

Advances in On-Board Data Compression for Future SAR Systems: Research Activities at the DLR Microwaves and Radar Institute

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Synthetic aperture radar (SAR) represents nowadays a well-established technique for a broad variety of remote sensing applications, being able to acquire high-resolution images of the Earth's surface, independently of daylight and weather conditions. In the last decades, innovative spaceborne radar techniques have been proposed to overcome the limitations which typically constrain the capabilities of conventional SAR for the imaging of wide swaths and, at the same time, of fine spatial resolutions. In addition to that, present and future spaceborne SAR missions are characterized by the employment of multi-static satellite architectures, large bandwidths, multiple polarizations and fine temporal sampling. This inevitably leads to the acquisition of an increasing volume of on-board data, which poses hard requirements in terms of on-board memory and downlink capacity of the system. This paper presents an overview of the SAR raw data quantization and data volume reduction activities and related projects which have been developed in the last years or are currently under investigation at the Radar Science Group of the Microwaves and Radar Institute of the German Aerospace Center (DLR):

- We focus on the use of artificial intelligence (AI), and in particular of deep learning (DL), with the goal of deriving an optimized and fully adaptive bitrate allocation to be used for on-board raw data quantization, depending on a set of desired performance metrics and requirements in the resulting focused SAR/InSAR products, without relying on a priori information on the acquired scene. The derived bitrate allocation maps (BRMs) are employed for adapting a state-of-the-art block-adaptive quantizer (BAQ) to the local characteristics of the input raw data and to the desired final performance. This activity has been developed in the frame of the ESA Study entitled "Artificial Intelligence for Global Onboard SAR Quantization" (**SARGONAUT**). The results obtained on experimental TanDEM-X interferometric data demonstrate the potential of the proposed method as a helpful tool for performance budget definition and data rate optimization of future SAR missions.
- Future SAR systems will feature on-board processing capabilities to generate both SAR imagery and interferometric (InSAR) products directly in space, enabling rapid and efficient extraction of geophysical information and fostering the development of novel applications and early warning services. On-board InSAR product generation can also drastically reduce the volume of data to be downlinked, by exploiting the strong statistical correlations inherent to SAR data as well as possible resolution reductions suitable for specific products. Such compression efficiency may increase system acquisition capacity or help meet spatial and temporal coverage requirements under on-board resource constraints. For this purpose, adaptive quantization schemes based on local scene statistics can be exploited, along with predictive techniques such as Differential Pulse Code Modulation (DPCM) as well as the JPEG2000 compression standard. We focus the assessment and performance benchmark on simulated InSAR data that will be acquired and processed on board the upcoming VISAR system, a radar interferometer of the NASA-JPL **VERITAS** mission designed to map the surface of Venus at high resolution.
- Spaceborne Earth observation systems generate vast amounts of synthetic aperture radar (SAR) data, but limited onboard computing resources make it difficult to process this information in real time for environmental and security applications. In the frame of the 3-year EU-funded "Artificial intelligence for real-time guidance of onboard SAR applications" (**ARGOS**) project, started in June 2026, we will develop an end-to-end AI framework that processes raw SAR satellite data directly

onboard spacecraft, which will create an efficient processing chain that delivers near real-time, application-specific outputs, demonstrating this technology on power-constrained, space-qualified computing hardware.

- Smart on-board processing for Earth observation systems (**SOPHOS**) was a 3-year EU Horizon Europe project, whose main goal was to design and implement enabling technology for high-end data products produced on board spacecraft via the implementation of power-efficient high-performance space processing chains for various SAR Low-Earth Orbit (LEO) missions. The on-board processing algorithms selected for on-board implementation cover novel performance-optimized block-adaptive quantization (PO-BAQ) and SAR image formation.
- In the DLR advanced and miniaturized radar-enabling technologies (**ADMIRE**) project, one of the main goals is the investigation of efficient data compression for multi-static SAR configuration. In a typical multi-static SAR configuration, a master satellite transmits the radar signal, while a set of slave satellites receive the backscattered echoes from the illuminated scene. In particular, the received signals can be forwarded to the master satellite, which thus has access to a multi-static SAR data stack corresponding to the same area observed from slightly different geometries. The simultaneous availability of multiple SAR observations of the same scene leads to a rapid increase in the data volume to be stored onboard and transmitted to ground. In this context, onboard data compression becomes a key enabling technology for future multi-static SAR missions. The core idea is to exploit the redundancy and similarity among the multi-static SAR data acquired by different receivers in order to reduce the overall data volume, while preserving the quality of the SAR measurements.

In this contribution, the main findings and current status of the above-mentioned projects will be detailed and presented.