Super Resolution Reconstruction of Three View Remote Sensing Images based on Global Weighted POCS Algorithm

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***Abstract*—The spatial information compression and data unbalance of CE-1 three view images, which caused by the three-line-array CCD stereo camera imaging view angle and the gradient variety of the lunar surface landform, were seriously considered and an improved super resolution reconstruction algorithm based on global weighted POCS for remote sensing images was proposed in this paper. The global weighted coefficients were calculated by normalizing the mean gradient of original remote sensing images. The residual error and gray scale were introduced as constraint sets during the iteration reconstruction of the three view remote sensing images, by which, the spatial information of remote sensing images was mined and the reconstruction image resolution was compensated and enhanced. Experiment results showed that, the reconstructed images by using the global weighted POCS algorithm have better subjective discerning effect of image details and higher spatial resolution, compared with the widely used algorithm, such as the nearest neighbor interpolation POCS algorithm.**

Keywords-global weighted; super resolution reconstruction; mean gradient; information entropy; POCS

I. INTRODUCTION

Asynchronous push-broom remote sensing stereo imaging is the widely used aero-space imaging style[1,2]. On account of the view angle difference of the asynchronous push-broom imaging and the gradient variance of the lunar topography, the spatial information is compressed between the asynchronous push-broom remote sensing sequence images, which results in the 3D data loss. The asynchronous push-broom stereo imaging precision is reduced caused by the information unbalance of the three view remote sensing images. Studying the super resolution reconstruction method of asynchronous push-broom remote sensing images is of great importance to improve the stereo imaging definition and resolution.

The sequence images spatial resolution enhancement methods can be classified into two kinds[3]: the frequency domain method and the spatial domain method. Compared with the former method, the latter method is more widely used because of its flexibility and applicability. Based on the pixel scale, the pixels conversion and constraint are executed through the spatial-domain method and the complex motion model is processed together with the corresponding interpolation, iteration, and filtration. The currently common used approaches are the probability theory algorithm[4], iterative back-projection approach[5], regularization method[6] and so on. The mentioned spatial-domain methods above is disable to compensate the 3D data unbalance between the asynchronous push-broom remote sensing three view images, which will result in the spatial data loss of the remote sensing images during the super resolution reconstruction.

A global weighted POCS algorithm based on the mean gradient normalization of sequence images is given in this paper. The mean gradient normalization is applied to calculate the weighted coefficients and the residual error and gray scale constraint are introduced to the iteration of the three view remote sensing images to reconstruct new images.

II. PRINCIPIUM AND ALGORITHM

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A. The POCS theory

POCS (Projection Onto Convex Sets) algorithm is the iterative projection to acquire the optimum solutions from the given initial sets[7]. Using the set theory, all prior knowledge, such as positive definite, energy bounded, data reliable and glassy, of images to be reconstructed are defined as constraint convex sets: $\Psi_1,\ \Psi_2,\ \cdots\ \Psi_n$. The intersection of these convex sets is closed nonempty and defined as: $\psi = \left\{ \bigcap_{i=1}^{n} \psi_i \right\}$. The POCS algorithm is the process of starting from the initial estimation X_0, contained in the sequence images set ΦX, to reach the optimum solution X, by applying convex sets projection operators $P_1, P_2, \ldots, P_n$ to X_0. This iteration is shown in Fig.1 and can be mathematically described as:

$$X = \left(P_1, P_2, \ldots, P_n\right)^t (X) \tag{1}$$

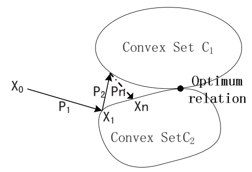


Figure 1. Iteration process of POCS

B. Global weighted POCS algorithm

The remote sensing sequence images $X_1, X_2, \ldots, X_n$ are contained in the known initial images set ΦX. During the iterative process of asynchronous push-broom remote sensing stereo imaging, the imaging angle difference of single-track three view images and the gradient variance of lunar surface landform lead to the spatial 3D information compression on the 2D image and information unbalance among single-track three view images. An improved POCS algorithm based on the image mean gradient global weighting was proposed here to compensate the 3D information unbalance and enhance the spatial resolution of the CE-1 remote sensing images. The global weighted coefficients are got by normalizing the mean gradient of initial sequence images; the residual error and gray-scale constraint are used to the single-track three view images to mine the spatial information of remote sensing images. Concrete steps are as follows:

- Calculate the mean gradient $grt_1, grt_2, \ldots, grt_n$ of sequence images $X_1, X_2, \ldots, X_n$, which are contained in the initial remote sensing image set ΦX;
- Normalize the mean gradient $grt_1, grt_2, \ldots, grt_n$; gain the final global weighted coefficient of remote sensing sequence images $X_1, X_2, \ldots, X_n$:

$$k^i = (grt_i) \Big/ \left(\sum_{i=1}^{n} \frac{grt_i}{n}\right), i = 1, 2 \ldots n \tag{2}$$

- Define the residual error constraint set as:

$$H_1 = \left\{ F \mid R^{(i)}(j,k) \le \eta^i(j,k) \right\}, i = 1, 2, \ldots, n \tag{3}$$

Wherein, η^i is the predetermined threshold; $R^{(i)}$ is the residual error, defined as:

$$R^{(i)}(j,l) = k^i * X^i(j,l) - \sum_{x=p-2}^{x=p+2} \sum_{y=q-2}^{y=q+2} E(x,y) F(x,y), i = 1, 2 \ldots n \tag{4}$$

Wherein, $X^i(j,l)$ is the pixel value of arbitrary point of the ith image in the initial image set ΦX. E is the current remote sensing image after information mining and resolution reconstruction. F is the image point spread function.

From (4) it can be found that, the weighted coefficients are introduced into the iteration reconstruction, which is the key point of the global weighted POCS algorithm different from the other methods.

C. Steps of global weighted POCS algorithm

The geomorphological feature region is drawn through preprocessing the CE-1 image data on the basis of gradient and dimension principle, by which the lunar surface landform areas with prominent gradient change are found in the whole-track remote sensing image which contains large quantity information and equably distributes numerous lunar landform factors. The necessary steps of the global weighted POCS algorithm are shown in Fig. 2.

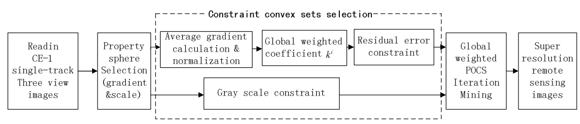


Figure 2. Steps of the global weighted POCS algorithm

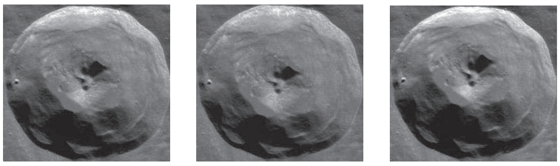
As the amplitude range of gray level image is [0,255], the gray-level constraint convex set is introduced into the confirmatory test, which is defined as:

$$H_2=\begin{cases}0 & , \quad E(j,k)\le 0\\ E(j,k) & , \quad 0<E(j,k)<255\\ 255 & , \quad E(j,k)\ge 255\end{cases} \tag{5}$$

Wherein, $E(j,k)$ is the gray value of the (jth,kth) pixel points in the current super resolution remote sensing image which is under reconstruction.

III. EXPERIMENTS AND DATA ANALYSIS

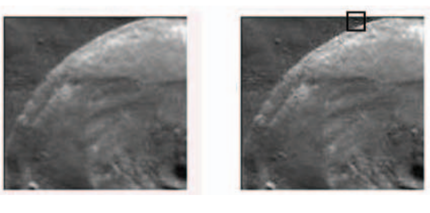
The nadir, the back and front view image are selected from the CE-1 CCD images database as the source data(CE1_BMYK_CCD-N_SCI_N_200801020) in this experiment. The data volume of whole track remote sensing image is excessively oversized. Part of the single-track image, such as a crater, can be well used in experiments because of its good edge property and apparent gradient variance.



（a）back view （b）nadir view （c）front view

Figure 3. CE-1 Single-track three view images of craters

Spatial information of the single-track three view remote sensing images is mined by using the global weighted POCS algorithm and the super resolution(SR) image is reconstructed. The initial image is interpolated and magnified. The contrast between the SR image and the interpolation image is shown in Fig. 4. The SR image, acquired by using the global weighted POCS algorithm to mine the spatial information, is evaluated through the subjective visual interpretation and the objective mathematical statistics.



（a）Initial image （b）Global weighted POCS

Fig.4. Contrast between the global weighted POCS and initial image

A. Subjective evaluation based on visual interpretation

From the contrast between Fig.4 (a) and (b), the results can be gotten: the remote sensing image reconstructed through the global weighted POCS algorithm has clearer image edge and texture detail, compared with the initial image. The existed terrain feature in initial image has been enhanced and there appears some new visible lunar topographical factor, which has been marked by rectangle frame in Fig.4 (b).

In order to intuitively demonstrate the texture enhancement area of the reconstructed SR images, the image difference and binarization are done between the super resolution remote sensing image which is reconstructed after 25 times iteration and the initial image of lunar craters. Results are shown in Fig. 5, in which, the white areas are the distinctly enhanced texture area or the increased cognizable feature after information mining and iterative reconstruction.

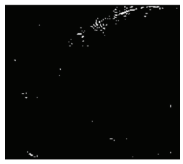


Fig.5. Enhanced or increased information in SR image

B. Objective evaluation based on mathematical statistics

The information entropy[8] and mean gradient are used as objective evaluation parameters to assess the remote sensing images reconstructed after the information mining by using the global weighted POCS algorithm. The information entropy reflects the information increasing level of remote sensing images. The mean gradient represents the image definition, reflects the expression ability of the images details and the improved degree of image spatial resolution.

Table 1 Contrast table of objective evaluation

	Information entropy	***Mean gradient***
Initial image	6.8300	3.2882
Nearest-neighbor interpolation POCS	6.5749	3.7389
Global weighted POCS	6.8887	3.9794

Table 1 lists the objective performance indices of three kinds images which are the initial image, the image using the nearest-neighbor interpolation POCS method and the image using the global weighted POCS method. The mean gradient of the latter two images are higher than that of the initial images, which raises to 3.7389 and 3.9794 from 3.2882. On the other hand, the information entropy of the global weighted POCS image raises to 6.8887 from 6.83 while the information entropy of the nearest-neighbor interpolation POCS image reduces to 6.5749.

It is clear that, by using the nearest-neighbor interpolation POCS to reconstruct the single-track three view remote sensing images of CE-1, although the image resolution is enhanced and the image detail is clearer, the information loss happens during the image iterative reconstruction, which is caused by its ignoring the spatial information unbalance among the asynchronous push-broom three view images. On the contrast, spatial information compression of CE-1 single-track three view images caused by the imaging angle difference and lunar surface landform variance is fully considered in the proposed global weighted POCS algorithm. Information unbalance is normalized during the iteration process. From the listed data in Table 1 it can be analyzed that, the gross information content is increased, the texture detail is enhanced and the image resolution is improved. It needs to point out that, the reconstructed images resolution has increased about 21.02 percentages.

In conclusion, the global weighted POCS algorithm outperforms the currently widely used algorithm in preserving the image gross information content, texture detail and high spatial resolution.

Table 2 Image mean gradient variance with iterations

Iteration times	5	10	15	20	25
mean gradient	3.9673	3.9762	3.9782	3.9790	3.9794

The positive correlative property is observed between the SR image spatial resolution and the iteration times during the iteration of the global weighted POCS algorithm. As shown in table 2, the image detail will be clearer and the spatial resolution will be higher alongside of the iteration times being more. The positive correlation is convergent and tends towards stability, which can be derived in Fig. 6. It is therefore clear that the global weighted POCS algorithm for remote sensing image super resolution reconstruction can receive an optimum solution.

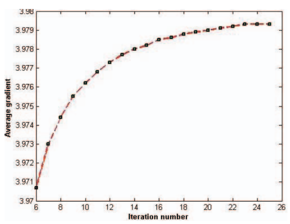


Fig.6.Iteration convergence curve of global weighted POCS

IV. CONCLUSION

The spatial information of the same track but different view images is compressed caused by the imaging angle difference and landform gradient variance of the single-track three view images during the asynchronous push-broom remote sensing stereo imaging. This results in the disability of spatial resolution enhancement algorithms, which are regularly used on sequence images, to mine spatial data and compensate the resolution unbalance among the asynchronous push-broom images. Based on this, the global weighted POCS algorithm was given in this paper. During the iteration of the spatial data mining, the weight coefficients of all views remote sensing images are calculated through normalizing the mean gradient, which will be introduced into the iteration. Results show that, the global weighted POCS algorithm can enhance the image detail and texture definition and improve the spatial resolution, while increasing the image information content.

V. ACKNOWLEDGE

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