RADARGRAMMETRIC IMAGE PROCESSING WITH A SOFTCOPY STEREO WORKSTATION[1]

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ABSTRACT

Modern radar imagery is created in a digital form aboard aircraft and satellites. Processing and analysis of radar pixel arrays requires considerable radar-specific capabilities, combined with geometric image processing tools.

We describe a new radargrammetric stereo image processing workstation, a powerful image processing workstation designed to optimally perform radargrammetric processing tasks for topographic mapping using aircraft and satellite radar images. We also report on first experiences of applying this tool to STAR-1 airborne radar images. In this application the system replaces existing and previously described STARMAP topographic mapping processes which are hosted upon a hybrid combination of an analytical plotter using film input, and image analysis workstation accepting digital input.

1. INTRODUCTION

Hosted on a high performance graphics work station (currently a STARDENT 3000), a radargrammetric softcopy system has been built around a sensor-generic stereo electronic light table and stereo cursor.[2] This permits the user to organize, display in stereo, and measure coordinates from overlapping images. Radargrammetric capabilities of the system include processing of radar images together with in-flight differential Global Positioning System (GPS) recordings or satellite ephemeris data, tying of individual image strips into a coherent *block coverage*, set-up of

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2. The work was performed by Vexcel Corporation, driven by a cooperation with Intera Technologies Ltd. who provided the radar images and configured the GPS-based airborne radar imaging system STAR-1 to produce radar image maps (Mercer et al., 1986).

proper stereo-models for stereo measurements of terrain elevation and planimetric data, processing of terrain elevation measurements into deliverable Digital Elevation Models (DEMs), and production of ortho-rectified radar images and image maps.

The system must furthermore deal with radar problems such as shadowing and merging of dissimilar opposite-look data, and with image sizes that are large, typically consisting of multiple strips, each containing at least 40MBytes of data.

A specific innovation is the operational implementation of so-called *shape-from-shading* to refine the description of terrain morphology using pixel brightness in overlapping radar images. This greatly improves the quality of the resulting DEM and the throughput of the mapping process. It also permits the user to obtain a number of derived or *secondary* image products, for example images in which the effect of terrain slope is reduced or eliminated.

We describe the flow of the radargrammetric mapping process and present its accuracies when applied to operational STAR-1 images.

2. MAPPING WITH RADAR IMAGES

The concept of an all-weather, day-and-night mapping system has caused considerable research efforts to be applied from the early 1960's on. The sensor to spawn these efforts was initially the Plan-Position Indicator (PPI) radar (Scheps, 1960; Macchia, 1967; Levine, 1960), later the Side-Looking Radar (SLR) (Yoritomo, 1972). The first large mapping project was in Panama in 1967 (Crandall, 1969).

However, to obtain a predictable, useful accuracy from radar images, one did have to use many ground control points, thereby destroying the practicality of the mapping approach (Gracie et al, 1970). It is only with the advent of the Global Positioning System (GPS) that a strictly airborne system became feasible, thereby completely eliminating the need for any fieldwork.

Mapping with SLR images today is an operational technology (Leberl, 1990); it produces deliverables, typically from a sensor with a resolution of 6 meters per pixel, as follows:

* ortho-image maps at scale 1:50,000 presenting about 8 pixels per millimeter and offering a planimetric accuracy of about 0.4 millimeters;

* digital elevation models with an accuracy at each posting of about 30 meters;

* contour lines at an interval of about 100 meters, with morphologically refined intermedi--ate contours at 50 meters;

* derived conventional line maps and data inputs to a Geographic Information System (GIS), derived from the ortho-image maps or from stereo observations.

The elevation data extracted from SLR images have a peculiar accuracy behavior that cannot easily be described in terms of conventional photography-based mapping terms. The issue derives from the fact that elevation data are obtained from two sources:

* conventional stereoscopic parallax measurements that exploit the geometric disparity between overlapping images;

* and variations in *shading* that refine the morphological detail, thereby exploiting the fact that gray values in the radar image are dependent to a significant extent on the radar's illumination direction and incidence angle (Thomas et al., 1990; 1991).

Consequently, while the *absolute accuracy* of elevation measurements is determined by the geometric parallax measurements, the *relative accuracy* is a result of inverting shading variations into terrain slopes and high frequency terrain relief.

Note that this *shape-from-shading* refinement of course also must be constrained by the condition that the resulting surface points be at the observed slant range. Therefore the technique of shape-from-shading does not solely rely on image gray values.

3. AN END-TO-END RADAR MAPPING SYSTEM

A radar mapping workstation processes data obtained from a complex sensing and sensor positioning system.The complete radar mapping system consists thus of the components described in Table 1. Most components of the system need careful consideration and calibration for a mapping application. A central issue is item 10, the radar image processing component.

Before development of the system described in this paper, radar mapping was based on film-based computer-driven analytical plotters used in photogrammetry. The use of such equipment required that:

* digital radar images which result from component 9 in Table 1 be recorded onto film;

* film imagery be subjected to preprocessing for overlap delineation, tie-point selection and *pugging*, i.e. physical marking of tie points between overlapping images;

* tie points be measured in a mono-, stereocomparator or analytical plotter, to be then

available for a *flight line adjustment* using GPS and motion compensation data;

* individual stereo models be used to extract data for digital elevation models in the analytical plotter;

* the DEM and original digital images be merged to ortho-rectify or geocode the digital radar images.

Table 1: Components of an airborne radar mapping system as seen from the map-makers perspective.

Item	Description	Comments
1	Platform (aircraft)	High altitude at 8 km or more above the ground
2	Antenna	Mounted on the fuselage of the platform
3	Radar electronics	Wavelength, resolution, look angles, swath
4	Motion compensation	Correct for perturbation of antenna motion
5	Airborne GPS component	Global positioning system receiver in aircraft
6	Terrestrial GPS component	Ground based receiver and recording system
7	Inertial Navigation System	Input to motion compensation system
8	Processing of navigation data	Differential GPS positioning of platform
9	Phase history processing	Conversion of radar echoes into pixel matrix
10	Radar image processing	Stereo, measurements etc.
11	Film writing	Conversion of pixels into hard copy
12	Drafting	Contour generation, planimetric detail, map legend
13	Reproduction and printing	Cartographic processing and final product

The result of this process consists of a DEM and a set of ortho-rectified radar image strips. These need now to be subjected to the creation of the final deliverable, a contour line map and image map consisting of the combined strips covering a map sheet.

Considering the need for careful quality control and the need to employ a multitude of input data, one finds oneself dealing with a fairly complex process involving point transfer devices, light tables, analytical plotters, graphics work stations, film recorders and a suite of software.

The creation of the radar mapping work station served to greatly streamline the entire process, increase the productivity and reduce the capital investment previously necessary for a radar mapping facility.

4. THE RADAR MAPPING WORKSTATION

We are describing a novel computer workstation to support the operational creation of radar image maps from digital side looking radar images. We denote the system as SSCS, the *Stereo Softcopy System.*

4.1 Data Quantities

Production type SLR images currently consist of perhaps 8,000 by 4,000 pixels. At a resolution of 6 meters per pixel, this covers 48 x 24 square kilometers. A map sheet at scale 1:100,000 covers 50 km x 50 km. It may be created from 14 radar images, 7 presenting a coverage from one side, for example looking east, the other 7 images covering the area looking west. A stereo model may be formed from image pairs taken with flight lines that are 10 kms apart. In this event, 6 stereo modelstypically ensure coverage of a map sheet.

At resolutions of 2 meters per pixel, the data quantities increase of course. However, even at 6 m per pixel the input data files for one map sheet are in the range of 500 MByte. With ortho-rectification and quality control one needs to be prepared for 2 GByte of data to be available on a system capable of processing a map sheet.

4.2 The Digital Light Table

The heart of a softcopy radar mapping workstation is the software described as a *Stereo Digital Light Table*[3]. This permits the management, display, and the taking of stereo measurements from multiple digital images of large size. In principle, VXlt is dealing with monochrome or color images, stereo or monoscopic imagery. The features of relevance with radar images are:

* access to images of arbitrary size;
* set up of stereo pairs;
* ability to zoom in and out, and roam in stereo;
* ability to measure points and lines.

In this manner the digital light table evolves into a digital stereoscope, digital mono- and stereo-comparator and digital stereo plotter.

4.3 Major Functional Components

The workstation software consists of major software components that address the interactive work with images as well as the batch processes spawned from the user interface. The major ele-

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ments are described in Table 2. Particular innovations exist in the manner in which the DEM data are presented *with* the images for quality control and editing. This is implemented via a program called VXEdit in a monoscopic manner using the rectified radar images and final contour lines together with the elevation measurements. It is also implemented via VXIt by projecting the contour lines into the original stereo image pairs for quality checks and editing. Essentially both processes can be used for the same task, and we are in the process of determining their relative merits.

Correlation matching is available in two forms:

* as a batch process for the unattended search for match points to create a DEM;

* to support the human operator in the interactive measurement by refining the stereo-pointing accuracy.

Table 2: Components of the Radargrammetric Processing System

Item	Description	Comment
<u>Foundation</u>		
1	Digital Light Table	Central software element
<u>Flight Line Processing</u>		
2	Tie point management	Proper tie point identification in 3 images
3	Flight line adjustment	Use of GPS and tie points
<u>Surface Measurements</u>		
4	Stereo model set up	Parallax removal per image pair
5	Terrain data collection	Contours, grids, break lines, drainage
6	Elevation modeling	Integrated third party software
7	Terrain Window	Real time DEM visualization
8	Image correlation matching	Tracking correlation and batch correlation
<u>Image Orthorectification</u>		
9	Image resampling	Use of DEM and GPS data
<u>Quality Control and Editing</u>		
10	Elevation editing	VXEdit to merge image and contour lines
11	Tracking correlation	Manual surface measurements, machine check
12	Shape-from-shading	Refine DEM, densify DEM
13	Stereo quality control	Visualization of stereo imagery with contour lines and editing

4.4 Shape-from-Shading

Of particular interest is the refinement of digital elevation models by a process of shape from shading.(Thomas et al., 1990, 1991). This is of interest in radar images since a major portion of the radar echo reaching the antenna is determined by the terrain slopes towards the antenna. This can be used to *invert* image gray values into slopes and to integrate the slopes into terrain elevation . The following constraints apply:

* the resulting surface needs to satisfy the slant range constraints;
* the process should employ multiple images to be robust against noise in the image and against the ambiguity between terrain slope and surface properties that also influence image gray values;
* the surface must be continuous;
* the surface must be integratable.

Essentially one refines the stereoscopically measured DEM to make a surface entirely consistent with the terrain as manifested in the image. A full description of the rationale behind radar shape-from-shading is presented elsewhere (Thomas et al., 1990, 1991).

4.5 Hardware and Software Platforms

The radargrammetric mapping software is written in the C language, with components in Fortran 77. The user interface is implemented in X-Windows with Motif.

Hardware is a graphics super-workstation, the STARDENT 3000 computer with a G3 graphics board, and Tektronix SGS625 stereo monitor. A reasonable configuration of the computer is with a minimum of 32MByte of memory and 2.0 GByte of disk space.

This hardware can be configured to perform at a rate of 128 MFLOPS and 128 MIPS.

5. EXPERIENCES

At the time of this writing we are assembling throughput data for the operational processing of maps at scale 1:50,000 and 1:100,000. An initial impression is a 40% increase in the rate at which elevation data are manually collected. Reasons for this increase are *suspected* to be the ability to change the radiometry and contrast, the instant stereo-superposition of measurements over the stereo imagery, and the absence of any inertia due to mechanical motion. This speed increase does not yet account for:

* the reduced need for quality control due to the vastly improved visualization techniques available on a graphics super-workstation;

* the ease of dealing with all procedures in a coherent single workstation environment, instead of the fragmentation in the analog/digital equipment components used previously;

* the avoidance of writing digital images on film since *all* processing is in the digital domain;

* the increase in quality due to the incorporation of shape-from-shading;

* the ability to employ radar-naive operators due to the use of batch- and tracking correlation where quality of the stereo observation is determined by the machine rather than the stereo acuity of the operator.

The ease of creating mapping and data visualization products for subsequent analysis by the professional user and geoscientist is a well-documented feature of graphics super-workstations. It has not been subject to experimental assessment.

6. CONCLUSIONS

We have created an *operational* end-to-end system for mapping of remote areas at scale 1:50,000 and smaller at day and night and under any weather. Accuracies support these scales producing errors of about 0.4 mm at this map scale. We describe the innovative processing system hosted on a graphics super-workstation by STARDENT that supports all image processing and coordinate transformation functions needed for mapping from radar images. Expectations are that the use of this integrated approach may reduce the cost of processing radar images for mapping by a factor of at least 2.

7. REFERENCES

Crandall C.J. (1969) Radar Mapping in Panama. *Photogrammetric Engineering*, Vol. 35

Gracie G. et al. (1970) *Stereo Radar Analysis*. US Army Engineer Topographic Laboratory, Report No. FTR-1339-1, Ft. Belvoir, VA

Leberl F. (1990) *Radargrammetric Image Processing.* Artech House Inc., 685 Canton Street, Norwood, MA 02062

Levine D. (1960) *Radargrammetry*. McGraw-Hill., New York.

Macchia R.P. (1967) Radar Presentation Restitutor. *Photogrammetric Engineering,* Vol. 33.

Mercer B., R. Lowry, F. Leberl, G. Domik (1986) Digital Terrain Mapping with Star-1 SAR Data. *Proceedings* of the IGARS Symposion in Zuerich, Switzerland, pp. 645-650

Scheps B. (1960) To Measure is to Know -- Geometric Fidelity and Interpretation in Radar Mapping. *Photogrammetric Engineering*, Vol. 26.

Thomas J., W. Kober, F. Leberl (1991) Multiple Image SAR Shape-from-Shading. *Photogrammetric Engineering and Remote Sensing.* Vol. 57, pp 51-59.

Thomas J., W. Kober. F. Leberl (1990) Radarclinometry -- Shape-from-Shading. Chapter 15 in *Radargrammetric Image Processing* by F. Leberl, Artech House, Norwood

Yoritomo K. (1972) Methods and Instruments for the Restitution of Radar Pictures. *Archives of the International Society for Photogrammetry*, 12th Congress in Ottawa, Canada, Invited Paper, Commission II.

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