DINSAR EXPERIMENTS FOR SHANGHAI GROUND SUBSIDENCE MONITORING BY USING ALOS PALSAR DATA

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The Advanced Land Observing Satellite (ALOS) PALSAR data is used to take two pass interferometry for extraction of ground subsidence in Shanghai China. At first a set of two pass interferometry with baseline less than 1km are taken and corresponding coherence factor are used to indentify persistent scatterers (PS) so as to form a time series of differential phase of every PSs. A linear subsidence model is applied at all PS points and the subsidence rates of all PSs are obtained through a stacking of the time series. The obtained subsidence rates are calibrated with existing leveling results and show a good agreement with the leveling. In addition, a strip area including the Shanghai maglev line is chosen for similar DInSAR processing to extract ground subsidence nearby. Keywords: InSAR, ALOS PALSAR, stacking, persistent scatterers, ground subsidence

1. INTRODUCTION

Ground subsidence has become a major geological disaster in Shanghai, as a result of underground water extraction and huge engineering constructions such as undergrounds, skyscrapers [1]. Therefore, a variety of methods have been used to monitor ground subsidence. Conventional high precision leveling has been used for monitoring ground subsidence since 1921 [2]. A GPS network composed more than 34 stations have been build up since 2002 with an annual campaign surveying [3]. In recent years, InSAR technology, for its larger area coverage, high spatial resolution, all weather running, cheap cost, and automatic operations, has also been used for monitoring Shanghai ground subsidence [4]. In this research we aim to apply ALOS PALSAR data to extract ground subsidence information in Shanghai downtown area.

ALOS PALSAR is an L-band synthetic aperture radar. Its wavelength is 23.6 cm, which has the following capacity over C-band SAR such as Envisat and ERS 1/2: (1) deeper penetration of vegetated areas results in less temporal decorrelation; (2) longer critical baseline results in more usable interferometric pairs. In addition, PALSAR is operated in some different modes that could enhance the interferometric capabilities [4].

In the following, we first introduce the methodology for two pass interferometry and extraction of ground subsidence rates based on time series of interferometric phases of persistent scatterers. Then the ground subsidence rates are estimated based on the PALSAR data from 2007 to 2009.

2. METHODOLOGY

By taking two pass interferometry, the observed interferometric phase difference $\phi$ can be written as follows:

$$\phi = \phi_{def} + \phi_{dem} + \phi_{orb} + \phi_{trop} + \phi_{noise} \quad (1)$$

where $\phi_{def}$ is the phase related to ground deformation, $\phi_{dem}$ is the phase caused by DEM errors, $\phi_{orb}$ is the residual orbital phase, $\phi_{trop}$ is the phase related to atmospheric delay, and $\phi_{noise}$ is random noise due to various reasons.

For overcoming the orbit and atmospheric errors, a polynomial fitting is applied to remove the trend errors from orbit and atmosphere [5][6]. External DEM is required for two-pass DInSAR to eliminate the topographic affects in the interferometric phases [7]. Here, the Shuttle Radar Topography Mission (SRTM) 3 arc DEM products [8] is used for topographic correction in all two pass interferometries.
2.1 POLYNOMIAL FITTING

As mentioned above, for the linear systemic errors such as orbit errors, the polynomial fitting method is applied to fit the errors. We suppose that the deformation between the two SAR images is very small so that it can be ignored to some extent. Then the residual orbital error can be expressed as:

\[
\phi_{orb} = ax + by + cxy + d
\]

(2)

where \(x, y\) are pixel coordinates in range and azimuth respectively. Using the least squares method, the parameter \([a \ b \ c \ d]\) can be acquired and the residual orbital phase is estimated. Actually the linear part of atmospheric error is also be eliminated by this polynomial fitting. On the other hand, we should not use the whole image pixels for the polynomial fitting, only the persistent scatterer points with high coherence are chosen [9].

2.2 INTERFEROGRAM STACKING

After taking the polynomial fitting, atmospheric delay, especially tropospheric delay can be regarded as random signal. The influence of tropospheric delay in the interferometric phases can be reduced by stacking the series of interferograms, and the average linear deformation rate can be acquired. Suppose we have \(N\) interferometric pairs, phase \(\phi_i\) is acquired between two SAR images with time interval \(t_i\) (in unit of year), and then the phase rate can be expressed as:

\[
v_i = \frac{\phi_i}{t_i}
\]

(3)

Suppose the surface deformation is linear, a model can be formed:

\[
\phi = \bar{v} \cdot t_i
\]

(4)

To get credible results, we only choose the persistent scatterer points of high coherence. Define the average coherence coefficient as

\[
\bar{\gamma} = \frac{1}{N} \sum_{i=1}^{N} \gamma_i
\]

(5)

where \(\gamma_i\) is the coherence coefficient of a pixel in the \(i\)th interferogram. A threshold is chosen and the point will be used as the persistent scatterer only when \(\bar{\gamma}\) is larger than the threshold.

Further, we set \(\gamma_i\) as the weight of the interferometric phase in the least squares estimation, and we get the phase rate as:

\[
\bar{v} = \sum_{i=1}^{N} \gamma_i \cdot \phi_i \cdot t_i / \sum_{i=1}^{N} \gamma_i \cdot t_i^2
\]

(6)

And the standard error is

\[
\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\phi_i - \bar{v} \cdot t_i)^2}
\]

(7)

3. PALSAR INTERFEROMETRY EXPERIMENT

3.1 THE SHANGHAI DOWNTOWN AREA

In this paper we use 13 scenes of ALOS PALSAR 1.0 repeat-path data (Path No. 441, Frame 610) covering Shanghai area, from February 2007 to April 2009. Fig. 1 shows the geocoded image of the frame. For speeding the data processing, only the downtown area (see white box in Fig. 1, about 180km\(^2\)) are chosen for this study. At first all the FBD mode images are oversampled to keep the same sampling rate as the FBS mode, and then interferograms are taken one by one using JPL/Caltech ROI_PAC software [10]. With the limit of the baseline less than 1km, 27 interferograms are obtained and the corresponding master and slave images with spatial and temporal baseline lengths are listed in Table 1. After taking earth curvature and topographic correction with external STRM EDM, the wrapped interferometric phase images are obtained. Fig. 2 shows all the 27 interferograms. We can see that three of them (071125-080527, 080110-080527, 080225-080527) have abrupt changes. Considering the three temporal baseline less than 1 year and the ground subsidence is subtle, these abrupt changes are thought to be the effects of the atmospheric delay, properly related to the bad weather of the common slave image. So in the following data processing, these three interferograms are not included.

![Fig.1 Geocoded image of frame 610 path 441. The white rectangle indicates the region of test area.](image-url)
Table 1 Information of interferometric pairs

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On the other hand, considering the chosen area is quite small, the ground subsidence is subtle for the period of each interferogram, the phase unwrapping is not necessary to be taken, the possibility of existing ambiguity points are deleted as the blunder errors. By setting the minimum correlation threshold as 0.25 and minimum average correlation threshold as 0.45, 27,415 points are indentified as the persistent scatterers (PS density is about 300/km²). After taking polynomial fitting, interferogram stacking is used for extraction of linear subsidence rate and EDM error at each PS, see Fig. 3 for the results obtained. The relative subsidence rate is less than 10mm/a. The EDM error is less than 10m which reflects the stated precision of SRTM EDM products.

The ground subsidence rates obtained above are relative to a reference point (the triangle point in Fig.3), the absolute subsidence rate is not available. So we chose the existing 9 leveling benchmarks in the downtown area with known subsidence rates to calibrate the ground subsidence rates obtained by interferograms. Fig. 4 shows the distribution of the 9 benchmarks in the area. At first, the differences of ground subsidence rates between the PSs to the nearest benchmarks are used to calculate the calibration value:

\[
C_{\text{calibration}} = \frac{1}{9} \sum_{i=1}^{9} C_i,
\]

where \( C_i = v_{\text{leveling}} - v_{\text{CP}} \) (8)

where \( v_{\text{leveling}} \) is the known ground subsidence rate obtained by the repeated high precision leveling and \( v_{\text{CP}} \) is ground subsidence rate of corresponding nearest PS (the LOS rate has been reduced to vertical rate in advance).
Fig. 3 Relative ground subsidence rate and EDM error (The red triangle is the reference point. Top: ground subsidence rate and bottom EDM error)

Fig. 4 Test area in Google earth and distribution of leveling benchmarks (the triangles). The green one is chosen as reference point for interferometry.

Fig. 5 Calibrated ground subsidence rate of PSs

Fig. 6 The differences of ground subsidence rate between PS and corresponding benchmark

Fig. 5 is the calibrated ground subsidence rate of all PSs. Most of the downtown area has no significant ground subsidence with subsidence rate less than -5mm/a. And there some places with local subsidence rate greater than 10mm/a. The maximum subsidence rate is located in the upper right of Fig. 5 and with a value of about -30mm/a, where is the south of Yangpu district. Fig. 6 shows the difference between calibrated ground subsidence rates of PSs with that of corresponding leveling benchmarks. There are 3 points with the differences larger than 7mm/a and the differences of the other 6 points are all within 4mm/a to show a good agreement with the subsidence rates from the leveling.
**3.2 THE SHANGHAI MAGLEV**

The running of Shanghai maglev requires a stable ground support bases. We applied ALOS PALSAR data to study the ground subsidence along the maglev zone. Based on the similar procedures as in 3.1, eight PALSAR images covering the Maglev zone during 2007 to 2008 have been used to form 7 interferograms using DInSAR method. Table 2 lists the parameters of the 7 interferometric pairs. The maximum spatial baseline is less than 600, and the time separations are all 46 days.

![Fig.7 Relative LOS displacement rates of the points along the two test profiles](image)

Tab.2 Information of interferometric pairs

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For taking a case study, two profiles across the maglev have been chosen for extraction of ground subsidence rates. And the relative subsidence velocity of the two profiles obtained by the stacking method. Fig.7 shows the relative subsidence rates along the two profiles. In Fig.7, the middle point is on the rail and chosen as the reference point, and each 20 points on left and right side of the rail are chosen to draw the profile. We can see that a tendency of subsidence uniformly distributed on both side of the maglev, indicating higher stability of basement of the maglev. More details can be found in [11].

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**4. CONCLUSIONS**

Two pass SAR interferogrammetry with selected spatial and temporal baselines are used to get the time series of LOS displacements of PSs and further applied to extract of ground subsidence rates. 13 PALSAR images from February 2007 to April 2009 in Shanghai area are used for extraction of the linear ground subsidence rates at the downtown area. The results show that the most places of the downtown area have no significant subsidence. There are some places with significant local subsidence rates at about -10mm/a or even more. The maximum ground subsidence rate is -30mm/a which locates at the south of Yangpu district. In addition, 8 PALSAR images covering the Shanghai maglev are used for study the ground stability along the rail. According to the two chosen profiles, the result shows that the ground basis of the Shanghai maglev is quite stable.

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**REFERENCES**


