

Recent Developments of Radar Remote Sensing Air- and Space-borne Multimodal SAR Remote Sensing in Geophysics: Advances in POL-SAR, IN-SAR, POLinSAR and POL-DIFF-IN-SAR Sensing and Imaging with Applications to Environmental and Geodynamic Stress-change Monitoring

#Wolfgang-Martin Boerner and Jorge J. Morisaki

Department of Electrical and Computer Engineering, University of Illinois at Chicago
900 W Taylor St, SEL-4210, Chicago, IL/USA 60607-7018, boerner@ece.uic.edu

Abstract

Radar Polarimetry Radar Interferometry and Polarimetric SAR Interferometry represent the current culmination in 'Microwave Remote Sensing' technology, but we still need to progress very considerably in order to reach the limits of physical realizability. Whereas with radar polarimetry the textural fine-structure, target orientation, symmetries and material constituents can be recovered with considerable improvement above that of standard 'amplitude-only' radar; by implementing 'radar interferometry' the spatial (in depth) structure can be explored. With Polarimetric Interferometric Synthetic Aperture Radar (POL-IN-SAR) imaging, it is possible to recover such co-registered textural and spatial information from POL-IN-SAR digital image data sets simultaneously, including the extraction of Digital Elevation Maps (DEM) from either Polarimetric (scattering matrix) or Interferometric (dual antenna) SAR systems. Simultaneous Polarimetric-plus-Interferometric SAR Imaging offers the additional benefit of obtaining co-registered textural-plus-spatial three-dimensional POL-IN-DEM information, which when applied to Repeat-Pass Image-Overlay Interferometry provides differential background validation and environmental stress-change information with highly improved accuracy. Then, by either designing multiple dual polarization antenna POL-IN-SAR systems or by applying advanced POL-IN-SAR image compression techniques, will result in 'POL-arimetric TOMO-graphic' (Multi-Interferometric) SAR or POL-TOMO-SAR imaging. By advancing these EWB-D-POL-IN/TOMO-SAR Imaging modes, we are slowly but steadily approaching the ultimate goal of eventually realizing air-borne and space-borne 'Geo-Environmental Background Validation, Stress Assessment, and Stress-Change Monitoring and Wide-area Military Surveillance of the Terrestrial and Planetary Covers'.

1. INTRODUCTION

Very decisive progress was made in advancing fundamental POL-IN-SAR theory and algorithm development during the past decade [1], which was based on the underlying accomplishments of fully polarimetric SAR [2] and differential SAR interferometry [3] and its current merger [4]. This was accomplished with the aid of airborne & shuttle platforms supporting single-to-multi-band multi-modal POL-SAR and also some POL-IN-SAR sensor systems, which will be compared and assessed with the aim of establishing the hitherto not completed but required missions such as tomographic and holographic imaging. Because the operation of airborne test-beds is extremely expensive, aircraft platforms are not suited for routine monitoring missions; those are better accomplished with the use of drones (UAV). Such unmanned aerial vehicles (drones) were hitherto developed for defense applications, however currently lacking the sophistication for implementing advanced forefront POL-IN-SAR technology. This shortcoming will be thoroughly scrutinized resulting in the finding that we do now need to develop most rapidly also POL-IN-SAR drone-platform technology especially for environmental stress-change monitoring subject to severe operational constraints due to adverse unsafe flight conditions with a great variance of applications beginning with flood, bush/forest-fire to tectonic-stress (earth-quake to volcanic eruptions) for real-short-time hazard mitigation. However, for routine global monitoring purposes of the terrestrial covers neither airborne sensor implementation - aircraft and/or drones - are sufficient; and there-fore multi-modal and multi-band space-borne POL-IN-SAR space-shuttle and satellite sensor technology needs to be further advanced at a much more rapid pace. The existing ENVISAT and ALOS-PALSAR with the forthcoming RADARSAT-2, and the TERRASAR 1 & 2 will be compared, demonstrating that at this phase of development the fully polarimetric and polarimetric-interferometric SAR modes of operation must be treated as preliminary algorithm

verification support, and at this phase of development are still not to be viewed as routine modes. The same considerations apply to the near future implementation of any satellite-cluster bi/multi-static space-borne tomographic imaging modes, which must however be developed concurrently in collaboration of all major national or joint continental efforts in order to reduce proliferation of space-platforms and for cost-cutting reasons. Prioritization of developmental stages will be assessed according to applications, and will differ for air-borne to space-borne sensors with the aim of developing a permanently orbiting fleet of equidistantly space-distributed satellites – similar to the GPS configuration, however each equipped with the identical set of multi-band POL-IN-SAR sensors.

2. ADVANCES IN THE DEVELOPMENT OF SAR POLARIMETRY AND POL-IN-SAR TECHNOLOGY

Radar polarimetry and polarimetric SAR theory, algorithm development and technology have developed to a highly matured state although not yet fully driven to the limits of physical realizability [1]. It has been clearly demonstrated beyond an iota of doubt that fully polarimetric (scattering matrix) SAR image data take acquisition – as complicated as it is regarding calibration and validation – provides input for highly improved environmental image feature interpretation although lacking depth information [2]. Similarly, non-polarimetric (single amplitude) SAR interferometry has provided reasonable Digital Elevation Maps (DEM) however lacking the ability of differentiating the origin of the backscattering returns from which the interferograms are being constructed [5]. This deficiency was overcome with the implementation [6] of the POL-IN-SAR “*polarimetric-interferometric contrast phase optimization methods*” for delineating the canopy, from the under-store versus ground returns so enabling three-dimensional SAR-Imaging. This 3-dim imaging method was further enhanced with the implementation of multiple bistatic (repeat-pass) fully polarimetric “*tomographic*” TOMO-SAR image data take acquisition, which in the limit results in polarimetric SAR holography, from which three-dimensional voluminous imagery of vegetation structures can be reconstructed subject to the sensor frequency and bandwidth [7]. However, what has not yet been demonstrated is how “*fully polarimetric Differential SAR interferometry*” – based on multiple repeat-pass POL-IN-SAR imagery - will improve the three-dimensional depiction of lateral, sheared and torsionally skewed surface and volumetric underburden deformations, which is one of the major unresolved research topic to be addressed in the forthcoming decade [8].

3. COMPARISON OF AIRBORNE MULTI-BAND POL-SAR & POL-IN-SAR TEST PLATFORMS

There by now exist about 15 or more aircraft-platforms for supporting POL-SAR and some also POL-IN-SAR imaging capabilities, but not a single one of them was designed to

satisfy the ideal performance conditions for conducting Multi-band POL-IN-SAR Imaging. This is truly a very sore dilemma and ought to be removed by realizing the design of the ideally designed *POL-IN-SAR Aircraft Imaging Platforms*. From a thorough comparison it seems that currently the DLR ESAR, the CRL PISAR and the ONERA RAMSES multi-band POL-(IN)-SAR are leading in advancing this vital remote sensing technology, and also have integrated high-precision repeat-pass GPS co-registration capabilities. In order for realizing fully Polarimetric (scattering matrix) Differential SAR Interferometry both the ideal platform design for sustaining on-board POL-IN-SAR imaging and highest possible precision of GPS co-registration become paramount [8]. Definitely, for the testing of novel multi-modal imaging algorithms aircraft platforms will be required for a long time to come, and therefore design of aircraft dedicated for SAR-imaging missions is fully justified.

4. THE NEED FOR DEVELOPING DRONES (UAV) MONITORING PLATFORMS WITH MULTI-BAND POL-SAR AND POL-IN-SAR REPEAT-PASS IMAGING CAPABILITIES

The maintenance and operation of any sophisticated imaging test-aircraft platform requiring crews of three to twelve pilots including the sensor operators such as for Multi-band POL-IN-SAR is extremely costly; and therefore it is justified and necessary to develop rapidly mission dedicated drones (UAV) for carrying out regional routine remote sensing and environmental stress-change monitoring missions. However, the design of such multi-purpose drones must accommodate the most advanced Multi-band POL-SAR and POL-IN-SAR operational modes that had been tested and performance-hardened previously with the aid of the aircraft test-platforms, and also with the aid of the highly successful shuttle SIR-C/X-SAR mission. Under no circumstance must we regress to a ‘*venerable Landsat technology of the 1970-ies*’ as impressive as those products truly are; and the remote sensing SAR user’s community must wake up and be challenged to utilize the immense additional novel monitoring capabilities *Multi-band POL-IN-SAR* sensors have to offer, and especially with the aid of less costly drones. Indeed, we do now need to develop most rapidly the most advanced POL-IN-SAR drone-platform technology especially for environmental stress-change monitoring subject to severe operational constraints due to adverse unsafe flight conditions with a great variance of applications beginning with flood, bush/forest-fire to tectonic-stress (earth-quake to volcanic eruptions) for real-short-time hazard mitigation.

5. ACCELERATION OF ADVANCEMENT OF MULTI-BAND POL-SAR AND POL-IN-SAR SPACE –BORNE SENSOR-TECHNOLOGY FOR SHUTTLE AND SATELLITE DEPLOYMENT

One of the most successful and ingenious space-borne remote sensing accomplishments was that of the two SIR-C/X-SAR missions of April and September/October 1994 demonstrating

at C-Band & L-Band how useful and irreplaceable fully polarimetric SAR image acquisition also from space truly is. More so, its well co-registered sets of repeat-pass C&L-Band POL-SAR image data takes along the Baikal rift zone of Inner Asia made possible the testing and verification of the novel POL-IN-SAR algorithms developed by Cloude and Papathanassiou [6] at DLR. In hindsight, some of us be-mourn (*or are still weeping bitterly about*) the fact that it was not possible to make the otherwise rather successful SRTM mission also fully polarimetric because so much more could have been gained on properly determining global vegetation cover and in highly improved soil parameter acquisition [9]. Therefore, we desire to have that SRTM mission concept be enlarged and extended to include a fully polarimetric X/C/L/P-multi-band POL-IN-SAR performance capability and to have it redone at the earliest possible date. In fact, all of the brilliantly designed and executed “SAR Remote Sensing Shuttle Missions” were so successful and irreplaceable for the rapid advancement of satellite-borne SAR technology so that those must not be abandoned but continued. As regards the advancement of Space-SAR technology a crucial milestone was achieved during the recent ESA POLinSAR-03 Workshop [8] during which the implementation of fully polarimetric (scattering matrix) SAR modes for all future satellite-born SAR systems of ESA, DLR, NASA and also NASDA was in essence decided, and the first step in this direction was achieved with the successful launches of ENVISAT (ASAR) and of ALOS (PAL-SAR), and then towards Fall 2006 RADARSAT-2 and of TERRASAR following soon thereafter. Here, it needs to be emphasized that to consider the implementation of the fully polarimetric POL-SAR and the POL-IN-SAR capabilities to be just another “*technology push*” is absolutely unacceptable in that it has been demonstrated beyond any further doubt that proper and more correct biomass and soil estimation parameters [9, 10, 11] can only be obtained with multi-band POL-IN-SAR imagery; and similarly it will be shown shortly that more correct and complete lateral, sheared and torsion-twisted surface and volumetric underburden deformations can only be recovered with onboard POL-IN-SAR satellite sensors operated in contiguous repeat-pass orbital modes – both of which provide most essential and basic inputs at arriving at more reliable global change predictors.

6. BI-STATIC MULTI-BAND POL-IN-SAR SATELLITE CLUSTERS & DEVELOPMENT OF PERMANENT FLEET OF MULTI-BAND POL-IN-SAR SATELLITES

In order to improve the detection capability of objects occluded under vegetation cover from space, it is necessary to implement tomographic and holographic imaging principles – next to frequency diversity – and for space-SAR satellite implementation that asks for the design of orbiting clusters of equidistantly gyrating satellites as proposed with the ESA Cartwheel and the USAF High-Tech Space-SAR concepts. Although somewhat more sophisticated, the implementation of fully polarimetric POL-SAR sensors for each of the symbiotic

cluster sub-satellites must also be developed and it is feasible. The space SAR cartwheel concept can only be viewed as the partial forerunner of developing the orbiting fleet of equidistantly grid-distributed multi-modal multi-band POL-IN-SAR satellites very similar to the configuration of equidistantly grid-distributed GPS satellites; however in the imaging case replacing each of the orbiting individual satellites by a cluster of three to eight parasitic satellites gyrating around a central POL-IN-SAR Transceiver Satellite and each one carrying a set of multi-modal multi-band POL-IN-SAR sensors. Another mode of operation includes the use of existing communications satellites as sources with orbiting clusters of passive satellite sensors, and so on.

7. CONCLUSION

By means of placing such an orbiting fleet of satellites into space - *in the long run* - will reduce the exorbitant cost for establishing a viable “*home-globe security protection*” technology. It will provide rather accurate global change data E eventually on an hourly basis accessible to all who need to know. The pertinent National and International airborne and space borne multi-modal, multi-band SAR remote sensing and security conflict surveillance support agencies are herewith invited for co-sponsoring our proposal as time proceeds, in that it is timely and POLinSAR platforms are urgently required to be placed into space [8].

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