliminated compulsively by specified method. This process is called as feather process. The method of eliminating the visible boundary line based on histogram matching was usually used[5], but in this paper, the remote sensing image is processed by histogram matching, the effect is not very good, and the visible boundary line is still appear. So in this paper, we adopt a method of eliminating the visible boundary line based on weighted-average fusion.

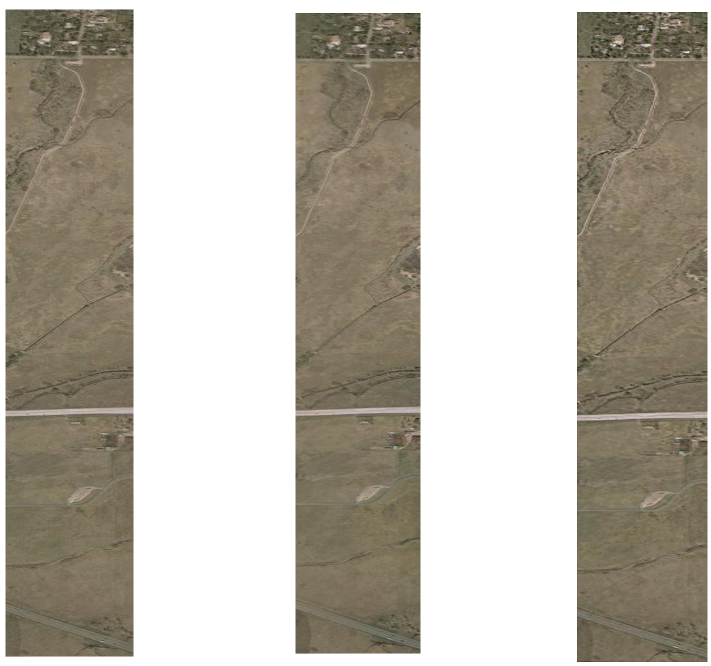
3. EXPERIMENTAL RESULTS

3.1 Results of image fusion

Experiments were carried out on the original images and which were shown as Fig. 1. At the same time, experimental results ware compared with ones for two kinds of image fusion approaches of the side scan sonar based on wavelet[6] and corner matching[7]. Experimental results for three approaches are shown in Fig. 2: (a) variance method; (b) weighted-average fusion; (c) the proposed method.

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

Fig. 1 Experimental images to test the mosaic approaches for overlapping area and their corresponding overlapping areas: (a) and (b): the two original images; (c) and (d): corresponding overlapping areas of the two original images



(a) (b) (c)

Fig. 2 Experimental results for three image fusion approaches: (a) variance method; (b) weighted-average fusion; (c) the proposed method

3.2 Results of eliminating visible boundary line

Experimental results of eliminating visible boundary line for above three fusion images (our presented fusion approach) are shown in Fig. 3: (a)variance method in high frequency component[6], (b) weighted-average[7], and (c)weighted-average in this paper.

(a)

(b)

(c)

Fig.3 The mosaic image is processed by two different methods of eliminating visible boundary line: (a) unprocessed image; (b) histogram matching; (c) weighted average fusion.

3.3 Qualitative analysis

(1) Qualitative analysis of the fusion images

The purpose of image fusion is to enhance the spatial and spectral resolution, and it is thus necessary to propose quality indicators to measure the quality of the images generated by different image fusion methods. Up to now, several indices have been proposed for assessing image quality, which can also be applied to assessing the quality of a fused image. A final overall quality judgment can be obtained by, for example, standard variation, information entropy[13] and definition[14].

Evaluation results of the fusion images are listed in Table. 1. Results show that the information entropy, standard variation and definition of Fig. 2(c) are larger than these of Fig. 2(a) and Fig. 2(b). It illustrate this paper's algorithm not only let image's information entropy increase, but also reflect more detail characteristics of the image.

Table.1 Evaluation results of the fusion images in the Fig.2 (a), (b) and (c)

	variance method	weighted-average	the proposed method
Information entropy	11.61	11.85	12.97
Standard variation	15.67	16.12	17.96
Definition	7.14	6.56	10.15

(2) Qualitative analysis of the mosaic images

In order to test the objective result of eliminate the visible boundary line, the improved “Canny” operator is used again in the process, we obtain edge information of the three mosaic images respectively, and the edge information of the three mosaic images are shown in Fig. 4. Results show from the square marks in Fig. 4 that the effect of (c) is better than ones of (a) and (b). The method of eliminating the visible boundary line based on weighted average fusion is better than that of eliminate the visible boundary line based on histogram matching.

(a)

(b)

(c)

Fig. 4 the edge information of the three mosaic images: (a) unprocessed image; (b) histogram matching; (c) weighted average fusion

4. CONCLUSION AND DISCUSSION

We have now developed a new aerial remote sensing image mosaic approach which can create large remote sensing image mosaic in a real-time. First, the wavelet-based fusion adopts three layer wavelet fusion. The edge extraction is performed on the two overlapped images respectively, the edge component of image use variance fusion; Second, the value of the two overlapped images' SSIM is calculated, after more tests and analyzes proceed repeatedly, we calculate a threshold value (T=0.9). If the value of SSIM is larger than the threshold value, the component pixels should be adopted by weighted average fusion. Through the visual and objective tests, the image's entropy of information decrease obviously, and apparent boundary line phenomenon in the processing of aerial remote sensing image's mosaic have been improved obviously. The proposed approach has low computational complexity, and hence is suitable for real time applications.

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