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SMART - A PROGRAM FOR RADAR STEREO MAPPING ON THE KERN DSR-1

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BIOGRAPHICAL SKETCH

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ABSTRACT

SMART (Stereo Mapping with Radar Techniques) is a software package using the Kern DSR-1 analytical plotter for mapping from radar pictures that are presented on film in analog form. Single radar images as well as radar stereo models may be processed; the images may be produced by either real or synthetic aperture systems. The Radar images represent a range projection based on recording the times of imaging and (for slant range presentations) the slant ranges of a point in object space. The orientation parameters and parameters to convert time and range to image coordinates x, y may be found by a radar block adjustment with the cocircularity conditions as basic equations. They define a circle in object space for the location of an imaged point. The computations are in cartesian X,Y,Z - coordinates. The DSR-1 analytical plotter can be used for real-time contouring or planimetric mapping in a parallax-free radar stereo model.

INTRODUCTION

Modern analytical plotters have it made possible to employ other types of images than metric aerial photography for stereo-plotting. Instead of a fixed mechanical or optical analogon for the projection ray one has a flexible computer to relate image xy-coordinates to the cartesian XYZ model system.

Norvelle (1972) probably was the first to actually program an analytical plotter for stereo radar, in this case the AS-11 A. The flexibility of earlier analytical plotters was hampered by the available computers and the use of low-level programming languages. Prior to Nc.velle work stereo-radargrammetry was developed in the context of basic studies, e.g. by Rosenfield (1968) and Gracie et al.(1970), and had led to a rather unique and specific radar stereo mapping instrument (Yoritomo, 1972; Graham, 1972).

The current generation of analytical plotters employs general purpose computers, distributed processing and high level programming languages. Therefore the effort required to program them is much reduced when compared to the early systems. This fact is combined with an increased interest in radar remote sensing as documented by satellite and other radar imaging experiments. Therefore it appears increasingly meaningful to study radar stereo mapping. Autometric (1982) has embarked on a system employing the analytical instrument APPS IV and more recently the AS-11.

In an effort to demonstrate the flexibility of current commercial analytical photogrammetric instruments and in order to explore more fully the capabilities and limitations of stereo radargrammetry we have developed a procedure and software system for the analytical plotter Kern DSR-1 to set-up, and plot from, radar stereo models. This paper is a first and preliminary report on this development, emphasizing a broad description of the procedures of SMART -- Stereo Mapping with Radar Techniques.

The paper will discuss the procedure and demonstrate it with a unique data set. Common radar image acquisition is with parallel flight lines. It is an added complexity to use intersecting flight lines. As will be shown the DSR-1 is able to handle this type of data and produce a digital terrain elevation model of an accuracy commensurate with the radar input.

CHARACTERISTICS OF THE ANALYTICAL PLOTTER

The DSR-1 standard configuration consists of three independent digital processing units, which are denoted as P1, P2 and P3 (Chapuis, 1980). Processor P1 is the host computer. It serves for development and execution of application programs and performs data transfer between the other processors. The computation of set-up parameters for the radar stereo model is done in P1. Processor P2 receives the radar image orientation parameters from P1 and uses them to convert in real time model coordinates X,Y,Z to radar image respectively DSR-1 plate coordinates x',y' and x",y". P2 also transfers image, model or object coordinates to processor P1 if requested. Processor P3 is an added convenience for the operator and controls an operator control panel which may be used for communication between operator and DSR-1.

The Kern DSR-1 therefore uses three computers as opposed to other plotters which may employ only one. What seems to be an added complexity in fact is an advantage: the real-time operations are performed by a seperate processor P2 with a clearly defined software interface for a user working with the host P1. The user will therefore work in a familiar, gen al purpose multi-user environment with an unmodified operating system. The critical real time operations are singled out.

The Kern DSR-1 software is written in PASCAL; also SMART has therefore been written in this language. Current operating systems for the DSR-1 are RT-11 and TSX-11.

OVERVIEW OF SMART MODULES

The programs for stereo radar are organized in seperate modules. The entire process of model set-up follows radargrammetric formulations presented earlier and reviewed by Leberl (1983). Essentially the procedure requires sufficient ground control for the transformation of radar coordinates to the object space. The individual images are processed first to obtain approximate values for the rigorous radargrammetric solution. In the terminology of classical photogrammetry one first solves resections in space for the two images to then continue with a bundle adjustment using both images simultaneously.

Should no ground control be available then one has to work with given or assumed parameters of the flight path and sensor attitude. The preliminary resections would be skipped.

(a) Information and Initialization Module: This task enables the input and manipulation of initial project and image parameters. It serves for general information for the operator, such as for example project name, available images for the project or image and orbit data information.

(b) Control Point Management Module: This module is for the input and manipulation of ground control point data. The ground coordinates are in an orthogonal cartesian coordinate system, usually referenced to an origin within the area to be mapped and the Z-axis pointing along the local vertical of the origin.

(c) Orbit or Flight Data Management Module: This is for input and manipulation of sensor position measurements. SMART assumes the orbit or flight to be represented with time polynomials so that sensor positions $\underline{s}$ may be expressed as follows:

$$\underline{s} = \underline{s}(t) = \underline{a} + \underline{b} \cdot t + \underline{c} \cdot t^2 + \ldots \quad (1)$$

where t is the time. Approximations for the orbit coefficient vectors ($\underline{a}$, $\underline{b}$, $\underline{c}$, ..) will be determined in the orbit data management module. Input are the position measurements, output is an array of polynomial coefficients. Joint low-order polynomials will be used instead of higher order polynomials if the need exists.

(d) Single Radar Image Processing: This module represents the equivalent of a resection in space to compute the orientation parameters for a single radar image with inner and exterior orientation. Plotting with a single radar image may be done on either a spherical surface of chosen radius or in a three-dimensional X, Y, Z - coordinate system with known constant Z.

(e) Stereo Radar Image Processing: This module includes the actual set-up of a radar stereo model. It follows the use of the single radar image module to determine approximations of the exterior orientation parameters of the two overlapping images. After elimination of y-parallaxes this module serves to plot contour-lines or planimetric features. Results are either directly plotted on an xy pen plotter or are entered into a digital data base for further processing. One example that is currently operational is for digital terrain elevation models with the Graz Terrain Model (GTM) program system (Oswald, Raetzsch, in print).

RADAR STEREO MODEL SET-UP

As previously described the radar stereo model set-up in SMART is realized in two steps consisting of the computation of the elements of inner orientation of the radar image pair, followed by an exterior orientation with a radar bundle adjustment.

Inner Orientation: The inner orientation requires the establishment of a relationship between plate or image x, y coordinates and the physical radar measurements of time t and slant range r (Leberl, 1983). The system uses a so-called 'range reference line' at the near range edge of the image; it would correspond to the start of the sweep on the image recorder. It should be defined by some distinct tick marks (fiducials). In the event that no such marks exist the operator has to create artificial marks and determine the inner orientation in a process of self-calibration together with the exterior orientation.

Exterior Orientation: Measurement of homologue orientation points can first of all be as in a comparator by removing manually the x- and y-parallaxes. Secondly after a preliminary resection with each image one is in a nearly parallax-free stereo model and observation of homologue points is made more convenient. In contrast to analog stereo photogrammetry the analytical plotter does not need a relative orientation task seperate from absolute orientation. The parameters of relative and absolute orientation are found simultaneously with a so-called bundle adjustment. In SMART this approach is the one used for radar images. The basic equations for the radar stereo adjustment consist of two types:

(a) The squint [illegible]le condition:

$$\dot{\underline{s}} \cdot (\underline{p} - \underline{s}) - \sin \tau \cdot |\dot{\underline{s}}| \cdot |\underline{p} - \underline{s}| = 0 \qquad (2)$$

(b) The range condition:

$$rs - |\underline{p} - \underline{s}| = 0 \qquad (3a)$$

for slant range presentations

$$(rg^2 + H^2)^{1/2} - |\underline{p} - \underline{s}| = 0 \qquad (3b)$$

for ground range presentations.

Each measured point gives rise to two equations of type (2) and (3). In addition each pair of homologue image points produces one additional condition. This is called the cocircularity condition, which defines the location of an imaged imaged point in object space by the intersection of two circles, each defined by two equations of type (2) and (3). The equations are non-linear. Linearized forms are used in an iterative solution.

Observations for the computations are sensor position measurements, image coordinate measurements of ground control points in one or in both images and pairs of homologue image coordinate measurements of stereo model orientation points. Unknowns to be determined within the adjustment are:

- the coefficients of the orbit time polynomials;
- the radar imaging parameters (inner orientation) to convert radar image coordinates to range and time;
- the parameters of a correction polynomial to describe radar image deformations;
- a value for the squint angle.

The solution for the unknowns in each iteration of the non-linear equation system is obtained in processor P1 in a least squares adjustment using the method of conjugated gradients (Schwarz, 1970). This solution method is iterative and may have some advantages for larger equation systems when a small computer must be used and both computing times and storage requirements are limited. Furthermore there is evidence that the method is more robust for this special problem than a strict Gauss solution of normal equations.

Depending on the quality of the approximate values the adjustment process must be repeated iteratively until results satisfy specified termination criteria.

EXAMPLE OF RADAR STEREO PLOTTING WITH SIR-A SATELLITE DATA

A Space Shuttle Imaging Radar SIR-A stereo image pair of the greek islands Cephalonia and Ithaka was used to illustrate the procedure of extracting a digital height model (Figure 1). A more detailed study of the stereoscopic computations from such data is presented by Kobrick et al.(submitted). Viewing limitations were discussed by Domik et al.(1983). After model set-up the topographic elevations were digitized in the object coordinate system using profiles and ridge lines; the measurements were entered into the terrain model system GTM. The GTM program enables one to generate contour line plots at chosen interval, to obtain axonometric views of the terrain data and various other products.

Figure 2 shows an axonometric view of the digital elevation model (DEM) of the islands extracted from a map 1 : 200 000, Figure 3 presents the DEM created on the Kern DSR-1 analytical stereoplotter. A comparison of the two DEM's is possible with the GTM-system and reveals that the root mean square differences over all DEM points of the islands amount to ± 98 meters.

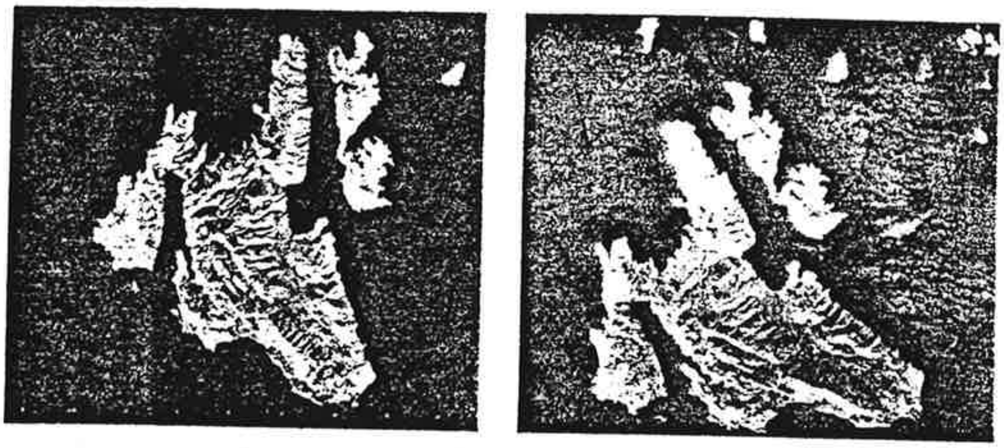

Figure 1. Space Shuttle Imaging Radar SIR-A stereo radar image pair of the Greek islands Cephalonia and Ithaka, taken at 34^{o} angle between flight lines at 45^{o} look angle off-nadir.

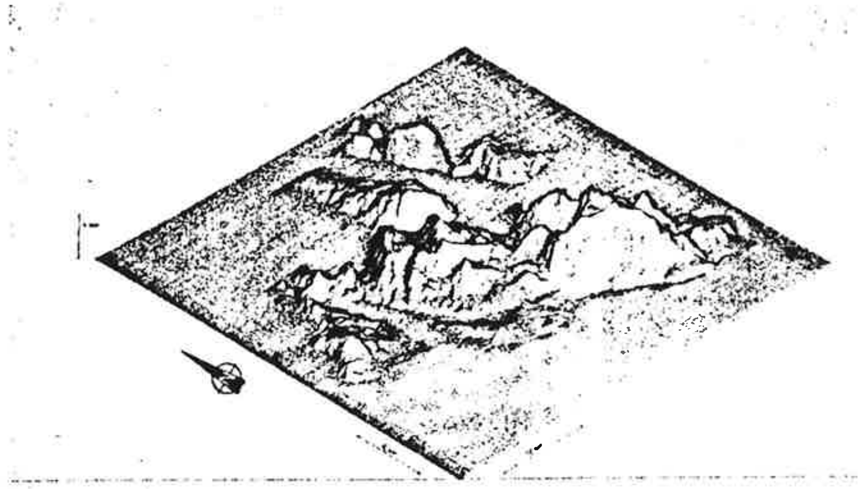

Figure 2. Digital elevation model of the Greek islands Cephalonia and Ithaka in axonometric view. Data are extracted from a map 1 : 200 000.

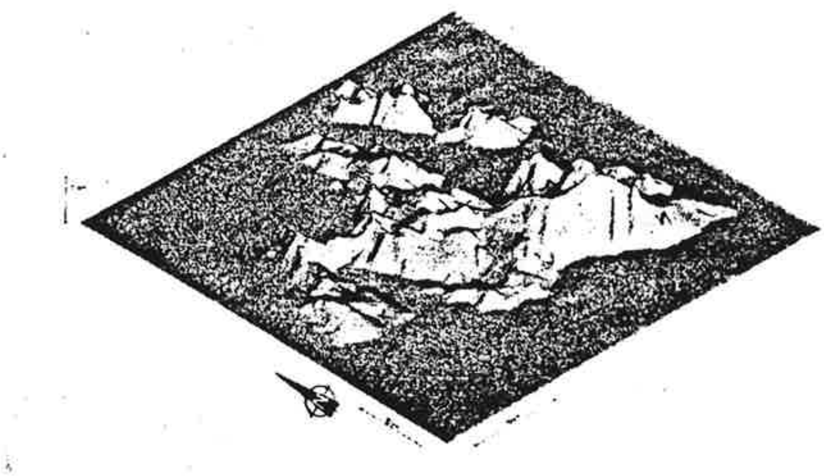

Figure 3. Digital elevation model of the greek islands Cephalonia and Ithaka in axonometric view. Data digitized at KERN DSR-1 stereoplotter.

CONCLUSION

A progress report is presented on a stereo mapping system for radar images in an analytical plotter Kern DSR-1. The procedure and mathematical solution are reviewed and an example is shown with a radar stereo data set from the Space Shuttle Imaging Radar SIR-A. The technique creates a parallax-free radar stereo model and allows one to plot contour-lines and planimetric features at operating speeds that are common in classical photogrammetry.

Future satellite and aircraft radar images will be produced in a digital format. Digital stereo mapping systems will therefore at some point in time replace the analytical stereo plotter in applications to such digital images. Currently, however, radar stereo mapping can be done on existing plotters without extra investments in hardware and in an operational mode. Applications could develop in special cases to support thematic mapping or to create data for image rectification. So far heights obtained from radar stereo have not been accurate enough to serve as a data set in its own right in competition against heights obtained from metric photography. We hope to have shown that an analytical plotter can do the work of stereo radar mapping where this is meaningful.

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REFERENCES

Autometric (1982): "Program Documentation for Analytical Mapping System Radar Model". US Engineer Topographic Laboratory, Ft. Belvoir, Virginia 22060.

Chapuis A. (1980): "Das Kern System DSR-1/GP-1. Analytisches Stereo-Auswertegeraet und graphisches Peripheriegeraet". 14th ISP Congress, Commission II, Hamburg 1980.

Domik G., Leberl F., Raggam J.(1983): "Evaluation of Radar Stereoscopic Viewing". Final report on contract Nr. F49620-82-C-0053, European office of Aerospace and Development, London. DIBAG - Report Nr. 11, Graz Research Center, A-8010 Graz, 127 p.

Fuchs H., Leberl F.(1982): "CRISP -- A Software Package for Close Range Photogrammetry for the KERN DSR-1 Analytical Stereoplotter". Proceedings, Symp. of Comm. II, Precision and Speed in Close Range Photogrammetry, York, United Kingdom, pp. 175 - 184.

Gracie G. et al.(1970): "Stereo Radar Analysis". US Engineer Topographic Laboratory, Report on Contract FTR-1339-1, Ft. Belvoir, Virginia.

Graham L.(1972): "An Improved Orthographic Radar Restitutor". Pres. Paper, 12th Congress of ISP, Ottawa, and Goodyear Aerospace Corp. Report GERA - 1831.

Kobrick M., Leberl F., Raggam J.(submitted): "Convergent Stereo with the Shuttle Imaging Radar". Manuscript, Jet Propulsion Laboratory, MS 183-701, Pasadena, California 91109.

Leberl F.(1983): "Photogrammetric Aspects of Remote Sensing with Imaging Radar". Remote Sensing Reviews, Harwood Academic Publishers, London. pp. 71 - 158.

Norvelle F. R.(1972): "AS-11-A Radar Program". Photogramm. Engineering, Vol. 38, pp. 77 - 82.

Oswald H., Raetzsch H. (in print): "A System for Generation and Display of Digital Elevation Models". Geo-Processing, Geo-Data, Geo-Systems and Digital Mapping; Elsevier Scientific Publishing Company, 1000 AH Amsterdam, Netherlands.

Rosenfield G.(1968): "Stereo Radar Techniques". Photogrammetric Engineering, Vol. 34.

Schwarz H. R.(1970): "Die Methode der konjugierten Gradienten in der Ausgleichsrechnung". Zeitschrift fuer Vermessungswesen, Vol. 4/1970, pp. 130 - 140.

Yoritomo K.(1972): "Methods and Instruments for the Restitution of Radar Pictures". Archives of the ISP, Inv. Paper, Comm. II, 12th Congress, Ottawa.