Radar Interferometry

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RADAR INTERFEROMETRY

Persistent Scatterer Technique

by

BERT M. KAMPES
German Aerospace Center (DLR), Germany

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Cover image: Estimated linear displacement rates for the Berlin test site for different thresholds on the a posteriori variance factor. Figure 6.6(c) (also see p. 96)

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To Jill and Madeline

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Preface

Soon after the first attempts at Delft University of Technology to apply the radar interferometric technique for the monitoring of subsidence due to gas extraction in the province of Groningen, the Netherlands, it was recognized by Usai and Hanssen (1997) that man-made features remained coherent in radar interferograms over long time spans, while their surrounding was completely decorrelated. This particular area in the northern part of the Netherlands is well-known for its subsidence. Due to the slow subsidence rate—the maximum is approximately 1 cm/y—long temporal baselines needed to be used. Even though only interferograms with short perpendicular baselines were generated, temporal decorrelation severely limited the analysis, see (Usai, 1997, 2000; Usai and Klees, 1999). The Groningen data set was also used by Hanssen (1998), who analyzed artifacts of atmospheric origin in coherent interferograms with short temporal baselines. Aside from temporal and geometrical decorrelation, atmospheric signal is the main problem for the interpretation of interferometric signal of current day spaceborne sensors on board, e.g., ERS, ENVISAT and RADARSAT (Hanssen, 2001).

The Permanent Scatterers (PS) Technique was developed shortly after, see (Ferretti et al., 2000a, 2001). It aims to bypass the problem of geometrical and temporal decorrelation by considering time-coherent pixels. Furthermore, by using a large amount of data, atmospheric signal is estimated and corrected for. The PS technique offers a convenient processing framework that enables the use of all acquired images, irrespective of baseline, and a parameter estimation strategy for interferograms with low spatial coherence. The advantages of this method can be measured from the increasing attention it has received at major conferences For example, in the proceedings of the IGARSS conferences of 1999 to 2003 there are respectively 1, 5, 4, 17 and 26 direct references to the term Permanent Scatterer. The "Terrafirma" initiative further underlines the high potential of this technique. This project aims to provide a Pan-European ground motion hazard information service, to be distributed throughout Europe via the national geological surveys. All large towns in Europe are to be studied with the PS technique. In total, 189 towns in total are identified, equalling 27% of the total population. In the longer term, areas will be included that suffer risks from ground motions caused by, for example, landslides or mining, see (Terrafirma, 2005).

Additionally, once the PS technique demonstrated that using a large number of images is a way to reduce atmospheric artifacts and to obtain highly precise estimates despite decorrelation, this sparked the development of a number of related techniques, e.g., Coherent Target Monitoring (Van der Kooij, 2003; Van der Kooij and Lambert, 2002), Interferometric Point Target Analysis (Wegmuller, 2003; Werner et al., 2003), Stable Point Network analysis (Arnaud et al., 2003), Small Baseline Subset Approach (Berardino et al., 2003, 2002; Lanari et al., 2003; Mora et al., 2002), and Corner Reflector Interferometry and Compact Active Transponders Interferometry (Nigel Press Associates, 2004). These techniques partly seek to improve the PS technique using a modified approach (some even assume distributed scattering of multi-looked pixels, although still use concepts similar to the PS technique), but also partly try to avoid disputes over the patent of the PS technique. The term *Persistent Scatterer Interferometry* (PSI) is now used to group techniques that analyze the phase time series of individual scatterers.

This book revisits the original PS technique and presents a new PSI algorithm, the STUN algorithm, which is developed to provide a robust and reliable estimation of displacement parameters and their precision.

Audience

This book is intended for scientists and students who want to understand and work with Persistent Scatterer Interferometry. Particularly of interest for this group of readers are the derivation of the functional and stochastic model, the description of the estimation using integer least-squares and variance components, and the alternative hypothesis testing procedure, see Chapter 2, 3, and 4, respectively. The software toolbox on the CDROM explain these key concepts using practical demonstrations, see also Appendix E. The modular programs can be easily adapted and be further developed by the interested reader for specific problems.

Secondly, this book is intended to provide insight in the problems and pitfalls of Persistent Scatterer Interferometry for users of PSI products and of commercially available PSI processing software, and to enhance their understanding of this technique. This group of readers includes geo-information professionals and high level decision makers who do not perform PSI processing themselves. The description of the reference PS technique and potential improvements upon it, see Chapter 2, and Chapter 6 on real data processing may prove to be most useful for this group.

The reader is assumed to be familiar with general radar concepts and conventional radar interferometric processing, as for example described in (Bamler and Hartl, 1998; Hanssen, 2001; Klees and Massonnet, 1999; Rosen et al., 2000). The PS technique is regarded as an extension of the conventional differential interferometric technique. Background knowledge of the PS technique is not required to understand this work. A geodetic background is helpful, but not necessary. However, geodetic concepts are used, particularly concerning the integer least-squares estimator, variance component estimation, and alternative hypothesis testing. These issues are explained in detail in the chapters and appendices to make this work self-contained.

The technique described in this work can be applied to data obtained by current-day radar sensors and data of future systems. However, most emphasis is on ERS–1 and ERS–2, because data of these sensors are available for the test areas over extended time intervals.

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But above all, I am grateful for the persisting support of my wife Jill.

Bert Kampes
Munich, March 2006

Summary

Persistent Scatterer Interferometry is the latest development in radar interferometric processing, which offers a practical way to reduce the main errors in conventional processing methods; temporal and geometrical decorrelation, and atmospheric artifacts. This is achieved by the analysis of the interferometric phase of individual long time-coherent scatterers in a stack of tens of differential interferograms with one master image. In this study the original PS technique is revisited and geodetic techniques are applied to improve the quality of estimated parameters that describe displacement. For this reason the STUN (Spatio-Temporal Unwrapping Network) algorithm is developed. The first step in this algorithm is to establish a reference network of coherent points. The points are initially selected based on their amplitude time series, which is expected to be related to the phase dispersion. A large number of estimations between points of the network are performed, followed by a least-squares adjustment to obtain the displacement and topography at the points. The estimations are performed between nearby points (distances less than ~2 km) in order to limit atmospheric signal, which could prevent successful estimation using the wrapped data. An alternative hypothesis testing strategy is carried out to identify incorrectly estimated parameters and incoherent points. The parameters are estimated with the integer least-squares estimator using the wrapped data. This estimator has the highest probability of finding the correct integer ambiguities for data with a multivariate normal distribution. A variance component model is developed to describe the dispersion of the double-differenced phase observations used in the estimation. This new model accounts for random noise and atmospheric signal at the acquisition times. The variance factors of the variance component model are estimated using the least-squares residuals of an initial estimation. The displacement is modeled using a linear combination of base functions. This generic approach allows for the estimation of non-linear displacements using wrapped data. Second—once the parameters at the points of the reference network are computed—more selected points are estimated with respect to the reference network. Based on the estimated a posteriori variance factor, a set of reliable points is selected and a Minimal Cost Flow sparse grid phase unwrapping algorithm is used to obtain the unwrapped phase at these points. The final estimation is performed using the unwrapped data. The precision of the estimated parameters is described by the propagated variance-covariance matrix with respect to a chosen reference point.

The STUN algorithm is successfully applied to two urban test areas. Several tests are performed to assess the sensitivity of the algorithm to various parameters such as the number of available interferograms, the distance between points in the reference network, etc. The first test site, Berlin, was not expected to undergo significant displacements. It was selected to validate the developed algorithm and software. However, an uplift area is identified to the west of Berlin, with a maximum displacement rate of ~4 mm/y. Most likely, this uplift is related to underground gas storage at that location. Data of two adjacent tracks are used in a cross-comparison of the estimated displacement. Contrary, the second test site, Las Vegas, undergoes significant displacements. A combined linear and sinusoid displacement model is used to model the displacements. The maximum estimated subsidence rate is ~20 mm/y and the maximum amplitude of the seasonal component is ~20 mm. The results compare well with estimates by the reference PS technique. Finally, combined use of ERS and ENVISAT data is demonstrated.