SUBSIDENCE AT DUK-PO AREA REVEALED BY DINSAR AND INTERFEROGRAM STACKING

SANG-HOON HONG, SANG-WAN KIM, and JOONG-SUN WON

Dept. of Earth System Sciences, Yonsei University
134 Shinchon-dong, Seodaemun-gu, Seoul, Korea 120-749
Ph.) +82-2-2123-2673 / Fax) +82-2-392-6527
e-mail) hongsh@yonsei.ac.kr

Abstract. Radar interferometric phase is sensitive to both ground topography and coherent surface displacement. The basic tactics of differential interferometric synthetic aperture radar (DInSAR) technique are to separate the two effects. Applications of DInSAR to Duk-Po area in Busan were studied. In the study area, an abrupt subsidence, possibly caused by sub-way construction, was observed by JERS-1 SAR interferometry. Differential interferograms were generated using twenty-three JERS-1 SAR data acquired between April 24, 1992, and August 7, 1998. Because the area is relatively flat with little topographic relief, the topographic effects were not removed. A phase filtering and interferogram techniques were applied to increase fringe clarity as well as to decrease decorrelation error. The stacking improves the quality of interferograms especially when the displacement is discontinuous. The interferograms clearly show the evidence of subsidence along Duk-Po subway railroad. These results demonstrate that the interferogram stacking technique can improve the detectability of radar interferometry to an abrupt displacement and DInSAR is useful to geological engineering applications.

Ⅰ. INTRODUCTION

Differential interferometric synthetic aperture radar (DInSAR) has been widely used to monitor ground surface deformations with a centimeter to millimeter accuracy in geophysical applications [1]. Some studies with DInSAR technique have revealed subsidence areas in the city of Paris [2], Napoli [3], and Pomona [4]. Stacking of interferograms could be used for high resolution topographic maps or distinct subsidence maps [5-6]. General approach requires phase unwrapping, because each interferogram has the phase ratio of perpendicular baseline. However phase unwrapping is not always achievable, especially when the coherence is low or radar distortion such as layover and shadowing exists. Since phase gradient due to topography is proportional to the perpendicular baseline, stacking of interferogram using that is available without phase unwrapping [7].

We apply DInSAR and stacking techniques to the Duk-Po area in Busan, Korea, in order to observe the subsidence possibly caused by underground works.

Ⅱ. DATA PROCESSING

We computed six suitable interferograms from twenty-three JERS-1 SAR images acquired between April 24, 1992, and August 7, 1998. All the complex images were registered with sub-pixel accuracy. The topographic phases were not removed, since the study area is relatively flat with little topographic relief. The phase difference with modulo 2π in the DInSAR interferograms corresponds to about half-wavelength of surface deformation along the line of sight. To avoid significant phase noise within interferograms, low-pass filtering was used in frequency domain for the phase gradient operation. Because gradient operation will increase the high frequencies or the short wavelength noise.

Ⅲ. STACKING INTERFEROGRAM

The phase gradient can be immediately computed from the complex interferogram without phase discontinuity problem. Interferograms can be stacked using averaging of phase gradient without phase unwrapping. Staking of interferograms of different baselines will reduce temporal and baseline decorrelation.

The gradient of the phase $\phi = \tan^{-1}\left(\frac{I}{R}\right)$ can be expressed as follows [7]:

$$\nabla\phi(x) = \frac{R\nabla I - I\nabla R}{R^2 + I^2} \quad (1)$$

where R and I are the real and imaginary part of interferograms. In practice, complex conjugate method is more efficient in the computation of phase gradient:

$$\nabla\phi(x) = C_{x+1} \cdot C_x^* \quad (2)$$

where C_x is complex interferogram. Since phase gradient from complex interferogram, unlike the phase, are usually continuous function, we can generate stacked interferogram from arithmetic average of phase gradient [7]:

$$\overline{\nabla\phi} = \frac{1}{N}\sum_{i=0}^{N}\nabla\phi_i \quad (3)$$

Although the phase gradient has some advantages over the original phase, they cannot be converted directly into topography or surface displacement. So phase unwrapping or phase gradient integration is still required.

In frequency domain, phase can be reconstructed using the relationship as follows:

$$\phi(x) = \sum_{k=0}^{N-1}\Phi_k \frac{e^{\frac{i2\pi k}{N}x}}{e^{\frac{i2\pi k}{N}} - 1} - \frac{1}{N}\sum_{k=0}^{N-1}\Phi_k \frac{1}{e^{\frac{i2\pi k}{N}} - 1} \quad (4)$$

In practice, the first term of Eq. (4) is a scaled fourier transform of phase gradient and the second term is a simple summation.

Ⅳ. RESULTS

Fig. 1 shows the amplitude image of study area, which corresponds to sub-way construction through urban area. This area is quite flat area near to the Nak-Dong river.

Fig. 1. Amplitude image around the study area. The interferograms of the selected rectangle area is shown Figure 2.

Fig. 2 presents the six interferograms used for monitoring surface subsidence. These interferograms have a large temporal baseline about 2-3 years. While interferogram phase appears very noisy and shows low coherence in vegetated areas, there are some fringes related to ground deformations in urban area with all a large temporal baseline and flat area. The unique phase corresponded to subsidence was located in surroundings on Duk-Po and Mo-Ra stations at the centre of image.

The phase values of the elongated fringe pattern increase across the fringe, which indicates that it is related to not an uplift but a subsidence effect.

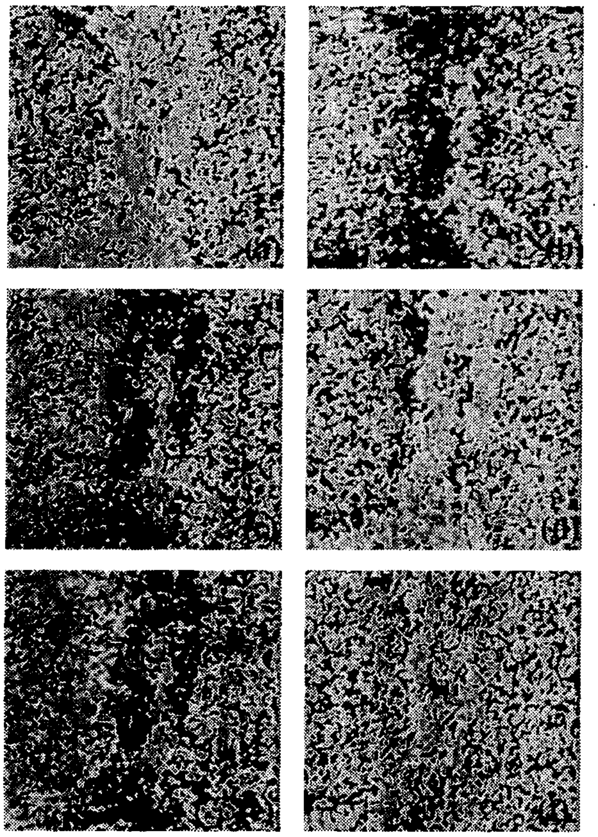

Fig. 2. Differential interferograms. (a)08/11/95-25/11/ 97, (b)08/11/95-08/01/98, (c)08/11/95-21/02/98, (d)08/ 11/95-03/07/98, (e)08/11/95-16/08/98, (f)08/11/95-29/ 09/98. All interferograms show the fringe pattern caused by subsidence effects.

Simulated phases for stacking algorithm are shown Fig. 3. We modeled the wrapped phases of two and three fringes respectively. The stacking technique on simulated phases through the phase gradient method provides a good result of merged and wrapped phases.
However, there is some problem caused by a high frequency in the result of stacking using phase gradient algorithm, since differential interferograms have still some noises around the area of interest. We applied phase gradient using real phase instead of complex data to stack interferograms.
Although stacking of interferograms is efficient to increase fringe clarity and to decrease decorrelation error phase filtering is needed for reduction of noise in case of low coherence or low signal to noise ratio. The stacked interferogram after filtering is shown Fig. 4 has clearer fringe pattern than that of Fig. 2. The general shape of deformation fringe pattern along sub-way line suggests that the subsidence phenomenon is due to underground construction work.

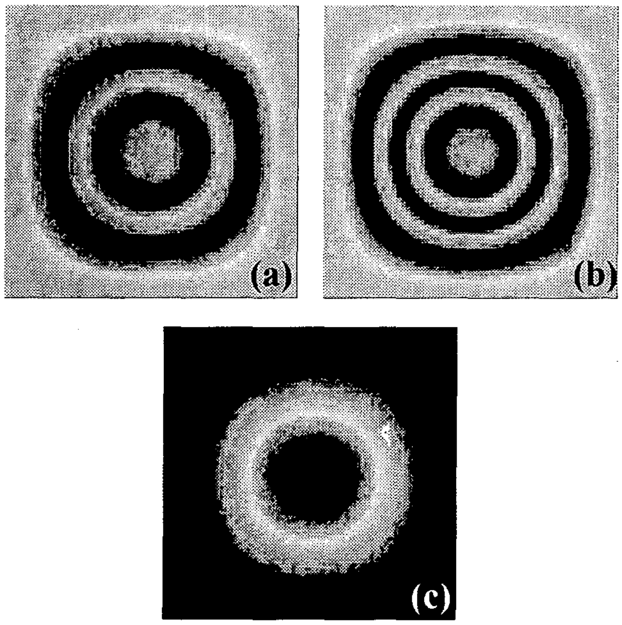

Fig. 3. Simulated phases for the stacking of interfero gram. (a), (b)Fringe patterns of two and three wrapped phases respectively. (c)Stacked interferogram (unwrap ed phases) using phase gradient operation.

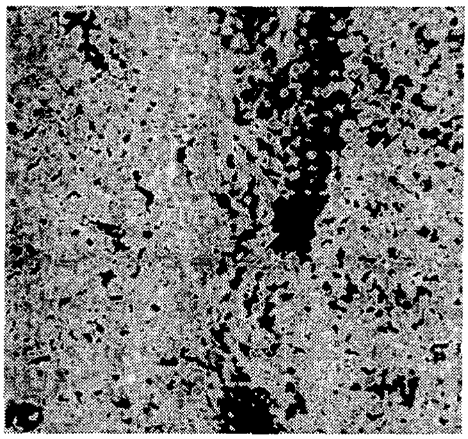

Fig. 4. Stacked differential interferograms. The phase pattern shows ground deformation is located at the centre of image.

should be zero along the image boundaries.

V. CONCLUSIONS & DISSCUTIONS

We have detected the subsidence along sub-way line around Duk-Po area using the differential interferograms generated from JERS-1 SAR images acquired in 1995-1998. To enhance of the fringe pattern and to decrease decorrelation errors, interferogram staking and filtering technique were applied. Stacked interferogram also provides clearer unique phase variation caused by ground deformation. This phenomenon is probably related to elastic deformation, caused by sub-way construction work, rather than a natural compaction of ground.

We obtained the poor results from the phase gradient processing using complex image data after stacking interferograms. It may result from the low coherence due to temporal decorrelation. Noises such as speckles caused by the low signal to noise ratio generated the phase discontinuities and hampered the phase gradient operation. To stack interferograms efficiently, only the long wavelength information through the low pass filtering is required. However, the processed interferograms have still significant short wavelengths even after filtering. Since this area is flat with little relief, we assumed the phase related to the ground deformation does not have the phase discontinuities except high frequency noises, and applied the phase gradient algorithm on the real phase values.

The phase gradient is not suitable in case of very noisy data, because it has the significant problem on the high frequencies. This means that the phase is propagated with a wrong value and can not be recovered when it is integrated.

In practice, the boundary condition has to be thought carefully when the phase gradient is summed. Because the data is subject to discontinuous region, the integration using the undesirable boundary condition results in poor phase restoration to wrong direction. Generally the outward component of the phase gradient should be zero along the image boundaries.

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