NOVEL SAR CONCEPTS FOR WIDE-SWATH SHIP MONITORING AND SINGLE-PASS DEM GENERATION

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ABSTRACT

This work focuses on some novel mono- and multi-static synthetic aperture radar (SAR) concepts for dedicated Earth observation applications, in which the final products are obtained without prior generation of high-quality SAR images, but through extraction of the desired information from one or more low-quality (noisy and ambiguous) SAR images. A first range of applications involves the detection of point-like or extended targets over large areas, e.g., for ship monitoring or displacement measurements through persistent scattering interferometry [1], [2]. While conventional SAR modes can only map wide swath at the expense of a degraded azimuth resolution, which results in limited detection performance for weak or small targets, a novel staggered ambiguous mode is proposed, in which a wide beam is adopted in both transmit and receive and the pulse repetition interval (PRI) is continuously varied and is much smaller than the minimum PRI imposed by the swath width [3]-[5]. Swaths of over 100 km can be imaged with azimuth resolution in the order of 2 m. This mode recalls in some aspects the staggered SAR mode, but does not foresee the use of digital beamforming on receive and can thus be easily implemented in most spaceborne SAR systems [6]-[11]. As the receive beam is characterized by a lower gain and the multiple echoes coming back from the swath cannot be separated on receive, the produced SAR images will be noisy and corrupted by strong range ambiguities of both point-like and extended targets and the background clutter [4], [12], [13]. For the same observed swath, however, it can be demonstrated that this mode has significantly better detection performance than ScanSAR due to the higher azimuth resolution and the ambiguity blurring effect due to the PRI variation [4]. Waveform alternation can be moreover explored to further blur ambiguities and increase the mapped swath [14] and in principle to help suppressing range ambiguites as hinted in [15]. Spaceborne demonstrations of ship monitoring in both open sea and coastal areas were conducted through experimental acquisitions using the TerraSAR-X satellite [14], [16]. The focused SAR data are shown in Fig. 1, where ambiguities are highlighted. The comparison with data broadcasted by the automatic identification systems of the ships allowed an additional validation of the results. Furthermore, demonstrations of displacement measurements are currently being conducted and will be presented at the workshop. A second relevant application is the generation of accurate, high-resolution digital elevation model (DEM) of an observed scene in a single pass using a cluster of small satellites. An important application example for the generation of DEMs in a single pass is the assessment of permafrost degradation through the difference of DEMs acquired at short time intervals, from which accurate estimates of volume changes over time can be derived. A cost-effective, multi-static SAR system can be devised that enables the generation of high-quality DEMs from large sets of noisy and undersampled data acquired by a cluster of receive-only smallsats with small antenna apertures, e.g., using a further transmit-only satellite. The smallsats should be flown in formation with different along- and across-track baselines. The raw data acquired by each receiving satellite are independently focused (the full Doppler bandwidth is processed). The height of each pixel is then estimated by maximizing the generalized likelihood, as detailed in [17]. The height estimation is essentially based on comparing estimated covariance matrices from the data with a model based on the Gaussian statistics for distributed scatterers. Fig. 2 (a) shows a block diagram with the processing steps. In this way, multi-channel azimuth ambiguity suppression and multi-baseline SAR interferometry for robust phase unwrapping are combined in a distributed SAR system. This approach represents a radical paradigm shift from state-of-the-art systems and techniques and takes advantage of the fact that a large amount of the information contained in the currently-used multi-dimensional data sets is redundant. This concept can help reduce the antenna size of the radar satellites and therefore make single-pass, multi-baseline interferometric SAR system more affordable. To demonstrate this technique tomographic data with numerous baselines have been acquired over a mountainous area in Southern Germany using the F-SAR airborne sensor of DLR. This data set allowed processing of subsets of the available tracks and/or azimuth samples to assess to which extend subsampled data can still produce a high-quality DEM. The first results of the processing of the data were reported in [17]. Fig. 2 (b) shows a DEM generated from undersampled F-SAR acquisitions emulating a cluster of eight smallsats with small aperture (total aperture of all satellites in the order of the total aperture of the two TanDEM-X satellites). Besides some wrong height estimates, in spite of the significant slopes in the area, the overall topography of the area is retrieved with accuracy comparable to TanDEM-X's one. Additional postprocessing steps might further improve the DEM quality. It has to be stressed that this concept optimize the DEM quality and minimize the number and/or aperture size of the receivers, but do not deliver a high-quality SAR image. If desired, however, the concept can be adapted to include a train of satellites, that also deliver a high-quality SAR image and can be in principle also used for along-track interferometry. In conclusion, low-quality, noisy and ambiguous SAR imagery can be effectively utilized for specific applications such as wide-area ship monitoring and single-pass DEM generation. Space and airborne demonstrations show that these concepts are mature for implementation in future missions.

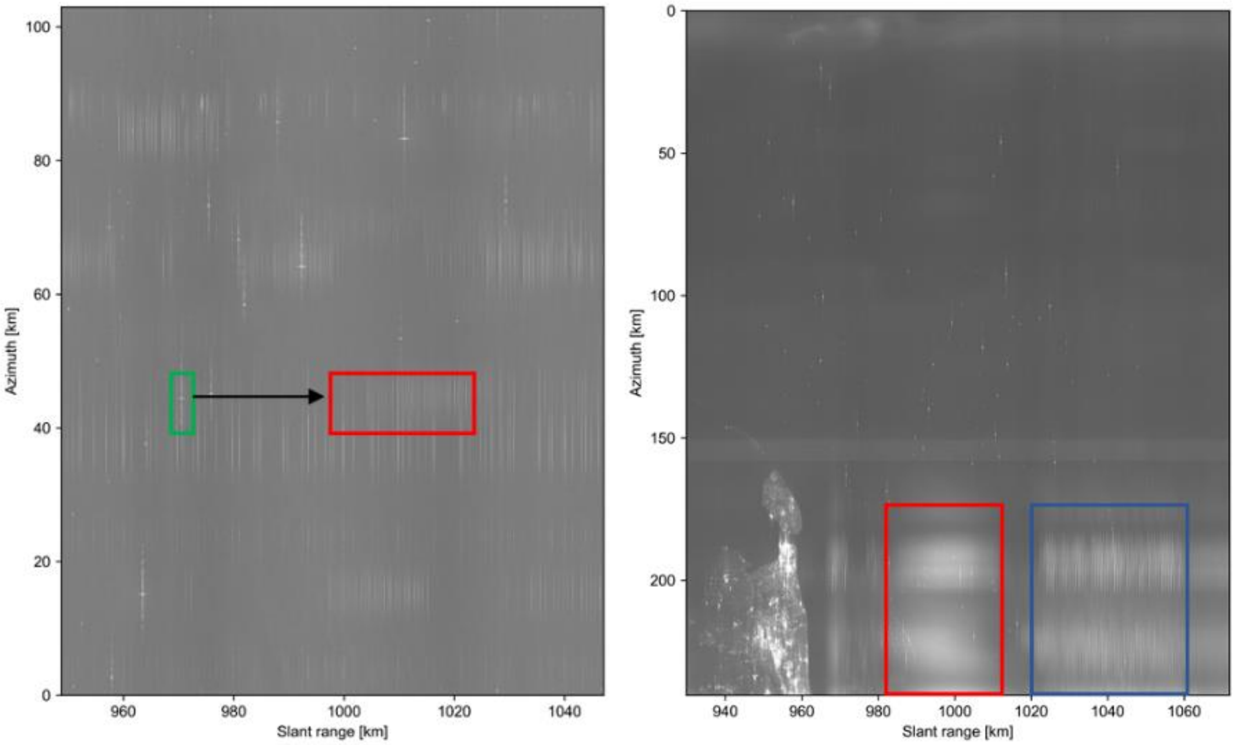
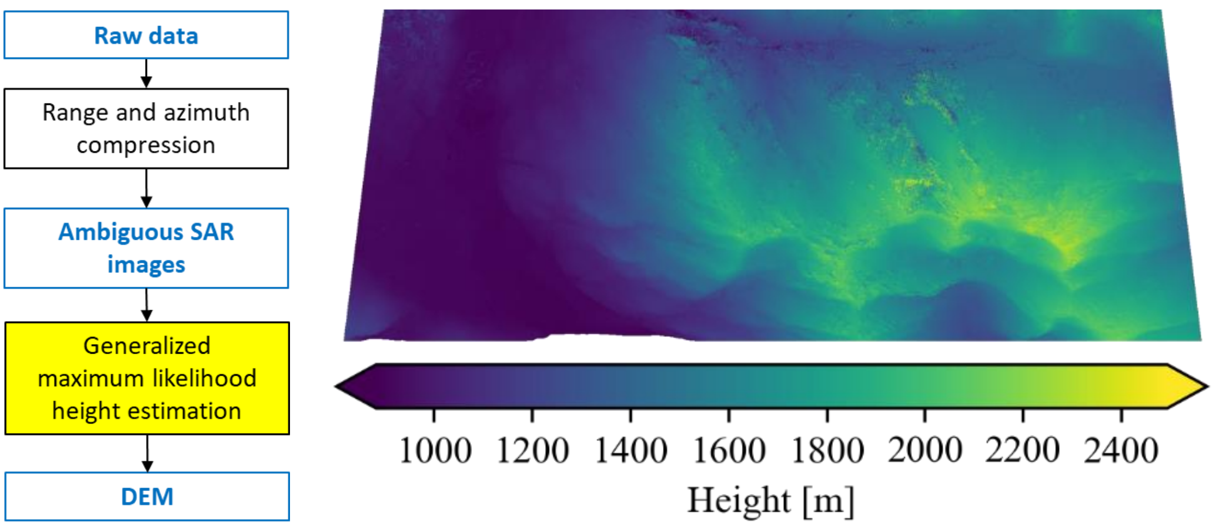


Fig. 1 Spaceborne demonstration of the staggered ambiguous mode. (left) Focused SAR image acquired in open sea by TerraSAR X in staggered ambiguous mode with ~2 m azimuth resolution over a scene of about 10 000 km^2. The green rectangle highlights one of the large ships in the scene and its sidelobes, the red rectangle highlights a part of the image affected by the first-order range ambiguity of the ship in the green rectangle. (right) Focused SAR image acquired in a coastal area by TerraSAR-X in staggered ambiguous mode with alternating up- and down-chirps with ~2 m azimuth resolution over a scene of about 33 600 km^2. The red rectangle and the blue rectangle highlight the first-order and the second-order range ambiguities from the land, respectively.



(a) (b)

Fig. 2 (a) Conceptual diagram of the generation of a DEM from noisy and undersampled data acquired by a cluster of smallsats. (b) DEM generated on a mountainous area in Southern Germany from undersampled acquisitions emulating a cluster of eight smallsats.

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