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RADARGRAMMETRIC ASPECTS OF SAR DATA EVALUATION

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ABSTRACT

The present paper results from a number of recent studies which make clear that radargrammetric concepts and processing methods are of considerable importance for the generation of radar data which display a satisfying geometric accuracy.

Besides, current issues of radargrammetric image analysis are discussed with emphases on the applicability for geology and land snow and ice mapping. The results of these application studies lead to conclusions for future radar satellite missions.

A method to create digital elevation models from radar stereo-images is outlined. Moreover, some remarks on radar stereo viewability are given.

Keywords: Side-Looking Radar, Rectification, Product Simulation, Stereoscopy, Geology, Snow/Ice, Digital Elevation Model

1. INTRODUCTION

One of the important systems for satellite remote sensing is side-looking imaging radar (SLR). Today, there exist satellite radar data sets from the Apollo 17 Lunar Sounder, SEASAT, SIR-A and SIR-B missions for use in scientific work. Additional imagery is scheduled to become available through the European Remote Sensing Satellite program (ERS-1) and the Japanese ERS as well as the Canadian Radarsat experiment.

One may well state that the availability of radar data for application studies is still rather limited when only considering satellite systems. This is different from the situation with aircraft side-looking radar. Since the early 1960's ongoing aircraft activities have led to the coverage of areas in the size of several hundreds of thousands of square kilometers.

The increased thoroughness of SLR research has led to a need for better image geometry for the comparison of radar images to other remotely sensed data acquired by different sensors, to topographic maps and to radar images taken at different times. While early radar mosaics have been compiled with comparatively little attention to geometric accuracy, there is now an increasing interest in techniques of "radar photogrammetry", i.e. "radargrammetry".

For an increasing number of applications analyses of radar imagery require proper consideration of image geometry and the development of procedures to convert the image into map-type products.

A basic task of radargrammetry is to define a mathematical model for relating an object point in any three-dimensional cartesian x, y, z coordinate system to the time and range coordinates t and r, measurable from the radar image. Numerous authors have thus formulated rigorous radar projection equations. In Ref. 7 a comprehensive review on the topic is given. On the other hand, various models describe how the raw electronic signal acquired by the antenna is converted into image points (Ref. 3).

However, a rigorous mathematical model of the imaging process and the electronic signal processing may not be able to reconstruct the entire chain of physical events leading to the image. Therefore, in radargrammetry supplementary interpolative methods, which use geometric ground control data, have been developed and are successfully applied when it is required to relate image and object space.

For reviews of the basic radargrammetric principles and existing algorithms for radar image data processing the reader is kindly referred to Refs. 1 and 8.

This paper discusses concepts and methods where radargrammetry substantially contributes to improved utilization of radar imagery and evaluation of specific parameters relevant for radargrammetric applications.

2. APPLICATION ASPECTS

Radargrammetric processing of radar images is required as a preparatory step in a multitude of subsequent applications and as a research object of its own. Among the various radargrammetric aspects the following are of major importance:

- Geographic "referencing" which may result in the computation of ground coordinates from given image coordinates or in the production of a geometrically rectified image, a so-called "radar ortho-image";

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- Exploration and development of optimum radar stereo-capabilities for enhanced image interpretation and reconstruction of third dimensions of objects;
- Assistance in the systematic and repeated coverage of larger areas with blocks of images and development of concepts for efficient and rapid conversion into maps;
- Processing of radar together with other remote sensing and collateral data to take advantage of data synergism in geographic information systems.

2.1 Image Rectification and Simulation

Users of radar imagery are frequently confronted with the problem that subjective interpretation and quantitative analysis of spatial relationships are hampered or even inhibited due to the strong distortions of images. Thus it is of particular interest to deal with procedures which generate geometrically and radiometrically rectified digital images.

It has been demonstrated that correct mapping of a pronounced mountain topography is efficiently feasible only with a rectification technique that utilizes a digital elevation model (DEM) and a method to determine the exterior orientation elements of a scene, to model the aircraft or spacecraft path and attitude using these elements and to simulate the radar projection and imaging process. (Refs. 5 and 10). In a multi-step procedure the radar scene is registered to the elevation data file, where the correlation between DEM addresses and image coordinates is calculated by the simulation. As the DEM is presented in a standard projection geometry, the product of this process is a radar image which spatially corresponds to a topographic map. A graphic presentation of the procedure is given in Figure 1.

During the rectification process only effects of topography and not the thematic contents of the terrain need to be simulated. Therefore, homogeneous backscatter properties of the terrain are assumed. This also permits the removal of the dominating slope effect - strongly backscattering fore slopes versus darker back slopes - by substracting the corresponding grey values in the original radar image or in the geometrically rectified image from the brightness values in the simulated image. By this the thematic context of distributed targets is enhanced.

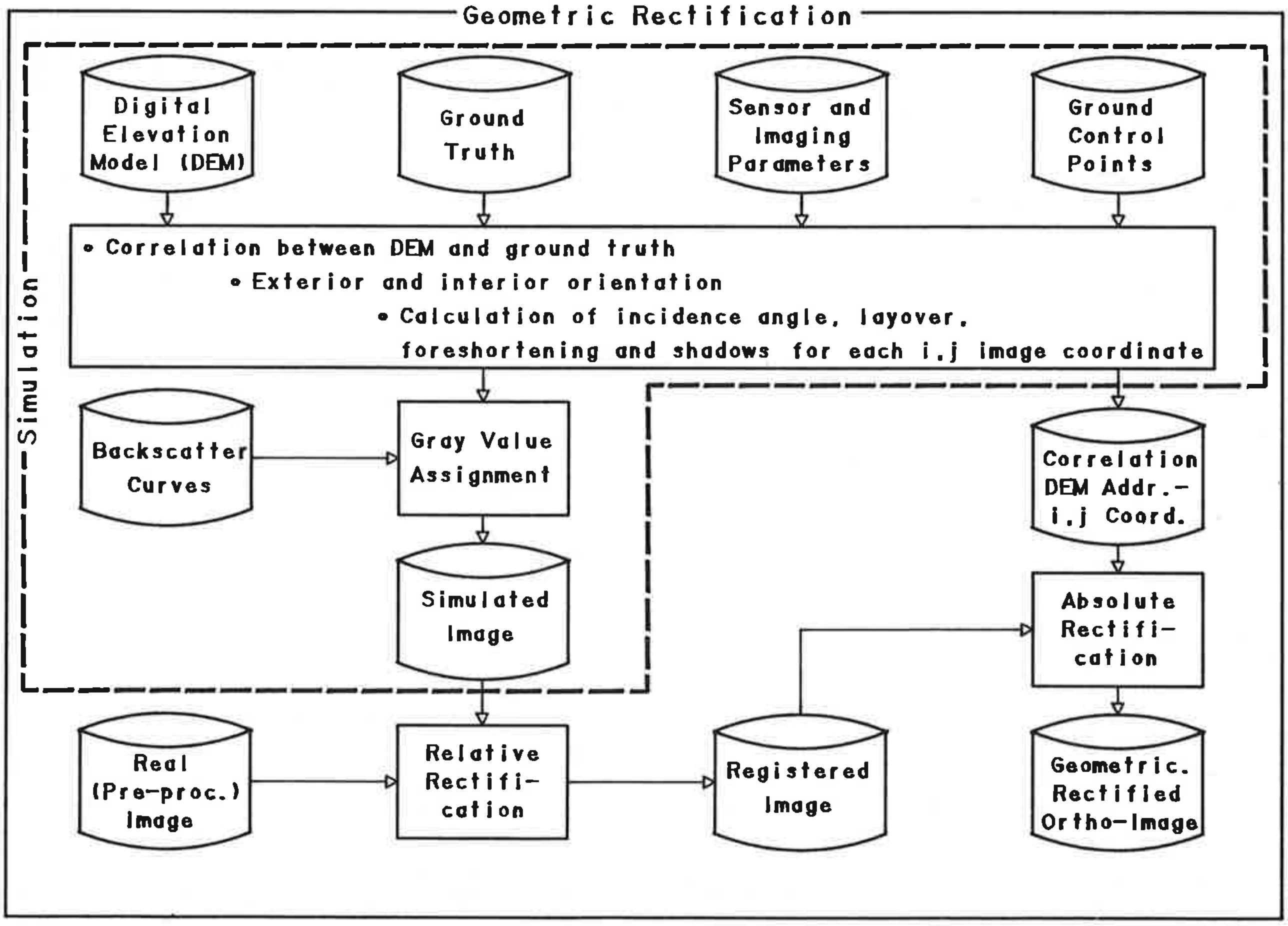

Figure 1: Radar Image Simulation and Rectification System.

To produce simulated imagery of realistic appearance ground truth information, thematic data and speckle noise have to be included in the simulation. All over the world considerable efforts were made to generate comprehensive backscatter data bases for this purpose.

2.2 Radar-Stereoscopy

Many of the aircraft- and satellite radar missions yielded overlapping strips of radar images. Like in photogrammetry, on the one hand stereo-images are useful to improve image interpretation; on the other hand the reconstruction of three-dimensional models of an imaged object by using stereo-evaluation is possible.

For the human interpreter who wants to exploit radar stereo-images visually, stereo-viewability is of basic relevance. The stereo-partners should be similar in image brightness, whereas they have to be different in geometry to show distinct parallaxes for height perception. Stereo-radar data, however, are obtained by illuminating the terrain from at least two different sensor positions, which besides the differences in image geometry, also implies differences in the grey value distribution of the stereo-partners. Therefore, good stereoscopy in terms of its geometric definition in a way conflicts with good stereo-viewability.

A study on radar stereo-viewability with real radar data is presented in Ref. 9. In general, only a limited number of real data sets with varying stereo-configuration is available. Therefore, to support a more comprehensive viewability analysis, stereo-images of arbitrary configurations have been generated by image simulation. Results on this subject are given below and more detailed in Refs. 4 and 6.

Methods to compute object coordinates from radar stereo-image coordinates are reviewed in Refs. 7 and 8. In an operational mode radar stereo-mapping became possible with the employment of computer-controlled photogrammetric instruments, the analytical plotters. For the analytical plotter Kern DSR-1 a software system for mapping from single or stereo-radar images has been described in Ref. 12. It uses rigorous radargrammetric relations for the reconstruction of the orientation of the images within a radar bundle adjustment. Parallax-free stereo-models are obtained by the intersection conditions of homologue image-coordinate measurements. So the analytical plotter can be used for real-time contouring or digitizing of spot heights, polygons or a raster of object points in the stereo-model.

3. RESULTS OF RECENT INVESTIGATIONS

Recent research activities addressed a variety of application topics for radargrammetric processing and analysis (Refs. 6 and 14). Table 1 summarizes some facts on the performed studies.

The data sets available for a thorough radargrammetric assessment of the use and characteristics of SAR in the various geo-scientific fields are rather limited. For the investigations carried out synthetic images were generated by again employing the above mentioned simulation software. These images turned out to be important supplements.

The interpretation of radar imagery is influenced by sensor parameters like elevation angle and flight direction, and target parameters, e.g. the electrical and other physical properties of the imaged objects. There exist no generally approved guide-lines for the optimal sensor parameters with respect to specific applications. Therefore, elevation angle and flight direction have been selected to be the most relevant parameters for more in-depth investigation. Target reflectance and backscatter data have been included for simulation of thematic properties.

3.1 Antenna Elevation Angle

The elevation angle is defined as the angle between a vector from the sensor position to the nadir and the line connecting sensor position and terrain point. Depending on this geometric parameter, in non-flat terrain one has to cope with the characteristic radar effects of foreshortening, layover and shadows. For any type of terrain foreshortening and layover are relatively

Table 1: Test-sites, radar data and study objectives, which yielded the presented results

Test-Site	Radar Data	Procedure Applied	Evaluation of Applicability
Sardegna, Italy	SIR-A, SEASAT	Simulation Rectification	Geologic Information Extraction Stereo-Viewability
Ithaka and Cephallonia, Greece	SIR-A	Simulation Rectification	Derivation of DEM from Radar Stereo-Data Stereo-Viewability
Mt. Shasta, USA	SIR-B	Stereo-Restitution	Derivation of DEM from Radar Stereo-Data
Ötztal, Austria	SAR CV-580	Simulation	Land Snow and Ice Analysis Simulation with Thematic Contents
Leibnitz, Austria	-	Simulation	Land Snow Analysis

higher for steep elevation angles. On the contrary, shallow elevation angles create larger areas of radar shadows. The degradation of image usefulness caused by the above mentioned effects has been determined quantitatively.

Data sets with varying elevation angles but otherwise fixed system and target parameters were needed. Since those can hardly be found among the real radar data available, simulated data have been chosen for the investigation. Furthermore, another advantage of the simulator has been used: for each synthetic imaged surface element of the DEM a value for the slant range has been calculated and, if necessary, a shadow indicator has been stored. A simple calculation can be performed to sum up the percentages of the specific image distortion and shadow. Table 2 gives a comparison of a set of simulated radar images of different test sites with varying elevation angles.

Table 2: Effect of elevation angle on image information content. Note: Loss by shadow means no information at all, whereas layover and foreshortening keep the terrain structure still viewable. The assumed flight altitude is 260 km unless stated otherwise. - Terrain type A: Coastal lowlands and mountains. - Terrain type B: Hilly landscape with alluvial plains. - Terrain type C: Alpine mountain ranges.

Elev. Angle (Deg.)	Shadow (%)	Layover (%)	Foreshort. (%)
Terrain Type A			
15.45 1)	0.00	9.66	50.24
20.00	0.00	5.03	43.29
30.00	0.06	1.35	35.18
45.60 2)	0.27	0.28	22.31
50.00	0.97	0.08	18.25
60.00	3.48	0.01	11.43
70.00	13.12	0.00	6.10
80.00	35.97	0.00	2.30
Terrain Type B			
20.00	0.0	8.9	49.40
40.00	0.5	0.8	33.20
60.00	7.3	0.0	14.30
Terrain Type C			
20.00	1.1	19.2	30.00
40.00	2.2	2.5	28.50
60.00	20.1	0.2	15.60

1) Elev. Angle for SEASAT (Flight Altitude: 795 km)
2) Elev. Angle for SIR-A (Flight Altitude: 260 km)

Obviously, there should be a differentiation between the loss of information by radar shadow (no information) and the loss by layover and foreshortening, where the terrain structure can still be viewed. On the other hand low elevation angles even enhance the geomorphologic structures in radar images (Ref. 2).

The comparison between the layover statistics (Table 2) gives a somewhat distorted picture with regard to the usefulness of the different antenna elevation angles, as the simulations have been carried out in slant range projection and have not been geometrically rectified for this calculation. Thus, at 20 degrees a distinct number of pixels with layover represents a significantly larger part of surface area than the same percentage of shadow pixels at 60 degrees. Rectified images would permit optimum comparison.

A conclusion that can be drawn from this analysis is that for snow and ice mapping optimum antenna elevation angles will be in the range between 40 and 60 degrees, depending on the percentage of shadow on a particular site.

3.2 Illumination Direction

The second geometric sensor parameter with influence on the interpretability of radar imagery is the flight path direction relative to the terrain structures of the illuminated area.

In radar images linear geomorphological structures oriented perpendicular to the illumination direction, i.e. parallel to the flight path, are strongly enhanced, whereas they hardly can be viewed when they strike parallel to this direction. Therefore, at least two flights with clearly intersecting paths are needed to provide sufficient data for the extraction of all major linear topographic features (lineaments, Refs. 11 and 15).

Under the assumption of ERS-1 imaging parameters (flight altitude 777 km, elevation angle 23 degrees mid-track) multidirectional illuminations of the test-site Sardegna in steps of 22.5 degrees have been simulated and their effects on the image examined. For the limited arrangements investigated it can be stated that - only for the studied type of terrain - any two different flight paths are enough to extract all major linear geomorphologic features. However, in areas with only subtle changes in relief and/or vaguely expressed lineaments which strike subparallel to the illumination direction, two simulated flight paths with only some 20 degrees difference, would certainly be insufficient. More definite statements on that topic would need more intensive investigations with different types of terrain.

3.3 Radiometric Analysis

Synthetic images were generated to investigate also target discriminability in SAR data using the above defined concept for correction of the grey value distribution due to slope effects and enhancement of thematic reflectance properties.

In the test-site Sardegna only two out of six lithological classes (granodiorites and Mesozoic limestones) provided significantly enough grey values to be distinguishable in the radar images with a reasonable degree of certainty (Ref. 6).

The detection of areas covered with seasonal snow in SAR data of the test-site Ötztal also proved to be feasible by means of radiometric rectification, although a rather differentiated thematic content complicates the interpretation.

3.4 Simulation of Thematic Contents

For the radiometric rectification a homogeneous backscatter model determined by the standard Muhleman function (Ref. 5) has been chosen.

Furthermore, the available simulation algorithm was extended by the introduction of different surface cover types (wet snow, grassland, snow free moraines and rocks) and measured backscattering functions (Ref. 13). For the Ötztal site a thematic map based on aerial photography and ground surveys, which shows the snow coverage on the day of the SAR CV-580 overflight, was available.

In order to demonstrate the difficulties in providing realistic simulations, difference images of the real SAR CV-580 image and the image simulated using thematic backscatter functions were calculated.

3.5 Viewability of Same-Side Stereo-Radar

In Refs. 4 and 6 evaluation results of stereo-viewability for same-side stereo-image pairs were discussed for the test-sites of the Greek islands Cephallonia and Ithaka and of the Italian island Sardegna (cf. Table 1). In both cases a set of simulated radar images with assumed elevation angles ranging from very steep (10 degrees) to very shallow (80 degrees) was used. Without taking into consideration the different surface-cover types, homogeneous backscatter curves were used to obtain similarity in the thematic contents of the stereo-partners.

Each combination of two stereo-partners was judged for its intensity of the stereo-impression by several test-persons and ranked with numbers from 1 (no stereo-fusion) to 10 (excellent stereo-viewability).

Due to the topography of the investigated test-sites intersection angles of up to about 25 degrees were found to be best. For larger intersection angles the difference in the geometric contents of the two images would be too large for a good stereo-impression. In the case of very steep look angles (high amount of overlays) or of very shallow look angles (high amount of shadows) the stereo-fusion is rather poor, even with small intersection angles. For the Greek test-site the elevation angles of the best-ranked image pairs were 70 and 50 degrees respectively, i.e. an intersection angle of 20 degrees. For the Sardegna test-site 55 and 30 degrees respectively, i.e. 25 degrees intersection angle, were best.

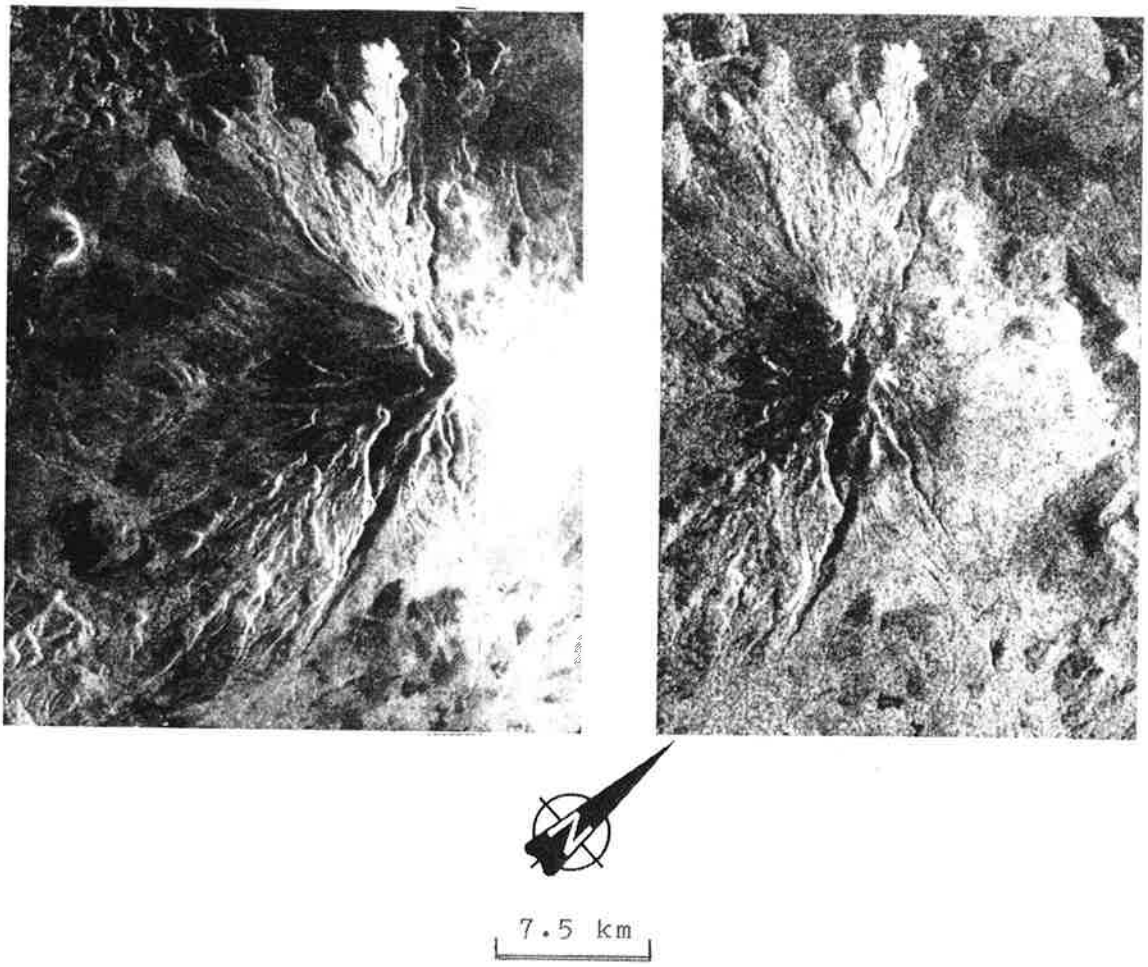

Figure 2: SIR-B radar stereo-pair of Mount Shasta, California, USA, in ground range presentation. Resolution 25 meters, flight altitude 230 km, elevation angles 60 and 29 degrees respectively, wavelength 25 cm. The images are mounted for stereoscopic viewing.

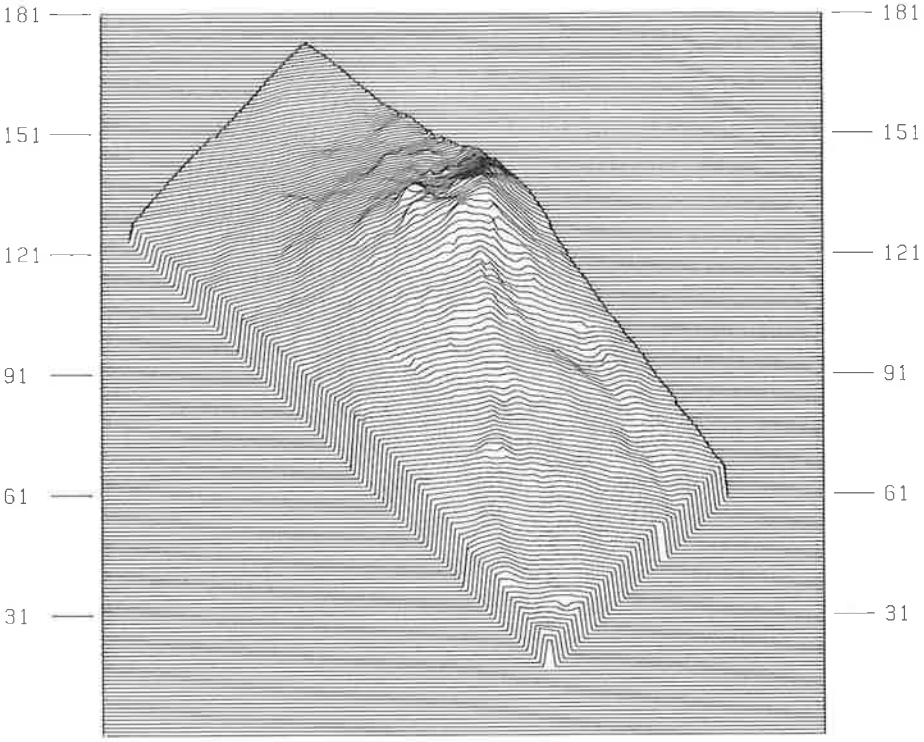

Figure 3: Digital elevation model of Mount Shasta, California, in axonometric view. The basic data were digitized in real time from the analogue SIR-B images using a Kern DSR-1 system stereoplotting.

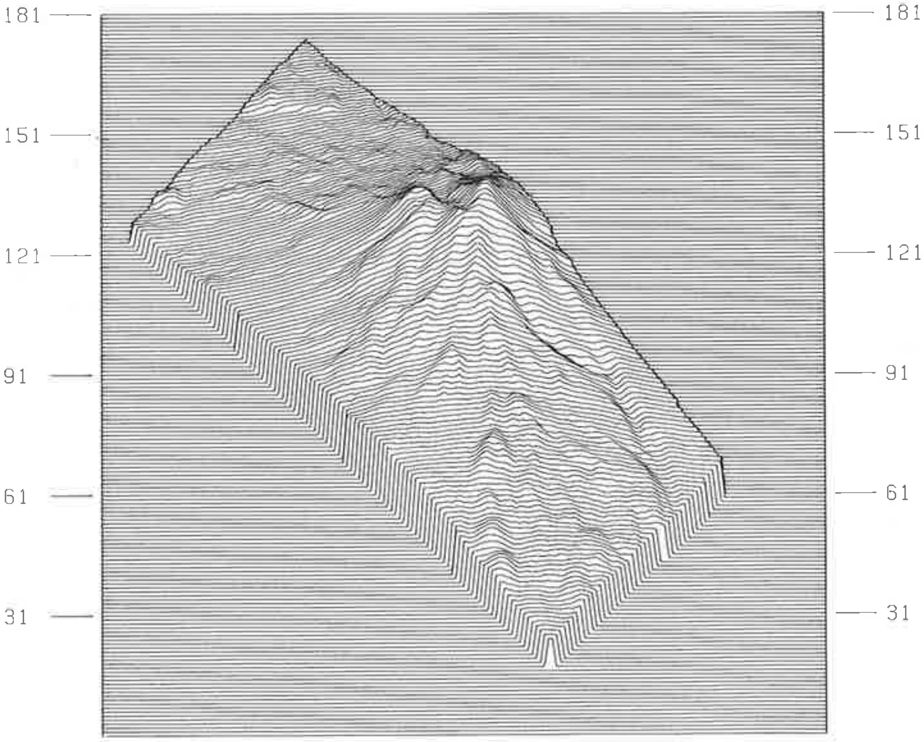

Figure 4: Digital elevation model of Mount Shasta, California, in axonometric view. The basic data were extracted from a 1 : 62 500 topographic map with 40 feet interval contour lines. The displayed topographic features show no significant difference to Figure 3. Further explanations on the comparison of the two DEMs depicted in Figure 3 and 4 are given in the text.

3.6 DEM Derived from Radar Stereo-Pairs

In a case study the software package referenced in section 2.2 was used together with a programm system for DEM generation (GTM package) in a case study to create a digital elevation model of the Mount Shasta test-site (see Table 1) with actual SIR-B satellite radar data. In Figure 2 the stereo-partners used for the study of this area are shown. By means of the stereo-radar software estimations of the restitution accuracy can be made. It amounts to approximately 80 meters in planimetry and some 50 meters in height.

Contour lines and break lines were digitized in real-time and subsequently entered into the GTM program system for interpolation into a height raster. An axonometric view of the generated DEM is shown in Figure 3. Moreover, using the GTM system, a digital elevation model of this very test area was created by scanning the contour lines of the 1 : 62 500 map sheets and additional interpolation of the raster heights. For comparison this DEM is also shown in an axonometric presentation in Figure 4.

As can be seen in Figures 3 and 4, the radar- and the map-derived elevation models correspond very well. In comparison with previous stereo-models of SIR-A radar images of the Greek islands Cephallonia and Ithaka (given in Ref. 12), which were evaluated for a first demonstration of the capabilities of DEM generation with stereo-radar images on the analytical plotter Kern DSR-1, the result is obviously to better. This mainly refers to the kind and quality of data digitized at the stereoplotter. In the SIR-A study polygons (drainage and ridge lines and quality) were digitized with a point density of about one point per square kilometer, while for the SIR-B stereo-model contour lines were selected with a density of digitized terrain points some ten times higher.

4. PROSPECTS

Geometric and radiometric rectification of SLR imagery is a valuable processing step for evaluation and information extraction. The solution of various problems connected with this processing turned out to consume more resources than anticipated, but most investigators have been unaware of these problems.

As shown in this paper, a number of algorithms and procedures have already been developed, most of them, however, still being in an experimental or prototype state. In many cases, where the radargrammetric approach could provide a reliable basis for subsequent investigations, applicability suffers from insufficient accuracy in geometry, navigation parameters or signal processing quality.

At present, besides others, the preparatory program for ERS-1 will catalyze the installation of facilities for operational processing of radar data to deliver high precision products. To meet the requirements of operationality, which also mean a high throughput of products, possibilities to speed-up image rectification procedures need to be identified and materialized. Algorithms, which will dispense a time-consuming involvement of human operators, have to be developed and realized in fully automated processes. Easy and quick access to DEM data bases will essentially improve the procedure's performance.

Operational aspects of radar stereoscopy might also be decisive for future efforts. In this context the possibility to derive DEMs directly from digital radar imagery without analogue processing steps is one of the challenging goals.

On the other hand, the assessment of characteristics and use of SLR image data for various application fields has not yet fully given evidence of the major capability of this remote sensing technology. However, recent research results are conclusively pointing to the fact, that with the availability of sufficiently accurate data its applicability will rise. The effects of the essential radar parameters, for instance those examined from the perspectives of the performed studies, will still need thorough investigations. Until present, many of the study results have been achieved only for one specific test-site, one single data set or one particular sensor system. Hence, extension of expertise in these fields is required and should be subject of further research.

Fortunately, an increasing number of data acquisition concepts takes into account the needs of the geo-scientific community of researchers. Application studies which up till now were only possible with simulated data sets become more and more interesting and important. Within the forthcoming years, e.g., spaceborne radar data of the same site acquired from the Space Shuttle with different elevation angles will become available.

As to the thematic contents of radar images, the existing simulation software has to be improved by including models for variation of geometric resolution and speckle generation. The process should consist of three steps which will be described in the following.

Out of the relative grey values computed from the slant range presentation for each DEM cell derived from the respective incidence angles and backscatter curves, a weighted sum is computed over these grey values corresponding to a particular image pixel. The weight function is a normal distribution in both range and azimuth direction. As a last step speckles are added using specified random number generators.

The result of this process will be an inhanced image simulation that permits one to consider resolution and speckle as parameters in analysis studies.

An effective evaluation of SLR data will require the employment of techniques, which are capable of including in the analysis not only image but also ancillary data from other sources, especially digital maps. Algorithms for automated image correlation, map-to-image correspondence and feature extraction will have to be developed. An increased involvement of adequate image processing techniques will enhance clearness of data contents.

For all these issues, may they support a comfortable visual interpretation or an efficient digital exploitation of image data, radargrammetry will provide the frame of reference wherever it is necessary to precisely correlate image with/and object space.

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