SURFACE MOTION STUDY ALONG THE MARITIME SILK ROAD BASED ON C-BAND SAR OBSERVATION

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Abstract:
Land subsidence is caused by consolidation or compression of underground soft soil under the action of natural or man-made factors, resulting in vertical deformation of ground in a certain area, which will become a kind of geological disaster in serious condition. Monitoring of surface motion including subsidence can not only avoid property loss caused by major accidents, but also conducive to the sustainable development of the economy and society. According to the wide coverage demand of subsidence monitoring, time series InSAR technique has been introduced into studying the surface motion trend along the maritime silk road in China. In this study, we take advantage of C-band SAR Sentinel-1A images to implement multi-temporal InSAR analysis at two study sites, namely, Hong Kong International Airport and Shantou. Subsidence patterns have been analyzed at these two sites. Several typical abnormal settlements have been detected and the triggering factor of the subsidence is clarified according to relative research.

Keywords: ground surface subsidence; multi-temporal InSAR; maritime silk road; Sentinel-1A; Hong Kong International Airport; Shantou

Introduction

21st century Maritime Silk Road (MSR) plays an important role in the development of Asia economy. As a part of national strategy of China, it has great significance to national development. One Belt One Road run through three continents including Asia, Europe and Africa. There is a huge natural distinct along the belt and road and the type of disaster varies with a wide range and a high-frequency occurrence. With a background of global climate change, various ground surface hazards tend to be more active. In the meantime, One Belt One Road is facing great risk by involving a large number of cross-border and overseas transportation, energy and other infrastructure construction. As a consequence, deformation trend as well as infrastructure health in the key hubs along the MSR is a key issue. However, deformation monitoring in this region is limited to in-situ monitoring and less attention is paid to regional deformation trend in wide coverage. This often leads to the monitoring lagging behind the occurrence of disasters, which would threaten people's lives and property as well as the safety of basic infrastructure.

The technical measures of deformation monitoring include geodetic survey, Global Positioning System and geological patrol monitoring methods. There are a multitude of mature and reliable methods based on these techniques. However, observation is discrete and limited by manpower, material resources and the terrain visibility conditions. In recent years, InSAR is regarded as the most promising deformation monitoring technology, which can achieve a large coverage and continuous observation. The measurement accuracy of InSAR arrives at a millimeter-level and the complementary between InSAR and other techniques can increase the reliability of the results of surface deformation monitoring. Therefore, deformation monitoring along the MSR based on InSAR techniques are of great importance, which may provide scientific basis for geo-hazard early warning.

In this study, we conduct deformation monitoring cases along the MSR using Permanent Scatterer InSAR. C-band SAR observation Sentinel 1-A are used to extract deformation velocity. Velocity map of the test site along the MSR is generated. Risk assessment and health diagnose will be done on the infrastructures including both sea port and airport. The significances of this study will benefit urban planning and risk management along MSR.

Methodology

Permanent scatterer interferometry is proposed by Professor Fabio Rocca for the first time in 2000[1-2]. Then T.R.E company applied for the patent relying on this technology. Since the theoretical framework and technical route of this technology have been put forward, a series of new methods based on the permanent scatterer interferometry have been proposed [3-4]. These methods are designed to overcome the influence of the geometric decorrelation, time decorrelation and the atmospheric effects on extracting surface deformation.

Considering the factors of baseline and Doppler center frequency, one image is selected as the main image from the SAR image data set. Then the other images are registered to the master image. Interferograms are generated from master and slave images by complex conjugate operation and differential interferograms are obtained by removing topographic phase.

Amplitude deviation is introduced to select coherence candidates. Amplitude deviation can be defined as following:

$$D_A = \frac{\sigma_A}{\mu_A}$$

μ_A is mean value of amplitude and σ_A is standard deviation. Deviation is bulid based on coherence candidate and the phase difference of two adjacent points is:

$$\Delta\phi_{diff} = \Delta\phi_{defo} + \Delta\phi_{DEM-error} + \Delta\phi_{atmos} + \Delta\phi_{noise}$$
$$= \frac{4\pi}{\lambda}(T\Delta\text{v} + \Delta D_{non-linear}) + \frac{4\pi}{\lambda}\frac{B_{\perp}}{\rho\, sin\theta}\Delta\text{h} + \Delta\phi_{atmos} + \Delta\phi_{noise}$$
$$= \frac{4\pi}{\lambda}T\Delta\text{v} + \frac{4\pi}{\lambda}\frac{B_{\perp}}{\rho\, sin\theta}\Delta\text{h} + (\frac{4\pi}{\lambda}\Delta D_{non-linear} + \Delta\phi_{atmos} + \Delta\phi_{noise})$$

And the residence e is:

$$\text{e} = \frac{4\pi}{\lambda}\Delta D_{non-linear} + \Delta\phi_{atmos} + \Delta\phi_{noise}$$

When $|e| < pi$, phase unwrapping is implemented and

$$|\gamma| = \left|\frac{1}{M}\sum_{k=1}^{M}\exp(je)\right|$$

Δh is the estimation of linear deformation and Δv is the estimation of DEM error. And after removing these two terms from the original phase, the phase residence includes non-linear deformation phase and atmospheric phase. According to relevant research [5], non-linear phase and atmospheric phase can be separated by spatial filtering and temporal filtering.

After estimating and removing APS from the differential phase, the coherence of candidates will be re-calculated and the points with coherence below the specified threshold will be eliminated. Phase unwrapping is performed on the remaining coherent targets to extract accurate estimates of deformation information

Result and discussion

- **Case study at Hong Kong airport**

Hong Kong international airport locates in the marine reclamation land at Lantau Island. Due to its unique geological structure, the airport experiences significant surface subsidence. Using Sentinel-1A images, we conduct deformation monitoring of

Hong Kong airport and its surrounded area. Forty S1A images with a time span from June 2015 to February 2017 are used for PS-InSAR analysis. The temporal and space baseline is proposed in Figure 1. The image acquired at 22 April 2016 is selected as the master image and others are selected as slaves. Figure 2 shows the deformation velocity map of Hong Kong International Airport. From the deformation velocity maps we can figure out that there is regional trend in the airport. Red points with high displacement rate are detected in pile soil area, terminal and pass way. There is also linear trend in the build-up area in the northeast of the airport. The maximum subsidence velocity reaches -29.5mm/year. As Sentinel 1-A is medium-resolution SAR sensor, we cannot get point-like targets with a density as high as TerraSAR-X. However, this result has a good accordance with TerraSAR-X results.

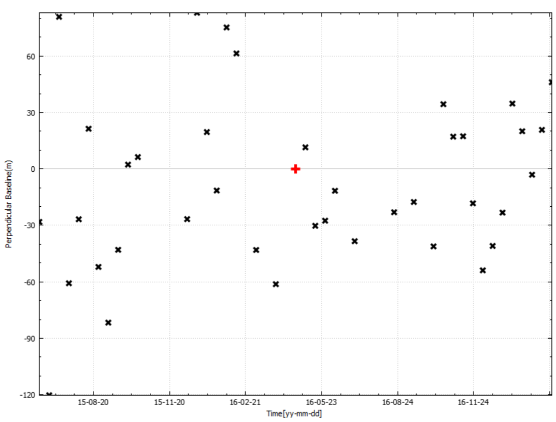

Figure 1. Space and temporal baseline distribution

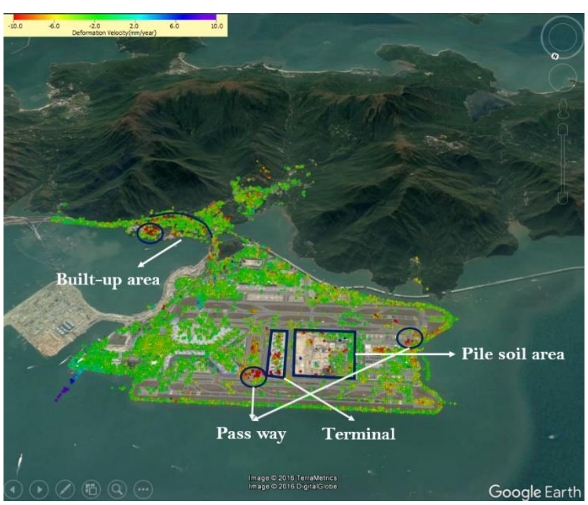

Figure 2. Deformation velocity map of Hong Kong International Airport

- **Case study at Shantou**

Shantou is a typical subsidence area along the MSR. We process 33 Sentinel-1A images to conduct multi-temporal InSAR analysis and the result is shown in Figure 3. From the result we can figure out that the ground surface of Shantou is sinking in the past three years and the deformation trend displays as subsidence funnel. There are several typical abnormal settlement areas at Chendian Town, Simapu Town and Zhanlong Town. And the subsidence gradient at the center of these areas is relatively large and the largest deformation velocity reaches as fast as more than 90mm per year.

Geological survey show that Shantou is located in the estuary of the river. For space distribution, continental facies fallout and marine facies fallout interleave in the soft soil layer. The thickness of the upper soil layer is ten of meters. this layer has a relatively higher water content, lower shear strength and higher compressibility. The lower soil layer consists of fine sand, medium sand and coarse sand. The cause of subsidence formation in this area includes natural sedimentation and groundwater extraction.

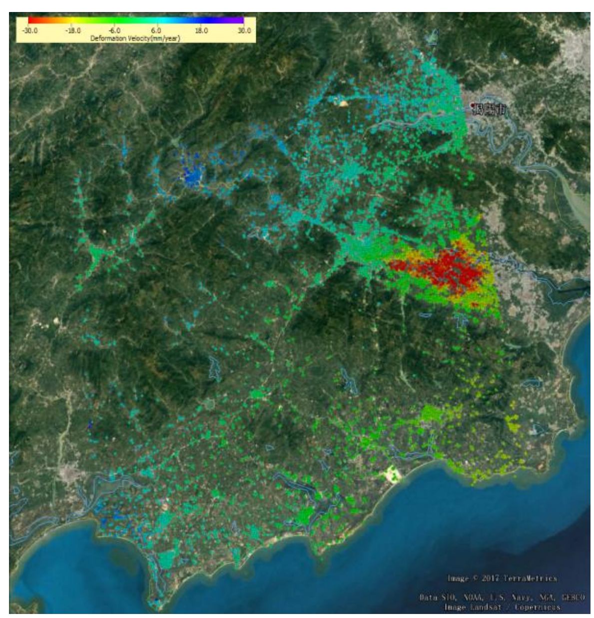

Figure 3. Deformation velocity map of Shantou

Conclusion

In this study we introduce the multi-temporal InSAR technique to explore the surface of some specific test sites along the maritime silk road. The experimental result verified the application availability of monitoring land subsidence in wide area with high density. The detected subsidence trend can help to determine the location, time interval of occurance and deformation magnitude which can provide a reference for geological disaster prevention and early warning. Further studies will be carried out on regional velocity map generation of the maritime silk road in China.

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