ADAPTIVE SCAN-ON-RECEIVE BASED ON SPATIAL SPECTRAL ESTIMATION FOR HIGH-RESOLUTION, WIDE-SWATH SYNTHETIC APERTURE RADAR

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ABSTRACT

In this work we investigate the possibility of applying direction of arrival (DOA) estimation methods to high-resolution, wide-swath Synthetic Aperture Radar (SAR) spaceborne systems, based on Scan-On-Receive (SCORE) technique.

Spaceborne SAR for remote sensing applications is experiencing a golden age, as testified by the number of the recent and forthcoming missions, e.g. ALOS PALSAR, TerraSAR-X, COSMO-SkyMed, RADARSAT-2, TanDEM-X, Sentinel-1. Nevertheless, the current generation of spaceborne SAR sensors suffers a basic limitation: it does not allow for high resolution imaging and, simultaneously, wide coverage [1, 2]. For instance, a spatial resolution around 1 m could be achieved over a swath width of 10 km; whereas coverage of 200 km allows for SAR final products with a resolution in the order of 100 m [3]. The importance for many remote sensing applications to overcome this limitation has motivated an intensive research within the frame of Smart Multi-Aperture Radar Technique (SMART) (see [4, 5] and the references therein).

Main characteristics of SMART SAR systems are the use of multiple transmit/receive channels and the introduction of digital signal processing techniques in the conventional SAR processing [4-6]. It is worth noting that the intrinsic huge quantity of information associated with high-resolution and wide-swath imaging, together with redundancies involved by the multichannel acquisition, could place critical requirements on the downlink data rate.

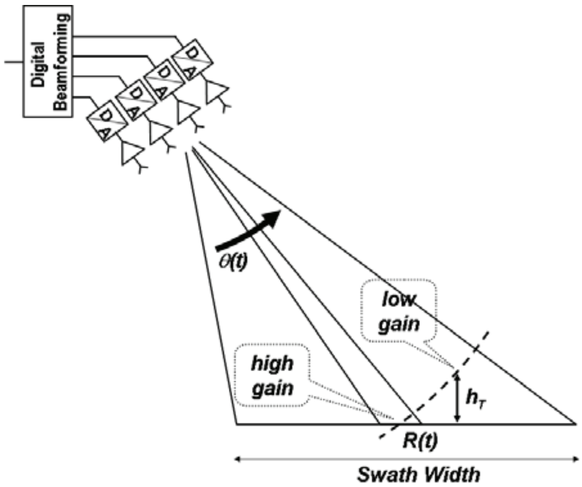

Figure 1. Vertical, slant-range, plane: DBF performed by SCORE; effect of topographic height (h_T) .

Among SMART SAR, the system proposed by Suess *et al.* [7, 8], denoted as HRWS, merges the advantages of an extensive illumination capability with the high gain and directivity of a large antenna, and combines the flexibility offered by a multi-channel architecture with a limited download data volume. The HRWS SAR system is based on an algorithm for steering of the elevation beam pattern, called SCORE: a wide swath is illuminated by using a small transmit antenna; whereas in reception a large multi-channel antenna and Digital Beam-Forming (DBF) are employed in order to obtain a sharp and high gain pattern, which follows the pulse echo as it travels along the ground swath. The steering direction of the receive pattern corresponds to the expected DOA of the echo, which is assumed *a priori* known. In particular, according to [8], it is computed based on the vertical, slant-range, plane acquisition geometry, under the hypothesis of a stringent spherical Earth model, i.e. no topographic height is taken into account. In fact, under this assumption, the DOA of the echo received from a point-like target is univocally related to the target slant range position [8]. Nevertheless, in real acquisition scenarios, characterized by mountains and relief, there will be a displacement between the actual DOA and the steering (i.e. maximum gain) direction; which results in a gain loss with respect to the ideal operational conditions (see Figure 1). The extent of this loss mainly depends on the topography and on the receive beam sharpness. Results obtained so far show that losses of several dB could be reached when no information about surface height is used to steer the beam. Moreover, this steering approach neglects not only the effect of the actual topographic profile along the slant-range elevation plane, but also the effect of surface variations along the azimuth direction.

These observations suggest the option to compute *adaptively* the steering direction of the receive beam, by (digitally) processing the signals available from the vertical subapertures of the multi-channel receive antenna. In fact, the vertical sampling provides a "spatial history" of the signal, which could be used to evaluate the distribution of the received energy as a function of the DOA; then the receive beam steering direction could be selected as the one associated with the strongest signal, eventually within a roughly expected spatial sector.

According to this approach, the receive beam steering algorithm is cast into the frame of Spatial Spectral Estimation and DOA estimation. This topic has been extensively studied in array signal processing theory [9, 10], and also with reference to the Interferometric SAR application [11]. Nevertheless, HRWS SAR spaceborne application shows specific challenges. First, the processing of the signals available from the vertical subapertures should be performed on-board, in order to reduce the downlink data volume. This requires dealing with broadband signals and imposes additional constraints on the complexity of the processing method [10, 12]. Moreover, in case of wide illuminated swaths, the useful signal could be superimposed to range-ambiguous echoes having a power comparable with that of the signal of interest. Finally, instrument parameters, such as dimension of the antenna, number of elements, noise level (NESZ), whose values strongly affect the ultimate estimation performance, do not allow for many degrees of freedom, due to imaging requirements and physical/economical constraints.

The full paper will show the effect of topographic height on conventional, not adaptive, SCORE performance: the steering displacement and the corresponding gain loss introduced by model mismatch will be evaluated as a function of the acquisition geometry and of the receive antenna architecture and pattern shape, with reference to a realistic SAR system operational scenario. The potentials of an adaptive receive beam steering mechanism for spaceborne high-resolution, wide-swath SAR systems will be evaluated by the Cramér Rao Lower Bound (CRLB) analysis [10]: the minimum variance on the DOA estimation and the corresponding gain loss will be computed versus the main SAR instrument parameter values. A new algorithm for adaptively steering of the receive beam pattern according to the actual spatial distribution of received signal power will be proposed. The performance of the proposed algorithm will be evaluated by Monte Carlo simulations and compared with that of the conventional, not adaptive, SCORE and with the CRLB.

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