MONITORING GROUND DEFORMATION OF SUBWAY AREA DURING THE CONSTRUCTION BASED ON THE METHOD OF MULTI-TEMPORAL COHERENT TARGETS ANALYSIS

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ABSTRACT:

Multi-temporal coherent targets analysis is a high-precision and high-spatial-resolution monitoring method for urban surface deformation based on Differential Synthetic Aperture Radar (DInSAR)， and has been successfully applied to measure land subsidence, landslide and strain accumulation caused by fault movement and so on. In this paper, the multi-temporal coherent targets analysis is used to study the settlement of subway area during the period of subway construction. The eastern extension of Shanghai Metro Line. 2 is taking as an example to study the subway settlement during the construction period. The eastern extension of Shanghai Metro Line. 2 starts from Longyang Road and ends at Pudong airport. Its length is 29.9 kilometers from east to west and it is a key transportation line to the Pudong Airport. 17 PalSAR images during 2007 and 2010 are applied to analyze and invert the settlement of the buildings nearby the subway based on the multi-temporal coherent targets analysis. But there are three significant deformation areas nearby the Line 2 between 2007 and 2010, with maximum subsidence rate up to 30mm/y in LOS. The settlement near the Longyang Road station and Chuansha Town are both caused by newly construction and city expansion. The deformation of the coastal dikes suffer from heavy settlement and the rate is up to -30 mm/y. In general, the area close to the subway line is relatively stable during the construction period.

1. INSTRUCTIONS

DInSAR technology can get deformation in line of sight in large range and high precision (Prati C et al. 1992；Massonnet D et al. 1993), so it is widely used in seismic deformation, volcanic movement, landslide, glacier movement, mining subsidence, ground subsidence and so on （Rosen et al. 2000；Bamler et al. 1998；Fujiwara et al. 1998；Ge et al. 2001）.

The time and space decoherence and atmospheric delay limits the accuracy of deformation monitoring of DInSAR technology (Hanssen, 2001). In order to eliminate the decoherence factors, some high coherence points that have relatively stable backscattering characteristics are found in the time series images. These points are called permanent scatterers which can keep high coherence in a long time sequence. On this basis, deformation can be extracted from the interferometric phase of permanent scatterers (Ferretti et al.1999). Based on the permanent scatterers, a variety of time series analysis methods are formed, called as multi-temporal coherent targets analysis methods(MTA) (Berardino et al. 2002; Mora et al. 2003; Werner et al. 2003; Andrew Hooper et al. 2006; Ferretti et al. 2011; Zhang et al. 2011). With the increasing number and improvement of high resolution SAR, MTA has been widely applied in small surface deformation, especially urban land subsidence (Yue H et al. 2005; Wang Yan 2007; Prati C et al. 2010; Ng H M et al. 2012; Herrera G et al. 2013; Notti D et al. 2014; Bianchini S et al. 2015; Armas I et al. 2015; Costantini M et al. 2016).

This paper will use time series method to monitor the settlement of the surrounding area of the subway in order to study the safety status of the railway line.17 PalSAR images between 2007 and 2010 are used to analyze the phase displacement of high coherent targets. By monitoring the settlement of the buildings surrounding the line, the deformation changes above the subway construction is analyzed during the construction, and the relationship between the development of the subway construction and the surrounding building settlement is analyzed and evaluated to study the safety status of the railway line.

2. MTA

MTA is used to monitor the settlement of the surrounding area of the subway line. All SAR data are processed to form interfergrams, and the coherent targets in the time series are selected from the interferograms. According to the temporal and spatial characteristics of the phase components, the phase of the surface deformation is separated and then the settlement velocity in line of sight is retrieved. The key algorithms mainly include two parts: the recognition of coherent points and the inversion of deformation information.

2.1 Identification of coherent targets

Coherent targets extraction is a key part of long time sequence method. At present, there are three ways to extract coherent points: pixel amplitude dispersion, coherence coefficient and phase analysis of time series. In this paper, we consider the stability of both amplitude and phase to select coherent targets. Amplitude stability is judged by amplitude dispersion index (Hanssen, 2001):

$$D_A = \sigma_A / \mu_A \quad (1)$$

D_A stand for amplitude dispersion; σ_A and μ_A respectively denote the standard deviation and mean value of the amplitude of a point in time series. The smaller the amplitude dispersion, the more stable the coherent pixels.

Some points are first selected by amplitude dispersion, and then the coherence coefficient of these points are eliminated in time series to obtain the reliable coherent points.

2.2 Inversion of Deformation

InSAR uses the phase difference information of two single look complex radar images to determine the small deformation of ground targets. The obtained interferometric phase difference ϕ can be written as follows (Hanssen 2001):

$$\varphi = \varphi_{def} + \varphi_{topo} + \varphi_{atm} + \varphi_{orb} + \varphi_{noise} \qquad (2)$$

Where φ_{def} is the phase related to surface motion, φ_{topo} is the topographic phase corresponding to curve surface of the earth and ground elevation, φ_{atm} is the phase related to atmospheric delay, φ_{orb} is the phase caused by orbit error, and φ_{noise} is random noise due to other uncertainties.

Atmospheric error can be correlated according to its statistics in space or in time ,and topographic phase is correlated with DEM. Then we get the deformation phase difference ϕ_{def} from M interferometric pairs. Supposing the surface deformation is linear during the time interval t_i (in unit of year), the difference displacement rate v along LOS can be expressed as:

$$\Delta v = \lambda \sum_{i=1}^{M} \phi_{def} \cdot t_i \Big/ \left(4\pi \cdot \sum_{i=1}^{M} t_i \right) \qquad (3)$$

3. EXPERIMENT

3.1 Study area and Images

Shanghai is one of the most serious cities affected by land subsidence. The ground subsidence in Shanghai began in 1921. The the most serious ground subsidence was between 1921 and 1965. The total subsidence of the central city reached 1.6m in 45 years(Xue Yuqun et al. 2008). Since 2000, the ground subsidence has been controlled. The average annual settlement in the downtown of Shanghai was less than 10 mm, and the linear trend was more obvious. Settlement will bring difficulties to the construction and operation of subway, and the construction of subway will also cause some settlement around the subway. In this paper, multi-temporal coherent targets analysis method is used to monitor the subsidence of the surrounding area of the subway line during the construction.

The eastern extension of Shanghai Rail Transit Line 2 is taken as an example for subsidence study. The eastern extension of Line 2 starts at Longyang Road station, and ends at Pudong airport station. It has 11 stations and the total length is 29.9km.The east extension of line 2 connects Pudong airport to the urban traffic network, making the whole Line 2 connecting the two major airports in Shanghai, which bring great convenience to the travelling people. Study area is shown in Figure1 as following:

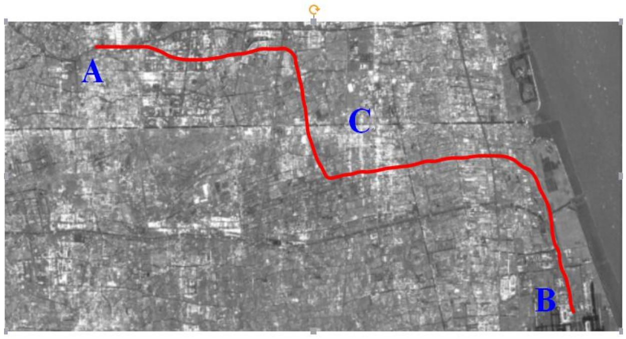

Figure 1. Study area

In Figure 1, the red line stands for the railway line. A stand for Longyang Road Station, B stand for Pudong Airport, and C stand for Chuansha Town. By monitoring the settlement of the buildings surrounding the line, the deformation changes during the subway construction is analyzed, and the relationship between the development of the subway construction and the surrounding building settlement can be used to evaluate the safety of the railway line.

3.2 Data processing

17 PalSAR images between 2007 and 2010 are used to analyze the LOS displacements of high coherent targets. The vertical baseline is limited to 800m, and 43 interferograms are generated, as shown in Figure 2.

Figure 2. 43 interferograms

In Fig.2, the interferograms are smoother without any large phase jumps, and the phase changes do not exceed one cycle. The multi-temporal coherent targets analysis method is applied to get the LOS deformation rate of the coherent points showning in Figure 3:

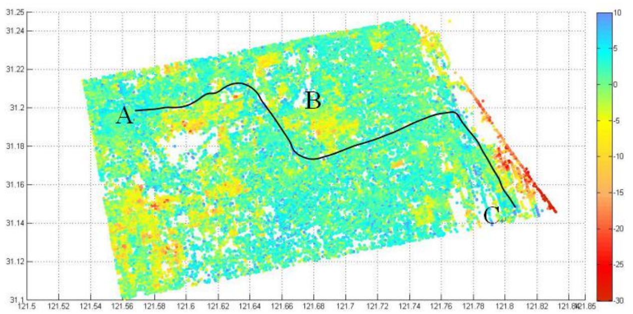

Figure 3. Deformation rate of the coherent points in LOS

In Figure 3, the black line stand for the extension of Line 2. A stand for Longyang Road Station, B stand for Pudong Airport, and C stand for Chuansha Town. It can be seen from Figure 3 that the distribution of coherent targets is relatively uniform. The subsidence rate in LOS is -30 to 10 mm/y and the negative stand for settlement. It can be seen that in between 2007 and 2010 there are mainly three significant deformation areas nearby the Line 2: the first is close to the Longyang Road station(A), where is a new development area; the second is in Chuansha Town forming a small settlement funnel; and the last one is near the Pudong airport(B) especially on the coastal dikes, and the settlement rate is up to -30 mm/y. The zone along Line 2 is relatively smaller and more stable.
In general, the settlement occurs mainly in the new development area, and the settlement belong to the temporary settlement of the newly built buildings. For example, there is a large settlement belt on the lower left corner. The settlement funnel in the Chuansha town(C) is also caused by the construction of a large number of new residential areas. The settlement trend is obvious, so that two newly buildings lean to each other in XinYuanXiYuan Ditrict in 2012. The settlement at the right corner is relatively large, mainly due to the reclamation of land and the soil compaction.

4. COCLUSION

This paper uses time series analysis method to monitor the subway settlement of the extension of Shanghai subway Line 2. Results showing that the ground subsidence along the line 2 is relatively smaller and more stable. But there are three significant deformation areas nearby the Line 2 between 2007 and 2010, with maximum subsidence rate up to 30mm/y in LOS. The settlement near the Longyang Road station and Chuansha Town are both caused by newly construction and city expansion. The deformation of the coastal dikes suffer from heavy settlement and the rate is up to -30 mm/y. In general, the area close to the subway line is relatively stable during the construction period.

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