URBAN MONITORING USING PERSISTENT SCATTERER INSAR AND PHOTOGRAMMETRY

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ABSTRACT:

The purpose of this paper is to monitor deformation due to groundwater extraction in urban area using Persistent Scatterer InSAR (PSInSAR) and Photogrammetry. Theoretically, PSInSAR technique allows for millimetre precision ground deformation mapping based on the utilization of long period of interferometric SAR data. One main advantage of PSInSAR method, compared to conventional deformation surveying methods such as levelling and Global Positioning System (GPS), is the coverage of large area. However, PSInSAR method has difficulty in explanation of each single object or detail information of small objects because of current space-borne radar imagery which has approximately 25m spatial resolution. In order to solve this problem, we used aerial photogrammetry method to survey detail information of objects in selected area identified by PSInSAR.

1. INTRODUCTION

Nowadays, continuous monitoring of urban area represents one of the most interesting and major subjects of research in remote sensing whenever a Synthetic Aperture Radar (SAR) instrument is used. Typically, the aerial photogrammetry and Light Detection and Ranging (LiDAR) methods which have high spatial resolution were used for urban monitoring. Major cities have rapidly changed and extended during last century and over 50 percentage of the population now live in towns and cities. Much population who lives exists in the city consuming huge amount of water everyday. Water supply is main element of city life maintaining. Surface water and groundwater are two major water sources in Australia. Water shortage is one of the major social and economic environmental problems in Australia. Australia is the driest inhabited continent on Earth, with highly variable rainfall patterns. The amount of water usage has increased dramatically in Australia which leads to significant increase in demand for groundwater resources due to the limit amount of surface water supplies available. Normally, there are two surveying methods used for ground deformation monitoring which include the Levelling and Global Positioning System. However, it is very difficult to cover the large area and set up bench marks for the ground survey. Therefore, Persistent Scatterer Radar Interferometry is used as a complementary method to conventional surveying method. Theoretically, the Differential Interferometry Radar (DInSAR) has the potential to precisely observe the ground deformation along the Line-of-Sight (LOS) direction up to a few millimetres. However, there are four main problems, including (1) atmospheric disturbances causing noise from signal delays, (2) temporal decorrelation of surface scatterers due to seasonal vegetation and/or other surface change, (3) geometrical decorrelation due to large baseline between two images acquisition result in incoherence and (4) ambiguity, have limited this technique to achieve its full operational capability. PSInSAR technique allows for millimetre precision ground deformation mapping based on the utilization of long time series of interferometric SAR data and huge area covering. However, current space-borne radar imagery which have approximately 25m spatial resolution are difficult to support the PSInSAR for detection of each building or detail information of small objects [Ge et al, 2001; National land, 2000; Ng et al. 2007].

2. PERSISTENT SCATTER TECHNIQUE

Space-borne radar interferometry has already proven its potential for ground deformation monitoring application, for example, mining, earthquake and volcano studies, due to its high precision and spatial resolution [Colesanti et al, 2003]. Theoretically, the space-borne radar interferometry has the potential to precisely observe the ground displacement along the LOS direction up to a few millimeters. There are four main problems stated in previous section limited the conventional DInSAR technique from achieving its full operational capability. There four main problems are (1) atmospheric disturbances, (2) temporal decorrelation, (3) geometrical decorrelation, and (4) ambiguity problems. In the conventional DInSAR process, these problems may not be identifiable in the interferograms which have many noises. In PSInSAR process, however, the elevation and linear velocity rate corresponding to these problems can be estimated, as well as the atmospheric disturbances [Ferretti et al. 2000, 2001]. The PSInSAR method first identifies all the PS points and a 2D deformation analysis is then applied to these points. Millimeter deformations can be achieved with this method which is more precise than the conventional method. The Persistent Scatterer (PS) technique is recent development in radar interferometric processing, which offers a practical way to reduce the main errors in conventional DInSAR processing method; temporal and geometrical decorrelation, and atmospheric artefacts. Atmospheric phase contributions are spatially correlated within a single SAR scene, but tend to be uncorrelated on time scales of days to weeks. Thus, atmospheric effects can be estimated and removed by combining data from long time series of SAR images, averaging out the temporal fluctuations. Radar scatterers that are affected by temporal and geometrical decorrelation are used, allowing exploitation of all available images regardless of imaging geometry. In a radar image, the reflected wave from a resolution element is the coherent sum of individual wavelets scattered by many discrete scatterers. Positive and negative interference of these waves takes increase to variation in the phase and amplitude of the pixel with view angel and relative position changing of the scatterers. The main characteristics of multi-image processing method are that it utilizes a single master stack of differential interferograms and that only time-coherent pixel. According to the description of the PS technique which base on Colesanti et al., Ferretti et al., the key processing steps of the PS technique are the following (1)Computation of the interferograms, (2) Computation of the differential interferograms using a digital elevation model, (3) Preliminary estimation of the presumably most coherent pixel, (4) Refinement of third step; the coarse grid of PS candidates estimate the long wavelength part of the atmospheric signal. After interpolation of these estimates, the differential interferograms are corrected, and additional PSs are computed [Ferretti et al, 1999, 2004; Hooper, 2006].

3. AERIAL PHOTOGRAMMETRY

Traditionally, Photogrammetry has defined as the process of deriving metric information about an object through measurements made on photographs of the object. Aerial photogrammetry is the taking of photo from the air with a camera mounted on an aircraft, helicopter, and similar vehicle. Aerial photogrammetry is used in land-use planning, archeology, environmental and surface monitoring and other fields [Jensen 2007]. In aerial photogrammetry, the reference coordinate system, or datum is defined by the Ground Control Points (GCPs) [Mikhail et al, 2001]. In this research, coordinate systems were defined to UTM-56 and WGS84. GCPs are surveyed by *Leica GPS-500 system*. Each GCP was measured using static method and operating time was over 30min. 6 GCPs were used. GCPs coordinate are table 1.

ID	Latitude	Longitude	Hight
181cp1	-33.89042579	151.2336121	90.48899
181cp2	-33.88435260	151.2489353	56.73410
181cp3	-33.90650849	151.2317450	54.84594
181cp4	-33.90785047	151.2474110	91.80488
181cp5	-33.91723083	151.2264035	51.00231
181cp6	-33.91877307	151.2459852	55.55110

Table 1. Coordinates of Ground Control Points

Figure 1. GCP Surveying using GPS

4. EXPERIMENT

The test field is residence area at Sydney in the New South Wales, Australia. In the PSInSAR process, test field is covered all Sydney area (15×15km). In the aerial photogrammetry that to get detail information, test field is minimized small confined region (1.5×1km).

Figure 2. GCP Surveying using GPS

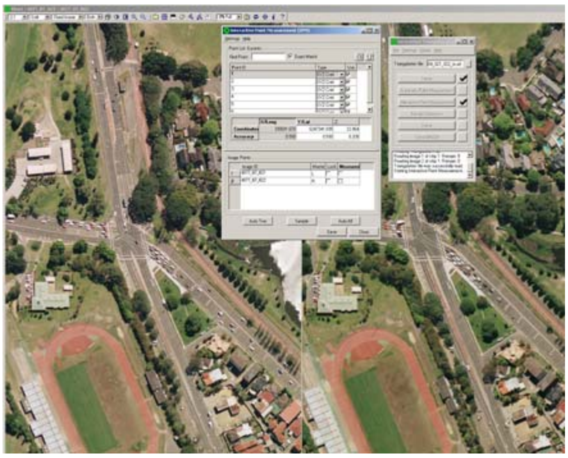

Figure 3. Aerial photo processing using SOCETSET

Figure 4. Test Field in Sydney (Google Earth)

This research used European Remote Sensing 1 and 2 (ERS-1/2) radar images (C-band) using PSInSAR and Aerial photo using Photogrammetry to investigate the ground deformation at Sydney in the state of New South Wales, Australia. The 18 images of ERS-1/2 (04/1992~04/1997) were found in the search for the available images over the Sydney area. The Persistent Scatterer candidate identification process was progressed to identify all the stable natural reflectors according to the amplitude dispersion index of the point targets in a time series of SAR images. Image coregistration was generated prior to identifying the PS candidate. Each pair of interferogram was processed with respect to the master image. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) which has three arc-second resolution was used to remove the topographic phase and generate the initial differential interferograms. Finally, displacement of PS candidate was estimated. It involved phase unwrapping as well as correction for linear deformation, DEM error, baseline error and atmospheric noise. The PSInSAR results were interpreted and compared to investigate with the effect of groundwater over extraction to urban deformation. The GIS software is used to interpret the PSInSAR result. The combined methods between PSInSAR and GIS allow an integration of information from various sources and hence improve the efficiency for interpreting the data.

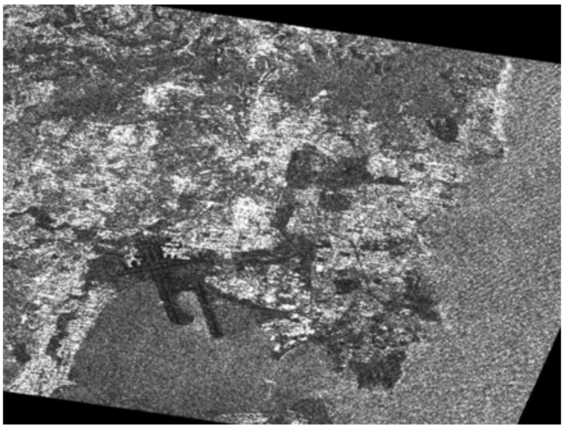

Figure 5. SAR image at test site

To compare with DInSAR methods, which is normally used to ground subsidence monitoring, we were used CRC-DInSAR software. Theoretically, differential radar interferometry can survey deformation to high level (up to 1cm) of accuracy over large spatial extents with high spatial resolution. [Ge et al, 2007]. However, source of DInSAR has limitation of temporal baseline and perpendicular baseline. In our research, test field is located in the city area and deformation of ground is small per year. So it is too difficult to detect the deformation in the city area. Figure 6 is the interferogram of test area using DInSAR.

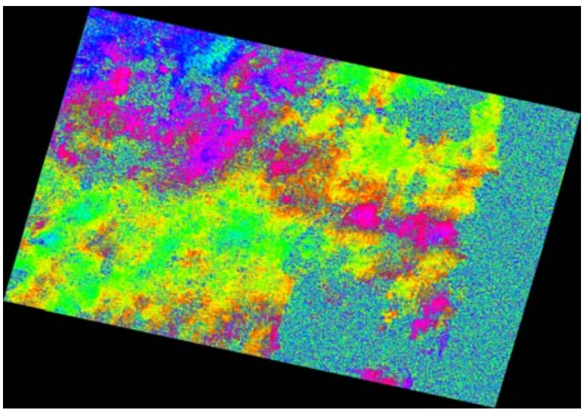

Figure 6. Interferogram of test site using DInSAR

From the interferogram shown in figure 6, it is not able to obtain much useful information of land deformation around test region. For long term deformation monitoring, PSInSAR technique is more powerful, precise and fully operational tool than DInSAR method [Kampes 2006].

Photogrammetry used two pairs (10/1994, 10/2004) of aerial photography for investigation of small area deformations which are detected from PSInSAR results. Each projects of aerial photo are processed and detected using SOCETSET software. Ground Control Point (GCP) was achieved 10mm resolution from GPS surveying for external orientation. Building extraction of subsidence area was conducted by feature extraction method in SCETSET. The ArcGIS software was used to interpret the building deformation result. The aerial photo information and image are shown in table 2 and figure 7.

DATE	ID	Frames	Focal Length
1994/10	NSW 4224	161&162	152.76
2004/10	NSW 4877	21&22	152.76

Table 2. Information of aerial photo

Figure 7. Aerial photo of test site

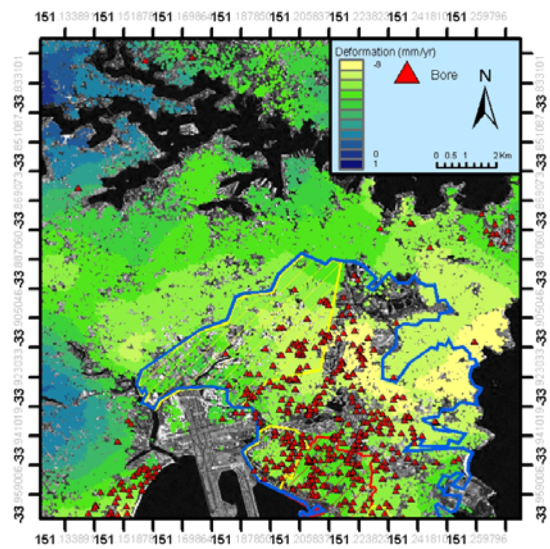

Figure 8. Deformation result using PSInSAR

5. RESULT

The PSInSAR results measured an average of 5 millimetres deformations per year in study area while aerial photogrammetry results are observed approximately 2.8 millimetres per year in same test area. Table 3 is mean and standard deviation of deformation from PSInSAR result at research area.

	μ Deformation	σ Deformation
PSInSAR	-5 mm/yr	2 mm/yr

Table 3. Deformation result of PSInSAR

By having the PSInSAR results overlaid with the optical image and groundwater extraction sites in ArcGIS, it is possible to recognize the location of the highset deformation rate corresponding to the period of times. Furthermore, it is possible to investigate the effect of groundwater extraction on the urban deformation. In addition, aerial photogrammetry result confirms the deformation rate from PSInSAR result and investigates the deformation of each object.

Figure 9. Aerial photogrammetry result superimposed on the Google image

	μ Deformation	σ Deformation
Aerial photo	-2.8mm/yr	2.7 mm/yr

Table 4. Deformation result of Aerial photogrammetry

6. CONCLUSION

In order to observe the patterns of overall deformation rate, spatial filtering was applied to the Sydney result. We can show the overall patterns of subsidence rate towards underground structures such as aquifer in this way. In PSInSAR result, the highest deformation rate, up to -9 mm/yr, is observed in Eastern Suburb especially along the Botany Sands Aquifer which is the biggest aquifer in Sydney. The rain water comes in from the north, it soaks into the sandy aquifer which begins at Centennial park and flow to the Botany Bay. In the PSInSAR result, around Kensington has been observed with highest deformation. This might due to the reduction in groundwater level in area surrounding Centennial Park. The groundwater extraction along the groundwater flow path caused the groundwater in Centennial park flow to Botany Bay where the mineral in the sand is carried away by the groundwater. Aerial photogrammetry result shows the detail information due to the groundwater extraction at the biggest deformation region; around the Centennial Park. The highest deformation rate is approximately -10mm/yr and some building is arise 0.2mm/yr. PSInSAR and aerial photogrammetry results have similar subsidence pattern in the test field. In this study, we can confirm that PSInSAR and aerial photogrammetry have different advantage in ground deformation analysis. Aerial photogrammetry results have detail information of each building and object. However, research coverage is small and it is difficult to find the overall pattern. PSInSAR results have large coverage and overall pattern in the test field. In summery, combination of two methods for ground monitoring is not only supporting the each technique weakness but also saving the processing time and improving the effectiveness of PSInSAR data.

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