The European Network
RADAR POLARIMETRY: THEORY AND APPLICATIONS
Goals, Structure and Results

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1. Introduction

The European Commission has founded a program called TRAINING AND MOBILITY OF RESEARCHERS (TMR). Within that program a network has been established in April 1998 entitled: Radar Polarimetry: Theory and Applications

The Goal of the network is to make polarimetry available for use and application in reconnaissance and remote sensing for detection, identification and classification of point-, area-, and volume targets in both mono-static and multi-static systems. The project objectives are to conduct investigations in the main designated specific research areas of: Basic Polarimetry Theory, Polarimetric Inversion Studies, and Radar Calibration and Measurement. The central task is herewith to involve post and pre doctoral candidates in this research to mobilize the participating expert European Teams on Radar Polarimetry in order to promote the research work for improving the current state of the art and, most important training young prospective scientists.

All the activities should have relevance in practical application and should be directed to advancing the state of the art of radar and SAR remote sensing by improving the identification, classification and characterization of radar targets.

Goal of the presentation is to present the network, the partners involved and the results obtained up to now in order to generate interest in creating similar TMR networks elsewhere.

2. The Partners

There are 9 European organizations involved, each has nominated a scientist in charge (SiC):

1. German Aerospace Center(DLR), Germany SiC and Network Coordinator: Dr Wolfgang Keydel
2. Danish Defense Research Establishment (DDRE), Denmark, SiC: Dr. Ernst Krogager
3. University of Essex, United Kingdom, SiC: Dr. David Bebbington
4. Politecnica Cataluña, Spain, SiC: Prof. Antony Broquetas Ibars
5. MOTHSIM Co., France, SiC: Dr. Frederic Molinet
6. University of Rennes-1, France, SiC:Prof. Eric Pottier
7. University of Chemnitz, Germany, SiC:Prof. Gerd Wanielik
8. Fluid Gravity Engineering Ltd, United Kingdom, SiC: Prof. Shane Cloude
9. Joint Research Center (JRC), Ispra, Italy, SiC: Dr. Guiseppe Nesti

3. The Scientific Activities and Results

3.1 Basic Polarimetry Theory

The work done in this area led to a rigorous, logical and generally new formulations of the theoretical framework for describing and manipulating polarimetric quantities and descriptors in radar context. The accomplished work, therefore, sets out terms of reference for a framework within which polarization standards and convention can be uniformly, unambiguously, and consistently described. The results particularly took into account the goal of addressing the dilemmas of describing consistently the polarization states of electromagnetic waves travelling in opposite directions, and establishing a standard for coordinate transformations, and yet retaining the invariant polarimetric properties of the scatterers (targets).

The investigations have as a result clarified some basic definitions in Polarimetry and resolved some traditional ambiguities between terms defined in the field. In doing so, some light-shedding concepts were introduced. The key scientific results established include:

- Link between traditional Kennaugh matrix descriptors and the covariance formalisms that have been more recently exploited in the polarimetric community.
- Development of the concept of phase reference flag and distinguishing between active transformations which rotate the reference frame into alignment with wave vectors and passive transformations which change the local basis labels.

- Application of spinor methods directly in electromagnetic problems, such as Faraday rotation and wave propagation in anisotropic dielectric media.
- The development of Mathematica packages for applying spinor algebra to polarimetric problems and for visualizing wave and polarimetric geometric properties.

In the process of obtaining these results, two generic scattering formulations were identified. These formulations enable us to interrelate principal scattering conventions, thus allowing a better understanding within the unified framework of polarimetric transformations in mono-static and bi-static scattering. Another important output of these investigations is the identification of bistatic-scattering invariants, thereby laying the foundations for the development of a general bistatic theory.

For the first time, we are able to integrate not only the polarimetric conventions but also polarimetry with electromagnetic formalism to give a complete and consistent framework of analysis.

<u>3.2 Specific Area 2: Polarimetric Inversion Studies</u>
One of the most important aspects in remote sensing is the inversion of observational data in order to extract target information. It is, therefore, hardly surprising that the subject of polarimetric inversion studies is the largest and the broadest area of research in this network project. Practically all partners have contributed to the progress noted in this research area. Noting that considerable amount of work has been reported in this area, we are, indeed, pleased that all research objectives of the reporting period have been met with a surplus of results. Broadly, several partners developed and demonstrated multi-polarization techniques for interpreting polarimetric scattering data using appropriate scattering theory and target modeling. Both incoherent and coherent scattering processes were considered. During the course of the first half of the project-period, two key objectives in this area were addressed.

- Quantitative analysis and retrieval of physical parameters
- Polarimetric Interferometry

The multitude of reported contributions, therefore, cover several aspects of remote sensing:

- Scattering and Propagation
- Development of algorithms for interpreting coherent and partially coherent scattering data
- Testing of the newly developed algorithms using data from partners who have the measuring facility

Radar scattering models and their application to radar data were reported for different types of targets: forests, clouds, rain, and roads (in particular icy roads). The reported results showed that multi-parameter analysis of such scattering data was capable of identifying key target properties, e. g. forest height, cloud stratification, convective rainfall structure, hydrometeor canting properties, icy road conditions, etc.

A detailed analysis of creeping waves accounted for progress in the field of scattering theory. Also, a wide range of polarimetric observables were either recorded or modeled and reported within the network. The motivation was to demonstrate the link between scattering theory for random targets and polarimetric observables. In this context, the quantities analyzed in the network are:

- Differential Propagation Phase (for estimating propagation effects in SAR applications)
- Co-to-Cross-polar phases in stratiform rain (for target identification, e.g. the melting band)
- Entropy-Alpha analysis of convective rain clouds (first time ever computation of entropy-Alpha signatures of weather targets for revealing fully polarimetric details of clouds). This is a noteworthy step in extending complete S-matrix analysis to weather targets, which traditionally have been investigated using only a subset of S-matrix elements
- Stokes parameters (for assessing mean canting angle and rain intensity) and
- Euler parameters (for extracting target orientation properties in random media)
- Coherency matrix framework extended to interferometric and polarimetric SAR measurements (a new methodology from this theory led for the first time estimation of forest height)

Another important aspect addressed in the area of inversion studies relates to optimization methods. Specific contributions demonstrated polarization methods for speckle filtering, noise minimization and application of wavelet transformations.

Target decomposition methods have always played a central role in polarimetric applications. Within the network, scientific advances were noted in the formulation of different approaches.
The Coherency matrix decompositions were based on eigenvalue analysis and the S-matrix decompositions included sphere/diplane and the roll Invariant formulation (sphere, diplane and helix).

Aspects of physical parameter extraction were covered by results reported in the estimation of Biomass, canopy height/density and surface roughness. Very important progress can be noted in the new results regarding the estimation of soil moisture from both polarimetric and interferometric measurements. The classification of radar targets (Earth terrain, man-made targets and clouds) with polarization data was demonstrated by several partners. In particular, the potential use of interferometric polarization data for parameter retrieval was reported. The range of activities mentioned here has led to new collaborations both between partners within our European Network and groups within the US equivalent of polarization network WIPSS. The results of the various joint efforts involved in the reported work have been presented at major international conferences and workshops involving established experts and young researchers. Furthermore, the results achieved in the diverse areas of remote sensing, such as determination of forest height and soil moisture, are clear examples of advancement of the state of the art in polarimetric interferometry and polarimetric remote sensing. Polarimetric measurements and the results derived from them also have shown a new relatively simple solution of the ever-present image effects from multi-path problems in ground-based, air-borne, and space-borne radar measurements. It may also be noted that grand scale international projects such as the successful SRTM mission will be able to benefit from the new methodologies developed in the framework of this network project; especially, however, with respect to polarimetric calibration which is the topic of the next section.

3.3 Specific Area 3: Polarimetric Radar Calibration and Measurements

One of the main objectives in this work packet was the creation of an electronically accessible data resource of polarization measurements. All data-providing partners have already identified, listed and detailed the available data sets at their sites. Some of the partners, in particular (JRC, DLR and DDRE), have already provided access to their data sets in electronic form (Web site or CD ROMS). While further progress is being made in this area, in the present reporting period, an adequate data resource has been established in keeping with our technical milestones. Indeed, the availability of this data resource has already led to collaboration between several partners. As the *'data bank'* continues to grow in time, even more widespread use of this shared resource is expected. Clearly, the polarimetric data resource now established is a very unique (and fairly expensive) data bank accessible to all partners free of cost. This is clearly an achievement of great significance for it brings together some of the unique data resources within Europe, under the aegis of this TMR project!

The JRC has created a web site where selected EMSL data sets are accessible to registered users. An extensive data set concerning vegetation (rice, maize, trees etc) and rough surfaces (including real soils and artificial targets) is already available to all members of TMR. Partners who have directly benefited from the EMSL data include AEL, UPC and MOTHESIM. This interaction between data provider and analyst has already led to several joint publications and collaborations mentioned elsewhere in the report. DLR has distributed to all partners an exhaustive list of fully polarimetric C-Band weather radar data and polarimetric E-SAR data in P-, L-, S-, C-, and X-Bands. In X-Band, single path interferometry data are available and distributed among interested partners. Also, P- and L-Band multi-path interferometry data are available. The list was made available on floppy disc and more recently via the Internet. A special archiving facility is currently under preparation. Under the network, the availability of data, enabled UPC to started analyzing fully polarimetric weather radar data. This is a new area of work for UPC that arose out of this network. This is a timely new development because Spain is planing to upgrade and further develop its weather radar network. DDRE has likewise distributed polarimetric SAR data on CD-ROMs amongst all partners. The availability of the data resource in this project and its applications has not only provided a unique opportunity to all network partners but has also led to harmonization of data formats and processing tools. Likewise the electronic mode of data access and transfer has attained a more mature status concerning its use amongst researchers.

In the field of radar observations a new polarimetric method of radar measurements using hybrid polarization bases has been reported. This method suggests using the different transmit and receive polarization bases. For instance, the radar echo, following a radar pulse transmitted along circular polarization, is received simultaneously along vertically and horizontally polarized channels. This method embodies the concept of Mueller matrix measurement and at the same time it allows the measurement of quantities (scattering amplitudes) that often strongly decorrelate in the conventional S-matrix mode of measurement. The theory and application of this method has been successfully tested with the DLR weather radar data. This is again an example of innovation at the level of front line research. It may be noted in passing that DLR has established an extended calibration test site with full polarization capability for both air-borne and space-borne SAR systems

4. Collaboration between Partners

Clearly a network such as this will lead to cooperation between the participating European teams. The list of partner collaboration has steadily grown and this is an evidence of the high degree of interaction between the participants. A list of some joint activities follows:University of Essex (David Bebbington), and IRESTE (Dr. Eric Pottier) are collaborating in the area of bistatic polarimetry.University of Essex (Dr. David Bebbington) and DLR (Dr. Keydel et al) are jointly analyzing fully polarimetric DLR weather radar data. A paper on multiple scattering effects has been written and was presented at the last radar Meteorology conference**.** DLR (Dr. Keydel et al) and UPC (Dr. Broquetas et al) are cooperating to develop parameter retrieval from weather radar data and calibration methods for polarimetric weather radars. UPC also has delivered a geocoding algorithm to DLR, which allows to recover highly accurate Digital Elevation Models from E-SAR data taken in polarimetric interferometry modes. DLR (Task coordinator for training), University of Essex, University of Rennes and University of Chemnitz have been developing the training program. MOTHESIM (Dr. Molinet), and AEL (Dr. Cloude) are jointly analyzing the data made available by JRC.

5. Joint Publications and Patents

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3. Cucurachi, A., Molinet, F., Nesti, G., ”Application of Decomposition Theories to Experimental Scattering Data from Dielectric Rough Surfaces”, 29th European Microwave Conference, Munich, Conference Proceedings, ISBN-0862131529, pp. 323
4. Chandra, M., Pottier, E., “Recent Advances in Inversion of Polarimetric Measurements”, 29th European Microwave Conference, Munich, Invited Talk, 1999
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