SPACE-BORNE HIGH RESOLUTION TOMOGRAPHIC INTERFEROMETRY

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ABSTRACT

Synthetic Aperture Radar (SAR) tomography aims at mapping the 3-D reflectivity function from multi-pass SAR data by retrieving the distribution of scatterers along the elevation direction. It is essentially a spectrum estimation problem. The complex values of a specific range cell in a SAR image stack as a function of baseline are closely related to the Fourier transform of the reflectivity function in the elevation direction. Compared to the computed tomography, SAR tomography is complicated due to the sparse and irregular sampling.

In recent years, with ideal experimental conditions or by using airborne systems, a few experiments for SAR tomography were carried out. However, for the spaceborne case, demonstrations of 3-D SAR tomography are limited so far. Even though the importance of spaceborne SAR tomography has been recognized and the basic principle is well described and understood from the theoretical point of view, there are not many examples from real data. The performance has been limited either by the relatively low spatial resolution of satellite SAR data acquisition or by the complexity of the problem itself.

The new generation of SAR satellites, like TerraSAR-X, allow for the first time building up high-resolution SAR data stacks on a regular basis. TerraSAR-X in its high resolution spotlight mode provides data of 0.6 m slant range resolution. It has been shown already that persistent scatterer interferometry (PSI) benefits enormously from this new quality of data. The data stacks used for PSI in urban areas can also be used to derive tomographic information.

This paper presents the first demonstration of space-borne high resolution SAR tomographic reconstruction. It focuses on urban areas with the typical massive layover and multiple scattering. Different spectrum estimation strategies both non-parametric and parametric are evaluated, e.g. based on the Singular Value Decomposition (SVD) and Nonlinear Least Squares estimation (NLS). The techniques are compared using both simulated data and TerraSAR-X high resolution spotlight data over Las Vegas with focus on the difficulties caused by a sparse and irregularly spaced sampling. Experiments using simulated data based on typical TerraSAR-X orbit histories reveal the ill-conditionedness of the problem. Therefore, regularization tools such as Truncated Singular Value Decomposition (TSVD) and Wiener filter are utilized to overcome this problem. Wiener filtering appears to be more stable and has better performance even though the resolution may be slightly reduced. Regardless of the high computational effort due to the required multi-dimensional search in elevation, NLS shows the best performance under low noise. For validation, a TerraSAR-X data stack with a relative small baseline range of about 200 meters is used which gives an elevation resolution of 45m. The corresponding spectrum estimation results are compared to the plausible ground truth and show reasonable results.

In a second step of processing, model selection criteria such as the Bayesian Information Criterion (BIC), Akaike information criterion (AIC) and Minimum Description Length criterion (MDL) are applied to the spectral estimates in order to determine the number of scatterers inside one resolution cell which is an important prior knowledge required for more accurate PSI estimation. The probability of correctly detecting the number of scatterers and the accuracy of the corresponding elevation estimates are evaluated from simulated data. Under the critical SNR for PS processing (2dB), the probability of correctly detecting the number of scatterers better than 75% can be reached and the accuracy of the

corresponding elevation estimates is better than 87%. For the purpose of validation, model selection results with TerraSAR-X data are analyzed and reported.

SAR tomography as a straightforward extension to the PSI technique is integrated into DLR's PSI-GENESIS processor to support the deformation estimation, improve the 3D localization and facilitate a better PS detection by a more precise signal-to clutter-ratio SCR estimation. First processing results using TerraSAR-X data are presented that confirm the capability of space-borne high resolution SAR tomography for resolving multiple targets within the same azimuth-range cell and to map the 3-D scattering properties of the illuminated scene.

Finally, differential SAR tomography, which is a new interferometric mode crossing differential SAR interforometry and the 3D multibaseline tomography concepts, is analyzed. It can provide the capability to retrieve the elevation and deformation information of multiple scatterers inside an azimuth-range resolution cell and therefore obtains a space-time 4-D map of point scatterers. Differential SAR Tomography processor is implemented to simulated data with different acquisition and motion conditions and the simulated results are reported.