A Patch Analysis Based Repairing Method for Two Dimensional Fiber Spectrum Image

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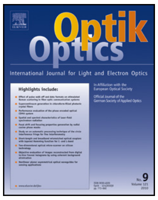

A patch analysis based repairing method for two dimensional fiber spectrum image

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ABSTRACT

As production of the telescope observation system, spectrum CCD images are affected by cosmic rays, dust, atmospheric and other natural conditions, which add noise to the spectrum information in image and make the image data difficult to study. The process of repairing the noise influence for CCD image is important. Existing methods such as median filter process and template matching cannot get balance for speed and precision. This paper presents a method based on local patch analysis. First, source image is compressed in order to target the noise area patch efficiently. Second, noise area patches in source CCD image are captured by building mapping relationship of noise area patches between compression image and source image. Finally noise area patches are fixed by using the local patch analysis method. Experiment proves that this algorithm can get better result and remove the cosmic rays affect efficiently.

1. Introduction

The spectrum CCD images are produced from the observation system of telescope's process .These images are influenced by natural conditions, such as cosmic rays, weather condition, the intensity of light, particles in the universe. The original spectrum CCD images with noises are hard to use in further research. Therefore it is important to remove the natural conditions affect in the image.

Through research of spectrum CCD images, it is clear that there are obvious regulations in the spectral information area, but not in the noise pollution area. Pixels' gray values in noise pollution area are random. According to this analysis we build the algorithm to judge if the pixel in the image is noise or not. Some existing methods remove the noise pollution in CCD image by classical filter process; other methods build the match patches to analyze the spectrum CCD image and rebuild noise pollution area. Using classical filter can remove noise pixels and get a good result for natural images especially for the noise in accordance with Gaussian distribution. But for CCD image, it can't work well in some noise pollution area when the noise's distribution is different with salt noise. The method based on patch match thought can get a better result than classical filter; however it requires more compute time to establish the matching patch set and the result will be affected by strategy for selecting the match patches.

In this paper, the CCD image is repaired in three steps. An image pyramid technique is used to reduce computation in the first step. Generally, the image's structural information after compression process will not be destroyed; the boundaries and texture information are retained in the image compression result, as well as noise pollution area. So we run a down-sampling

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process for the original image to reduce image resolution, it does not affect the location of noise pollution area and can accelerate computing. After this step, we use local patch analysis method and build a mapping between image compression process result and the original image to locate noise pollution area. Finally we use a patch analysis based repairing method to complete the CCD image repair work. Our method can effectively reduce the operation cost and improve the quality of the result.

The specific implementation steps are as follows: Original CCD image is compressed by using the nearest neighbor method with down-sampling scale coefficient determined by the accuracy of the CCD image. Next patches on compression result is analyzed and represented as a parameter value according to an evaluation function. Noise pollution patches on compression image can be located by comparing this parameter value with a predefined threshold value. According to the mapping between original image and the compression result, the noise pollution area patches in the original image can be located efficiently and be repaired in the next process. According to the self-similarity of spectral information an improved nearest patch mean smooth based repairing method is presented in this paper, which finds the nearest spectrum patch and repairs the noise pollution area patch by replacing with it. All the steps of this process are regulated based on the distribution of spectral information.

Experimental results demonstrate that, our method successfully repair the noise pollution area and make the CCD image clear both effectively and efficiently. Although some normal areas are erroneously determined as the noise pollution area, the results were not affected.

2. Related work

Removing the cosmic rays in the CCD image is important [1], early methods take two or more pictures in the same scene and synthesis one picture to determine the spectral information. The core idea is adding more information for one scene to complete repair work [2]. But such methods are limited by the conditions of practical application, including the natural conditions, the weather and the normal change of the spectral information. Now main repair methods are based on a single image.

In introduction, the median filter method has been mentioned to solve the single image repair work, include some ideas to optimize median filtering's structure [3]. It can get a good result when the noise pollution area's distribution likes salt noise. However, when the noise pollution area's distribution regulation significantly different from the salt noise, then the method need process the image once more to get the better result. It also be affected by the change of normal spectral information in the spatial direction, make the result in blurred.

Establish function model [4] and classifier [5] to complete image restoration also be used in this field. Such methods distinguish spectral information by establishing a series of process steps, and then targeted and repair the noisy information. The methods can obtain accurate results, but the time cost is obviously. Especially for mass spectral image restoration, the performance is not well.

In order to improve performance, the original method was applied by GPU acceleration technology [6,7]. Using GPU's powerful parallel computing ability can effectively improve the original method of the low operating efficiency. [9]. Based on template matching method is good for the application of GPU acceleration. It needs to build a template set to match the spectral information. Using GPU parallel arithmetic can parallel match, accelerate method's speed effectively. But it is necessary to ensure its accuracy by the accurate algorithm. The algorithm's quality will influence the realization of the method, which is restricting the method [8].

Some methods are based on spectral structure repair and have a wide use in information reconstruction [10,11]. In spectral space, various natural conditions also have complex noise in image. Different bands of spectral space have different kinds of noisy, which seriously interfere information extraction and analysis based on spectral analysis [12,13].

3. Image compression

Image pyramid technology has been extensively used both in up-sampling and down-sampling methods. The classical up-sampling methods include nearest neighbor algorithm, bilinear algorithm and bi-cubic interpolation algorithm. These methods can keep the image structure after the process, make picture clear and smooth the saw tooth effect. It can also be applied inversely in down-sampling to compress the image. This process can keep the structure and reduce the resolution of the original CCD image, an instance is shown in Fig. 1. In order to improve the performance, high resolution original CCD image is down-sampled to lower resolution image, which be used to get position of noise pollution area. Choosing a suitable down-sampling method is important. In this paper a nearest neighbor based algorithm is used to compress image because it is the fastest method and satisfy requirement of keep the structural information's precision. Scale coefficient selection for down-sampling is also important because it has a big influence to determine the location of the pollution area of precision.

As shown in Fig. 1, the left picture is the high resolution original image; the right is the lower resolution compression result image. By analyzing the noise pollution area in CCD image examples we found that the smallest cosmic pollution patch's size is about 7 * 7 pixels. So in theory, if down-sampling scale coefficient is less than 7, the noise pollution area can be kept in lower resolution compression image without wrong judgment. As this conclusion is captured statistically, so a down-sampling scale coefficient less than 7 is selected to keep balance of performance and precision. The details for scale coefficient choosing is shown in the next section. During this down-sampling process smoothness is not required, so we

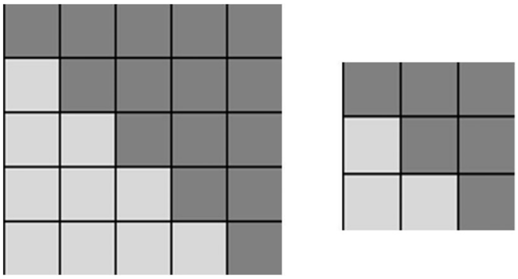

Fig. 1. The high resolution original image and the lower resolution compression image.

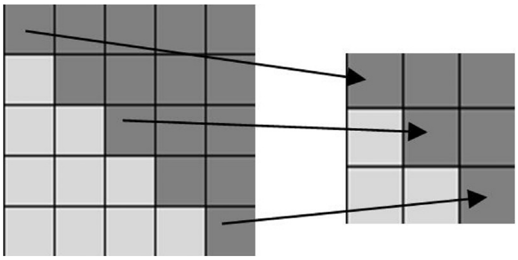

Fig. 2. The image compression process illustrate, the multiple parameter is 5/3.

don't apply the time consuming methods such as bilinear algorithm and bi-cubic interpolation algorithm. In this paper, an improved nearest neighbor algorithm is used to reduce the compute cost as possible. As shown in Fig. 2, the down-sampling scale coefficient is used as a gap size and only pixels on the boundary of gap sizes are copied to constitute the lower resolution compression result image.

$$P_{down}(x, y) = P_{source}(x * b, y * b) \tag{1}$$

Where, P_{down} is the lower resolution compression image; x and y are the position information of pixel; P_{source} is the high resolution original CCD image; b is the down-sampling scale coefficient.

4. Patch analysis

4.1. Target noise pollution area

After the image compression process, a lower resolution compression image with noise pollution information is got from the high resolution original CCD image. The following work is to target noise pollution area by analyzing patches in lower resolution compression image. There has an obvious regulation in the normal spectral information area. Through research of CCD image we found that, in normal spectral area, the rate of pixel's gray value varies insignificantly in dispersion direction. But the noise pollution area don't follow this regulation and the pixel's gray value changes severely. Spectral pixel's variation can be described as the Bezier curve [8], which can be used to distinguish between normal spectral information and noise pollution area.

In the actual data statistics, every normal spectral information patch in the direction perpendicular to the dispersion of pixel distribution also presents certain regularity. However considering the time cost, only distribution in one direction is chosen as the judging basis.

It can be clearly found in Fig. 3 that the pixels in noise pollution area without a regulation and have an obvious tremendous change in pixel's gray value, we build the evaluation function based on this study. Use the Bezier curve synthesis method to create a continuous curve for the pixel's gray value on the dispersion direction; calculate the curve's rate of the change, the noise area is distinguished if its rate value is higher than the set threshold.

It is still a time consuming work if we use the Bezier curve to represent the rate of the pixel's gray value variation and analysis all patches in CCD image directly. So we don't synthesis the curve and just use a similar convolution formula to solve this problem.

$$M = \left\{ \begin{array}{l} (x_0, y_0), (x_1, y_0) \ldots (x_k, y_0) \\ (x_0, y_1), (x_1, y_1) \ldots (x_k, y_1) \\ \ldots \\ (x_0, y_k), (x_1, y_k) \ldots (x_k, y_k) \end{array} \right\} \tag{2}$$

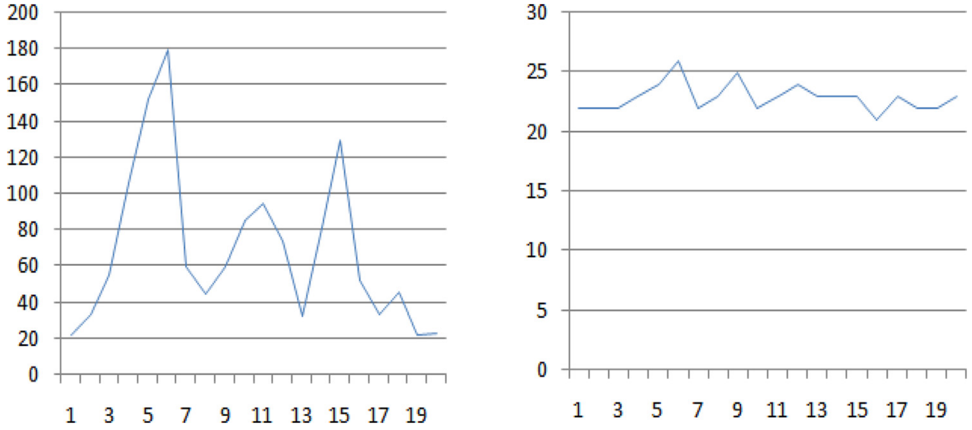

Fig. 3. The left picture shows variation of pixel's gray value in noise pollution area. The right picture is the normal spectral information pixel's gray value. The ordinate is gray value; the abscissa is number of pixel in dispersion direction.

$$S = \{M|F(M) > Y\} \tag{3}$$

$$F(M) = \sum_{j=0}^{k}\sum_{i=0}^{k} |(x_j, y_i) - (x_j, y_{i+1})| \tag{4}$$

Where, M is the patch waiting for analysis with size k. S is a set of the noise pollution area patches. F is the similar convolution formula we used as analytic function, which compute the pixels' gray value's difference for all the adjacent rows, get absolute value and sum these value to one parameter. Through the compute of the F, every patch gets a value. Y is the threshold for judging whether the patch is the noise pollution area or not. If the patch is the noise pollution area, put the patch into S.

In order to improve the accuracy of the analysis function F, our analysis process in practical application use sum of square of pixels' gray value difference between adjacent rows while not sum of the absolute value difference. We get the square value replaces the absolute value because it can increase the penalties for noise pollution area and make determine accurately.

$$F(M) = \sum_{j=0}^{k}\sum_{i=0}^{k} \left\{(x_j, y_i) - (x_j, y_{i+1})\right\}^2 \tag{5}$$

4.2. Establish mapping

Now the set S of noise pollution area patches in the compression image has been targeted. Next we want to find the position of noise pollution area in original image. So a mapping based on our image compression method should be built during this process.

$$N = \left\{ \begin{array}{l} (x_0, y_0), (x_1, y_0)...(x_{kb}, y_0) \\ (x_0, y_1), (x_1, y_1)...(x_{kb}b, y_1) \\ ... \\ (x_0, y_{kb}), (x_1, y_{kb})...(x_{kb}, y_{kb}) \end{array} \right\} \tag{6}$$

$$S\{M\} \rightarrow S_{new}\{N\} \tag{7}$$

Through the process of mapping, we get a new set $S_{new}$from the S. N is the noise pollution area patch inS_{new}. We have already mentioned in the previous section that the down-sampling scale coefficient have a big influence to image compression process. Combining image compression and mapping operations, we choose multiple numbers to be the down-sampling scale coefficient respectively and three kinds of size to build the patch. Experiments proves that the best parameter configuration is to use 3 as down-sampling scale coefficient and use 5*5 as the patch size.

5. Patch restoration

All the noise pollution area patches in set S_{new} (shown in Figs. 4 and 5) should be repaired. In this paper an improved method called mean smooth process is used to increases the accuracy of repair.

Mean smooth process can be easily done by finding the neighbor pixels, compute the average value and use it to replace the pixels in noise pollution area. But in practice, we found that mean smooth process can't reconstruct some spectral pixels

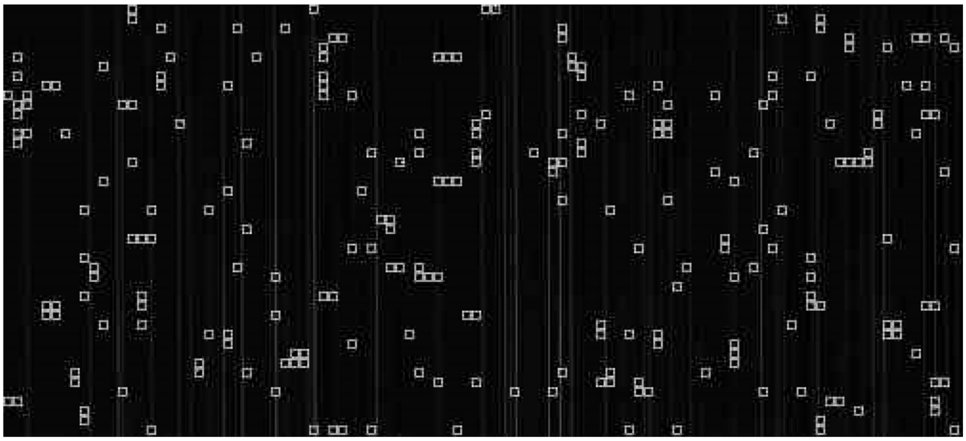

Fig. 4. Target the noise pollution area. The gray block is the noise pollution patch.

Fig. 5. The left picture is the patch of the noise pollution area; the right is normal spectral information.

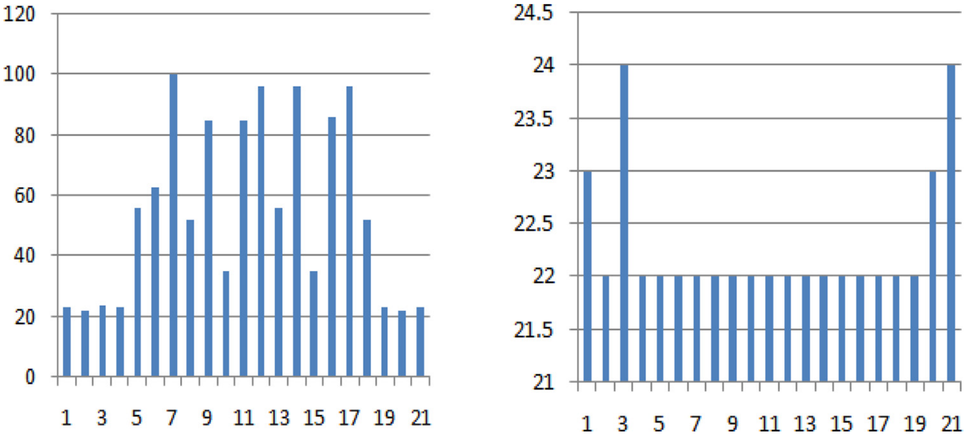

Fig. 6. The left picture is the noise pollution patch's gray value distribution; the right is restoration result after the mean smooth process.

in the noise pollution area and also can't satisfy the normal spectral information's distribution regulation of pixels. After the process, there will generate some discontinuity area as shown in right picture of Fig. 6. It is obvious that the smooth process result has a "cliff" for gray's value.

An improved mean smooth process is proposed in this paper by using self-similarity of spectral information. A set of candidate vectors are got from normal spectral pixel series, which are used to fix the noise pollution area and can retain distribution regulation of spectral pixels as well. Details list as following and as shown in Fig. 7:

$$Q\{L|L(l_1, l_2, l_3, l_1 - l_2, l_3 - l_2)\} \tag{8}$$

$$Q_t(l_1, l_2, l_1 - l_2) \tag{9}$$

For each column of patch N in the noise pollution patch set $S_{new}\{N\}$(Fig. 7A), construct its candidate vector set Q (Fig. 7C) by searching along both direction away from two borders of the noise pollution patch in current column. Every adjacent 3 pixels in this column build a candidate vector L, where l is the row index and all the value be used in the function are gray value. Each candidate vector L is represent by the 3 adjacent pixels' gray values together with difference values of adjacent

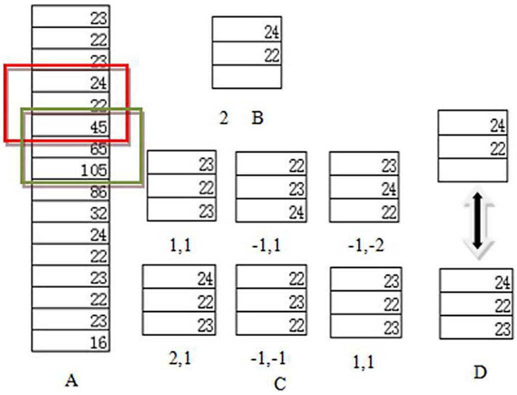

Fig. 7. Process of repair. A is the gray value column from noise polluted patch N and two adjacent patches .The green block is column in N. The red block is a match vector Q_t; B is the Q_t in the red block of A; C is the candidate vector set Q; D shows the fixed result of Q_t by search optimal match in Q.

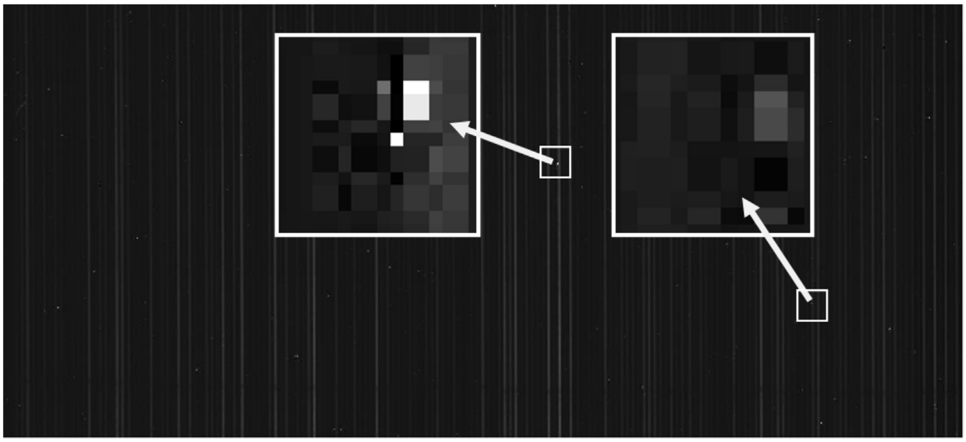

Fig. 8. The original image.

Table 1
Average error of different methods for different patch scale.

Method	Error 5*5	Error 10*10	Running time
inverse harmonic mean filter	>500	>500	7.98s
median filter	386	462	6.58s
median filter with 3 recursive processes	165	183	13.2s
our method without sampling	<100	<100	7.65s
our method	**<100**	**<100**	**3.8s**

pixels. Noise pollution region need to be repaired can be predicted one by one by searching a optimal match in candidate vector set$Q$for each match vector Q_t(Fig. 7B). Finally we use $Q_t$to fix the noise pollution patch N. InQ_t, it has two known gray values and a value need to be predicted. According to the self-similarity of spectral information, the unknown pixel in $Q_t$can be predicted and filled with truly value by searching from the candidate vector set$Q$(Fig. 7D). This method can keep the continuity of the spectral information and make the result accurately.

6. Result and conclusion

For the test our method has an improvement in compute time and precision through the image compression process, especially for large size of CCD image. We use patch match method to the reference, and use some classical filter methods for contrast. All the results show in Figs. 8–12 and Table 1.

We use some CCD images with high resolution (4098*3024) to be original data. In Fig. 8 we found some noise pollution area patches even can't be observed by eyes. For our method some parameters should be determined. The scale of the patch is 5*5 and the down-sampling scale coefficient is 3 in our method. We define the error of repairing method for CCD image. One measure is the patches with noisy information should become consistent with adjacent normal patches. We compute

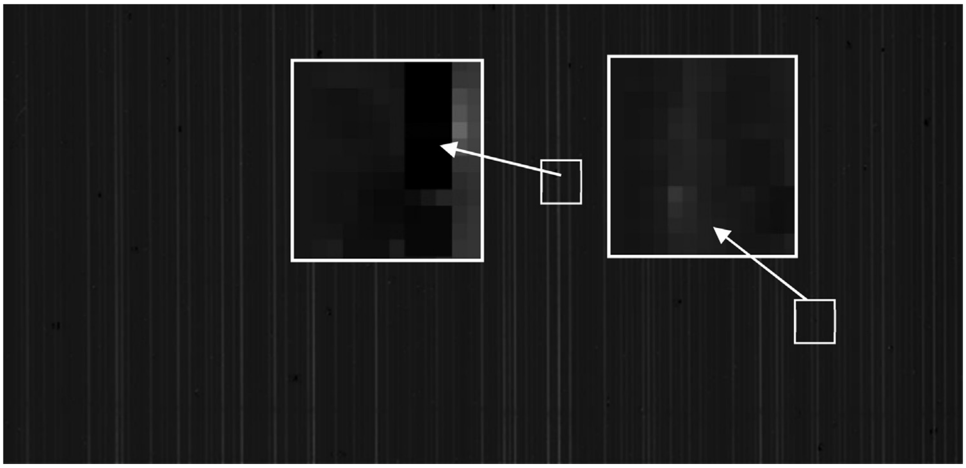

Fig. 9. The result of inverse harmonic mean filter.

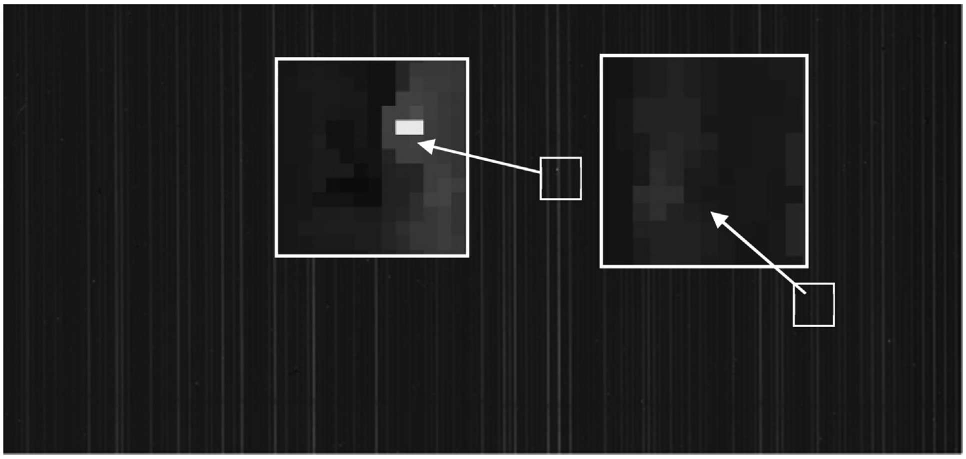

Fig. 10. The result of median filter.

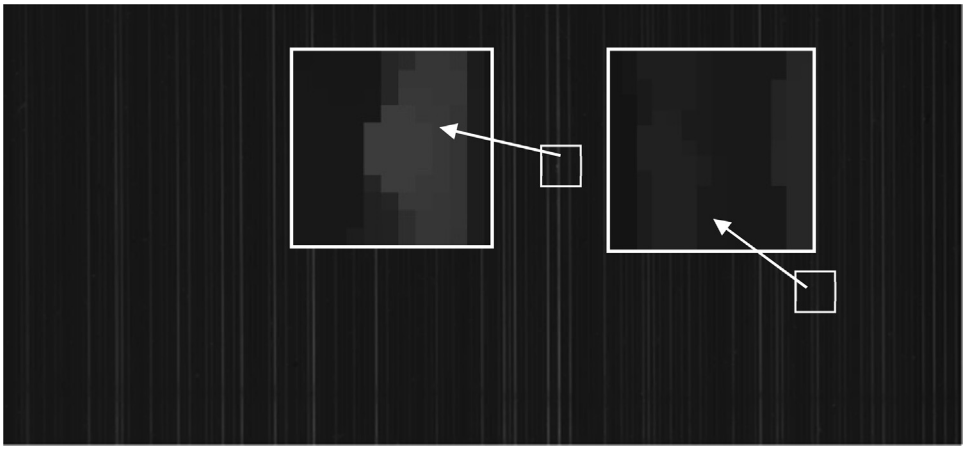

Fig. 11. The result of median filter with 3 recursive processes.

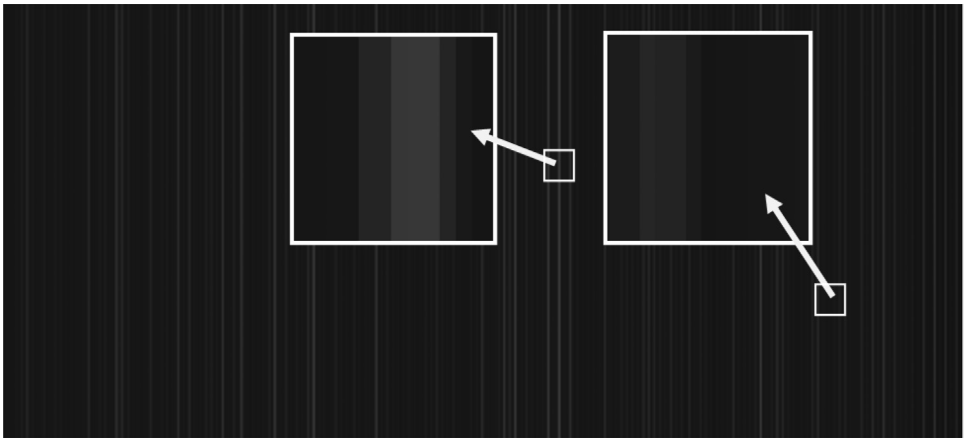

Fig. 12. The result of our method.

the absolute value of pixel difference between noisy patches and normal patches to be error. In Table 1, we show average absolute value for patch with different scale, it illustrates our method is accurate.

We don't find the match set, so our method's quality don't relate to any outside information or function and it is robust in mostly application environments. Patch analysis means the method relay on the patch unit to analysis the noise pollution area. Through the image compression process, the method can increase the speed for local information analysis (see run time in Table 1); after mapping process we can find the truly noise pollution area and the patch restoration method can complete the fix process and get the result finally.

In future research we consider using the GPU parallel computing to increase the compute speed. In step of patch restoration, it also needs the fast compute improvement. Our method‘s analysis based on patch so it can have an easy way to use some GPU parallel computing technology like CUDA. For the follow analysis for CCD image, it may need some special strengthen process for different study direction. Through automatic statistics pixels change of spectral information model, providing astronomical research more precise data to support research in the field of astronomy.

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