Nonlinear Subsidence Rate Estimation Using Permanent Scatterers in Differential SAR Interferometry

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***Abstract*—Discrete and temporarily stable natural reflectors or permanent scatterers (PS) can be identified from long temporal series of interferometric SAR images even with baselines larger than the so-called critical baseline. This subset of image pixels can be exploited successfully for high accuracy differential measurements. We discuss the use of PS in urban areas, like Pomona, CA, showing subsidence and absidence effects. A new approach to the estimation of the atmospheric phase contributions, and the local displacement field is proposed based on simple statistical assumptions. New solutions are presented in order to cope with nonlinear motion of the targets.**

***Index Terms*—Atmospheric measurements, digital elevation model (DEM) reconstruction, geodetic measurements, interferometry, phase unwrapping, radar data filtering, synthetic aperture radar (SAR).**

I. Introduction

THE MAIN goal of this paper is to present an extension of the permanent scatterers (PS) technique recently introduced in a paper submitted for publication [1]. In that paper, it is shown that scatterers exist that are coherent over several years. They can be identified from a series of ERS SAR images. A time and space analysis is then carried out to separate and identify the different contributions to the interferometric phase of each PS. Thus, relative elevation, motion, and travel path variation due to the atmosphere are jointly found, and the ground motion can be carefully measured.

The main steps of the technique can be summarized as follows [1], [2].

1) *Interferogram formation*: Given $N+1$ SAR images (all the available ERS-1 and ERS-2 images on the same track), N full-resolution interferograms are formed with respect to the same master image.
2) *Digital Elevation Model and differential interferograms formation*: A reference digital elevation model (DEM) (in most cases it can be generated using the available ERS tandem pairs) and precise orbital data are used to get N differential interferograms.
3) *Preliminary estimate of LOS motion, elevation error, and atmospheric contribution*: Due to the limited accuracy of the DEM (dependent on the number and the quality of the tandem acquisitions [3]), the local topography cannot be considered as perfectly removed, especially in high baseline interferograms. In fact, residual topographic phase contributions will be proportional to the normal baseline and the elevation error. Moreover, the motion of the target projected on the line of sight (LOS) will turn into a phase curve as a function of time. A constant velocity model is adopted for target motion. The atmospheric phase screen [1], [5]–[7], [9] (APS, i.e. atmospheric phase components) and possible phase contributions due to baseline errors are approximated (for each differential interferogram) as a linear phase term both in range and in azimuth direction. Provided that the SNR is high enough, elevation errors, LOS motion of each target (with respect to a reference pixel of known motion), and APSs parameters can be jointly estimated minimizing the temporal phase residuals. At this stage, only those pixels that are coherent enough are considered.
4) *Refinement of step 3*: The APS estimate is improved by spatial smoothing of the phase residues. The joint estimation of target elevation and LOS velocity is carried out again. This final step allows one to identify more PSs.

Although the results obtained with this technique were remarkable, two main limitations were noticed. Only small areas (less than 5 × 5 km large) could be processed. Considering larger areas, too many parameters should be estimated and the planar approximation of the APS becomes less accurate. This may prevent the algorithm from converging. Moreover, the algorithm does not cope with nonlinear target motion: coherent scatterers undergoing a complex motion (i.e., the constant velocity model is not valid) are not identified as PSs or, in other cases, the nonlinear term of their motion is considered as part of the atmospheric contribution. This is indeed a more subtle point that needed to be addressed. As it has been noted by R. Bamler and M. VanDerKooij [8] in their independent private communications, if the phase residues are spatially low-pass interpolated (see point 4, mentioned previously) the low wavenumber components of the motion that do not match the linear model are lost, since they are merged with the APS. The low phase dispersion with respect to the constant velocity model after APS removal can then be misleading.

The problem is then to find a more general approach that can cope with nonlinear motions without introducing too many parameters. To this end, it is necessary to move from a deterministic model for PS motion to a stochastic one. The basic idea is to separate the different phase contributions (motion, APS,

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