RADARGRAMMETRY AND MERGING OF MULTISENSOR DATA

F.Leberl
Technical University and Graz Research Center
Wastiangasse 6, A - 8010 Graz, Austria

ABSTRACT

This paper discusses current issues of radargrammetric image analysis. Specific equipment for radargrammetric work does not exist. However, existing analytical plotters, orthophoto instruments and digital image processing system can be succesfully employed for work with radar images.

1. INTRODUCTION

Special equipment for radargrammetry was presented by Macchia (1957), Levine (1963), Ambrose (1967), DiCarlo (1971), Graham (1972) and Yoritomo (1972). Radargrammetric equipment was thus not built after presentation of the so-called orthographic radar restitutor by Yoritomo (1972) and others. However, studies and applications of radargrammetry were continuously generated since these early developments. An extensive review was by Leberl and Raggam (1982). Of significance in the current context are radargrammetric processing systems based on analytical plotters (Norvelle, 1972) and on digital mono- plotting (Greve and Cooney, 1974).

These modest efforts have experienced a recent revival due to satellite radar imaging by SEASAT, SIR-A and several proposed radar missions. The emphasis is on digital image processing technology applied to single image and stereo radar in conjunction with collateral data (digital terrain models) and with images from other sensors. There is also a renewed interest using analytical stereo plotters for stereo radar images. The various developments are discussed in the following sections.

2. SINGLE IMAGE RADARGRAMMETRY

2.1 The Role of Radargrammetry

Radargrammetric considerations have traditionally been of minor concern in the design, construction and application of imaging radar systems. Instead, geometric and radiometric image resolution were of dominating importance. However, as technology progresses one has to move from the mere "picture" to an engineering tool of specified quality leading to useful products. The proper consideration of image geometry and the development of procedures to convert the image to mapping products are thus of increasing importance, be it in the application to tropical small scale mapping, to sea ice monitoring , to geological structural analysis or to extraterrestrial mapping.

A basic task of radargrammetry is to relate the image to the object space. One can differentiate between the projection of a radar image point onto a reference surface, for example in the form of a digital terrain model, and the "resection in space", where an object point is found in the image.

2.2 Single Image Radargrammetric Performance

There is an extensive body of literature on the various aspects of single image radargrammetry. The interest currently focusses on the engineering performance of single radar images.

Existing aircraft radar images have been studied in the past to quantify the geometric performance capabilities of side-looking radar mapping. From this it is clear that the inherent radar image accuracy is rather limited, essentially to about - 100 to - 150 m. It is only with the use of fairly dense ground control points that an accuracy is achieved that is near the geometric resolution capabilities.

Of particular interests are recent satellite radar images. Tests with such images from the SEASAT - satellite were conducted with an urban as well as an arctic scene and with variations of resolutions and multiple looks. Table 1 is a summary of the achieved results. It is to be noted that all experiments were done with images on film, be they generated by an optical or digital correlator.

One can conclude that optimum accuracies are obtained if the highest geometric resolution is available irrespective of radiometric resolution. Given the choice between a 2-bit or 4-bit image it is obviously the latter that is preferred.

The sources of remaining geometric errors are, in the limiting case of dense control, due to geometric resolution. As ground control becomes more scarce, the instabilities of the flight track or orbit and the lack of synchronisation between the imaging process and orbit dominate. The relationship between recorded x, y - image coordinates and physical measurement entities time and range, t, r, is so far not well defined in existing radar systems. Curlander (1981) was successful in establishing -- for SEASAT-SAR -- some parameters relating x, y to r, t; however, this was the result of extensive work after actual imaging was completed. In this respect SEASTAT was unsatisfactory: a set of design specifications should have been defined before hand and implemented in the system.

2.3 Applications of Single Image Radargrammetry

Single image mapping can consist of one of the following problems:

(a) Computation of object coordinates of points observed by the radarThis can be done only if the shape of the object is known (Z=f(X,Y);digital terrain model or ellipsoid).

(b) Generation of a rectified image: this follows task (a) and rearrangesthe image geometry to conform to a specified map projection. The result is a radar ortho-image. Expamples were produced by Leberl et al. (1981), Guindon et al. (1980) or Naraghie et al.(1981). Various techniques are available for this purpose, for example common computer-controlled orthophoto-equipment and procedures of digital image processing.

(c) Radar image mono-plotting consists of tracing significant detail off the radar image and of subsequently plotting the digitized lines and points after a geometric transformation according to step (a). Greve and Cooney (1974) were so far the only ones to present a working system.

It is of particular interest to address the question of radar-orthophoto-graphy and the applicability of photogrammetric orthophoto-equipment.

It has been demonstrated that there is no reason why modern computer controlled orthophotos machines cannot be used to generate also radar orthophoto, provided the image deformation is known from prior computations (Leberl et al., 1981). However, one may argue that the mere geometric correction of radar images is not essential; it should be complementd by radiometric corrections as well. This, as a rule, is only successfully feasible with techniques of digital image processing.

Scene	Control Density		Coordinate errors (m)		Remarks
	Nr.of points	Area(sqkm)	x	y	
Arctic	0	40 000	15120	12 880	Time marks on image were off
Arctic	1	40 000	350	280	
Arctic	2	40 000	330	210	Points on both ends of image strip
Arctic	17	40 000	150	90	
Urban L.A.	38	6 400	22	12	Entire Los Angeles scene, digitally correlated
Urban L.A.	38	6 400	24	17	Entire Los Angeles scene, optically correlated
Urban L.A.	26	225	18	18	Section of L.A., 25 m resolution, 4 bit/pixel
Urban L.A.	26	225	32	34	Section of L.A., 100 m resolution, 4 bit/pixel
Urban L.A.	26	225	27	31	Section of L.A., 25 m resolution, 1 bit/pixel
Urban L.A.	26	225	33	44	Section of L.A., 100 m resolution 2 bit/pixel

Table 1: Geometric Accuracies achieved with SEASAT-SAR.

3. MERGING RADAR IMAGES WITH DIGITAL TERRAIN MODELS

In its crudest form, a radar image is related to a DTM by the use of control points with their planimetric and height coordinates. This was the basis for generation of analog radar orthophotos and for radar mono-plotting.

However, digital image processing has created new capabilities to merge images with collateral data using correlation techniques. Naraghi et al. (1981) presented the example of a data set consisting of a DTM and registered SEASAT radar image. The DTM was used to create a simulated radar image. This was then cross-correlated with the digital SEASAT image and the combined data set served to create a digital radar orthophoto.

Guindon et al. (1981) also create combined sets of radar and DTM data , but they employ ground control points. Thus the registration process seems to be based on manually identified control points rather than on an automated correlation of radar and DTM-derived synthetic images. Therefore the process is entirely equivalent to conventional orthophoto techniques. Use is made of the combined data set for improved classification of image contents based on feature vectors containing radar gray value, terrain slope, aspect angle etc. Also, shadow and layover areas are eliminated in the radar image analysis.

No other work has come to the attention of the author regarding radar - DTM combinations. One has to expect, however, that the integration is of increasing interest. The radiometric rectification is only feasible with a precise registration between DTM and image. Techniques are becoming available and have been tested with LANDSAT data (Horn and Bachman, 1978; Little, 1980; Seidel et al., 1982). Their use with radar is a logical next step.

4. MULTIPLE RADAR IMAGES - STEREO

Recently the interest in radar stereo analysis intensified. Overlapping radar images were examined first for stereo by LaPrade (1963). Little effort was done since to determine the capabilities and limitations of visual radar stereo. Stereo radar viewing is feasible if certain conditions are satisfied, namely that:

(a) image pairs are used that have the same thematic content (about the same illumination direction);

(b) geometric differences are not excessive.

Type of Radar	Number of Models Studied	Base Length (km)	Look Angles Ω'	Type of Stereo	Intersection Angle $\Delta\Omega$	Type of Terrain	Stereo Viewability
SEASAT	10	25 - 75	20°	Same-side	1°.2 - 4°.8	Rugged	very convenient
SAR	1	550	20°	Opposite-side	40°	Rugged	not possible
Aircraft SAR	4	0.7 - 13	68°	Same-side	0°.2 - 23°	Rugged	very convenient
Goodyear	2	30	68°	Opposite-side	120°	flat to Rugged	only when flat
Aircraft Real Aperture	1	10	81°	Same-side	6°	flat to hilly	convenient
Motorola	1	48	80°	Opposite-side	160°	flat to hilly	only when flat
Lunar Apollo 17 ALSE-SAR	19	0.7 - 10.3	10°	Same-side	0°.3 - 5°.3	flat	convenient
						Rugged	only with $\Delta\Omega < 1^{\circ}.9$

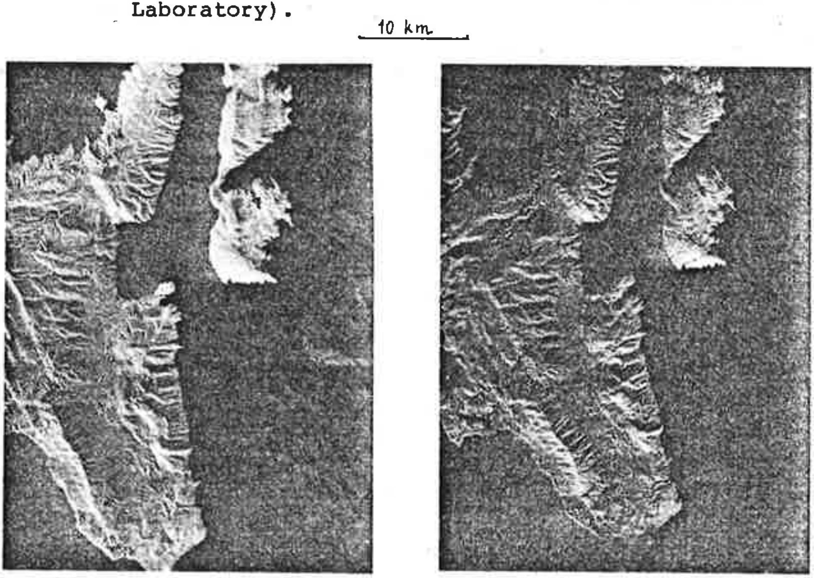
Table 2: Summary of viewability test for radar stereo with actual imagery.

Table 2 summarizes the results of an extensive review of radar stereo pairs to determine the feasibility for visual stereo fusion: the material availaible today clearly shows that there are broad ranges of imaging configurations where valid stereo is produced. However, this material only provides coarse direction towards the limits that exist for successful radar stereo viewing. Conlusions are evident from Table 2.

Interesting recent data are from the Space Shuttle's SIR-A experiment. Figure 1 is a stereo pair from this mission with comparatively good performance: this is measured by indicating the size of the differential stereoparallax compared to common stereo photography: it is 600 m for a height differene of 1 km in photography, and it amounts to 560 m in the example shown as Figure 1.

The subjective depth perception through stereo radar is of use in the analysis of the imaged terrain through an interpreter. For systematic descriptions of shape one has to measure topographic height. Available results are of the order of multiples of resolution.

Figure 1: Stereopair obtained from Space Shuttle SIR-A (Courtesy C. Elachi, M. Kobrick, Jet Propulsion Laboratory).



The accuracy of radar heights is insufficient to serve as a useful independent height measurement. One can expect, however, that the height values can support a successful rectification of geometry and radiometry. Therefore it is of interest to develop and study radar image correlation techniques.

No work seems to have been reported so far on digital radar stereo correlation for parallax measurement.

5. MULTISENSOR DATA - IMAGE SYNERGISMS

There is considerable speculation about the usefulness and applicability of mulitsensor image data sets. Significant combinations of sensors have yet to be determined. Current investigations have addressed

active (radar) and passive microwave sensing;

radar, LANDSAT and aircraft scanning;

combinations of different radars.

LANDSAT-radar combinations have already given rise to a body of literature (Ahern et al, 1978; Daily et al., 1978; Li et al., 1980; Harris and Graham, 1980; Guindon et al., 1980; Teillet et al., 1980). At the Canada Centre for Remote Sensing a particular effort is being made to develop techniques for multisensor data sets. Teillet et al. (1980) include also 11-channel airborne MSS in the aircraft radar-LANDSAT combination. Similary, geology- oriented research at the Jet Propulsion Laboratory aims at using satellite radar in conjunction with LANDSAT (Daily et al., 1978, Elachi et al., 1982)

Regarding the combination of active and passive microwave data, Hall and Bryan (1976) have presented early results, whereas Stiles and Ulaby (1980) report on the physical responses of materials in these two sensing domains.

Combinations of radar images to a multispectral data set is not considered a multisensor system if it concerns e.g. simultaneous X- and L-band images. However, efforts were performed to co-register Seasat and Sir-A radar images (Elachi et al., 1982).

The emphasis so far is on demonstrations of the usefulness or synergistic complementation of mulitsensor data rather than on specific techniques of creating the data sets. The co-registration of images has exclusively been by manual identification of ground control points, with or without incorporation of DTMs for differential rectification.

6. CONCLUSION

There is no significant equipment development for radargrammetric image analysis, apart from early experimental systems. The current trend is towards programming of existing computer-controlled photogrammetric equipment and of digital image processing systems for radar. These serve to create radar ortho-images by combining the raw radar image with an existing digital terrain model, and to do stereo-analysis, e.g. with an analytical plotter. Multi-sensor data sets including radar are not a widely studied tool.

We therefore see a situation that is at an initial stage: one is at a point where radar images are expected to increase in importance due to planned satellite missions and refined analysis techniques. However, these analysis techniques need still to be fully developed, even in experimental laboratory environments.

ACKNOWLEDGEMENT

I am grateful for the information provided by B. Guindon of CCRS regarding multi-sensor work and radar-DTM combination.

REFERENCES

AHERN F.J. et al. (1978)
Simultaneous Microwave and Optical Wavelength Observations of Agricultural Targets.Canadian Journal of Remote Sensing, Vol. 4, No.2, pp 127-142.
AMBROSE W. (1967)
A Radar Image Correlation Viewer. Photogrammetric Engineering. Vol.XXXIII.
CURLANDER J. (1981)
Sensor to Target Range Determination. Jet Propulsion Lab. Interoffice Memorandum 334.7 - 80 - 056, Pasadena, USA

DAILY M. et al. (1978)
Application of Multispectral Radar and Landsat Imagery to Geologie Mapping in Death Valley. Jet Propulsion Laboratroy Technical Publication 78-19, Pasadena, USA, 47 pp.

DICARLO C. et al (1968)
All Weather Mapping. Presented Paper, Congress of the Intl. Federation of Surveyors(FIG), London, England.

ELACHI C., D.EVANS, P.ROBILLARD (1982)
Comparative Analysis of Co-Registered SIR-A, Seasat and Landsat Imagery. Presentation at IEEE IGARSS'82, Munich, W.Germany (no written paper).

GRAHAM L. (1972)
An Improved Orthographic Radar Restitutor. Presented Paper, 12 th Congress of the Intern. Soc. of Photogrammetry, Ottawa Canada.

GREVE C., W. COONEY (1974)
The Digital Recitification of Side Looking Radar. Proceedings of ASP, Annual Convention, Washington D.C.

HALL D., M.L. BRYAN (1976)
Personal Communication, Jet Propusion Laboratory, Pasadena, USA.

HARRIS G., L. GRAHAM (1976)
Landsat-Radar Synergism. Presented Paper, 13th Congress of ISP Helsinki, Finland, 26 pp.

HORN B., B.BACHMANN (1978)
Using Synthetic Images with Surface Models. Comm. ACM, Vol. 21, Nr. 11, pp 911-924.

LAPRADE G. (1963)
An Analytical and Experimental Study of Stereo for Radar. Photogrammetric Engineering, Vol. XXIX.

LEBERL F., H. FUCHS, J. FORD (1981)
A Radar Image Time Series, Intl. Journal of Remote Sensing, Vol.2, Nr.2.

LEBERL F., J. RAGGAM (1982)
Satellite Radargrammetry - Phase I. DIBAG-Report Nr. 4, Graz Research Center, A - 8010 Graz, Austria, 220 pp.

LEVINE D. (1963)
Principles of Stereosopic Instrumentation for PPI-Photographs. Photogrammetric Engineering. Vol.XXX.

LI R.Y., F.ULABY, J. EYTON (1980)
Crop Classification with a LANDSAT-Radar Sensor Combination. Proceedings Symp. Machine Proc. of Remotely Sensed Data.

LITTLE J. (1980)
Registration of LANDSAT Images and Digital Terrain Models. MSc-Thesis, Dept. of Computer Science, University of British Columbia, Vancouver, Canada.

MACCHIA R.D. (1957)
Radar Presentation Restitutor. Photogrammetric Engineering, Vol. XXIII.

NARAGHI M., W.STROMBERG, M. DAILY (1981)
Geometric Rectification of Radar Imagery using a Digital Elevation Model Manuscript, Jet Propulsion Laboratory, Pasadena, USA.

NORVELLE F.R. (1972)
AS-II-A Radar Program. Photogrammetric Engineering Vol.XXXVIII.

SEIDEL K., J. LICHTENEGGER, F. DOLE (1982)
Argumenting Landsat - MSS Data with Topographic Information for Enhanced Registration and Classification. Proceedings of IEEE-IGARSS'82, Munich, W.Germany, Paper WP-2.

STITES W., F.T. ULABY (1980)
The Active and Passive Microwave Response to Snow Parameters 1.Wetness. J. of Geophysical Research, Vol. 85, No. C2, pp 1037-1044.

TEILLET P.A., B.GUINDON, D.GOODENOUGH (1980)
Integration of Remote Sensing Dat Sets by Rectification to UTM Coordinates with the use of Digital Terrain Models. International Achieves of Photogrammetry, Vol.XXIII, Part B3.

ULABY F.T., R.Y. LI, K.S. SHARAGON (1982)
Crop Classification Using Airborne Radar and LANDSAT Data. IEEE Transactions on Geoscience and Remote Sensing. Vol. GE-20, Nr.1, pp 42-51.

YORITOMO K. (1972)
Methods and Instruments for the Restitution of Radar Pictures. International Archives of Photogrammetry, Ottawa, Canada. Comission II.