POTENTIAL OF MULTI-STATIC SAR SYSTEMS FOR EARTH MONITORING AND THEIR DEMONSTRATION USING SWARMS OF DRONES

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ABSTRACT

Spaceborne synthetic aperture radar (SAR) is an essential tool for Earth observation. The combination of multiple SAR images taken from different viewing angles allows forming accurate digital elevation models and highresolution tomograms that unveil the three-dimensional structure of vegetation, ice, and dry soil. Whereas nowadays such images are mostly acquired sequentially, compromising product quality and hindering the monitoring of fast dynamics, multi-static SAR systems enable the simultaneous acquisition of all required data, paving the way for effective and powerful monitoring of our planet. One fundamental challenge is the conception of multi-static concepts that allow the generation of high-quality digital elevation models and tomograms from large sets of noisy and undersampled radar data acquired by clusters of smallsats with small antenna apertures. Swarms of drones, equipped with radars and localization systems, represent an affordable option to test multi-static concepts and acquire multi-static data with sub-hour temporal resolution.

Index Terms—Synthetic aperture radar (SAR), interferometry, digital elevation models (DEMs), tomography, multi-static concepts, satellite swarms, drones.

1. INTRODUCTION

Earth science benefits tremendously from spaceborne synthetic aperture radar (SAR) [1]-[3]. High-resolution wide-swath SAR systems allow for frequent imaging of the Earth's surface on a global scale and constellations of low-cost SAR sensors further reduce the revisit time on local areas and guarantee a timely response to natural disasters. SAR images can be combined to create accurate digital elevation models (DEMs) and high-resolution tomograms that unveil the three-dimensional structure of vegetation, ice, and dry soil [4]-[10]. The sequential acquisition of such images, however, compromises the product quality and, perhaps more importantly, hinders the monitoring of fast dynamics.

2. MULTI-STATIC SAR SYSTEMS

Multi-static SAR systems enable the simultaneous acquisition of all data required to form DEMs or tomograms and pave the way for effective and powerful monitoring of our planet [11]-[12]. An important application example is the assessment of permafrost degradation by the difference of DEMs acquired at short time intervals, from which accurate estimates of volume changes over time can be derived [13]-[15]. Another example is the mapping of biomass changes using single-pass tomograms that helps to retrieve important variables of the carbon cycle. Whereas several concepts based on smallsats have been proposed in recent years for SAR imaging, e.g., to collect the raw data samples using multiple satellites in order to enlarge the swath and/or reduce power requirements [16]-[19], multistatic SAR will play a game-changing role for interferometry and tomography, as well as for novel techniques, such as multiple-input multiple-output-SAR (MIMO) tomography [20], and concepts that exploit large bistatic angles, as also envisioned in the European Research Council's (ERC)funded project "Distributed Radar Interferometry and Tomography Using Clusters of Smallsats (DRITUCS)".

A fundamental challenge is to design multi-static systems that do not demand expensive, high-quality SAR imagery to create digital elevation models and tomograms, but allow the generation of high-quality products from large sets of noisy and undersampled data acquired by clusters of smallsats with small antenna apertures. A promising solution is hinted in [21], where the smallsats of the cluster are arranged with different relative along- and across-track baselines and the acquired raw data are range-compressed and combined through beamforming to obtain a threedimensional radar image of the observed scene, i.e., a tomogram, which might still be characterized by a high level of noise and ambiguities. A DEM is then extracted from the noisy tomogram through multi-look and height estimation for each pixel of a two-dimensional grid. The height estimation is essentially based on the selection of the height for which the response is maximum for each pixel of the aforementioned grid, but can also exploit the local spectral characteristics of the signal and/or signals at different

positions to discriminate and coherently suppress azimuth ambiguities (Figure 1). In this way, multi-channel azimuth multi-baseline ambiguity suppression and 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 multidimensional data sets is redundant. A demonstration of this technique will be carried out in the coming months by acquiring tomographic data with numerous baselines over a mountainous area using the F-SAR airborne sensor of DLR and using subsets of the available tracks and/or azimuth samples.



Figure 1. Conceptual diagram of the generation of a DEM from noisy and undersampled data acquired by a cluster of smallsats.

An attractive feature of the cluster of smallsats is the opportunity to reconfigure it to acquire data that serve different applications, e.g., the unambiguous measurement of ocean currents using multi-baseline along-track interferometry [22]-[23].

3. SYNCHRONIZATION AND CALIBRATION

The synchronization of the satellites of the clusters can be achieved using the MirrorSAR concept and a dedicated synchronization link, through which a reference signal is directly sent to the receiver, combined with the radar echo and forwarded to the transmitter after up-conversion [24]-[25]. The forwarded radar signals are coherently demodulated within the transmitter using the same oscillator that generated the radar pulses, so possible frequency and phase drifts are cancelled as in a classical monostatic SAR. In order to avoid that the reference signal corrupts the radar data, an azimuth phase modulation can be employed to shift the reference signal outside the processed Doppler bandwidth.

Accurate measurement of the antenna pattern of the satellites is necessary to meet the imaging performance. Besides traditional approaches, an innovative in-orbit antenna pattern calibration concept is patent pending [26]. A dedicated calibration satellite with a spherical reflector onboard is flown on orbits with parameters slightly different than that of the radar satellite whose antenna has to be measured and reflects the pulses transmitted by the radar satellite. By changing the orbit parameters of the calibration satellite, different cuts of the two-dimensional two-way antenna pattern are measured.

4. DEMOSTRATION USING SWARMS OF DRONES

Multi-static intrinsically require multiple concepts transmitters and/or receivers and can be tested using swarms of drones, equipped with radars and localization systems, that can be deployed at an affordable cost [27]-[29]. While the main objective is the demonstration of spaceborne SAR techniques, swarms of drones can also be exploited to obtain a complete characterization of the bistatic scattering process of a surface and monitor local areas with sub-hour temporal resolutions. In this respect, the very large available bandwidth can be exploited for the generation of very accurate DEMs, where phase unwrapping errors can also be resolved using radargrammetry.

The wide fractional bandwidth of radar onboard drones can also be exploited to retrieve the three-dimensional structure of vegetation, ice, and dry soil through a novel technique based on systematic variation of the interferometric coherence as a function of the frequency [30]-[31]. Instead of obtaining the coherence for different wavenumbers by using different baselines under the assumption of a narrow band, interferograms formed using different portions of the range spectra of only two wideband images can be used. The resulting profile of coherence versus frequency is finally inverted by comparison with the expected profile resulting from theoretical models (Figure 2). For the case of a frequency-dependent extinction coefficient, a third image might be needed so that coherence profiles for further baselines are available and can be used to characterize the frequency-dependent extinction of the medium.

5. CONCLUSIONS

Multi-static SAR is a giant opportunity for radar remote sensing with a significant impact on numerous applications.



Figure 2. Concept for the retrieval of three-dimensional volume parameters through wideband (multibaseline) SAR interferometry.

Swarms of drones represent the ideal way to demonstrate multi-static SAR systems. The research in this field will pose the basis for future advanced Earth observation missions that will offer remarkable societal benefits and boost the emerging NewSpace sector [32].

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