INFORMATION EXTRACTION FROM HIGH RESOLUTION SAR DATA

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ABSTRACT

The article aims at presenting the most recent developments and trends in information extraction from Synthetic Aperture Radar SAR data.

NEW TECHNIQUES FOR POLARIMETRIC SAR IMAGING

The estimation of geo-physical parameters of distributed scatterers measurables are not directly related to the desired parameters. In this case, the extraction of geo-physical parameters requires the inversion of an established scattering model which relates the radar observables to physical parameters of the scattering process. The scattering model is therefore essential for the performance of the inversion. On the one hand the model must contain enough physical structure to interpret the radar observables. On the other hand it must be simple in terms of parameters in order to be determinable with a limited number of observables.

Due to the complexity of EM scattering processes, even simple scattering models contain more parameters than the number of observables offered by a conventional single-frequency, single-polarisation SAR acquisition. One approach to reduce the number of unknowns is to utilise a-priori information about the occurring scattering process or to introduce simplifying assumptions. The price to be payed is, in this case, the restricted applicability in terms of validity range or transferability of the resulting inversion algorithms. A more promising approach is to extend the dimension of the observation vector in terms of multi-parameter SAR data acquisitions. The progress in SAR technology over the last decade allowed the operation of radar sensors at multiple frequencies and/or polarisations as well as new remote sensing techniques and/or acquisition modes. High resolution, multi-frequency and/or fully polarimetric SAR data acquired in single- or repeat-pass interferometric modes with variable temporal resolution are today available to the remote sensing community. With respect to the parameter inversion problem, the selection of the observables is essential. The chosen observables have to be sensitive to the parameters of the model and to lead to well conditioned inversion problem.

One very promising way to extend the interferometric observation space is the combination of interferometric and polarimetric observations in terms of polarimetric interferometry at a single frequency. SAR interferometry is today an established technique for the estimation of the height location of scatterers through the phase difference in images acquired from spatially separated locations at either end of a baseline [1]. The high sensitivity of the interferometric phase and coherence to height and density variations of the penetrated volume makes the estimation of volume scattering parameters from interferometric observables at lower frequencies (C-, L-, or P-band) a challenge. On the other hand, scattering polarimetry is sensitive to the shape, orientation and dielectric properties of scatterers. This allows the identification and separation of scattering mechanisms of natural media employing differences in the polarisation signature for purposes of classification and parameter estimation [2]. In polarimetric interferometry both techniques, are coherently used to provide combined sensitivity to the vertical distribution of scattering mechanisms [3]. Hence, it becomes possible to investigate the 3-D structure of volume scatterers and to extract information about underlying scatterers using only a single frequency polarimetric radar sensor. This promises a break-through in essential radar remote sensing problems as surface parameter estimation under vegetation cover, and forestry applications.

SURFACE PARAMETER ESTIMATION

The main limitation for surface parameter estimation from conventional polarimetric SAR data is the presence of vegetation. This, combined with the fact that most natural surfaces are temporarily or permanently covered by vegetation, restricts significantly the importance of radar remote sensing for a wide spectrum of geophysical and environmental applications [4]. The sensitivity of the interferometric observables to the location of the effective scattering center inside the resolution cell, combined with the strong influence of ground scattering on the location of the scattering-center, provides for the first time a sensible way to estimate even weak ground scattering under vegetation. Additionally, the variation of the interferometric coherence as a function of baseline allows conclusions about the vegetation layer over the surface. On the other hand, polarimetry is important for the inversion of the surface scattering problem.

FOREST PARAMETER ESTMATION

Quantitative model based estimation of forest parameters has been recently demonstrated using repeat pass fully polarimetric interferometry at L- and P-band [3]. The inversion algorithm is based on single frequency, fully polarimetric, single baseline configuration. Using the interferometric coherence and phase information in three different polarisations it is possible to estimate forest height, average forest extinction, and, underlying topography through the inversion of a coherent scattering model. The underlying topography can be used directly for mapping applications while forest height is the most important single parameter for stem biomass estimation. The forest extinction coefficient is related to stand and/or canopy density and can be used potentially as an additional input parameter for a tree and stand biomass estimation model.

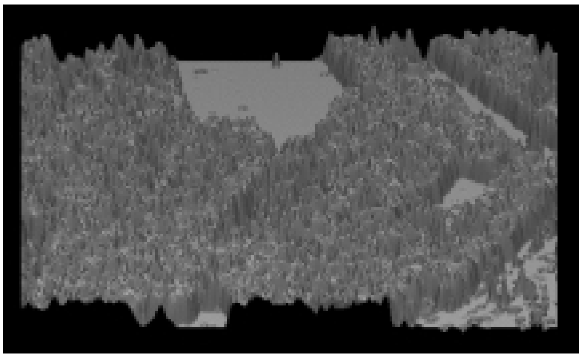

***Figure 1**: 3D representation of forest height obtained from polarimetric interferometry.*

SCENE UNDERSTANDING

The final goal of a large number of remote sensing applications is the understanding of the observed scenes, i.e. the recognition of the different imaged objects and their characterization by measurement of the properties of interest. Thus, a crucial step in data exploitation is the detailed and complete information extraction, because all subsequent processing stages, such as image classification, segmentation and target recognition, rely upon its results. In this context we proposed an alternative solution: the scene understanding approach [5]. Scene understanding is the attempt to extract information about the characterization, the structure and geometry of the three-dimensional scene from the two-dimensional SAR image. The task of the scene understanding process is to find the scene which best explains the observed data, and we proposed solutions frame of Bayesian inference.

STRUCTURAL INFORMATION EXTRACTION FROM METRIC RESOLUTION SAR

The basic structural information in metric resolution SAR images is, texture, edges and lines, and strong scatterers, point targets. The texture is affected by a multiplicative speckle noise and should be preserved by despeckling algorithms. Sharp edges between different regions and strong scatterers also must be preserved. To despeckle images we use a maximum a posteriori (MAP) estimation of the cross-section choosing between different prior models [5, 6].

The proposed model based approach uses a Gauss Markov random field (GMRF) model for textured areas and allows an adaptive neighborhood system for edge preservation between uniform areas. In order to obtain the best possible image reconstruction, an evidence maximization algorithm is used to estimate the texture parameters that provide the highest Bayesian evidence. We used the first and the second level of Bayesian inference to obtain a MAP estimate of the noise-free image. Borders between homogeneous areas are detected with a stochastic region-growing algorithm locally determining the neighborhood system of the Gauss Markov prior model. Smoothed strong scatterers are found in the ratio image of the data and the filtering results and those are replaced in the image. In this way, texture, edges between homogeneous regions and strong scatterers are well reconstructed and preserved. Additionally, the estimated model parameters can be used for further image interpretation methods.

Thus we proposed a new Bayesian approach for speckle reduction in SAR images. The emphasis lies on speckle removal without losing textural and structural information, which becomes more and more important in SAR image interpretation. Strongly related to the task of despeckling are methods for SAR image segmentation and feature extraction yielding an algorithm for SAR information extraction.

3D SCENE RECONSTRUCTION

The scene understanding problem, due to the complex phenomenology of image formation, is more difficult in the case of high resolution radar systems. The increased resolution, on the other hand, means that geometric information content is essential. Specific techniques must be applied that are not among the methods to analyse and interpret low resolution SAR data of natural scenes.

Interferometric phase, often regarded as the key content of InSAR observations, cannot be directly used as in traditional systems. In order to gain in robustness of scene understanding other information sources contained in the SAR signals have to be analysed. Correct phase unwrapping is a complicated problem, and noise has to be accounted for in some resolution preserving way. The common points of all the presented problematic items are the need to recognize and integrate all the different data sources available in a simple manner. Our concept uses a model based approach for the synergetic analysis of intensity and interferometric SAR data by defining a hierarchical model of the acquisition process and of its result starting from a set of three-dimensional features [7]. The proposed model is both deterministic and stochastic. The deterministic model describes the SAR imaging geometry and its peculiar effects on the acquired scene, and the spatial description of the different target structures. The stochastic model encapsulates instead prior knowledge about the SAR signal, and details specific signal attributes. The data analysis is carried out on both complex images themselves, for instance by means of frequency estimations, as well as on the different separate pre-processing products such as amplitude and wrapped phase or interferometric coherence. Simple 3d geometrical primitives as well as more specialized objects as graphs are used as a basis for the parametric modeling of simple geometrical structures. Multi-resolution, 2d to 3d and multiple 3d level-of-detail mixed approaches might be used to reduce the computational complexity of the method without compromising its performance and to be able to model effectively phenomena showing up at different scales. A semantic model is used as an important factor in the derivation of the results in order to provide a strong and robust discrimination criterion for the different elements showing up in the image as well as to simplify the separation of the different structures in an evoluted shape from shade approach. Bayesian inference is used to couple the different models, specifying dependencies and defining further parameter estimation algorithms.

Features identified as important for the information content, de-speckled intensity, Gibbs Random Fields modeled textural parameters, phase gradients, coherence estimates at different resolutions, unwrapped phase, are fed, separately from each other, into the unsupervised classification engine described in [8]. The resulting classes are used in a supervised Bayesian data fusion approach that takes advantage of the combined discrimination power of the different features in a simple and unified manner. The objects in the scene are clearly separated, and specialized techniques can be employed to estimate parameters of interest on limited data patches. 3d reconstruction of buildings is already possible, for instance by using absolute interferometric phase measures with built-up area maps by masking or by more elaborate techniques.

For instance, the extracted information of images can be employed to detect and recognize elements in the scene (building, trees…). Simple rules of fuzzy logic can allow a scene description. Each identified object can be reconstructed with a fully optimized processing. Figures *2a* and *2b* highlight the contribution of extracted information in the 3D reconstruction of scene, by comparing the resulting Digital Elevation Model (DEM) obtained from a classical interferometric method (with a 5×5 filter) and that produced by an optimized reconstruction based on a classification by fuzzy logic.

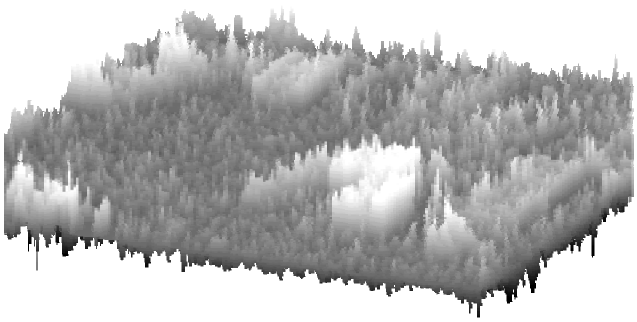

***Figure 2a**: a DEM obtained from a classical interferometric technique on a semi-built-up area.*

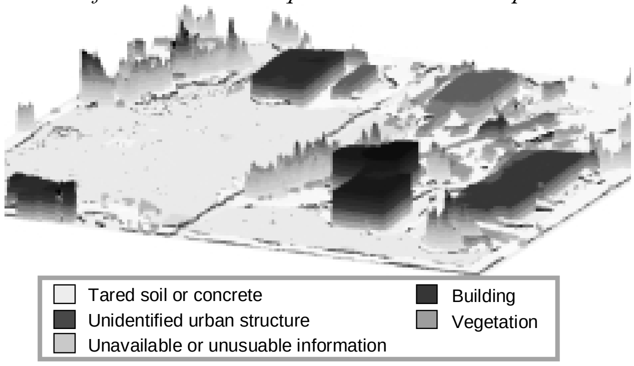

***Figure 2b**: a DEM obtained by an optimized reconstruction based on a classification by fuzzy logic. The area and source data are the same as those used for generating the DEM of the figure 2a.*

In this approach as in precedents, all available information is welcome, even though some new type of information are difficult for use, like slope in layover area [9] or spatial correlation of phase [10].

MULTIDIMENSIONAL DATA ANALYSIS TECHNIQUES

The understanding of a data set depends on the ability to extract pertinent information from it. Knowledge about the data allows for the understanding and characterization of the underlying phenomena they come from. The higher the dimensionality of the data is, the more difficult becomes the interpretation.

Polarimetry produces multidimensional data. So does SAR interferometry. In the case of high resolution SAR, a wide complex image spectrum can be split into several sub-looks. This technique, usually used for speckle reduction (incoherent addition of azimuth sub-looks), allows for the study of the behavior of targets during antenna synthesis. If we consider each sub-look as an individual image, we end up also with a multidimensional data set.

Multiple feature extraction from images (textures, for instance, but also other parameters) produces also multidimensional data.

Of course, the question is then : how to deal with these amounts of data? Or, how to extract the useful information from the data and give away redundancies?

Several classical techniques exist for dimensionality reduction and data compression as for instance the Principal Component Analysis (PCA). However, these techniques are based on correlation and signal power assumptions, without the use of measures of information.

Other less-known techniques like Independent Component Analysis (ICA) [11], Projection Pursuit (PP) [12], or Curvilinear Component Analysis (CCA) [13] have shown their power in extracting pertinent information from high dimensional data. Preliminary results [14] show the interest of these techniques in the field of SAR image processing.

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