

THE EFFECT OF SPECKLE REDUCTION ON COHERENCE ESTIMATION AND INTERFEROMETRIC PHASE OF INSAR

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ABSTRACT:

Synthetic aperture radar (SAR) images always suffer from strongly speckle noise, which is a great obstacle to coherence (or correlation coefficient) estimation and interferometric phase, furthermore hinders the accuracy of phase unwrapping and information extraction with SAR interferometry (InSAR) technique. In this article, we propose to suppress the speckle of SAR images with several self-adaptive filtering methods so as to evaluate how the filtering influences the coherence and the quality of phase map by quantitative and qualitative analysis. As an example, ERS SAR interferometric pair covering Shanghai is used for this study. The filtering algorithms we adopted include enhanced Lee, enhanced Frost, Gamma Map, and Kuan filtering, etc. In order to choose the optimal algorithm, we used four kinds of technical criterions, such as smoothness index, speckle noise index, equivalent number of looks (ENL), and normalized mean, etc. By comparing the former criterions, we can determine which kind of filtering will be used in the following data processing. Once the appropriate filtering is determined, we thus could move on and carry on operations of coregistration, Phase Conjugate multiplication, and flat earth phase removal, etc. Finally, we have got the coherence and interferometric phase maps by using the unfiltered and filtered interferometric pairs, respectively. The mean, standard derivation (SD), and statistical distribution chart are used to estimate the change of coherence. The mean, SD, and sum of phase difference (SPD) are adopted to evaluate the quality of interferometric phase map. The results show that the speckle reduction did not improve the quality of interferometric phase map and nearly have no impact on the coherence coefficients. The next study is which kind of other measures should be adopted under the condition of small temporal and spatial baseline in the interferometry.

1. INTRODUCTION

InSAR (Interferometric Synthetic Aperture Radar) is a new hot space technique in Microwave Remote Sensing as well as Geodesy for its great ability to extract landscape topography and its deformation during day and night under any weather conditions by involving two or more SAR images, see e.g. Zebker[1], Ferretti [2], Hassen[3], for a general introduction of this technique.

Speckle in SAR image is a troublesome factor, which may has a great impact on the accuracy of terrain, land-use classification, and scene interpretation. For the sake of extracting more accurate and useful information, speckle filtering become very important in the case studies.

From the open issued literature, we can find that researches on SAR speckle filtering, InSAR data processing and its applications have got enough concerned during the past decades. However, the studies on how the speckle filtering influenced the coherence estimation and interferometric phase seems to be paid little attention, which is an unignorable factor according to our preliminary analysis. In this paper we emphasized our focus on speckle filtering technique and attempted to investigate the relation between the SAR speckle filtering in the time domain, and the coherence and interferogram.

2. SAR SPECKLE FILTERING METHODS

In past years multilooking operation is generally used to reduce the speckle of the SAR images. However, for InSAR technique, this operation will breach the premise of phase preserving. Therefore this method is out of our consideration in this paper.

Besides multilooking, the filtering can be carried on in time domain and frequency domain. In time domain, there appeared

many kinds of filtering methods based on statistical and non-statistical models, such as (enhanced -) Lee, (enhanced -) Frost, and Kuan and Gamma MAP filtering, mean filtering, median filtering and order statistical filtering, etc. In frequency domain the wavelet transform is used most frequently.

Filtering algorithms based on statistical model have the advantage of adjusting the weights self-adaptively, it is thus widely used in relatively complicated signal processing e.g. two dimensional image filtering. We proposed to use four filtering methods, such as enhanced Lee, enhanced Frost, Gamma Map, and Kuan filtering, and then choose the most congruent one to continue our research that is how the speckle filtering influence the interferometry. It equals to investigating the effect of SAR pre-filtering in the InSAR technique.

3. DEFINITION OF COHERENCE ESTIMATOR AND INTERFEROMETRIC PHASE

Coherence coefficients and the quality of interferometric phase are usually used to evaluate the interferometric quality. SAR phase interferogram and coherence can be generated by complex conjugate multiplication of two coregistered SAR SLC images.

The coherence (or correlation) coefficients generally can be defined as

$$|\hat{\gamma}| = \frac{\left| \sum_{i=1, j=1}^{M, N} s_1(i, j) s_2^*(i, j) \right|}{\sqrt{\sum_{i=1, j=1}^{M, N} s_1(i, j) s_1^*(i, j) \sum_{i=1, j=1}^{M, N} s_2(i, j) s_2^*(i, j)}} \quad (1)$$

Where, $|\hat{\gamma}|$ is the coherence level; $s_1(i, j)$, $s_2(i, j)$ are echo signal of master and slave image; * is the conjugate of a complex; $M \times N$ is the window size during the coherence estimation.

The interferogram phase can be computed by

$$\psi = \arctg(s_1 \square s_2^*) \quad (2)$$

4. CASE STUDY

4.1 Data sets

Shanghai city, located in the east of china is selected as our experimental district. The SAR images and its location which are used to generate the interferogram covering Shanghai is showed in the Fig. 1, Tab. 1, and Tab. 2.

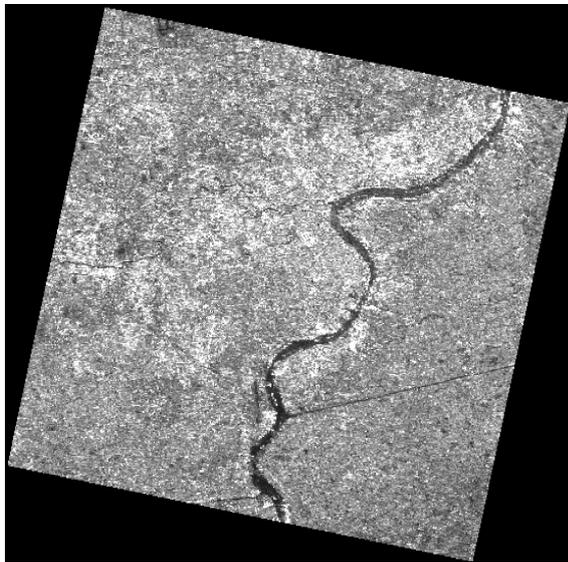


Figure 1. The SAR image of Shanghai test site imaged on Jun, 6 1992

Mission	Northwest	Northeast	Southwest	Southeast
Longitude	31° 19'	31° 17'	31° 06'	31° 09'
Latitude	121 °23'	121 °36'	121 °33'	121 °21'

Table.1 The Geographic coordinates of SAR test area

Mission	Master	Slave	ΔT (d)	B \perp (m)	Spectral overlap
ERS-1	19920606	19920919	105	-109.47	Range : 89.84% Azimuth: 95.96%

Table. 2 The basic parameters of the SAR interferometric pairs of Frame 2979

4.2 Comparison of several adaptive filtering methods

Filtering methods based on statistical model are the most of generally used methods in the image processing due to its obvious advantage of reduction of the standard derivation. And it proves that this series of filter not only filter the noise preferably but also preserve the edge for the better.

In our test algorithms such as Enhanced Lee, Enhanced Frost, Gamma Map, and Kuan filtering are used to remove the noise of the master and slave SAR images. To evaluate the efficiency of those methods, we select five criterions including SD (Standard Deviation), SI (Smoothness Index), SNI (Speckle Noise Index), ENL (Equivalent Number of Looks), and NM (Normalized Mean), seen in Tab. 3. For a quasi-homogeneous scene, SNI is an index which reflects the intension of speckle. The large SNI value means the high speckle noise level. In addition, the larger the SI and ENL, the stronger smoothness ability of the filtering algorithms is. The NM is more close to 1, the unbiased estimator is more approached.

By comprehensively considering the above assessment indexes, the Gamma Map filtering is verified the optimal filtering due to its highest ENL and SI, and smallest SD and SNI. The next step is to generate the coherence and interferogram using the unfiltered pair and filtered one, respectively.

Master 19920606	Original	Enhanced Lee	Enhanced Frost	Gamma Map	Kuan
SD	1547.7262	826.0680	793.7859	776.5155	1044.2183
SI	1.3487	2.5189	2.6123	2.6900	1.9990
SNI	0.7145	0.3970	0.3828	0.3718	0.5003
ENL	1.8169	6.3449	6.8241	7.2361	3.9960
NM	1.0000	0.9968	0.9934	1.0007	1.0000

Table. 3 Comparison of Four kinds of filtering algorithms

4.3 Interferometric data processing

The main steps in our interferometric test include coregistration, removal of the flat earth phase, generation of interferogram and coherence, filtering of the interferogram.

To reduce errors during the process of co-registration and flat earth phase removal, we used the precise ERS orbit data from Delft University of Technology. Consequently, we need execute general coarse to fine coregistration between the master and slave images. The final fine coregistration errors of unfiltered

and filtered pairs are both controlled in the range of 0.05 pixels along the range direction and 0.08 pixels along the azimuth direction. In order to compare the interferometric results under the same condition, we adopted the same window size during the estimation of coherence. To suppress noise, the SAR images are processed by a multi-look operation of 5 pixels along the azimuth direction to obtain a final resolution of 20x20m, and filter the interferogram with Gaussian filtering.

The interferogram and coherence are showed in Fig. 2, Fig. 3, Fig. 4, Fig.5, respectively

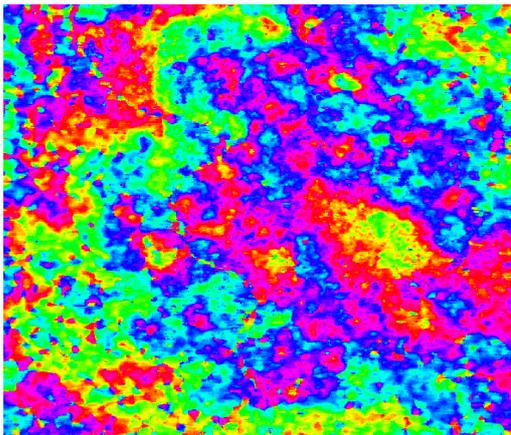


Figure. 2 Interferogram generated by unfiltered pair

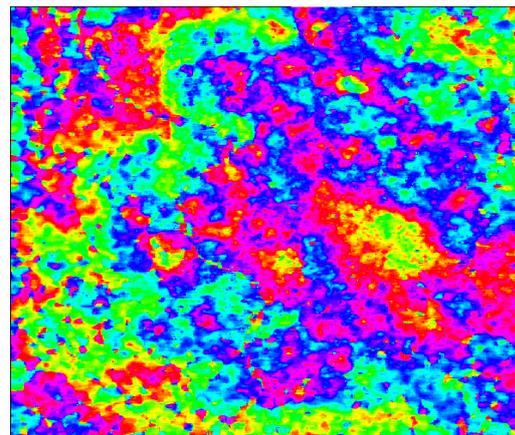


Figure. 3 Interferogram generated by filtered pair

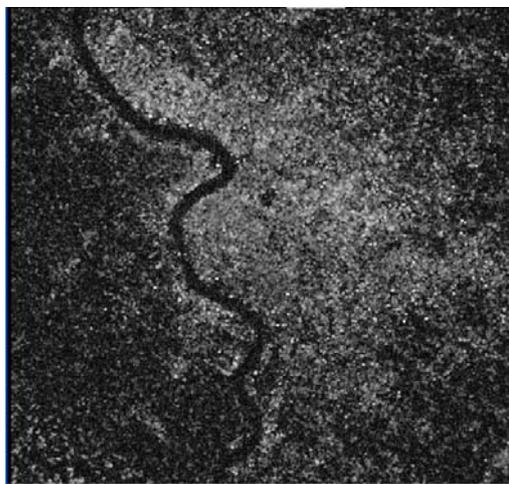


Figure. 4 Coherence estimated by unfiltered pair

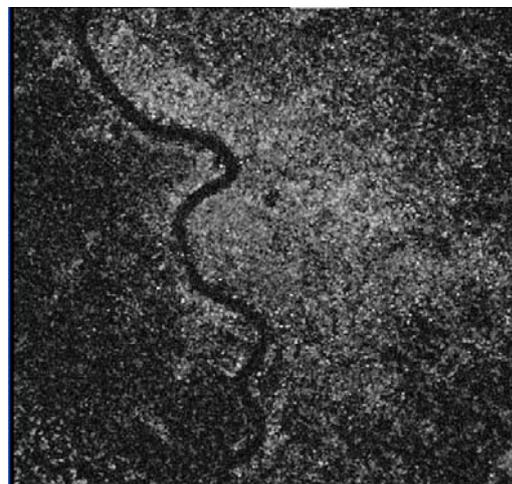


Figure. 5 Coherence estimated by filtered pair

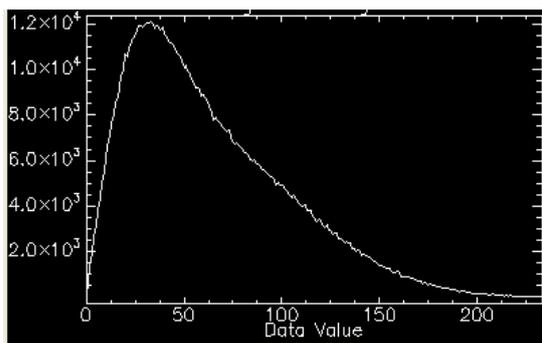


Figure. 6 Coherence Distribution obtained by unfiltered pair

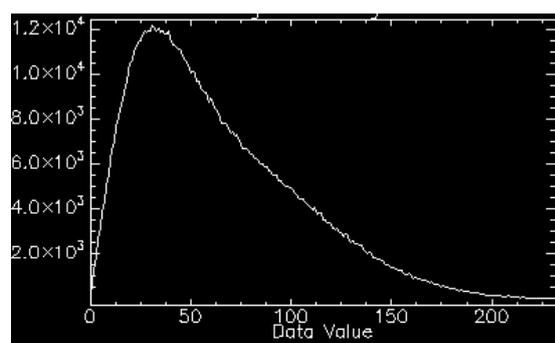


Figure. 7 Coherence Distribution obtained by filtered pair

Interferometric Phase	μ	SD	SPD	Coherence	μ	SD
Unfiltered pair	140.85	68.35	2.3922×10^5	62.95	39.97	
Filtered pair	140.89	68.42	2.3976×10^5	62.95	39.96	

Table. 4 Statistics of coherence and interferometric phase

By visual judgment, we could not discriminate which coherence and interferometry are better, and we thus use several statistics

of the coherence and interferogram - Mean (μ) SD, and SPD (Sum of Phase Difference) as the quantitative evaluating indexes.

From the Tab. 4 we can find that the pre-filtering nearly had no obvious impact on the coherence and interferogram because all the indexes are almost unchanged.

4.4 Conclusion

For the interferometry, time interval and spatial perpendicular baseline are the most important error sources. In the Tab. 2, we can find that the temporal baseline is not long, meanwhile the spatial baseline is also not large. Thus the decorrelation generated by temporal and spatial baseline are nearly ignored.

Exclude the temporal and spatial decorrelation, we initially guessed that the speckle is also an important error source which will destroy the interferometric result. However, the result- both the figures (Fig. 2, 3, 4, 5, 6, 7) and the tables (Tab. 4) did not validate what we expected that the pre-processing to the SAR pair can improve the coherence and the quality of interferogram.

5. DISCUSSION

According to the statistics of the master and slave image, the minimum, maximum, mean, and the standard derivation of the amplitude make a great deal of difference, which maybe represent the stability of the board and ground imaging system.

From the case study, we can draw a conclusion that if we encounter the situation of great difference between interferometric pair, the removal of speckle noise is not the first choice to solve the problem of interferometric phase map with low quality even although the time and space baseline are very small. We guess that the hardware may be one of the most fundamental causes of low coherence in this case study.

Our next work is to investigate whether the removal of speckle noise has impact on coherence and quality of interferometric phase on the condition of little difference between master and slave amplitude.

ACKNOWLEDGMENTS

This work is supported by Science & Technology Commission of Shanghai Municipality (06DZ22101), and the Knowledge Innovation Program of the Chinese Academy of Sciences.

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