IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 1, No 1, January 2013
ISSN (Print): 1694-0784 | ISSN (Online): 1694-0814
www.IJCSI.org

The study of Interferogram denoising method Based on Empirical Mode Decomposition

Changjun Huang[1, 2], Jiming Guo[3], Xiaodong Yu[4] and Changzheng Yuan[5]

[1] School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China

[2] School of Municipal and Surveying Engineering, Hunan City University, Yiyang, 413000, China

[3,4,5] School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China

Abstract

This paper proposes a new filter based on empirical mode decomposition that is based on different characteristics of signal with noise in different IMFS for suppressing speckle in SAR interferogram is proposed. At first empirical mode decomposition is used to divide signal and processed high-frequency IMF signals separately by adaptive filter. The denoising effect of the proposed method, usual filter and multiscale EMD filter was investigated by experiment. When the part related to the speckle is subtracted from the original interferogram, the speckle noise is reduced. The result is compared with the four other methods of mean filter, median filter and the adaptive filter, which shows that EMD filter method is powerful to interferogram speckle noise reduction, as well as it can preserve fine details in the interferogram that are directly related to the ground topography and maintain phase values distribution.

Keywords: *Empirical Mode Decomposition, Interferogram, noise, filter*

1. Introduction

Synthetic aperture radar (SAR) is a powerful tool to get geophysical characters of the earth and imaging with high resolution. A key problem of the radar image is the presence of speckle noise which is formed by the coherence of radar echoes from different scatters in an element. In the data processing of SAR interferometry, the interferogram is formed by conjugate multiplying of two coregistered SAR complex images. Because of the speckle noise of SAR image, the phase image of the interferogram is also degraded and many residues will be produced in phase unwrapping which can induce a inaccurate evaluation of the true phase values. In order to obtain a more accurate phase model, as a consequence, a better topographic model, a filtering step must be performed before the solution of phase ambiguities in the interferogram.

Some domestic and foreign scholars put forward some interferogram denoising methods, such as Seymour proposed the phase multiple optic filter of the interferometric complex [1], Eichel P.H and Lanar I.R proposed the circular cycle mean filtering and median filtering method [2]-[3], Lee proposed the adaptive filter [4], Zhu Daiying proposed Chirp-Z transform denoising method [5], and Goldstein and Werner proposed the classical frequency domain adaptive filter algorithm [6]. In general, these methods can be classified into two categories, there are two popular approaches to phase noise filter which are space domain filter and frequency domain filter; generally, these algorithms have adaptive filter window or bandwidth based on the local statistic character of the noise [1]. But due to INSAR interference noise and signal distribution in the data have its own characteristics, simple smoothing processing cannot achieve the good results.

Based on the above-mentioned shortcomings, this paper proposed a kind of filter algorithm based on the empirical mode decomposition (EMD) filter of interferogram phase noise suppression[7], which first decompose the real and imaginary parts of interferogram with the empirical mode decomposition method, and then determine phase value contribution for each pixel within the phase value of the filtered pixel phase template center in the complex domain, according to the interferogram gradient, achieve strong filter in low SNR region and weak filter in high SNR region, so that the edges of interferogram are preserved. The experimental results show that, the algorithm not only has the strong ability to suppress the speckle noise, and better maintain the edges and details of the interferogram, but also effectively reduces the loss of information in the interferogram, and ensure the phase purity of the phase image.

2. EMD Algorithm

The EMD involves the adaptive decomposition of given signal, $x(t)$, into a series of oscillating components, IMFs, by means of a decomposition process called sifting algorithm. The name IMF is adapted because it represents the oscillation mode embedded in the data. With this definition, the IMF in each cycle, defined by the zero crossings of, involves only one mode of oscillation, no complex riding waves are allowed. The essence of the EMD is to identify the IMF by characteristic time scales, which can be defined locally by the time lapse between two extrema of an oscillatory mode or by the time lapse between two zero crossings of such mode [8].

The EMD picks out the highest frequency oscillation that remains in the signal. Thus, locally, each IMF contains lower frequency oscillations than the one extracted just before. Furthermore, the EMD does not use any pre-determined filter or Wavelet function. It is fully data driven method. Since the decomposition of the EMD is based on the local characteristics time scale of the data, it is applicable to nonlinear and non-stationary processes. The EMD decomposes into a sum of IMFs that [9]: (1) have the same numbers of zero crossings and extrema; and (2) are symmetric with respect to the local mean. The first condition is similar to the narrow-band requirement for a stationary Gaussian process. The second condition modifies a global requirement to a local one, and is necessary to ensure that the IF will not have unwanted fluctuations as induced by the symmetric waveforms [9]. The sifting process is defined by the following steps:

Step 1) Fix $\varepsilon,\ j \leftarrow 1 (j^{th} IMF)$

Step 2) $r_{j-1}(t) \leftarrow x(t)(residual)$

Step 3) Extract the $j-th$ IMF:

(a) $h_{j,i-1}(t) \leftarrow r_{j-1}(t), i \leftarrow 1$ (i number of sifts);

(b) Extract local maxima/minima of h $h_{j,i-1}(t)$;

(c) Compute upper envelope and lower envelope functions $U_{j,i-1}(t)$ and $L_{j,i-1}(t)$ by interpolating respectively local maxima and minima of $h_{j,i-1}(t)$;

(d) Compute the envelopes mean:
$\mu_{j,i-1}(t) \leftarrow (U_{j,i-1}(t) + L_{j,i-1}(t))/2$;

(e) Update:
$h_{j,i}(t) \leftarrow h_{j,i-1}(t) - \mu_{j,i,-1}(t), i \leftarrow i+1$;

(f) Calculate stopping criterion:

$$SD(i) = \sum_{t=0}^{T} \frac{\left|h_{j,i-1}(t) - h_{j,i}(t)\right|^2}{(h_{j,i-1}(t))^2} \quad (1)$$

(g) Decision: Repeat Step (b)-(f) until $SD(i) < \varepsilon$ and then put $IMF_j(t) \leftarrow h_{j,i}(t)(j^{th} IMF)$

Step 4) Update residual: $r_j(t) \leftarrow r_{j-1}(t) - IMF_j(t)$

Step5) Repeat Step 3 with $j \leftarrow j+1$ until the number of extrema in $r_j(t) \le 2$ where T is the time duration. The sifting is repeated several times (i) in order to get h to be a true IMF that fulfills the requirements R1 and R2. The result of the sifting procedure is that $x(t)$ will be decomposed into $IMF_j(t), j = 1, \cdots, N$ and residual $r_N(t)$:

$$x(t) = \sum_{j=1}^{N} IMF_j(t) + r_N(t) \quad (2)$$

To guarantee that the IMF components retain enough physical sense of both amplitude and frequency modulations, we have to determine a criterion for the sifting process to stop. This is accomplished by limiting the size of the standard deviation SD computed from the two consecutive sifting results [10]. Usually, SD is set between 0.2 to 0.3. Note that the EMD does not use any pre-determined filter or Wavelet function. It is a fully data driven method.

3. Denoising Principle

According to the property of the decomposition procedures, the data are decomposed into n IMFs (fundamental components), each with distinct time scale. More specifically, the first component associated with the smallest time scale corresponds to the fastest time variation of data. As the decomposition process proceeds, the time scale is increasing, and hence, the mean frequency of the mode is decreasing. Based on this observation, we may devise a general purpose time-space filter as

$$x_{lh}(t) = \sum_{j=1}^{h} IMF_j(t) \quad (3)$$

where $l, h\{1, \cdots, \}, l \le h$. For example, when $l = 1$ and $h < n$, it is a high-pass filtered signal; when $l > 1$ and $h = n$, it is a low-pass filtered signal; when $1 < l \le h < n$, it is a band-pass filtered signal. In this paper, Eq. (3) forms the basis functions for representing interferogram data as described below, where we use it as a low-pass filter.

The EMD algorithm extracts the oscillatory mode which exhibits the highest local information from the data ("detail" in the wavelet context), and leaves the remainder as a "residual" ("approximation" in wavelet analysis). According to the major merits of EMD, the process of deriving the basic functions is empirical and the basic functions are obtained dynamically from the signal itself [11]. Therefore, it is reasonable to consider that the residual presents the basic characteristics of the interferogram and the detail denotes the variation of the noise represented by the highest local information. This is the motivation we use the EMD as a low-pass filter and only the distinct interferogram characteristics are utilized as discriminating features for accurate interferogram recognition.

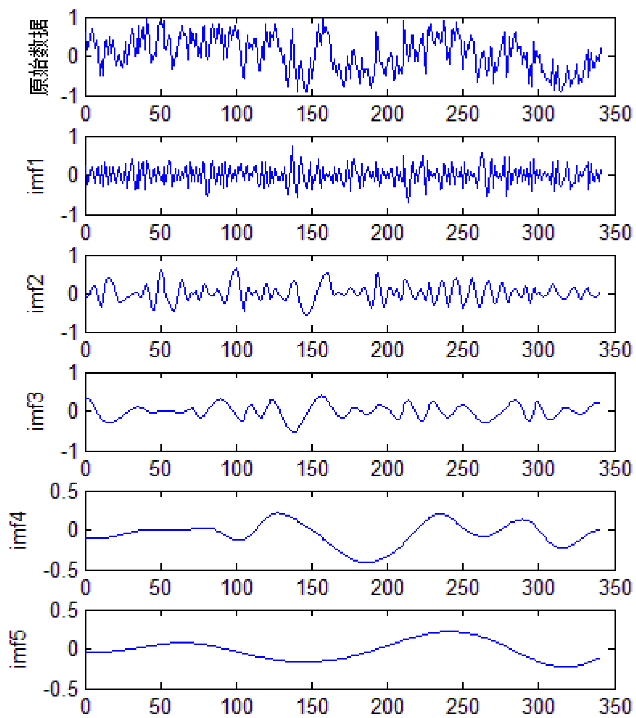
In this work different kinds of preprocessing are used: temporal filtering using Savitzky-Golay [10], Averaging, Median, and nonlinear transformation (hard and soft thresholding) [12].Accordingly, EMD can be extended to SAR Interferogram denoising. The different spatial scale information can be effectively separated by EMD which can process non-stationary, nonlinear information. Meanwhile the results of processing about spatial-frequency to singular signal can be controlled in a very small range, so that the abnormal vibration only impact the local, and will not spread to the whole region. Therefore, the methods of EMD can effectively separate scale images.

4. Experimental Results and Analysis

4.1. Experimental Data

The experimental data, the ERS-1/2, interval of 1 day and repeated track SLC data, whose size is 1800 x 2500.we obtain experimental interferograms after experimental data are removed the ground effect by the Swiss GAMMA software in this paper. After experimental interferogram data filtered by the empirical mode decomposition (EMD) method, we analyzed and compared the results with mean filter, median filter, and adaptive filter.

Taking the real component and imaginary component of original interferogram to compose the two data sets, we respectively decompose the real and imaginary parts of the original interferogram with the empirical mode decomposition (EMD) method, and choose different number of IMF to filter according to different needs and different form of noise. We can get filtered images after the real and imaginary parts filtered by EMD will be reconstructed, the filtered results shown in Fig.5. In order to analyze the EMD decomposition results, we select the 200th line of first 340 columns in the real and imaginary components of original interferogram that include both the region with more intensive interference fringes and the relatively sparse interference fringes, which have very strong representative to analysis for further. The EMD decomposition effect diagrams are shown in Fig.1 and Fig. 2.



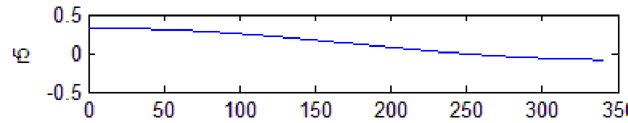


Fig.1 Obtained five IMF components and the residual (r5 on the bottom) from the real component of the original interferogram after applying the EMD method

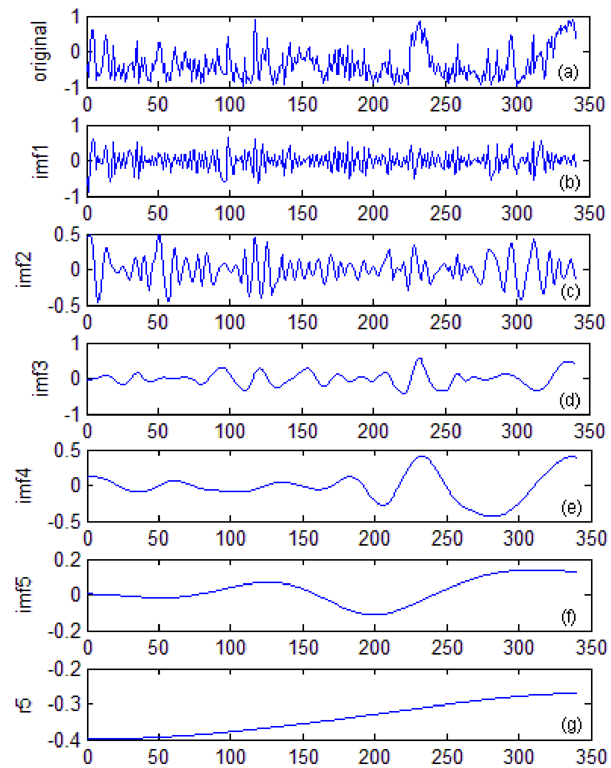
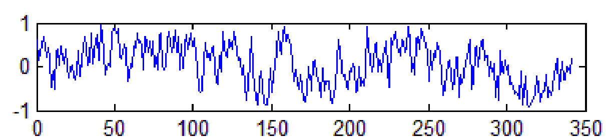
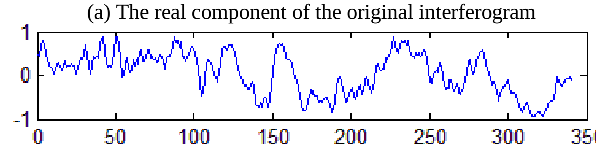


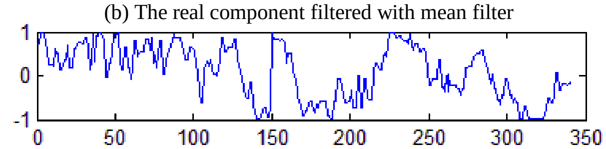
Fig.2 Obtained five IMF components and the residual (r5 on the bottom) from the imaginary component of the original interferogram after applying the EMD method



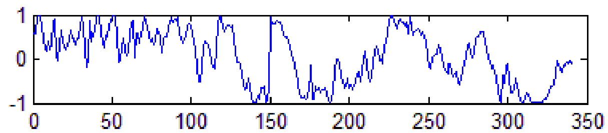
(a) The real component of the original interferogram



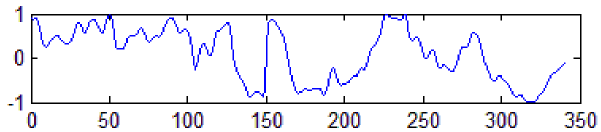
(b) The real component filtered with mean filter



(c) The real component filtered with median filter



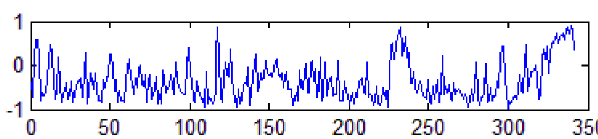
(d) The real component filtered with adaptive filter



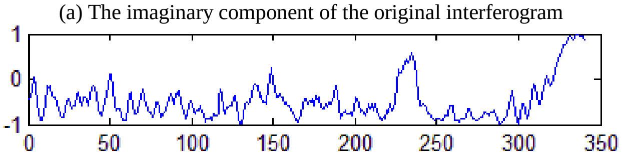
(e) The real component filtered with EMD

Fig.3. Real component filtered with different filters compared with original real component. (a) is the real components of the original data, (b),(c), (b) and (e)are the real components results filtered by the four filters.

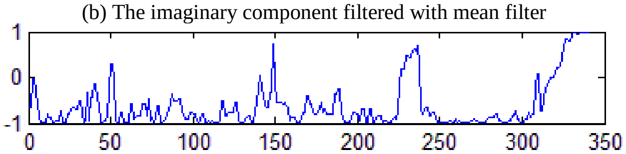
From Fig. 3 and Fig. 4, we can know that the image curves after filter denoising is smooth than the original real and imaginary parts information, which demonstrate the four filters remove a lot of noises. In (b) to (d) graphs, mean filter, median filter and adaptive filter method had some smoothing effect, but there still is difficult to remove some burrs, the effect of the three filter is similar; as can be seen in Fig.3 and Fig.4 (e), the empirical mode decomposition (EMD) method is obviously better than the former several filters methods whether in removing noises, or image smoothing degree, which remove the burrs, and achieve filtering smoothing effect.



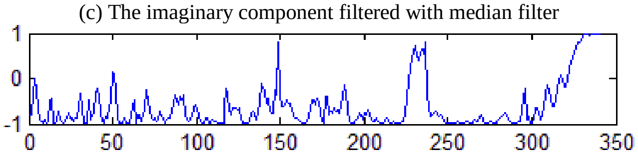
(a) The imaginary component of the original interferogram



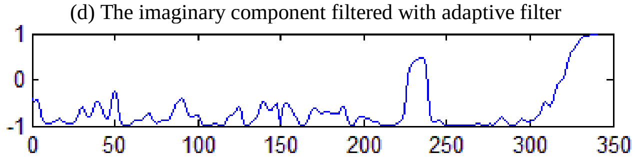
(b) The imaginary component filtered with mean filter



(c) The imaginary component filtered with median filter



(d) The imaginary component filtered with adaptive filter

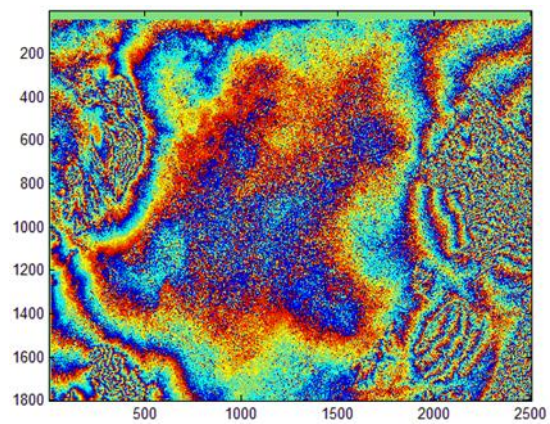


(e) The imaginary component filtered with EMD

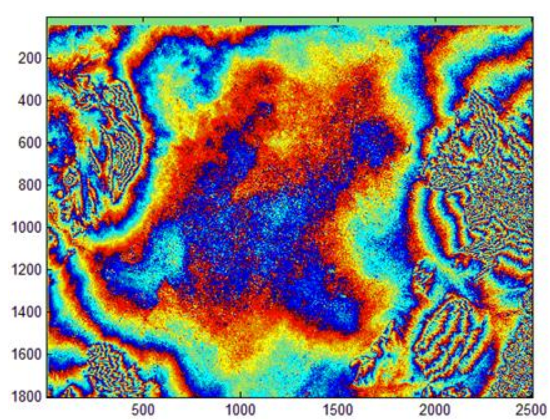
Fig.4. Imaginary component filtered with different filters compared with original imaginary component. (a) is the imaginary components of the original data, (b),(c), (b) and (e) are the imaginary components results filtered by the four filters.

4.2. Experiments Compare and Analysis

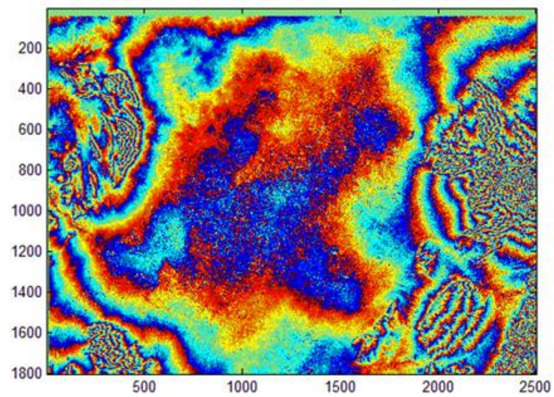
This paper chooses interferogram filtering quantitative evaluation indexes of RMS index, phase standard deviation (PSD) [13], Sum of Phase Difference (SPD) index [14] and residual index [15] to evaluate the above-mentioned four filter methods [16]. Fig.5 is interferogram filtered with different filters compared with original interferogram. In the interferogram filtered by the four filters, we select the phase diagrams of the 200th rows of 340 columns to further comparative and research the results of the four filters; the cross sections over the filtered interferogram are shown in Fig.6.



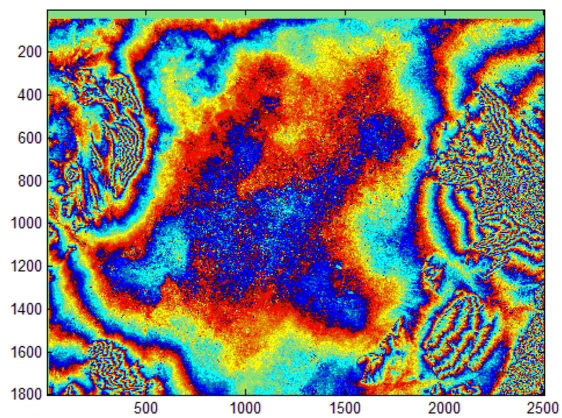
(a) The original interferogram



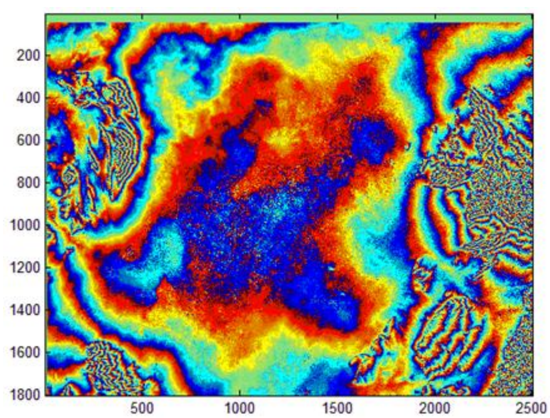
(b) The interferogram filtered with mean filter



(c) The interferogram filtered with median filter



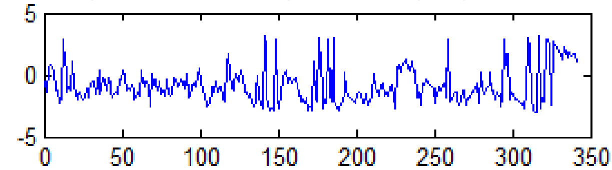
(d) The interferogram filtered with adaptive filter



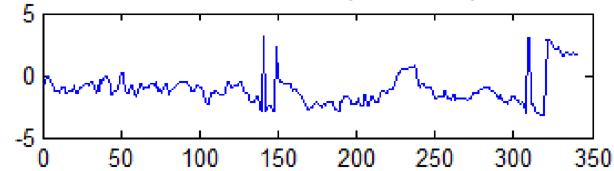
(e) The interferogram filtered with EMD

Fig.5 Interferogram filtered with different filters compared with original interferogram

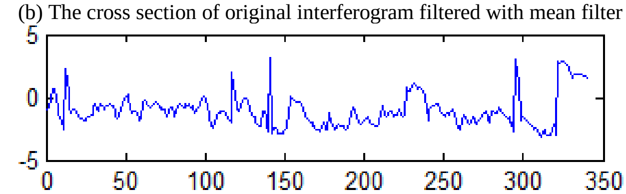
From Fig.5, we can know that the speckle noises of denoising interferograms are reducing in (b) to (d), but there are still some spots existing; from visual effect, the denoising interferograms of the mean filter and median filter have obvious speckle noise that is not eliminated; in (e), the denoising interferograms of EMD is very smoothing, no obvious speckles, where stripes are clear, and feature, structure characteristic and small target have been well maintained. From above-mentioned, the empirical mode decomposition (EMD) filter method is obviously better than the preceding three filters, whether in removing the noise, or image smoothing degree [17].



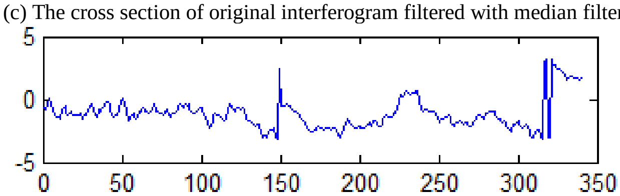
(a) The cross section of original interferogram



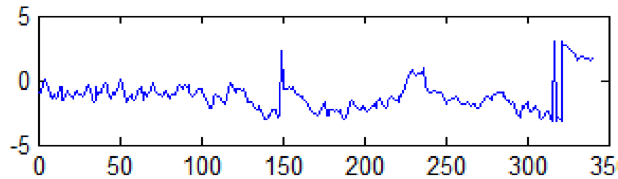
(b) The cross section of original interferogram filtered with mean filter



(c) The cross section of original interferogram filtered with median filter



(d) The cross section of original interferogram filtered with adaptive filter



(e) The cross section of original interferogram filtered with EMD

Fig.6. Cross section over the filtered interferogram

From shown in Fig.6, Compared with the other three filters, the interferogram fringes filtered by empirical mode decomposition (EMD) filter method have better continuity[18], whose noise suppression effect is very obvious, which are more consistent with the cross sections of the original interferogram.

Table 1 is statistics of various filter evaluation criterions. As can be seen, the RMS, PSD and SPD of interference phase diagram filtered by the mean filter, median filter and adaptive filter is reduced, which illustrate the 3 kinds of filtering algorithm play a smoothing effect to interferometric phase images, but the empirical mode decomposition filter method is superior to the 3 algorithms in keeping of the edge and phase details. So the denoising ability of the empirical mode decomposition filtering method is better than the three kinds filter methods.

Table.1. Statistics of various filter evaluation criterions

Denoising method	RMS	PSD	SPD	Residual points
original interferogram	1.8765	1.7608	4.7741E+005	201240
mean filter	1.0672	0.8888	3.5366E+005	5872
median filter	0.9275	0.7856	3.4568E+005	4217
adaptive filter	0.8536	0.6193	3.2767E+005	1028
EMD	0.3417	0.3569	2.3139E+005	685

5. Conclusions

A large number of noises in interferogram seriously affect the efficiency and accuracy of phase unwrapping algorithm. Therefore, in the processing of InSAR interferogram, we must effectively remove interference noise, and improve the operation efficiency and required accuracy. According to the characteristics of EMD, this paper introduces the empirical mode decomposition (EMD) method to SAR interferogram filtering. The experimental results show, the empirical mode decomposition is powerful to suppress speckle noise and phase noise while preserving edges than the classical filtering method, whether from the visual interpretation, or quantitative evaluation index. Our next research is to develop two-dimension filter based on EMD method.

Acknowledgments

The authors wish to thank the helpful comments and suggestions from my teachers and colleagues in Wuhan University and Hunan City University. This work is supported by the central college basic scientific research business expenses special fund (No.2012214020209) and the scientific research fund of Hunan provincial education department (No.12C0566).

References

[1].Seymour, M.S. Gumming, I.G. Maximum likelihood estimation for SAR Interferometry in Processing . IGARSS, 1994, 12, 2272-2278.

[2]. Eichel P.H, Ghiglia D.C. Spotlight SAR Interferometry for Terrain Elevation Mapping and Interferometric Change Detection. Sand: Sandia National Labs technology, 1993, 12, 2529-2546.

[3].Lanari R, Fornaro G. Generation of Digital Elevation Models by Using SIR_C/X_SAR Multifrequency Two-pass Interferometry: The Etna Case Study. IEEE Trans on GRS, 1996, 34, 1096-1115.

[4].GOLDSTEINRM, WERNERCL. Radar Interferogram Filtering for Geophysical Applications. Geophysical Research Letters, 1998, 25, 4035-4038

[5].Lee,J.S., Papathannassion, K.P. A. New Technique for Noise Filtering of SAR Interferometric Phase Images. IFFF. Trans. on GRS, 1998, 34, 1455-1459.

[6].Zhu Daingying, Scheiber, R, Zhu Zhaoda. Impacts of an efficient topography adaptive filter on coherence estimation and phase unwrapping. EUSAR, 2000,23, 318-320.

[7]. Yue Huanyin, Guo Huadong, Han Chunming, et al. A SAR Interferogram Filter Based on the Empirical Mode Decomposition Method. IEEE AGCS, 2011, 13, 2061-2063.

[8]. Boudraa A O,Cexus J C. Denoising via empirical mode decomposition. IEEE International Symposium on Control, Communication and Signal Processing (ISCCSP06), Morocco,2006.

[9]. N.E. Huang, Z. Shen, S.R. Long, M.C. Wu, H.H. Shin,Q. Zheng, N.C. Yen, C.C. Tung and H.H. Liu, "The Em-pirical Mode Decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis,"Proc. Royal Soc. London A , vol. 454, pp. 903-995, 1998.

[10].D.L. Donoho and I.M. Johnstone, "Ideal spatial adaptation via wavelet shrinkage," Biometrica, vol. 81, pp.425-455, 1994.

[11]. M.M. Goodwin and M. Vetterli, "Matching pursuit and atomic signal models based on recursive filter banks," IEEE Trans. Sig. Process., vol. 47, no. 7, pp. 1890-1901,1999.

[12].A. Savitzky and M.J.E. Golay, "Smoothing and differentiation of data by simplified least squares procedures". Analytical Chemistry, vol. 36, pp. 1627-1639, 1964.

[13].Tan Shanwen, Qin Shuren, Tang Baoping. Hilbert-Huang transforms filter and its application. Journal of Chongqing University, 2004.27, 109-120.

[14].BO YC, et al. A Wavelet-Based Filter for SAR Speckle Reduction and the Comparative Evaluation on Its Performance.Journal of Remote Sensing, 2003,7, 393-399.

[15].LEEJ S, JURKEVICHI. Speckle Filtering of Synthetic Aperture Radar Images: a Review. Remote Sensing Reviews, 1994, 12, 13-340.

[16].OLIVER CJ, QUEGAN Understanding Synthetic Aperture Radar Images. London: Artech House Inc., UK, 1998.

[17]. LEEJ S. Digital Image Enhancement and Noise Filtering by Use of Local Statistics. IEEE Trans. Pattern Analysis and Machine Intelligence, 1980, 2, 165-168.

[18]. BO YC, et al. A Wavelet-Based Filter for SAR Speckle Reduction and the Comparative Evaluation on Its Performance. Journal of Remote Sensing, 2003,7, 393-399.

Changjun Huang obtained the B.S. and M.S. degrees in Geodesy and Survey Engineering from East China Institute of Technology, China, in 2003 and 2006, respectively. Since September 2011, he is a PhD student in School of Geodesy and Geomatics, Wuhan University, China. His current research interests include InSAR interference measurement and application of InSAR in high precision deformation monitoring.

Jiming Guo received the Ph.D. degree in Geodesy and Survey Engineering from Wuhan University, China, in 1985.
From June 2002 to June 2003, he was a Visiting Researcher in GPS Group, Geodesy and Geomatics Engineering Department, University of New Brunswick, Canada. He is currently a professor, Ph.D supervisor in Wuhan University, China; he is concentrated on the research and education in engineering survey and GPS application.

Xiaodong Yu received the B.S degree in Geodesy and Survey Engineering from China University of Mining and technology, China, in 2011. Since September 2011, he is a master in School of Geodesy and Geomatics, Wuhan University, China. Currently, he researches the theory of InSAR and application of InSAR in high precision deformation monitoring.

Changzheng Yuan obtained the B.S degree in School of Geodesy and Geomatics, Wuhan University, China. Since September 2007 to June 2011.Currently, he is studying for a master's degree in the same school. The direction of his research is InSAR interference measurement and its application in deformation monitoring.