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Noise Removal of Spaceborne SAR Image Based on the FIR Digital Filter

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Abstract

The speckle effect inevitably exists in the image of the Synthetic Aperture Radar (SAR). The removal of the speckle noise is the necessary approach before automatic partition, classification, target detection and abstraction of other quantitative special information in the SAR image, so it is very meaningful to eliminate or furthest restrain the speckle noises when the spatial resolution of the image is not be reduced. In this paper, the FIR filter is used to remove the noise in the SAR image, and optimal filtering coefficient is selected through experiment and analysis in the filtering process. The results show that the FIR filter used to remove noises in the SAR image is better than other traditional filtering methods in keeping the radiolocation feature and restraining the speckle noises, and the filtering speed is quicker. At the same time, the selection of the filtering coefficient will largely influence the de-noising effect of the FIR filter.

Keywords: Speckle effect, SAR image, FIR filter, Noise removal

1. Introduction

Because the SAR image has the ability that can strongly penetrate through the unconsolidated sediment on the earth's surface and the advantage that can offer special information about the earth's surface through the microwave, so it is regarded as the important new generation remote sensing information source (Shu, 1997). The grainy noise on the SAR image is called the speckle, and it is the necessary result of the coherent imaging radar. The noise can largely impact the performance of the radar to judge the target, and when the speckle noise is serious, it will even make the geo-body feature lost. It is very important to remove the speckle noise for the SAR image processing and application, and it is always one of important research topics in the SAR image processing technology. From the 1980s, many filtering algorithms about the speckle noises begun to occur, but it is still very meaningful to remove or furthest restrain the speckle noises when the spatial resolution of the image is not be reduced (Zhang, 2006, P.4-6).

The usual methods to restrain the speckle noises of SAR image mainly include the average filtering, the mean filtering, the local filtering, the Lee filtering, the Sigma filtering, the Kuan filtering, the Frost filtering, the Gamma Map filtering and the threshold filtering based on the wavelet decomposition (Ding, 2008, P.390-394 & Cao, 2008, P.2862-2865 & Lu, 2008, P.1053-1055 & Yang, 2008, P.525-529 & Bai, 2008, P.1234-1241 & Zheng, 2008). Many of them have been adopted by the mainstream remote sensing image processing software. However, many algorithms such as the average filtering, the mean filtering, the local filtering, the Frost filtering and the wavelet de-noising filtering all mainly aim at the additive noise mode based on the Gaussian hypothesis, but the speckle noises in the radar image are just based on non-Gaussian distribution, so the de-noising effects are not ideal and the noises displayed in the edge disposed by the Lee filtering are not be smoothed.

FIR digital filter is a digital system which is used to filter the discrete time signals, and achieve the frequency domain filtering by mathematically processing the sample data, and its largest advantage is to realize the linear phase filtering, so it has been widely applied in the digital signal processing domain. At the same time, the FIR filter is a full-zero filter which does not need to consider the stability and can be implemented easily.

2. Implementation principle of the FIR filter

The FIR filter with the constant coefficient is called as the finite pulse response filter which is a kind of digital filter. Corresponding with the IIR digital filter, its unit pulse response f[n] only has finite data points. The relationship between the output with z-order or the length of z and the input time sequence x[n] is described as a kind of finite convolution quantity form as follows.

$$y[n] = x[n] * f[n] = \sum_{k=0}^{L-1} x[k] f[n-k] \tag{1}$$

Where, f[0]≠0 to f[L-1]≠0 are all the coefficients of z order of the filter. The formula (1) can be simplified as the form in the z domain.

$$Y(z) = F(z)X(z) \tag{2}$$

Where, F(z) is the transfer function of the FIR digital filter, and its form in the z domain is

$$F(z) = \sum_{k=0}^{L-1} f[k] z^{-k} \tag{3}$$

Figure 1 is the graphic analysis of the z order FIR filter. From the figure, the FIR filter is composed by one adder and one multiplier, and each operation number transferring to each multiplier is one FIR coefficient.

3. Approaches of designing FIR digital filter by the window function method

By the window function method, the design approach of the FIR digital filter can be described as follows.

First, confirm the required frequency response function $H_d(e^{j\omega})$;

Second, select the window function, and according to the allowed excess bandwidth $\boldsymbol{\Delta\omega}$, evaluate the length of the h(n) sequence, and generally $\boldsymbol{N=A/\Delta\omega}$ (where, A is the constant which is confirmed by the window function form, and $\boldsymbol{\Delta\omega}$ approximately equals to main lobe width of the frequency $w(e^{j\omega})$ of the window function);

Third, compute the unit impulse response of the digital filter;

$$h(n) = \frac{1}{2\pi} \int_{-\pi}^{\pi} H_d\left(e^{j\omega}\right) e^{j\omega\left(n - \frac{N-1}{2}\right)} d\omega \tag{4}$$

Fourth, window the h(n) by the selected window function;

$$h(n) = h_d(n)\omega(n) \tag{5}$$

Fifth, compute the frequency response of the filter;

$$H\left(e^{j\omega}\right) = \sum_{n=0}^{N-1} h(n) e^{-j\omega n} \tag{6}$$

Sixth, design a linear phase filter, and its inner extent of the pass-width is 1 and its inner extent of the block-width is 0, and the digital cut-off frequency is $\boldsymbol{\omega_c}$ (Wei, 2008, P.6-7).

To maximize the orders and minimize the error of the filter, the Kaiser window function method is adopted to design and realize the FIR digital filter, and the Matlab software can be used to design the low-pass filter according with requirements. The parameters respectively are [110 140], [1 0], [0.01 0.1] and 1000, and the feature curve of the low-pass filter is seen in Figure 2.

4. Factor selection and effect evaluation

According to this low-pass filter, select different parameters and de-noise the SAR image.

4.1 Visual effect

The de-noising effect in the research is seen in Figure 3. Various methods are implemented by the current remote sensing image processing software such as ERDAS, and the FIR filter de-noising method is implemented by the wavelet image processing software developed independently.

From the visual effect (seen in Figure 3), comparing with traditional de-noising algorithm, the de-noising effect of the FIR filter used in the research is very obvious, and it can not only remove the speckle noises to the large extent and give prominence to the useful information of the original image, but keep the edge details of the image as possible.

The selection of the FIR filter coefficient will largely impact the de-nosing result, and from Figure 3, the bigger the filtering coefficient is, the better the de-noising degree is.

4.2 Quantitative evaluation

To evaluate the filtering effect, different factors can be selected. The usual factor is the smoothing index ***F*** which is the ratio between the average of all pixels in the processed image and its standard error, and it indicates the smoothing ability of the filter to the image. The higher the value of ***F*** is, the stronger the smoothing function is. The computation formula is:

$$F = M/S \quad (7)$$

The edge keeping index denotes the keeping ability of the filter along the level direction or the vertical direction after filtering, and the higher the value of ***E*** is, the stronger the keeping ability is. The computation formula is

$$E = \frac{\sum_{i=1}^{m} | G_{R1} - G_{R2} | \text{ after filtering}}{\sum_{i=1}^{m} | G_{R1} - G_{R2} | \text{ before filtering}} \quad (8)$$

Where, ***m*** is the amount of the pixel in the image, and *GR1* and *GR2* respectively denotes the grey degree values of the left-right neighboring pixels and the up-down neighboring pixels (Zhang, 1997). In fact, the edge keeping index is contrary with the de-noising intensity, and the de-noising intensity is stronger, and the edge keeping ability is worse. At the same time, the edge keeping index can be the evaluation standard of the keeping degree of effective information in the image.

Therefore, the evaluation factor ***Q*** is defined by the arithmetic average of the smoothing index and the edge keeping index.

According to above evaluation indexes, compute various filtering schemes, and the results are seen in Table 1. The curves of control factors corresponding with different parameters in Table 1 are seen in Figure 4.

From the analysis result, as parameters increase, the smoothing index rise continually, i.e. the soothing effect is better and better and the edge keeping index is lower and lower. The evaluation factor curve has three wave crests, i.e. 0.78, 0.6 and 0.2. According to the definition of the evaluation factor, when the coefficient is 0.78, the occurrence of the wave crest is because the smoothing index is the highest one, i.e. the smoothing effect is at the best moment, but the edge index is at the lowest moment, which indicates that the effective information has not been kept enough. When the coefficient is 0.2, the occurrence of the wave crest is because the de-noising is not enough and the edge keeping index is at the highest moment, so this value should be given up. Therefore, the FIR filter with the coefficient of 0.6 has the best de-noising effect for the SAR image.

5. Conclusions

This experiment shows that the FIR filter has better effect to de-noise the SAR image. The filtering coefficient will largely influence the filter, and as the coefficient increases, the de-noising degree will become stronger, but the kept effective information will accordingly become less, so it is very important to select proper coefficient for the FIR filter to de-noise the SAR image.

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Table 1. Filtering image statistical features of various schemes

Filtered	Mean	Mean variance	Smoothing index F	Edge keeping index (level)	Edge keeping index (vertical)	Edge keeping index	Evaluation factor
Original image	104.35	63.85	1.63	1	1	1	1.315
0.2	90.5	36.81	2.46	0.84	0.85	0.845	1.6525
0.3	91.49	36.79	2.49	0.65	0.74	0.695	1.5925
0.4	91.06	37.1	2.45	0.64	0.73	0.685	1.5675
0.5	88.26	38	2.32	0.67	0.64	0.655	1.4875
0.6	95.84	37.29	2.57	0.63	0.49	0.56	1.565
0.7	92.37	36.79	2.51	0.63	0.44	0.535	1.5225
0.78	99.46	37.43	2.66	0.61	0.43	0.52	1.59
0.8	99.46	37.43	2.66	0.61	0.43	0.52	1.59

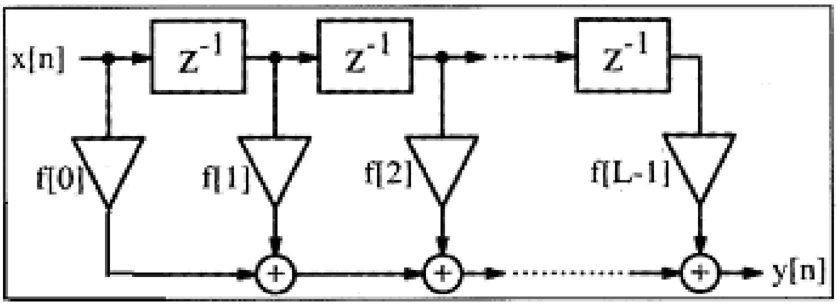


Figure 1. FIR Digital Filter with Direct Form

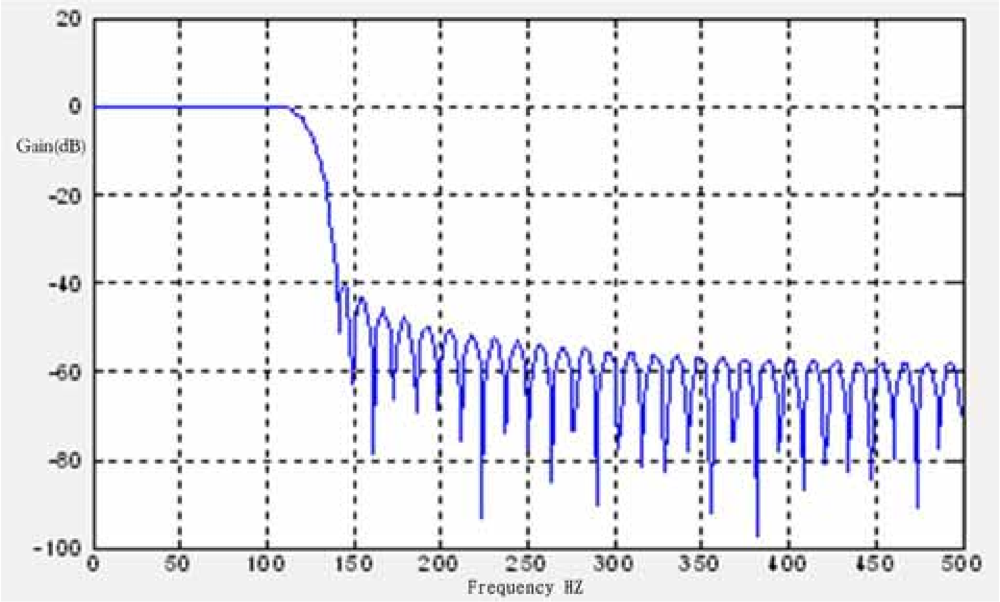
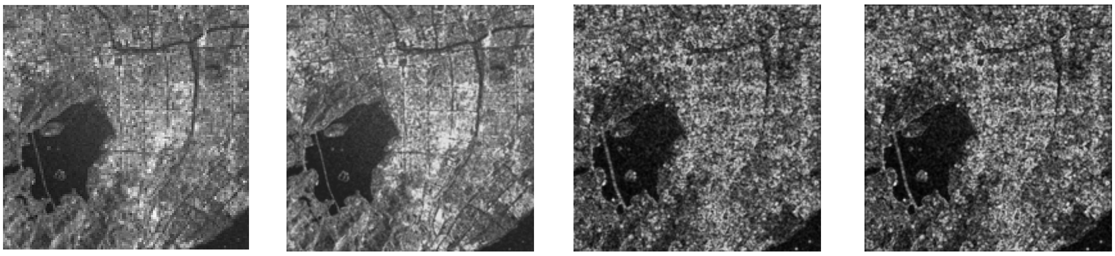


Figure 2. Feature Curves of the Low-pass Filter



(a) Original image (b) mean (c) robert (d) sobel

(f1) filter.a=0.2 (f2) filter.a=0.3 (f3) filter.a=0.4 (f4) filter.a=0.5

(f5) filter.a=0.6 (f6) filter.a=0.7 (f7) filter.a=0.78 (f8) filter.a=0.8

Figure 3. De-noising Results of Various Schemes

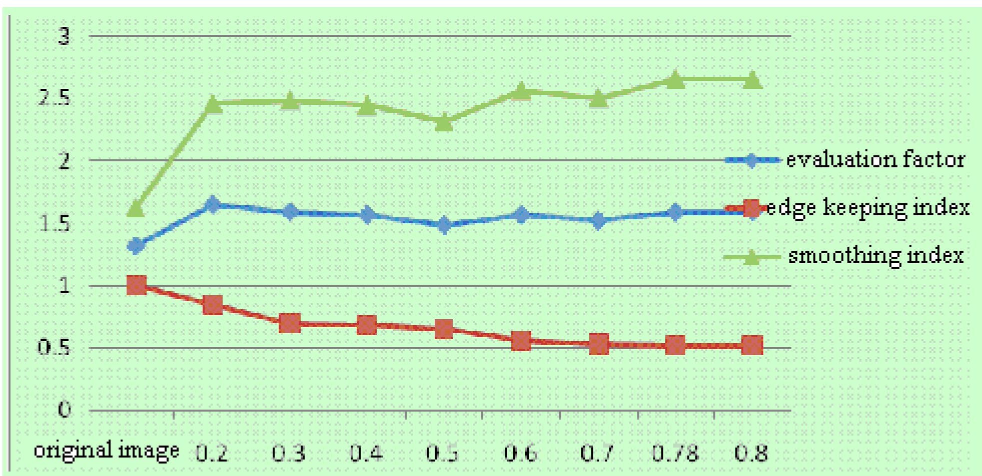


Figure 4. Control Factor Curve of Different Parameters