RECENT ADVANCES IN WISIP: WIDEBAND INTERFEROMETRIC SENSING AND IMAGING POLARIMETRY

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ABSTRACT: WISIP: 'Wideband (μHz - PHz) Interferometric Sensing and Imaging Polarimetry' has become an indispensable tool in wide area environmental monitoring of the terrestrial and planetary covers. It allows dynamic optimal image feature extraction of significant characteristics of desirable target and/or target sections with simultaneous suppression of undesirable background clutter/speckle at hitherto unknown clarity and of never achieved quality.

'WISIP' may be adopted to the detection, recognition and identification (DRI) of any stationary, moving or vibrating target versus arbitrary stationary, dynamically changing or moving geophysical/ecological environments. A comprehensive overview is presented on how these modern high resolution/precision complete polarimetric coregistered signature sensing and interferometric POL-SAR imaging techniques, complemented by full integration of novel navigational electronic tools, such as DGPS, will advance electromagnetic vector wave sensing and imaging towards the limits of physical realizability. Various examples utilizing NASA-JPL/AIR-SAR, NAWC/P3-POL-SAR, DLR-OPH/DO-POL-SAR airborne, ERS-1/2, JERS-1 satellite and SIR-C/X-SAR shuttle imaging data sets dealing with recent major flood and various earthquake surface deformation events as well as other geo-environmental applications will be presented for demonstrating the utility of WISIP.

1. Introduction

We find that our greatest threat today is not from other nations to conquer us, but from our own capacity to destroy our terrestrial and planetary environments and with it ourselves and our flora and fauna. Indeed, this is the greatest enemy of our times, one that we need to recognize and fight before we lose a battle that we did not foresee. To counter this threat, continously hardening due to the unabating population explosion and the associated dwindling of natural resources as well as toxic waste disposal sites, a worldwide paradigm shift is evolving on the irreversible transition from 'Nationalist Military' toward 'Global Environmental Defense'. One of the most pressing issues in 'Planetary Environmental Defense' must be the decisive advancement of continuous 'Day & Night, All-Weather Wide Area Environmental Air/Space-borne Monitoring of the Terrestrial and Planetary Covers' with the ultimate goal of the 'automatic Detection, instantaneous Recognition and short-to-long-term Identification (DRI)' of anthropogenic Intruders, hostile targets, toxic agents and/or natural hazards endangering our hydro/bio-spheres.

2. Wideband Radar Polarimetry

In order to develop associated Disaster Mitigation procedures, all available short/intermediate/long-term hazard prediction methods must be explored which requires the full and complete utilization of the

electromagnetic vector wave (amplitude, phase and polarization) interrogation capabilities over its entire wave spectrum from below 1mHz (ULV) to above 10PHz (UV), including (i) the lower ULF (below 1mHz: Earth-internal and coupled extra-terrestrial "gravitational sources" (with periods of days, weeks, months and years) which could trigger major global weather/climate changes; which, if detected early enough, could allow for sufficient time for some long-term wide area disaster mitigation); (ii) the upper ULF and ELF (1mHz - 1KHz: earth/seaquake and volcano activation precursor radiation; which if detected early enough, could lead to "well planned, deep earth disaster mitigation"); (iii) ELF-MF (1KHz - 1MHz: detection of otherwise "low observable objects" traversing the ionospheric fluid layer or skimming along the terrestrial surface which create acousto-electromagnetic, coupled terrestrial-ionospheric resonance phenomena); (iv) HF-VHF (1MHz - 1GHz: Ultra-wideband detection of low observables embedded in noisy background clutter, plus, passive wide area environmental security surveillance including penetration capabilities such as through foliage and into lossy soils); (v) m-sub-mm (about 1GHz - 100GHz: High Resolution target sensing and imaging in a wide area terrestrial boundary layer environment including polarimetric doppler radar and satellite IR imagers deployment for the sensing of severe storms and hail for relevant disaster prediction and warning); (vi) Sub-mm-IR ((20)100GHz - 100THz: Molecular spectroscopy and radiometric imaging); (vii) IR/OPT/UV (10THz - 10PHz: High resolution lidar sensing and imaging above the ionosphere and in atmospheric and oceanic environments: blue-green laser). Furthermore, the ever increasing sophistication of modern weaponry, its camouflaging capabilities into dynamically changing environmental background scenarios and its accomplished occlusion in complex volumetric underburden, demands the complete wideband (1mHz ~ 10PHz) sensing and imaging capabilities of the electromagnetic vector wave up to its limits of physical realizability; i.e., the complete wideband temporal and spatial amplitude, phase and polarization information must be recovered and the Polarimetric Entropy Coefficient (PEC), the Polarimetric Matrix Decomposition Algorithms (PMDA), the 'Optimal Polarimetric Contrast Enhancement Coefficients (OPCEC)', Optimal Image Feature Extraction (OPIFE), as well as, Polarimetric Matched Vector Signal/Tensor Image Filter (PMSF/PMIF) concepts must be developed for discriminating such stealthy objects from its heterogeneous surroundings. Such a more unified approach to 'Wideband Polarimetric Sensing and Imaging', based on the author's worldwide efforts of advancing this newly evolving discipline in concert with the international polarimetric expert community, is summarized in [1] and [2].

In these four volumes, a significant step toward the solution of these difficult, still unresolved problems is made. Whereas, at optical frequencies and also at cm-to-sub-mm wavelength (3GHz - to - 3THz) mainly the geometric and physical optics imaging algorithms apply, at VHF/UHF/microwaves (30MHz to 3GHz) the entire vector diffraction behaviour must be incorporated into the development of effective polarimetric wideband matched signal/image filter approaches. These aspects were co-sequentially pursued during the First, Second and Third International Polarimetry Radar Conferences as summarized in its proceedings[3],4,5] and more recently during the Fourth US MI-COM Advanced Research Workshop on 'Optical, IR, Terahertz, Millimeter/ Micro-Wave Polarimetry[6].

3. Suggestions on Guiding the Future Path of Polarimetric Radar Research

The past ten years, since the Fall of 1986, have seen significant growth in worldwide research activities focussed on the development of multi-spectral mono-polarization — via multi-polarization — to complete scattering matrix Synthetic Aperture Radar (SAR) known as POL-SAR imagers.

More recently during the past three to one years, both cross and along track inflight (CATI) single platform interferometric systems were developed such as the airborne US NAVY NAWC-ERIM P3 UWB-IF-POL-SAR and the DARPA-ERIM-IF-POL-SAR systems. Such systems need now be further advanced for implementation in space-applications in order to enhance the imaging capabilities of spaceborne SAR systems such as the mono-polarization ERS-1 and JERS-1 satellite platforms and SIR-C/X-SAR multiband (L/C/X) multi-polarization schuttle space platforms. It is essential to continue with the development of advanced electronic navigational tools such as global satellite positioning systems GPS(US), GLONASS(FSU) and GNSS-1/2(EU) plus Inertial Navigation Units INU so that long temporal base line (LTBL) airborne Repeat-Track and spaceborne Repeat-Orbit overflights with precise co-registered image swath overlays can be achieved. Moreso, in order to develop Hazard Alert Algorithms for inacting Disaster Mitigation procedures both for military and civil purposes, it is essential that multi-platform satellite communication and image signature data-take fusion be developed simultaneously. Although in this overview mainly environmental and eco-systems application of air/space-borne sensing, imaging and communications are broached, the total spectrum of applications is truly much wider in that ground/air/space-borne multi-platform UWB (10MHz - 100GHz) TOP-IF-POL-SAR sensing, imaging and communications technology will also become long-sought operational tools for various utilities such as Electric Power Generation and Transmission for the detection, recognition and identification of unbalanced radiating and corona-discharging high tension powerlines; of broken sub-surface sewer, gas, oil and water pipe lines, etc.. The international polarimetric radar (UWB-TOPIF-POLSAR) research community ought to be entrusted not only to develop the pertinent technologies and real-time sensor image processing and DRI algorithms[7,8], but also to develop expertise for data interpretation for addressing the following achievable missions[5,6]:

(a) UWB-TOP-IF-POL-SAR Sensor & Imaging Systems Technology Development
(b) Vector-Electromagnetic Dynamic Model Development
(c) Air/Space-borne UWB-TOP-IF-POL-SAR Applications in Routine Surveillance
(d) Regional to Global Environmental/Eco-Systems Parameter DRI in Wide Area Environmental Monitoring
(e) Forestral and agricultural eco-systems assessment
(f) Solid Earth Sciences and Topography
(g) Air/Space-borne UWB-TOPIF-POLSAR Remote Sensing Archeology
(h) Target Camouflaging (TARNUNG) in Nature.

4. Conclusions and Recommendations

A comprehensive overview of 'Wideband Interferometric Sensing and Imaging Polarimetry' is presented together with a well structured identification of various crucial unresolved problems. Based on the meticulous diligent analyses of radar polarimetry by the author and his international team of collaborators, very clear methods of solution (ANSÄTZE) are provided. First, basic polarimetric radar theory and metrology needs to be perfected and the last hurdles must be removed as proposed. In a second step, various vector electromagnetic radar inverse scattering theories of more complicated shapes need be solved in order to further perfect the PMSF/PMIF algorithms by simulteneous advancement of the OPCEC/OPIFE concepts. In a third step, it is proposed to rapidly develop Spread-Spectrum improved, DGPS-supported CATI-LTBL-MB/UQB-POL-SAR Image Interferometry, which has become feasible and can be resolved in the near future. Because of the tremendous impact 'WISIP' has on further perfecting 'All-Weather, Day/Night High Resolution Wide Area Surveillance of the Terrestrial and Planetary

Covers', the associated projects, here proposed for investigation by the international polarimetric radar research community, deserve the fullest support by the respective national/federal radar research funding organizations.

In concluding this Review on the 'Polarimetry in Wideband Interferometric Sensing and Imaging of Terrestrial and Planetary Environments', we have identified a well-structured set of urgent problems which we need to attack world wide at once[5]! The entire subject matter of 'WIDEBAND INTERFEROMETRIC SENSING AND IMAGING POLARIMETRY' is advancing rapidly in theory, metrology, processing and multi-altitudinal signature fusion and so are the associated UWB-TOP-IF-POL-SAR technologies so that all of us must be given the proper substantial increase in manpower, material, facilities and international campaign support[6]. In fact, the entire field of WISIP has gained so much in international importance toward the 'MISSION TO PLANET EARTH' that all pertinent WISIP research centers ought to encourage their home institutes to be singled out and given priority funding status among all other ongoing research efforts of various national air/space-borne imaging programs.

5. References

[1] W-M. Boerner, et al, eds., Inverse Methods in Electromagnetic Imaging, Proceedings of the NATO-ARW-IMEI'83, Bad Windsheim, FRG, 1983 Sept. 18-24, C-143, Pts 1&2, Dordrecht, D. Reidel, 1985;

[2] W-M. Boerner, et al, eds, Direct and Inverse Methods in Radar Polarimetry, Proceedings of NATO-ARW-DIMRP'88, Bad Windsheim, FRG, 1988 Sept. 18-24, NATO-ASI Series C, Vol C-350, Pts 1&2, Dordrecht, Kluwer Acad. Pub., 1992.

[3] J. Saillard, F.A. Molinet, et al., Eds., Proceedings of First International Conference on Radar Polarimetry, JIPR-1 (1990), IRESTE, University of Nantes, France, 1990 March 20-22.

[4] J. Saillard, E. Pottier, et al., Eds., Proceedings of the Second International Conference on Radar Polarimetry, JIPR-2 (1992), IRESTE, University of Nantes, Nantes, France, 1992 September 8-10.

[5] J. Saillard, E. Pottier, S.R. Cloude, et al., Eds., Proceedings of the Third International Conference on Radar Polarimetry, JIPR-3 (1995), IRESTE, University of Nantes, Nantes, France, 1995 Match 20-24.

[6] H.F. Anderson and R.A. Chipman, Co-Eds., Proceedings of the US Army Missile Laboratory Workshop on IR, THz and MMW Polarimetry, Sparkman Center Auditorium, Redstone Arsenal, AL, 1995 Dec. 05-07, (see: W-M. Boerner & J.S. Verdi, Polarimetry in UWB-IF Sensing & Imaging (87 pgs).

[7] W-M. Boerner, Introduction to Radar Polarimetry (76 pgs), in P.J. Moser, ed, Electromagnetic Wave Interactions, H. Überall 65th Birthday-Emeritation Lecture Series, Catholic University of America, 1995 June 03, World Sci. Publ. Co., PTE, Ltd., Farrer Road, Singapore 9128, 1996.

[8] W-M. Boerner, Wideband Interferometric Sensing and Imaging Polarimetry — The Realization of Complete Vector-Electromagnetic Propagation, Scattering and Diffraction, in A.W. Sáenz and P.P. Delsanto, Eds., New Perspectives on Problems in Classical and Quantum Physics, A Festschrift in Honor of H. Überall, Gordon and Breach Science Publishers, Newark, NJ, 1996.

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