TEMPORAL DECORRELATION EFFECTS IN SUPER-RESOLUTION 3D TOMOSAR

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ABSTRACT

Much interest is continuing to grow in advanced interferometric SAR methods for full 3D imaging, in particular of volumetric forest scatterers. Multibaseline SAR tomographic elevation beam forming, i.e. spatial spectral estimation, is a promising technique in this framework. In this paper, the important effect of temporal decorrelation during the repeat pass multibaseline acquisition is analyzed with focus on superresolution tomography with limited sparse data, considering in particular model based and adaptive beamforming methods. The comparison among the two methods has been carried out for varying decorrelation condition and acquisition configurations. Critical coherence conditions for SAR tomography are also discussed, showing for the first time that adaptive tomography can be more robust to temporal decorrelation than model based tomography. Finally, directions in the more general new framework of “differential tomography” are hinted.

1. INTRODUCTION

In the synthetic aperture radar (SAR) area, many efforts are spent in experiments and processing developments of advanced SAR methods based on acquisition diversity (e.g. multibaseline, multialtitude, or multipolarization interferometric acquisition) which will lead to the next generation of SAR products of 3D kind for imaging of multiple layers or volumetric scatterers [1]-[11]. Compared to SAR and conventional SAR interferometry, these techniques can produce more features for urban and geophysical parameter extraction. In this framework, studies for new spaceborne missions are being carried out, such as the ESA candidate Earth Explorer Core Mission BIOMASS [11] and the DLR TanDEM-L mission [12].

In particular, much interest has concentrated on multibaseline (MB) SAR tomography (TomoSAR), where a cross-track array is exploited which is synthetized, with current technologies, by many repeat passes of a monostatic SAR sensor. Future satellite cluster configurations, such as those of TanDEM-X and TanDEM-L, will allow multistatic acquisitions, i.e. more than one array phase center will be provided per pass [12]. The repeat pass MB data are focused through elevation beamforming methods i.e. spatial (baseline) spectral estimation, resulting in backscattering intensity profiling along the third dimension (Tomo profile). Efforts have concentrated so far on improving the typical unsatisfactory 3D imaging quality of conventional beamforming (BF) due to the limited and sparse baseline distribution [2], [6], [8]-[9]. Also model based techniques have been considered [3], [4], [10]. In particular, the MUSIC spectral estimator, matched to line spectra, has been applied to the tomographic processing [4], [11], [16], showing its effectiveness even in presence of elevation distributed forest scatterers.

However, the elevation focusing process relies on the sensed scene staying coherent, while physical changes typically occur during the repeat pass MB acquisition, especially for spaceborne sensors. As it is well known for conventional azimuth SAR focusing, partially coherent or moving scatterers can lead to blurring effects. In the Tomo-SAR case, elevation defocusing or misplacement effects can arise in the 3D imaging process, the distortions being worsened due to the typically space-irregular (non monotonic) temporal synthesis of the cross-track array [9], [13]-[15]. Such effects are recognized by ESA and NASA-JPL to be a possible development and application barrier of MB 3D tomographic imaging, especially for spaceborne sensors and forest areas.

In this work, the effects are quantified of temporal decorrelation on the formation of TomoSAR profiles from repeat pass MB data, considering in particular model-based and also adaptive ([4], [5], [13-15]) BF methods, typically employed in critical resolution conditions. To this aim, a representative long term temporal decorrelation model is used [9], [17]. The analysis will be carried out for a statistically simulated forest scenario, in terms of resolution probability and estimated elevation accuracies for varying decorrelation conditions and acquisition configurations. Indications of temporal criticalities will be derived.

Finally, a new processing approach targeted to reduce the possible Tomo-SAR image quality degradation from partial scene coherence is hinted in the more general framework of differential SAR tomography (Diff-Tomo). This framework, recently introduced by University of Pisa [18], deeply integrates the Tomo-SAR concept with the differential interferometry concept, allowing production of ‘space-time’ signatures of the scatterers in the SAR cell.
2. TOMOGRAPHY WITH TEMPORAL DECORRELATION

The effects of temporal decorrelation on model based MUSIC and adaptive BF Tomo-SAR methods are characterized, the simulated analysis concerning a typical forest scenario with canopy and ground contributions. The normalized baseline-time acquisition pattern is shown in Fig. 1; with circles we denoted the monostatic acquisition case, and with crosses the multistatic case with three simultaneous acquisitions at each pass. It is worth noting the sparse and irregular sampling, especially in the monostatic case.

The canopy volumetric scatterer width is 0.2 Rayleigh resolution units (r.u.), with a centroid elevation over the reference height of 0.4 r.u., and long term decorrelation time $\tau_c$ of 2.8 revisit time (r.t.) units. The ground scatterer is electrically stable and steady, and its power is 1/5 of that from canopy, which is representative of a L-band acquisition. The temporal correlation coefficients of the overall signal as a function of the acquisition index are reported in Fig. 2. The elevation of the compact ground scatterer with respect to the reference is -0.3 r.u., thus separation from the canopy centroid is 0.7 r.u. The number of independent looks is 16, and total SNR is 15dB.

2.1. Resolution behaviour of model-based and adaptive TomoSAR

In the ideal case of absence of temporal decorrelation, realizations of the MUSIC Tomo pseudo-spectrum are reported in Fig. 3 (a)-(b) for the monostatic and multistatic cases, respectively. In both cases, it is apparent the presence of a dominant peak corresponding to the canopy scatterer, and of another peak at a lower elevation, which corresponds to the ground scatterer. In the plotted realizations of the multistatic case, apparently the ground scatterer (less powerful than the canopy one) is located more precisely. In general, the two scatterers are rarely unresolved. When temporal decorrelation of the canopy scatterer is present, the obtained MUSIC tomo pseudo-spectra are reported in Fig. 4 (a)-(b) for both the acquisition kinds. In this case, two peaks are not often visible, not even in the more densely sampled multistatic acquisition. The strong temporal decorrelation resulted in a heavy resolution loss. Realizations of adaptive BF Tomo SAR are reported in Fig. 5 for the multistatic acquisition case in presence of the temporal decorrelation. Compared to adaptive BF Tomo SAR in the ideal case (not reported here), canopy and ground peaks are smoothed and the resolution is again worsened. However, compared to MUSIC Tomo SAR under the same decorrelation condition in Fig. 4 (b), adaptive BF shows better resolution capability.

2.2. Statistics and compared trends

Exploiting the Tomo profiles, elevation estimates can be obtained. The resolution probabilities and the root mean square errors (RMSEs) of the estimated canopy-ground separation in elevation (forest height) for MUSIC and adaptive BF Tomo-SAR have been measured by means of Monte Carlo simulation. They are reported in Tab. I for the multistatic case in absence of temporal decorrelation. In this fully coherent scenario, both Tomo SAR methods are fully operative. However, model based Tomo SAR takes a slight gain of resolution probability and accuracy over adaptive BF. Similar statistics have also been measured for a mild and the previous strong temporal decorrelation conditions, where the long term decorrelation time $\tau_c$ is 44 and 2.8 r.t. units, respectively. The resolution probabilities and RMSEs obtained by Tomo-SAR MUSIC and adaptive BF are reported in Tab. II, again in the multistatic case. It is apparent that even the mild temporal decorrelation of the canopy affects the resolution and the accuracy of estimated forest height of both Tomo-SAR methods, although an higher negative impact is noted for MUSIC Tomo SAR. Interestingly, adaptive BF Tomo-SAR now presents better resolution than MUSIC Tomo-SAR. A coherence condition is thus revealed for which the resolution ranking of the two methods is inverted. However, notwithstanding some resolution and accuracy losses, tomographic functionality is still preserved for $\tau_c = 44$ r.t.

Reducing $\tau_c$ to 2.8 r.t., the resolution probability loss further increases for both methods, especially for MUSIC Tomo-SAR. Similarly, a considerable degradation of the estimation of forest height is also noted. In this condition the model based SAR tomography functionality results to be practically not operative, the resolution probability being below 10%. Other analyses (not reported here) showed that for MUSIC Tomo-SAR the critical coherence condition is for decorrelation time of the canopy below 2~3 times the acquisition time span. Conversely, adaptive BF Tomo-SAR is still operative even for the strong decorrelation condition, maintaining a satisfactory resolution probability of 50%. It is thus revealed to be more robust to temporal decorrelation effects than the model based approach.

Exploiting the new Diff-Tomo processing framework [18], even better Tomo results in presence of temporal de-
correlation may be obtained [13]-[15]. The results in [19] indicate that temporal effects on SAR tomography can be lowered, especially in term of resolution loss. The analyses carried out in this paper can be useful in the planning of future missions such as ESA-BIOMASS, TanDEM-L, and SAOCOM.

3. REFERENCES