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Enhanced Destriping of Satellite Data of Ice Surface in Antarctica

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Abstract This paper briefly reviews the cause of the striping and then develops a tapered (Chebwin & Kaiser) window finite impulse response (FIR) filter and a constrained least squares FIR filter by reason of the striping of ASTER satellite data. Both filters minimize the stripes in the visible data and simultaneously minimize any distortion in the filtered data. Finally, the results obtained by using these new filtering methods are quantitatively compared with those produced by other destriping methods.
Key words advanced spaceborne thermal emission and reflection radiometer (ASTER), destriping, fast fourier transform (FFT), finite-impulse response (FIR), lowpass filter, histogram matching, moment matching

1 Introduction

The Antarctic continent is surrounded by Pacific Ocean, the Atlantic Ocean and the Indian Ocean, it is the isolated continent farthest from the mankind. Its Special geography and climate environment make the mankind very difficult to be close to it, which limits mankind's investigation of it and study to a great extent. Restriction caused of the geographical environment and the climate can be broken to a great extent with the aid of the modern remote sensing technology, it demonstrates incomparable superiority that remote sensing technology is used in the drawing of the Antarctic map.

Because the Antarctic area is the area with high latitude and covered by snow and ice, making use of image of the satellite to obtain Digital Elevation Model (DEM) of the Antarctic area effectively requires orbit inclination to be close to 90° as well as the basically same condition in observation: external climate, the solar irradiance, key elements of instruments, besides the spatial resolution is expected relatively much. Considering these factors simultaneously, in this paper, we choose two near infrared spectral bands (band 3N, 3B) of VNIR (Visible and Near Infrared Radiometer). As in the Antarctic area it is quite difficult to obtain control points on the ground, so the control point which can be used for producing DEM is limited. This demands less errors while choosing tie points, check points for stereo scenes, to obtain better precision. In practical application, the problem first is that strip noise of 3N band in ASTER L1A VNIR of Antarctic area is serious, which have serious influence to choose control points, check points and tie points accurately, so the strip noise must be removed at first For the research of destriping a image of 3N band is choosen which is located in Imery Ice Shelf in east Antarctica, dimensions of which is 618 × 715 pixels The image is offered by Chinese Antarctic Center of Surveying and Mapping in Wuhan Unviersity and acquired in August 23th 2002 In order to compare with the results of different methods, we especially choose image of the surface feature to have obvious difference between each other

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an advanced multispectral imager that was launched on board NASA's Terra spacecraft in December, 1999 The main purpose of ASTER project is to exploit and research the earth surface and various kinds of part and regional yardstick course that take place in the low atmosphere on the earth surface or nearly ground in depth, including the interaction of the earth's surface and atmosphere ASTER covers a wide spectral region with 14 bands from the visible to the thermal infrared with high spatial, spectral and radiometric resolution ASTER consists of three different subsystems the Visible and Near- infrared (VNIR) has three bands with a spatial resolution of 15 m, and an additional backward telescope for stereo, the Shortwave Infrared (SWIR) has 6 bands with a spatial resolution of 30 m; and the Thermal Infrared (TIR) has 5 bands with a spatial resolution of 90 m. Each subsystem operates in a different spectral region, with its own telescope(s), and is built by a different Japanese company. The spectral bandpasses are shown in Table 1, and a comparison of bandpasses with Landsat Thematic Mapper is shown in Table 2 It is not difficult to find that radiometric resolution of ASTER are all higher than the latter whether not at VNIR, SWIR or TIR.

Table 1 ASTER technical specifications

subsystem	Band No	Spectral Range(μm)	Spatial resolution, m
VNIR	1	0 52- 0 60	15
	2	0 63- 0 69	
	3N	0 78- 0 86	
	3B	0 78- 0 86	
SWIR	4	1. 600- 1. 700	30
	5	2 145- 2 185	
	6	2 185- 2 225	
	7	2 235- 2 285	
	8	2 295- 2 365	
	9	2 360- 2 430	
TIR	10	8 125- 8 475	90
	11	8 475- 8 825	
	12	8 925- 9 275	
	13	10 25- 10 95	
	14	10 95- 11. 65	

Table 2 Landsat-7 TM technical specifications

Band No.	Spectral Range(μm)	Spatial resolution, m
1	0.45~ 0.52	30
2	0.52~ 0.6	30
3	0.63~ 0.69	30
4	0.76~ 0.90	30

Since launching in 1999, ASTER has made very good result in the field of extensive scientific research with its high data quality. In General, if the surface feature of the area where the image is obtained is abundant, the condition of the formation of image is better, ASTER data will not have very obvious strip noise. But because the geographical sight of the Antarctic area is special, as the snow is main feature of the surface, contrast is relatively light, contrast of snow and other surface feature too big, it presents two kinds of special phenomena in the drawing of the Antarctic map: when expanding the contrast snow and surface, there will be appearance of the noise of the strip, and the density of other surfaces features (naked rock, sea water, glacier shade, thin ice of sea, etc.) is all moved to the lower, all forming dark hue, unable to distinguish all kinds of surface feature. On the other hand, because of decline wind close to Antarctic continent ice sheet generally called ′the wind blows the snow,′ formed following strong cyclone, makes the snow foam fill the ground low space called the opaque ′milky white weather,′ that interferes important reasons in forming the satellite remote sensing data noise too. If not removed, the strip conceals ground form information, and will lead to classify inaccurately (Wegener 1990) and the geophysics variable can not be retrieved correctly, for example the cloud covered, the albedo of the earth′s surface, the sun illumination, etc(Simpson *et al.* 1998).

Reason causing of noise is complicated, it is not only relevant to sensor launched in instrument but also relevant to systems, connecting with pretreatment course. ASTER employs pushbroom method while obtaining the image. Taking 3N band as an example, it consists of 4100 CCD. Difference of the sensors, the wearance of the instruments and components, consistency of working state of calibration system, scan system and attitudes stability of the satellite, etc., all will influence the data quality of the picture, may produce the noise of strip. But work discipline of sensor is very clear, and the location of arising noise of the strip can be also located easily. In fact, bigger difficulty of removing the noise and working stems from the ground pretreatment course after receiving the satellite data(Wang 1995). After image data convey to ground station from satellite, the data is clean up to series of scenes by professional equipment at first, then undergone radiometric and coarse geometric calibration, finally, written down on the high density data tape. This makes noise data from the satellite more complicated in the pretreatment. VNIR subsystem of ASTER compose of three arrays of CCD, each of them consists of 5000 CCD. Among them 4100 are used in routine to observe, the bands from them are 1, 2, 3N respectively. The line way of CCD is across track direction and to observe earth surface adopting of pushbroom way. Under the terms of the same spectrum incidence quantity, because the spectrum responding value of each sensor of lines is different, the vertical strip appears on each band. Original image with striping is shown in Figure 1.

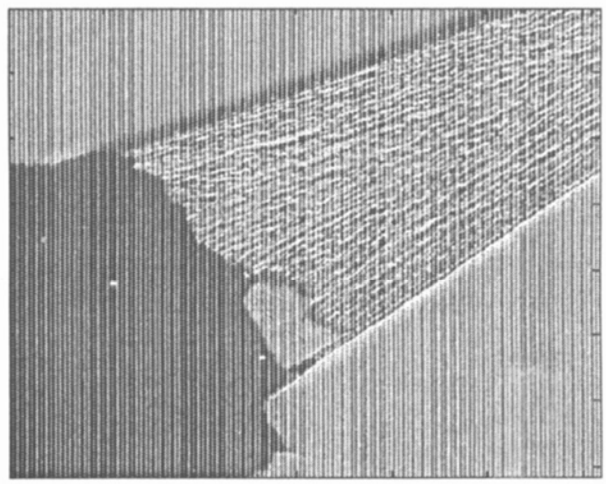

Fig 1 Original image with striping

2 General methods of destriping

Striping is a well-known phenomenon that arises in a large number of spaceborne and airborne multidetector spectromenter imagery, it is a kind of periodic noise appearing in the picture repeatedly, it often be caused because of the reasons in many aspects, such as difference of CCD optics natures, scanning mechanical movement, sensor platform, etc. A lot of scholars have already carried on research on its origin cause of formation and on the methods of destriping. To sum up, there are two methods with destriping. One is transferring the image to frequency domain using Fast Fourier Transform to get rid of periodic frequency composition of noise, then transferring the surplus component to spatial domain using Inverse Fourier Transform again, the shortcoming of which is not apt to choose the correct frequency composition. Another is a kind of match methods to make of picture grey level value normalized (standardize) and the characteristic, of which there are the typical methods: have histogram matching (Wegener 1999), moment matching (Gadallah *et al.* 2000).

The most simple method of destriping is low bandpass filter. This kind of method can't remove all noises and often causes the serious burr phenomenon, at the same time the fuzzy phenomenon result appears in the image. Result image is shown in Figure 2.

Moment matching bases on linear relationship among sensor paraments, in this case, adjusting means (offsets) and standard deviations (gains) of each sensor's data to a reference is sufficient. The assumption of similarity between subscenes is somewhat relaxed, since only the means and standard deviations of the subscenes are required to be similar. This assumption foundation limits its application of moment matching, as the processed image is very small or surface objects are complicated causing grey level distributing unevenly, this method usually raises the Banding Effect,' namely the picture bright discontinuity along the line direction will appears interphase of brightness and darkness, this is not accorded with the phenomenon of distribution of key characteristics of physical geography element

The essential reason of 'banding effect' lies on the assumption that regards approximate mean values as equal along the walk direction, thus resulting distortion of distribution of the earth's surface spectrum information, which are reflected on the picture finally (Gadallah *et al.* 2000). The result image is shown in Figure 3. Though with shortcomings, square matching has been improved into a developed method called 'improve and enhanced moment method', by introducing compensation method (Liu *et al.* 2002).

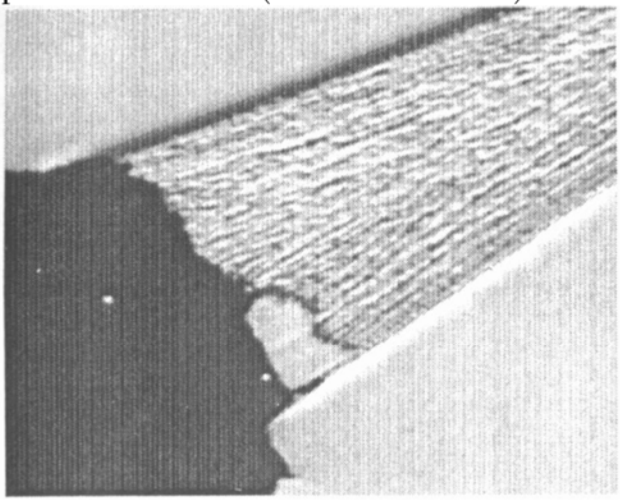

Fig 2 Filtered Image for lowpass filter

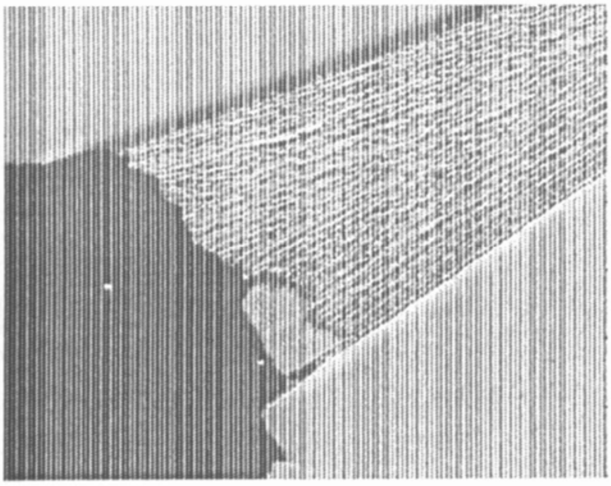

Fig 3 image for moment matching

Considering an image as built up from a number of interlaced subscenes, each subscene generated by one sensor, the histogram of each subscene is matched to the histogram of the overall image. Briefly, a histogram of the relative frequency of DNs is generated for each sensor and for the overall image. Next, cumulative probability functions (CPFs) are generated from these histograms. Using the overall CPF (i.e. the CPF generated from the overall image) as a reference function, each sensor's CPF is adjusted. For a given pixel, a cumulative probability value for its original DN is found from its sensor CPF, and that probability value on the reference CPF determines a corrected DN. This method will also cause radiometric distortion of surface feature spectrum information reflected on the picture. Result image is shown in Figure 4.

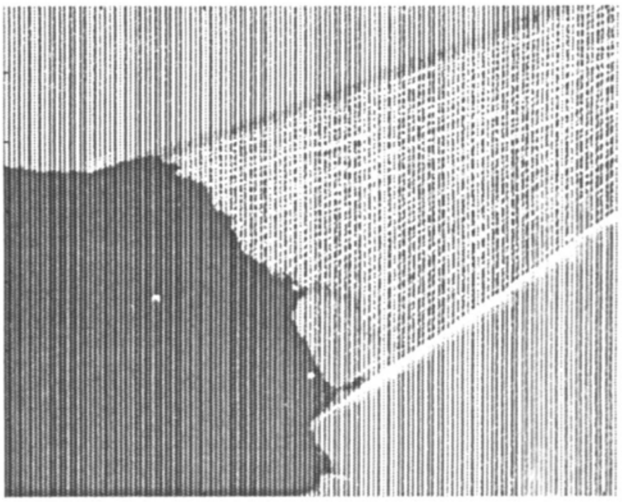

Fig. 4 Image for histogram matching

3 FIR Digital filters and its application in image of Antarctica

3.1 *Fundamental of FIR Digital filters (Chen 2002)*

In general, the digital filter is a time-invariant system, implemented with finite accuracy. The design filter general includes the following four steps: (1) confirm the performance index of the filter depends on the task the filter will perform; (2) utilizing steady consequence system function of discrete time-invariant system to approach the performance requests; (3) implement the system functions using finite accuracy arithmetic, which is including choosing the best filter structure, appropriate byte length and effective digital process methods; (4) realizing efficiently in hardware.

FIR digital filter is realized by adoption of nonrecursive algorithm, its transfer function as follows:

$$H(z) = \sum_{n=0}^{N-1} h(n) z^{-n} \tag{1}$$

So $H(z)$ is N-1 times of multinomial on z^{-1}. It has N-1 zero points, except N-1 entries apices lying at z=0, there are no other apices which can affect systematic function performance.

There are five kinds of FIR standard design methods: (1) Windowing Method; (2) Frequency resampling; (3) Frequency Transformation; (4) Raised cosine FIR filter design; (5) Constrained Least Squares FIR Filter Design. This paper will discusses the Windowing method and Constrained Least Squares method only, does not go into details in other methods.

3.2 *Windowing method and Constrained Least Squares (CLS) method*

Ideal lowpass digital filter is not implementable since its impulse response is infinite and noncausal. In order to create a finite-duration impulse response, it is necessary truncate it by applying a window. By retaining the central section of impulse response in this truncation, a linear phase FIR filter is obtained. Chebwin and Kaiser window can reduce 'Gibbs effect' to a great extent. Kaiser window define a group transformable functions, composed by Bessell function of 0 steps, its increasing beta widens the main lobe and decreases the amplitude of the sidelobes (increases the attenuation), window length is 71 and beta parameter is 7 in the job for a good result. Its function is

$$w(n) = a_n \times \frac{I_0\left[\beta\sqrt{1-\left[\frac{n}{n_p}\right]^2}\right]}{I_0(\beta)}. \qquad 0 \leqslant n \leqslant n_p \tag{2}$$

$$a_n = \frac{1}{n\pi}\left[\sin\left[\frac{n\pi f_b}{f_n}\right] - \sin\left[\frac{n\pi f_a}{f_n}\right]\right]$$

The Constrained Least Squares (CLS) is a kind of parameter filter relevant to Wiener filter, utilize Lagrangian multiplier to form the transfer function. CLS FIR filter design functions implement a technique that enables a design of FIR filters without explicitly defining the transition bands for the magnitude response.

3.3 *The instance of removing strip noise on ASTER image of Amery Ice Shelf district*

A good result can be acquired basing on the two following essential features: (1) remain noise data should be least; (2) distortion of image information must be minimize caused by the filter. Correspensively, two parameters called Noise Reduction (NR) and Image Distortion (ID) were introduced to estimate the performance of filters, *NR* is the noise reduction ratio achieved by the kth filter process, *ID* measures the image distortion introduced by the filter. Noise and image distortion measures for an image filtered by a filter *k*, can be defined as

$$NR = \frac{N_0}{N_K}$$

$$ID = \frac{S_K}{S_0}$$

Where N_0 is a noisy statistic of original image, N_k is a statistic after filtered by a filter *k*. S_k is a signal statistic after filtered by a filter k, S_0 is a signal statistic of original image. Theoretically, a good result requires that not only ID should be close to 1, but NR should be very close to ∞. But might not be the best when the wave filter is being designed. In practical application, the requirement is to try one's best to make NR be biggest, and ID be closest to 1. We can find out in Fig. 5, 6, 7 the strip noise on the original image can get very good elimination, and whole luminance of image changes very little, this can also be proved from Table 3. That is very difficult to distinguish the differences among the three methods by the image improvement. We can find that NR and ID are 7.17, 0.95 respectively for CLS and its precision is somewhat lower than those for the other two methods. The performance of Kaiser Windowing is better. In order to compare FIR filter with other traditional methods in destriping, a profile is choosed in Figure 1 ~ 7 located at line 46 for comparison, the results were shown in Figure 8, vertical axis represents grey value of pixel. We can find out that the profile of FIR filter's treated image is more consistent, and those of the other traditional methods are shaken badly, especially the result of the grey level histogram matching produces distortion distribution of the grey level image. The lowpass filter do remove partial noise as analyzing and observing Figure 2 and Figure 8-5, but the image changes a bit fuzzy simultaneously. FIR filter can keep the integrity of image information while getting rid of noise of the strip, reduce the distortion of the spectrum information of surface feature. Because the grey level of the primitive image in this example is distributed widely differently, utilization of grey level histogram match and moment match method can't remove the noise of image well(Figure 3, 4), and it produce certain distortion of the spectrum information of surface feature(Figure 8-6, Figure 8-7).

Table 3 Image Noise Reduction (NR) and Distortion Statistics for Various FIR Filters

	NR	ID
Chebwin	11.27 ± 3.42	0.96 ± 0.02
Kaiser	18.45 ± 2.57	0.96 ± 0.01
CLS	7.17 ± 2.31	0.95 ± 0.03

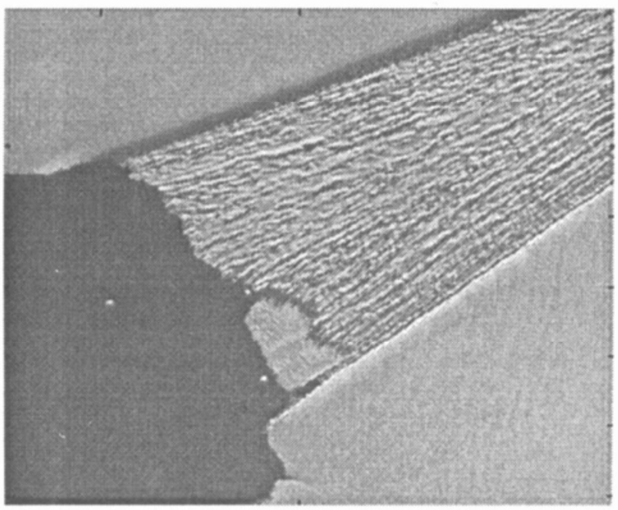

Fig. 5 Filtered Image for kaiser window.

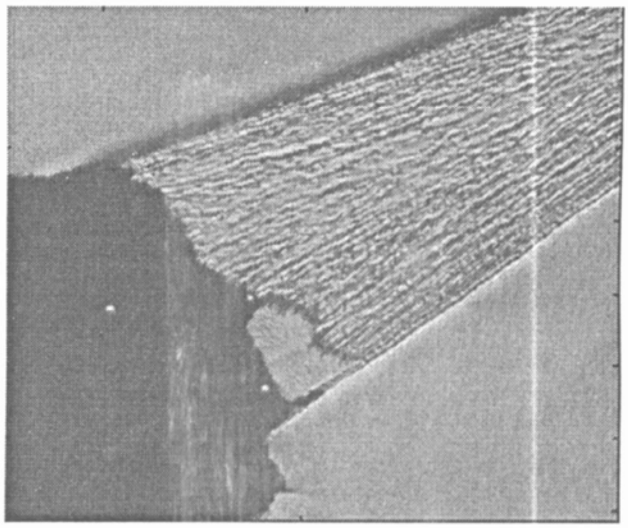

Fig. 6 Filtered Image for CLS FIR filter

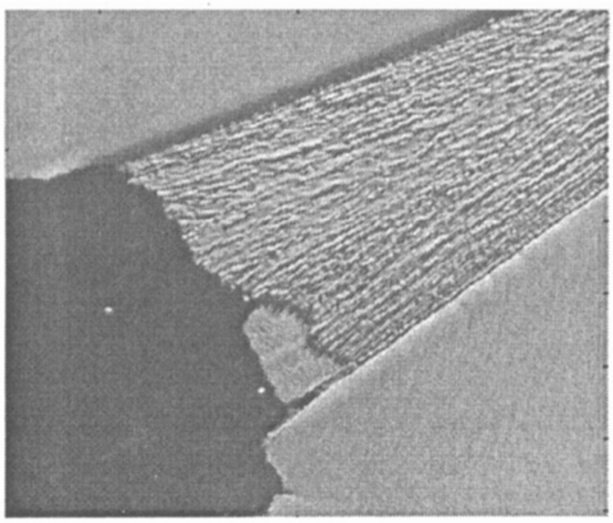

Fig. 7 Filtered Image for Chebwin window.

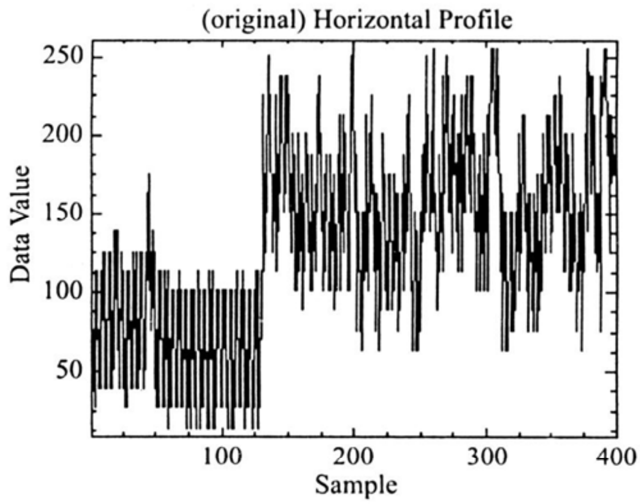

Fig. 8-1 Profile of original Image

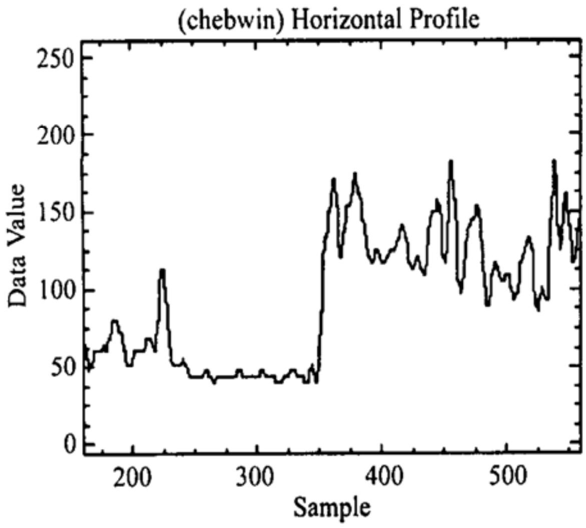

Fig. 8 – 2 Profile of chebwin window.

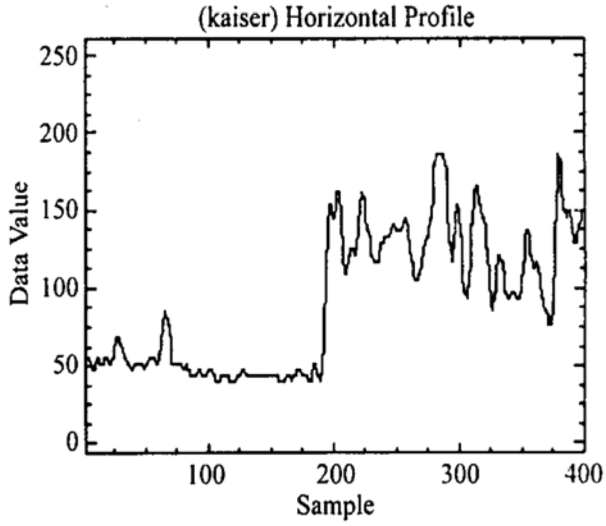

Fig. 8 – 3 Profile of kaiser window.

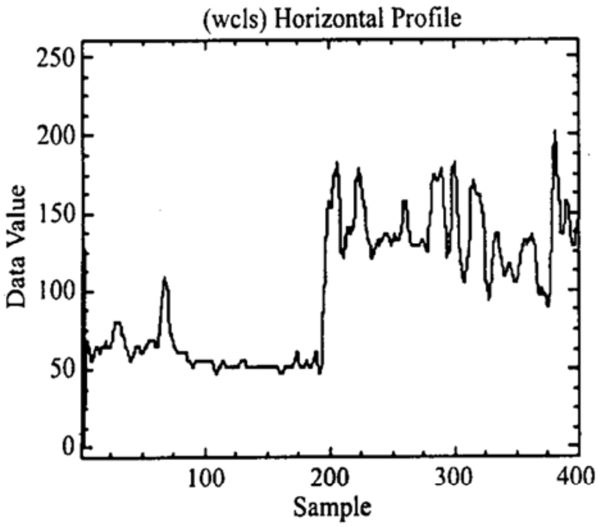

Fig. 8 – 4 Profile of CLS FIR filter.

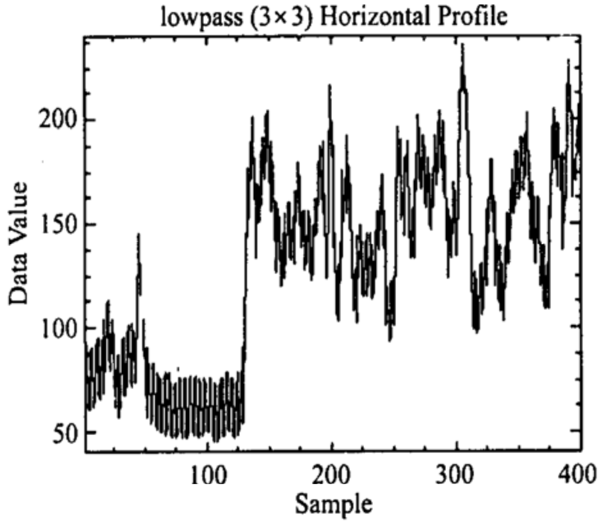

Fig. 8 – 5 Profile of lowpass filter.

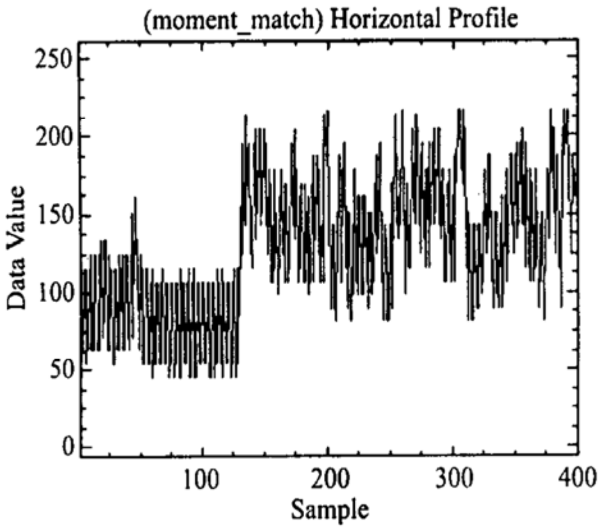

Fig. 8 – 6 Profile of moment matching.

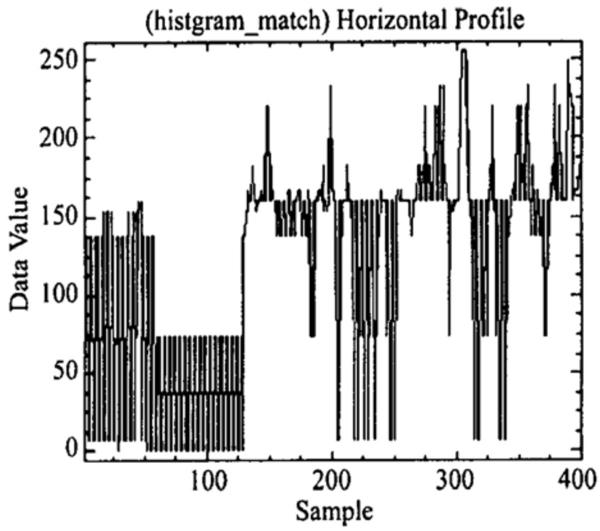

Fig. 8 – 7 Profile of histogram matching.

4 Discussion and conclusions

Investigation indicates that FIR filter can keep picture integrality of image information while removing the noise, and also that FIR filter is the main direction of modern signal processing. It can be applied in modern pattern process, such as, removing of noise of pictures, reconstructions of image information, analysis of the high spectrum image. For utilizing FIR filter, there are still a lot of problems remain to be solved, for instance, what about the end frequency, biggest deviation of passband and stopband, etc. Because nature of the Antarctic area and geographical environment are abominable, the quality of image drops to some extent. So effective application of FIR wave filter to deal with, resume and improve image quality is very worthy for studying Antarctic area image.

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