CONCEPTUAL FRAMEWORK FOR PS-INSAR DEFORMATION INTERPRETATION ASSISTED BY GEO-INFORMATION TECHNOLOGY

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KEY WORDS: (PS)-INSAR, Error, Interpretation, GIS, Spatial classification

ABSTRACT:

Although Persistent Scatterer (PS) InSAR deformation measurements may be very precise, this does not necessarily imply a reliable estimation of the parameters of interest. PS-InSAR deformation measurements may be caused by different deformation regimes, like gas extraction, shallow compaction or structural instabilities making unambiguous interpretation difficult. This research investigates the use of geo-information technology for the interpretation of PS-InSAR deformation measurements.

Utilizing geo-information technology, data sources with varying characteristics (spatial, temporal, qualitative, quantitative, two- and three-dimensional) can be integrated in a framework of geospatial information layers. This research investigates the existence and the type of functional relationships between PS-InSAR geospatial layers and additional layers like topographic classification information, for interpreting the deformation results.

This paper presents the framework of extended functionality offered by geo-information technology to respond to various queries using the concept of spatio-temporal modeling. Spatio-temporal modeling offers a functional toolbox for relating and combining the different geo-information databases together in a common reference system. Some of the intended goals are examining the spatial and functional relationship between the information layers, and quantifying an existing pattern of a layer for better understanding of the driving mechanisms. This relational information is used in answering queries related to spatial classification/validation of PS points and PS characterization based on their estimated locations and heights. This approach would further improve the understanding of neighborhood correlations between the PS points and other deformation mechanisms. The main focus is on the urban environment designing a framework for topographical classification of PS points and processes related to local land subsidence. The work comprises of a study carried out in the Rotterdam region in the Netherlands.

1 INTRODUCTION

Interferometric Synthetic Aperture Radar (InSAR) has been used since the early nineties to measure deformations of the earth's surface (Gabriel et al., 1989). Further, with the Persistent Scatterer (PS) InSAR technique (Ferretti et al., 2000),(Ferretti et al., 2001), it is now possible to monitor subtle systematic movements of buildings/urban areas with a precision of couple of millimeters per year. The technique exploits the temporal data archive of satellite images acquired over the deforming region and includes a time series analysis of deformation signals. Although the technical achievements in terms of the observations are the necessary ingredients for a new level of applications, it is paramount that new models need to be developed to link the observations to parameters describing the driving forces behind the deformations. In principle, the PS measurements do not necessarily imply a reliable estimation of the parameter on interest — the various deformation regimes. Moreover, in many cases there may be more than one mechanism responsible for the detected deformation. The separation of the deformation causes contributing to the derived PS measurement is aided by the interpretation of PS locations with respect to supplementary information sources in the area.

For this reason, geographic information systems become indispensable to systematically combine all possible sources of additional information that may contribute to the model formulation of spatio-temporal behavior of derived PS measurement of deformation or subsidence.

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2 THE PS-INSAR TECHNIQUE

The PS-InSAR technique is an extension of conventional InSAR, which has the advantage of overcoming the traditional InSAR problems of temporal and geometrical decorrelation. The PS technique (Ferretti et al., 2000), utilizes a long time series of radar images to detect potential coherent measurement points (e.g. for deformation) in the region. A master image is chosen from the available SAR images on the basis of favorable geometry related to all other images, high coherence and possibly minimum atmospheric disturbances. After the coregistration of master and slave images, a series of interferograms is constructed with the use of precise orbit information. A comparison of interferometric phase differences in time is done to obtain the potential PS points. Persistent Scatterers (PS) are temporally coherent natural reflectors in the SAR images, which are detected on the basis of their correlated phase behavior over time. The displacement of each individual PS point is estimated by the technique.

3 PS ANALYSIS CASE STUDY

With the availability of ERS SAR images, the process of local subsidence deformation in the Rotterdam region is revealed by the PS technique. The PS processing is performed using methodology developed at the radar research group at Delft University of Technology.

To perform the Rotterdam PS-InSAR analysis, 79 ERS-1 and ERS-2 SAR images have been selected in the period 1992-2002.

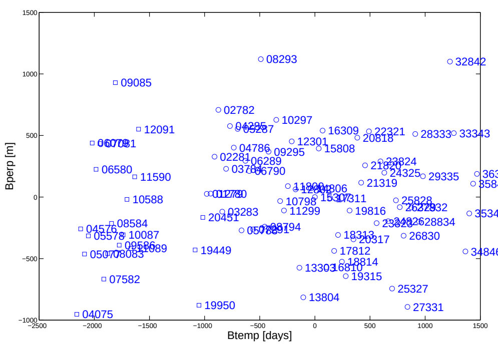

Figure 1. Baseline plot (temporal and perpendicular baselines).

Figure 1 shows the distribution of the images for temporal baseline against perpendicular baseline. It is necessary to refer all images to same reference geometry so that a single pixel corresponds to the same ground resolution cell in each acquisition. Therefore, a master image is chosen having an optimal relative temporal and perpendicular baseline and Doppler shift regarding the slave images (Ferretti et al., 2001). All slave images are coregistered to the master image geometry. The spatial resolution of the SAR single look complex data is 20×4 meters. The images are oversampled two times to reduce aliasing effect which subsequently makes the SAR pixel size of 10×2 meters.

Interferograms for all the slave images with the master image are generated as a first step. From these interferograms, a sparse grid of coherent point targets is identified based on statistical analysis of their amplitude returns (Ferretti et al., 2000),(Ferretti et al., 2001). These radar targets are called Persistent Scatterer Candidates (PSCs). The PSC are point scatterers with very high radar amplitude stability and these usually correspond to man made features like buildings, lampposts, exposed rocks, solid surfaces etc.

After densification of this point network, and estimation of topographic and atmospheric -phase contributions, systematic movement of persistent scatterer locations is detected. Note that this PS motion information is differential, that is, all measurements are referred to an arbitary reference point. After the PS analysis, a set of points with their detailed deformation profile, estimated heights, radar coordinates, time coherence, velocity rates, atmospheric parameters etc. is obtained. The number of selected PS locations depends on the coherence threshold value — a higher coherence value implies less detected PS.

The location of the Persistent scatterers was not known beforehand as it is by levelling and other conventional techniques of deformation monitoring. This shows the advantage of the detection of a multitude of deformation profiles from satellite images without the need of field work or expensive ground surveys. This gives an idea about the cost effectiveness of PS-InSAR techniques in comparison to other geodetic methods.

4 POSITIONING ACCURACY OF PS POINTS

Due to inaccuracies in the orbit parameters and in the reference point selection, it is possible that the geocoded results are not perfectly aligned on the reference grid. The absolute positioning error depends on the accuracy of the reference point used in the analysis.

However, out of the numerous error factors contributing to the PS positing, some errors are estimated in the present study.

4.1 Positioning accuracy based on radar geometry and atmospheric bias

Figure 2 shows the simplified geometry of satellite radar observations. Here we have considered the positioning accuracy of the satellite (in horizontal and vertical direction) and the variance of the satellite range measurement. It can be seen from Figure 2, that

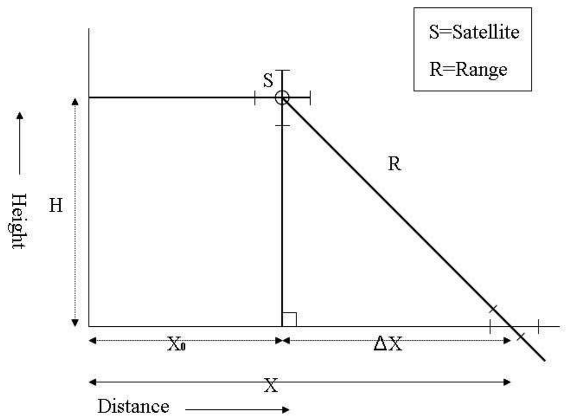

Figure 2. Satellite geometry for radar observations

$$X = X_0 + \Delta X \quad (1)$$

and,

$$\Delta X = \sqrt{R^2 - H^2} \quad (2)$$

Taking partial derivatives to X_0, R, H, we get,

$$dX = dX_0 + (\frac{R}{\sqrt{R^2 - {H_0}^2}}).dR + (\frac{-H}{\sqrt{R^2 - {H_0}^2}}).dH \quad (3)$$

where,

- dX horizontal offset of a point,
- dX_0 satellite position accuracy in horizontal direction,
- dR range accuracy, and
- dH satellite position accuracy in vertical direction.

The initial value of R is calculated considering the time for first signal in the master image(τ=5.5643960 ms) multiplied by velocity of light and the H value is taken as 780 Km. Further, the values of dX_0 and dH are taken as $\sim$ 10 cm in form of standard deviation (σ) (Hanssen, 2001) and dR as $\sim$ 2.5 $\pm$ 0.3 m (on the basis of atmospheric bias (Hanssen, 2001)). Now from equation 3, the variance of dX is calculated taking into account the variance of satellite orbit and range. The solution suggests that the accuracy of PS as radar observation may vary within a range of $\sim$28 meters (when atmosphere bias is taken into consideration) and $\sim$4 meters (when atmosphere bias is not taken into consideration) in 95 percent confidence interval.

4.2 Positioning accuracy based on height bias of reference point

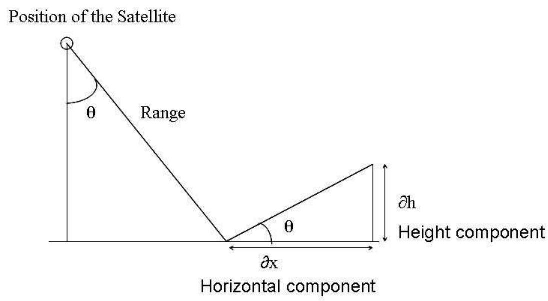

Figure 3. Satellite geometry for radar observations showing range deviation with reference to height

As shown in Figure 3,

$$\tan\theta = \frac{\delta h}{\delta x}, \quad (4)$$
$$\delta x = \frac{\delta h}{\tan 23^o}$$

which leads to,

$$\delta x = \delta h \cdot 2.355 \quad (5)$$

This solution gives an initial idea that 1 meter shift in the absolute height reference for PS analysis leads to a horizontal deviation of 2.355 meters.

The atmospheric deviations also add up into an error of a couple of meters to the absolute positioning error. The relative positioning error in PS-InSAR geocoding is limited by the SAR system resolution, resulting in $\sim$10 meters in range direction and $\sim$2 meters in azimuth direction.

5 USE OF GEO-INFORMATION TECHNOLGY FOR CLASSIFICATION OF PS

Although PS analysis estimates the deformation profiles at the estimated deformation locations, its still difficult to spatially interpret this deformation with reference to its triggering mechanisms. To have an understanding of the driving forces behind the deformation as shown by the PS-

InSAR processing, the Persistent Scatterers have to be classified first according the topographical features they represent. Here we have tried to incorporate supplementary geoinformation pertaining to physical features in the deformation study area. Local deformations are expected at or near man-made objects as buildings and infrastructure like roads and railroads.

Within the Netherlands these objects are mapped at different scales. The so-called Large Scale Standard Map, abbreviated in Dutch to GBKN (web, b), gives the most detailed topographical mapping. In suburban areas the scale of the GBKN is 1:500 or 1:1000. Utility companies use this map as a backdrop layer, so the accuracy is high but the content is limited to what is needed as a reference to e.g. cables, hence to buildings and roads. In our study-area the buildings are given by their polygonal boundaries.

A second source of geo-information used within this research is the Top10Vector map, maintained by the topographical department of the Dutch Land Registry Office (web, c). As implied by the name, the scale of this mapsource is 1:10000. Given this scale the buildings within urban areas could be gathered to collections of build up areas. Despite this disadvantage, it completely covers the (rail)road infrastructure and also the hydrographical features.

A last, but important, source of information to refer the Persistent Scatterers to, is the Actual Height Model , of the Netherlands (web, a). This detailed elevation model is obtained by Airborne Laser Altimetry. As most application demands an elevation description of the surface only, the points measured at houses and other man-made objects are usually filtered out of the dataset. As this information is crucial within our research we used the raw dataset, although the data points are interpolated to a raster with a spatial resolution of 5 meters.

All these reference datasets are given to the Dutch reference systems: the GBKN and the Top10Vector to the Rijksdriehoeksstelsel (RD) for the planimetric component and the AHN also to the National Ordnance Datum (NAP) for the height component (web, d). To combine the Persistent Scatterers with these datasets, a conversion from the SAR coordinates to WGS84 is being applied, succeeded by a projection to the RD system. The height value of the PS points is not given absolute to NAP but relative to the reference point in the analysis. If this reference point has given its appropriate NAP height, than the PS points are also known within NAP. Currently, this datum shift is applied manually.

Figure 4 shows a zoom view of combination data layer showing the overlay of arial photograph of Rotterdam area, GBKN building boundaries, and PS points.

Figure 4. Overlay of PS points, Arial photograph and GBKN Building Boundaries for Rotterdam

6 RESULTS

To determine which Persistent Scatterers are located at or near buildings, some basic GIS geoprocessing techniques are applied. ArcView GIS 3.2 is used as a basic tool for geoprocessing computations. To take the inaccuracy of the location of the PS points into account (see section 4), a buffer of 5 meters around the building boundary in the GBKN layer is calculated. With a spatial point-in-polygon overlay, the PS points within these buffers are selected. To distinguish between the PS points at the top of a building or at the street level, the AHN height data is taken into account. If the height of the PS point is more or less comparable with the AHN value than the PS point are classified accordingly. As an aerial image of the study area is also available a last visible check is made to this classification. The final set of Persistent Scatterers at or near buildings is now further analyzed to reveal the driving forces behind their deformation.

7 CONCLUSION

Here we presented the preliminary results of PS classification based on different information layers of the region. The scope is currently limited to preliminary results. However, in future studies the PS derived deformation will be interpreted to have a better understanding of the deformation mechanisms in the area.

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