Local frequency adaptive filtering method based on SNR for InSAR interferogram

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Abstract
Phase filtering is one of the key steps in interferometric synthetic aperture radar; its precision will directly lead to the phase unwrapping quality, thereby affect generating DEM reliability. For original algorithm causes inaccurate result in unevenly distributed noise region, so local frequency adaptive filtering method based on SNR is proposed. The local SNR is based on frequency estimation window size, and variable window is used to filter phase, this can make the areas with low SNR strongly filter, while those with high SNR weakly filter. Using simulation and real data to do experiments, results show that this paper method not only can effectively reduce noise, but also can better maintain detail stripes.
Key words: LOCAL FREQUANCY, PHASE FILTERING, SIGNAL TO NOISE RATIO

1. Introduction

Interferometric synthetic aperture radar generating digital elevation model or monitoring surface deformation depend on the quality of interfergram [1-2]. There are many factors affecting interferogram quality, such as systematic thermal noise, time and spatial decorrelation, Doppler decorrelation and atmospheric water vapor, and so on. All of this makes phase noise often lie in interferogram [3-4]. If phase noise cannot be effectively removed, it will cause a lot of residues, thereby phase unwrapping is hindered. Therefore, the interferogram must be filtered to reduce noise [5].Currently there are many filter methods for InSAR interferogram, such as mean filter method, Goldstein spectral smoothing method and its improved algorithms, local gradient adaptive filter method and so on [6-8].Mean filter method is widely used by the European Space Agency and JPL, but it easily make the edge of interfergram fringes blur. Goldstein spectral smoothing method is widely used, and its filtering effect is very good when noise is not strong.

Literature [9] proposed phase filtering method based on local frequency estimated, it can well maintain and filter phase in high signal to noise ratio region, but in low signal to noise ration region it is prone to streaks blur. For this deficiency, we propose local frequency estimated based on SNR for InSAR interferogram. This method uses signal to noise ration as adaptive filtering factor, so that size of filter window is made to adaptive changes depending on local SNR, this can make areas with low SNR strongly filtered, while those with high SNR weakly filtered.

The paper is organized as follows. In the second part local frequency adaptive filter based on signal to noise ratio is presented. The third part describes performance of the new method using simulation and real data, and compare with Wiener filter, mean filter and median filter, and conclusion is concluded in the fourth part.

2. Local frequency adaptive filtering method based on SNR

2.1. Definition of SNR

SNR is the standard to measure quality of interfergram. When SNR is high, it indicates interferogram quality well; conversely it indicates interferogram quality poor when SNR is low. Traditional signal to noise ratio is defined as ration between signal and noise power spectrum, but power spectrum is difficult to calculate. In this paper, approximately estimating SNR method is proposed, firstly local variance in interferogram is calculated, then maximum of variance is used as signal variance and minimum value is used as noise variance, and their ratio is obtained, finally its value is converted into bits, the formula is as follows:

$$SNR = 10\log_{10}\frac{\sigma^2_{\Phi,\max}}{\sigma^2_{\Phi,\min}} \tag{1}$$

Where, $\sigma_{\Phi,\max}$ and $\sigma_{\Phi,\min}$ are respectively maximum and minimum value of local variance.

2.2. Frequency estimated filter

Frequency estimated filter method estimates spatial frequency using two-dimensional Chirp-Z transform, and adjusts parameters based on terrain changes [9].The specific method is to overlap interfergram into pieces, each piece is made to lined approximation. After stripe is detected, filtered interfergram can be obtained using formula (2):

$$e^{j\varphi(f_j,f_k)} = e^{j2\pi(f_j^j+f_k^k)}e^{j\phi_0} \tag{2}$$

where, f_j, f_k are two-dimensional spatial frequency components, ϕ_0 is initial phase, here $e^{j\phi_0}$ is :

$$e^{j\phi_0} = \frac{\sum\limits_{j=j_0,k=k_0}^{J=J_0+N_j-1,k=k_0+N_k-1} I(j,k)e^{-j2\pi(f_j^j+f_k^k)}}{\left|\sum\limits_{j=j_0,k=k_0}^{J=J_0+N_j-1,k=k_0+N_k-1} I(j,k)e^{-j2\pi(f_j^j+f_k^k)}\right|} \tag{3}$$

where, $I(j,k)$ is intercepted interferogram, $j \in \lfloor j_0, j_0+N_j-1 \rfloor, k \in [k_0, k_0+N_k-1]$, $N_j \times N_k$ is size of interferogram selected.

2.3. Local frequency adaptive filter method based on SNR

When local phase noise in small estimation is accuracy in frequency filter method, and phase noise can be well removed. But when local phase noise is large, frequency estimation appears bias, so that interferogram fringes blurred. One hand, window selected is larger in order to improve SNR of local area, then frequency estimation can be got better; the other hand, larger window will cause smoother transition and reduce interferogram spatial resolution. For this reason, finding a balance between window size and frequency estimation is needed. So, adjusting window size based on local SNR is a viable strategy. When local SNR is low, frequency error estimation may be generated. So accuracy of filter can be improved through increasing window size to improve SNR in region. Specific steps are as follows:

The first step, the whole interferogram will be divided into small pieces; so that each piece overlap rate will reach 50%.

The second step, SNR is obtained from each small block, then calculating average of SNR, and using it as threshold value α to adjust size of window.

The third step, according to SNR in interferogram, two sizes of window are set to filter. When SNR is greater than α, indicating local SNR in region is higher, smaller frequency estimation window is selected; when SNR is smaller than α, indicating region has many noises, larger filter window is selected, and here larger window size is two times bigger than smaller one.

3. Experimental results and analysis

3.1. Simulation data experimental results and analysis

In order to verify the method effectiveness, the size $500\,pixel \times 500\,pixel$ of simulation interferogram is added coherence 0.85 noise as experimental data(Figure 1).Figure 2 are respectively filter results of original method, this paper method, Wiener filter, mean filter and median filter. From results can be seen, original method and mean filter retaining phase details ability are poorer, stripes generated are vaguer. Wiener filter appears more glitches at the edge of interferogram, but improved method and median filter method's filtering capability are stronger, and the ability to maintain edge information is better.

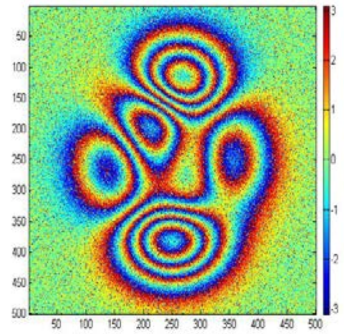
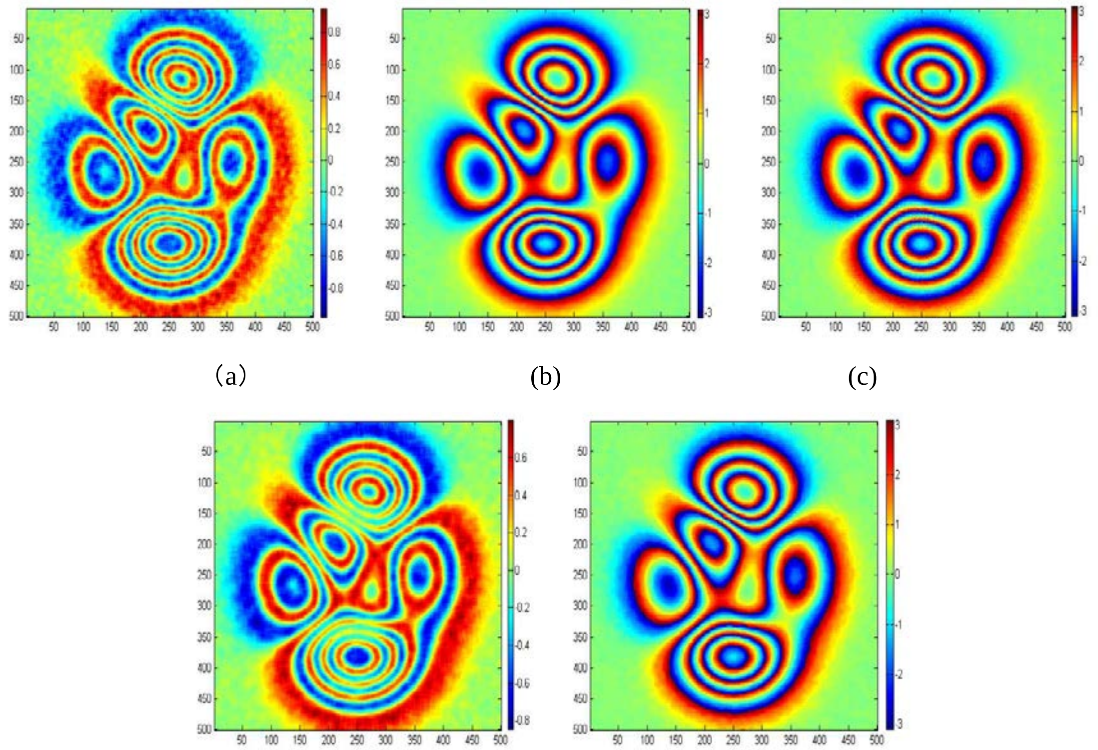


Figure 1. Interferogram with noise

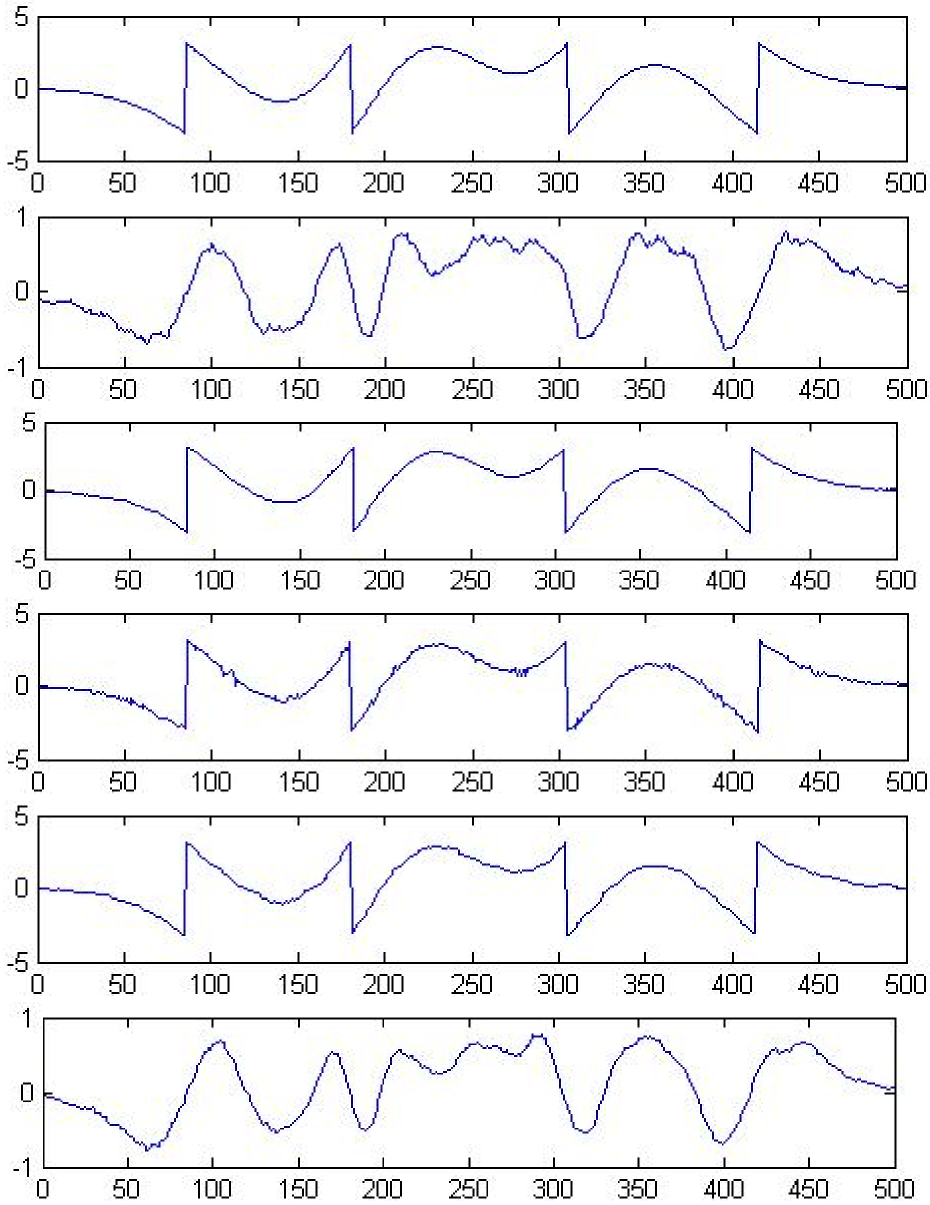


(a) (b) (c)

(d) (e)

Figure 2. Filtering results:(a) Original method;(b) This paper method;(c) Wiener filter method;(d) Mean filter method;(e) Median filter method

In order to illustrate this paper method effectiveness, 300th line sections of five methods' results are made in Figure 3. As can be seen from Figure 3, original method's and the mean filter methods have greater difference than original interferograms, and its amplitude has also change. Wiener filter method and median filter method's curve have glitches, but this paper method's curve is close to original profile's and stripes continuity is better, this indicate its suppression noise capability is stronger.



(a)
(b)
(c)
(d)
(e)
(f)

Figure 3. 300th line sections: (a)Section without noise; (b)Original method; (c)This paper method; (d)Wiener filter method; (e)Media filter method; (f)Mean filter method

3.2. Experimental results and analysis of real data

We use two ENVISAT satellite SAR images in Shandong are selected as primary and secondary image, and select part of interfergram (Figure 4) as experimental data. There are many noises in it, resulting in interference fringes rather vague, number of residues has reached 14188. Figure 5 are filter results using original method, this paper method, Wiener filter method, median filter method and mean filter method. From results can be seen, original method appear “island” phenomenon in result because filter window does not change according to noise ratio, number of residues has reached 1313.Wiener filter and median filter appear stripes overlap in noise dense region, mean filter produces streaks blur. But this paper method uses adaptive filter window to obtain result more accurate, and it maintains details of phase, number of residues is reduced to 513.

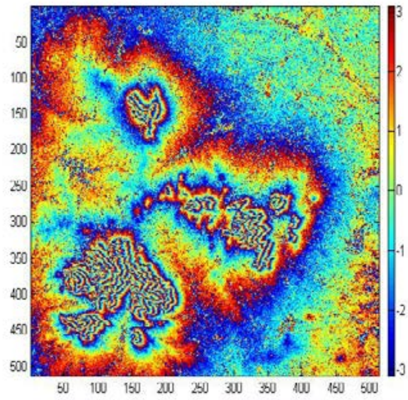
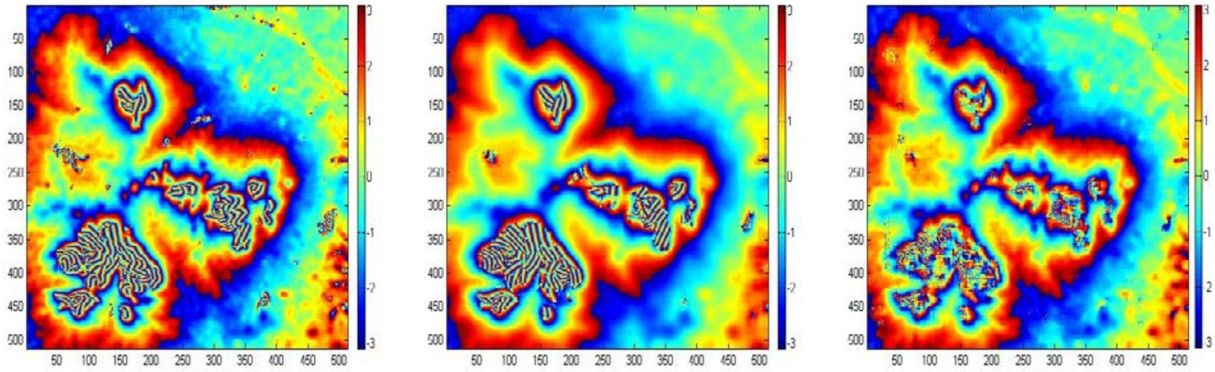
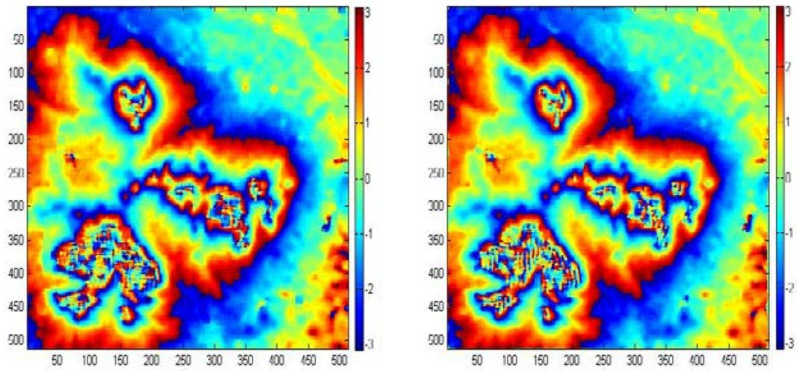


Figure 4 Interferogram



(a) (b) (c)



(d) (e)

Figure 5. Filter results: (a) Original method; (b) This paper method; (c) Wiener filter method; (d) Mean filter method; (e) Median filter method

Filter results are quantitatively evaluated from edge retention index, peak signal to noise ratio and RMSE.

(1) RMSE

RMSE is mainly used to measure deviation of filtered interferogram and original one. Its value is smaller, filter fidelity is better.

The formula is:

$$RMSE = \sqrt{\frac{\sum\left(\varphi_s(i,j)-\varphi_o(i,j)\right)^2}{N-1}} \tag{6}$$

Where, $\phi_s(i,j)$ is filtered phase, $\phi_o(i,j)$ is original interferogram phase, N is the number of sliding window.

(2) Edge preservation index

Edge preservation index illustrates filtered interferogram edge information preservation. Its value is closer to 1, filter's edge preservation ability is stronger. Its formula is：

$$EPI = \frac{\sum\left(\left|\phi_s(i,j)-\phi_s(i+1,j)\right|+\left|\phi_s(i,j)-\phi_s(i,j+1)\right|\right)}{\sum\left(\left|\phi_o(i,j)-\phi_o(i+1,j)\right|+\left|\phi_o(i,j)-\phi_o(i,j+1)\right|\right)} \quad (7)$$

In formula, $\phi_s(i,j)$ is filtered phase, $\phi_o(i,j)$ is original interferogram phase.

(3) Peak signal to noise ratio

Peak signal to noise ratio reflects the whole interferogram degree of distortion. Its value is larger, quality of filtered image is higher. Peak signal to noise ratio is defined as:

$$PSNR = 10\log\frac{255^2}{MSE} \quad (8)$$

Where, $MSE = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left(f(i,j)-f^{'}(i,j)\right)^2$.

As can be seen from Table 1,this paper method's and median filter method's edge preservation index are higher, but original method's is lower, which illustrates this paper method's ability which maintaining edge information is better; From the root mean square error, this paper method's is smaller, and this indicate original phase fidelity is better; From the peak signal to noise ratio, this paper method's and Wiener filter methods are slightly larger than the other methods, this show that this paper method's and Wiener filter method's filtering quality is higher.

Table 1 Five Methods Noise Evaluation Comparison Table

Filter method	EPI	RMSE	PSNR
Original method	0.206	2.546	43.708
Wiener filter	0.179	2.768	43.944
Mean filter	0.152	2.844	43.592
Median filter	0.140	2.832	43.609
This paper method	0.137	2.622	44.071

4. Conclusions

Local frequency adaptive filtering method based on SNR for InSAR interferogram has been proposed. And experiments are done by simulated and real data, compared with original method, Wiener filter method, median filter method and mean filter method. Results verify this paper method's feasibility and effectiveness. However, in the actual phase filtering processing topography distribution may be uneven, how to choose window size based on terrain slope will be the focus of future work.

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