# InSAR time series modelling based on regularized parameter estimation

Chang, Ling; Ku, Ou; Hanssen, Ramon

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## Scattering property based adaptive filtering of Dual Polarization Sentinel-1 Data for PS-InSAR application

**Mullissa, Adugna G.; Tolpekin, Valentyn; Stein, Alfred**
University of Twente, Netherlands, The

PS-InSAR interferometry is a well-established technique to estimate linear and non-linear ground displacements as well as the atmospheric phase screen (APS) in an InSAR data. It achieves the highest accuracy in measuring deformation. To reach this accuracy a high density of high quality points (PS) is required for model fitting. In rural regions, where the availability of PS points is limited, the density of high quality points is often too low to guarantee accurate results. To mitigate this, a common technique is to exploit distributed scatterers (DS) that have enough phase quality for it to be used in the PS-InSAR analysis. To increase the phase quality of DS and preserve PS points in the image scene, adaptive filtering of interferograms should be implemented prior to PS and DS candidate selection and PS-InSAR implementation.

This paper addresses the scattering property based adaptive filtering of dual polarized Sentinel-1 interferograms for application to permanent scatterer interferometry in a rural region. We first demonstrate the derivation of scattering mechanisms from 14 dual polarized Sentinel-1 data acquired between August 2015 and August 2016. We implemented an adaptive filtering procedure to estimate the complex coherences for different interferogram pairs to preserve PS and filter DS located in the image scene. We further implemented phase quality optimization to achieve high accuracy in differential phases for both PS and DS candidates. Finally, the selected candidates are processed jointly in a PS-InSAR processing work-flow to estimate ground deformation .

Preliminary results indicated that PS points were well preserved and that the signal to noise ratio of DS was increased by applying scattering property based adaptive filtering. Adaptive filtering and polarimetric optimization increased the number of pixels available for PS-InSAR analysis. A robust model fitting and a more reliable PS-InSAR analysis result is anticipated from the proposed filtering.

## InSAR time series modelling based on regularized parameter estimation

**Chang, Ling; Ku, Ou; Hanssen, Ramon**
Delft University of Technology, Netherlands, The

InSAR has a great capability for retrieving the deformation time series of huge amounts of ground objects on a bi-/weekly basis. Such time series unveil the evolution of geophysical processes, anthropogenic hazards and the structural health situation of public infrastructure. It is important to understand these processes in order to reduce the impact of natural and anthropogenic hazards and infrastructure degradation.

Unfortunately, time series modelling is not straightforward. Especially in urban infrastructure monitoring, every single radar scatterer may have its own dynamic behavior, irrespective of its neighbors, which implies that the applied functional models may differ for each point. Consequently, the problem is ill-posed unless additional constraints are introduced.

We have demonstrated that a probabilistic approach [1] can be used to determine the most probable time-series model of every InSAR measurement point. We use multiple hypothesis testing, given a library of potential physically realistic deformation models and a complete stochastic model of the measurements. We use the Gauss-Markov model to describe the functional and stochastic model, and we implicitly assume that the unknown parameters are deterministic and uncorrelated with each other. We consider the noise of the measurements due to atmospheric influence, sensor noise, and data processing errors, to determine the stochastic model.

However, in practice, adjacent InSAR measurement points may exhibit a homogeneous or smooth behavior, in either space or time. This implies that the parameters of interest may be correlated and considered to be stochastic variates. Without considering this parameter signal correlation information, parameter estimation would be biased and therefore unreliable. Yet, simply applying global smoothing/multi-looking in space or time to filter the signal, is too harsh and will invoke more biases. Therefore, in the current study we propose to apply regularization in the parameter estimation, per cluster of points, based on available a priori signal information. As the signal information cannot be derived directly from the InSAR measurements, we obtain this information from other external sources (expert elicitation) and use them as constraints. This approach improves the accuracy, precision and reliability of the InSAR results. We demonstrate this approach both via simulations and on real data.

[1] Chang, L., Hanssen, R.F., 2015. A probabilistic approach for InSAR time series postprocessing. IEEE transactions on Geoscience and Remote Sensing 54, 421–430.

## On the Predictability of PS occurrence and location based on 3D Ray-tracing models

**Yang, Mengshi (1,2); Dheenathayalan, Prabu (1); Biljecki, Filip (1); Hanssen, Ramon F. (1)**
1: Delft University of Technology, Netherlands, The; 2: Wuhan University,China

Using persistent scatterer (PS) time-series InSAR, deformation of objects can be measured in order of millimeters. However, the exact physical nature and location of each scatterer is poorly known. Unlike conventional geodesic methods, PS scatterers are generally not pre-defined receivers or benchmarks. The occurrence of PS is strongly dependent on the specific orientation, geometry, and other characteristics of objects on the earth's surface, in relation to the parameters of the transmitted radar signals (e.g. direction, wavelength, polarization). Thus, though high-precision deformation estimates can be achieved, these uncertainties are a limitation to the use of this technique.

One solution to solve this problem is to estimate the 3D coordinates of scatterers by multi-baseline datasets, like persistent scatterer Interferometry[1, 2], Stereo-SAR[3], or SAR tomography[4]. However, the estimated positions, which are in order of several meters in cross-range direction for PS-InSAR, are still insufficient to detailed interpretation. Stereo-SAR requires the identification of (physically) identical scatterers, visible in both imaging geometries, which is not always possible for data stacks from different orbital tracks. SAR tomography only distinguish scatterers if the distance between scatterers is longer than the Rayleigh resolution in elevation[5]. Another way is to extract physical information of scatterers (size, material and temperature etc.) by building the time series amplitude function [6, 7], which also requires to solve the phase ambiguities of the scatterers. Consequently, the most important problem still is the understanding the origin and nature of PS, and the accurate estimation of its position.

Here, we attempt to improve our understanding of scattering mechanisms in an urban context in a new way, by simulating urban landscapes with varying level-of-detail (LOD),see Fig.1. We use a 3D SAR simulator based on Ray-tracing[8] to predict the radar scattering by illuminating a 3D scene by a known SAR sensor. The 'rays' can follow multiple reflections within the object scene, yielding some 'points' to behave as PS point scatterers. These potential scatterers will be predicted and localized. As the detected scatterers change with various level of detail (LOD) 3D models[9], we will explore the LOD effect on the identified scatterers. This yields useful information to improve the interpretation of actual PSI results, since it can be assessed whether specific elements of, e.g., a building will behave as PS or not. We report on the differences observed by illumination from various direction, as well as the differences due to different radar sensors. The simulated signals with their 3D coordinates may further support the connection between radar scatterers and real objects.

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