WAVENUMBER CORRELATION ANALYSIS OF RADAR INTERFEROGRAM

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Abstract - The radar interferogram represents phase differences between the two synthetic aperture radar observations acquired in slightly different angle. The success of the radar interferometric application largely depends on the quality of the interferogram generated from two or more synthetic aperture radar data sets.

We propose here to apply the wavenumber correlation analysis to the in-phase and quadrature phase of the radar interferogram. The wavenumber correlation analysis is to resolve the highly correlated components from the low correlation components by estimating correlation coefficients for each wavenumber component. Through this approach, one can easily distinguish the signal components from the noise components in the wavenumber domain. Therefore, the wavenember correlation analysis of the radar interferogram can be utilized to design post filter and to estimate the quality of interferogram. We have tested the wavenumber correlation analysis using a Radarsat SAR data pair to demonstrated the effectiveness of the proposed approach.

Introduction

Techniques of the radar interferometry have been improved dramatically in this decade, and its applications to topographic mapping and disaster monitoring are getting very popular in the remote sensing society [1].

The common criterion for estimating the quality of an interferogram is the coherence that is nothing but a ratio of the cross-correlation of the two data sets to the auto-correlation in the wavenumber domain. The coherence, however, only shows a degree of correlation between the two images, not a degree of correlation for each wavenumber component. We propose here a new approach named the wavenumber correlation analysis in which the correlation for each wavenumber component is taken in account. The background theory is briefly described in the following section followed by the test results using a Radarsat SAR interferogram.

Wavenumber Correlation Analysis (WCA)

The wavenumber correlation analysis was initially developed for the analysis of geophysical potential data such as gravity and magnetic anomalies, and is to resolve the highly correlated components from the low wavenumber correlation coefficients [2]. The correlation spectrum in the wavenumber domain is defined by [3]

$$CC(k) = \frac{\mathrm{Re}[\vec{X} \bullet \vec{Y}^*]}{|\vec{X}(k)||\vec{Y}(k)|} \qquad (1)$$

where *X(k)* and *Y(k)* are respectively the spectra of in-phase and quadrature phase in our case.

The radar interferogram is a result of Hermitian multiplication of the two images, and the in-phase (cosine) and quadrature phase (sine) of the interferogram should be a sinusoidal function in the relatively smooth varying surface. Based upon this characteristic of radar interferogram, we replace ***Y(k)*** by ***iY(k)*** to estimate the wavenumber correlation coefficient ***CC(k)*** in Eq.(1).

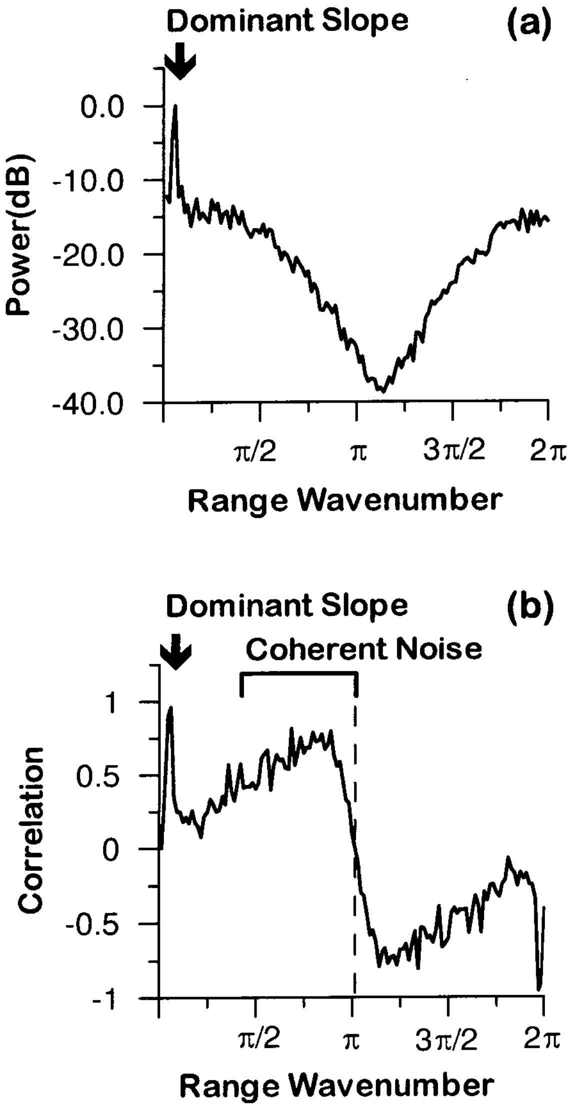


Figure 1. (a) Power spectra and (b) correlation coefficient in the wavenumber domain of the interferogram.

While the power spectra of the interferogram only shows energy concentration at the dominant slope in the interferogram, the wavenumber correlation coefficient of each wavenumber ***k*** accounts for the signal and noise components. If the slope of the Earth surface is relatively smooth, the in-phase and quadrature phase of the interferogram should be highly correlated in a certain wavenumber. The ***CC(k)*** of the random noise will have low or negative values, and that of coherent noise is of high values.

As shown in Fig. 1(a), the peak in the power spectra corresponds to the dominant slope and the rest of the spectra generally follow the Kaiser-Bessel window function. The ***CC(k)*** in Fig. 1(b), however, shows coherent noise as well as the dominant slope. Therefore one can easily discriminate the signal component against the noise component in the radar interferogram. There has not been a general method in the conventional method to determine the cut-off frequency of the post-filter, for instance [4]. The WCA is very useful to design the post-filter as shown in Fig. 1.

Test Results

We have tested the WCA using a Radarsat SAR interferogram. Once the signal and noise components are estimated in the wavenumber domain, there are several ways to remove the noise components including : i) replace the noise component by zero; ii) apply appropriate window function such as Hanning, Hamming, or Kaiser-Bessel window; or iii) design a new window function based on the expected wavenumber correlation coefficient. The first method is not suitable to the radar interferogram although it is often adopted in satellite potential data processing.

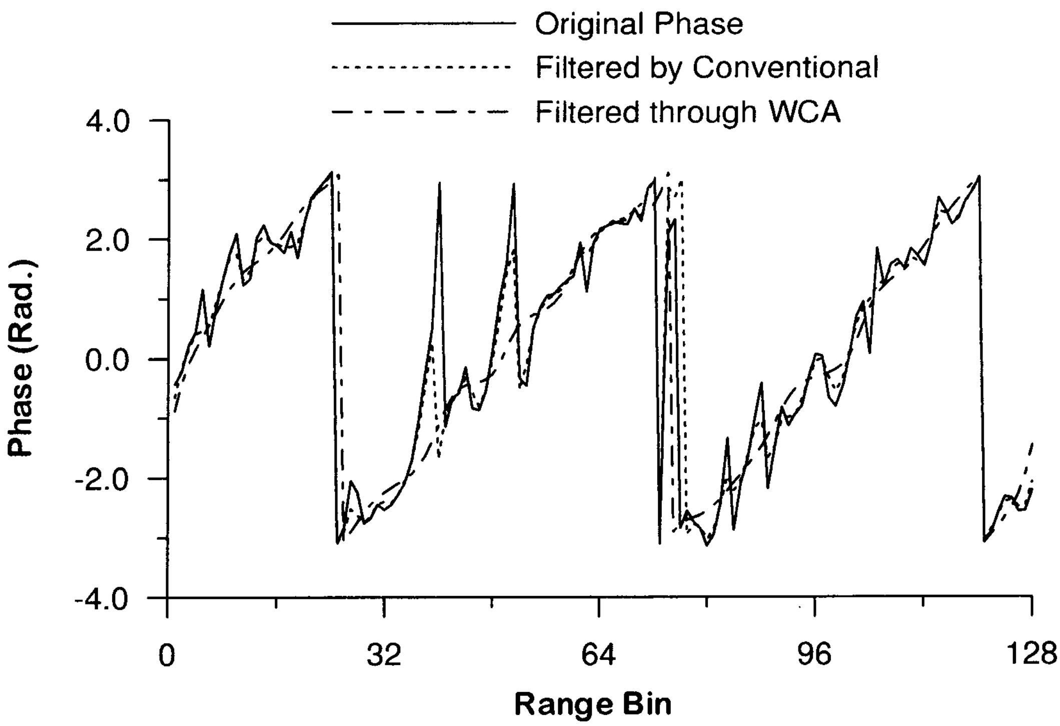


Figure 2. Test results of WCA: the filtered interferogram based upon WCA (dot-dashed line) shows smoother slope than the conventional approach(dotted line) described by [4].

The third approach has also been tested to have a promising result. However, it requires some more study to be complete. In this paper, we will only show the results achieved by the second approach.

The solid line in Fig. 2 is the original interferogram along a gentle slope in which the slope is distorted by noises. An improved interferogram can be obtained by applying a post-filtering [4] as shown by the dotted line in Fig. 2. Some noise effects still remain even after the conventional post-filtering. One can has the better interferogram plotted as the dot-dashed line in Fig. 2 by a post-filtering designed through the WCA. Now the slope of the surface is very much smooth after depressing the coherent noises that are mainly concentrated around high frequencies.

The improvement of the filtering can be more precisely evaluated by comparing the coherence histogram as shown in Fig. 3. The dashed line in Fig. 3 represents the histogram of the coherence map after conventional post-filtering (dashed line) and the post-filtering through WCA (solid line).

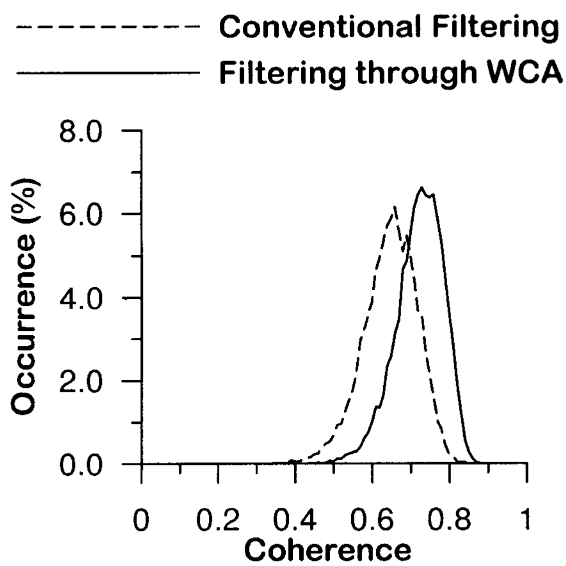
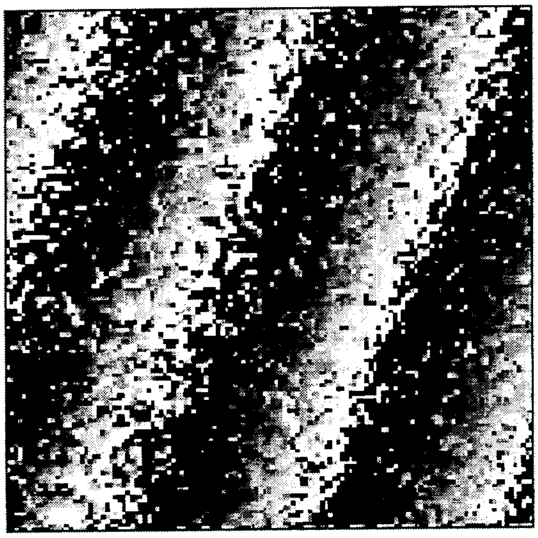
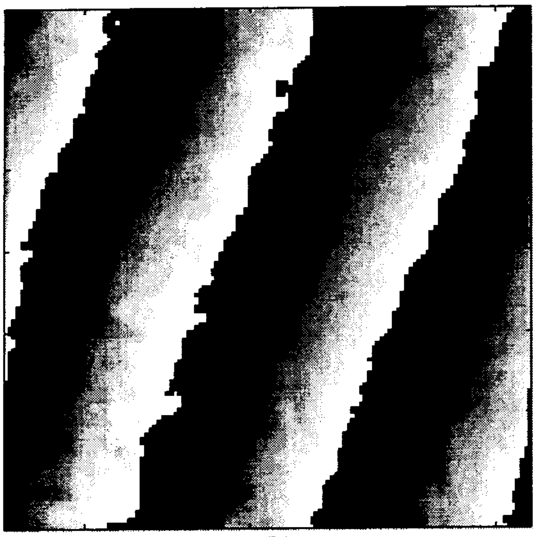


Figure 3. Coherence after (a) the conventional filtering and (b) the filtering through WCA.

The coherence histogram in Fig. 3 is estimated using an 8 by 8 (range-azimuth) sub window over the entire image. Fig. 3 demonstrates that the high coherence can be retained after the filtering through WCA superior to the conventional case. The tested Radarsat interferogram is shown in Fig. 4. There exist speckle in the original interferogram as in Fig. 4(a) that corrupts the sharp boundaries of fringe lines. After the post-filtering through WCA, the fringe line is extremely well recognized as in Fig. 4(b).



(a)



(b)

Figure 4. The interferogram (a) before and (b) after the post-filtering through WCA.

Summary and Conclusions

We have shown that the wavenumber correlation analysis can be utilized to characterize the radar interferogarm based on the fact the in-phase and quadrature phase are highly correlated in the wavenumber domain. The WCA can be applied before or after the flat Earth correction. It is very useful for designing post-filter especially when it is combined with power spectra analysis of the interferogram. Once the signal wavenumber components are estimated out of the noise wavenumber components, one can design a noise reduction filter. The detail of filter design needs to be studied further, but the current results show this approach is very effective to reduce the noise as well as retaining high coherency.

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