FIRST EXPERIENCE WITH STEREOCOMPILATION OF MOMS-02 SCENES ON THE ANALYTICAL PLOTTER

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ABSTRACT

The paper describes our experience with photogrammetric stereo compilation and 3-D restitution from high precision photo copies derived from spaceborne digital image data captured with the MOMS-02 three-line stereo scanner camera during the German D2 space shuttle mission in the spring of 1993. Basis of the experimental study is a real-time program module, *MOMS*, developed for the Planicomp P-series analytical plotters running both under VMS on VAXstation and UNIX on Silicon Graphics Indigo as host. The software package is complemented by *ORIMOMS*, an adjustment routine for the determination of the kinematic orientation of MOMS-02 stereo scenes. Performance and results of several experiments with MOMS-02 stereo imagery at scale 1:337,500 and 13.5m ground resolution are discussed in detail. The results indicate a surprisingly high accuracy potential, particularly for heights. Despite the problem of the identification of ground features and notwithstanding interpretation errors, external accuracy may be characterized by rms-errors in the range 4–10m. Inner precision, however, is in the range of 2–4m. Conventional contour plots at the scale 1:50,000 with 5m interval confirm this inner geometric consistency. The software package *MOMS* is ready for photogrammetric production work.

INTRODUCTION

The Modular Opto-electronic Multispectral Stereo Scanner, MOMS-02, developed in Germany, was specifically designed for the generation of high precision digital terrain models and ortho imagery from space in order to meet map specifications at 1:50,000 and larger. Complementary to this mapping function is multispectral imagery to support environmental remote sensing (Fritsch, 1994). In April 1993, MOMS-02 was carried into space for the first time on board the Space Shuttle, as part of the experimental German Spacelab D2 Mission. During a period of ten days, digital image data were captured from an orbit of 28.5° inclination at 300 km altitude over parts of Africa, Asia, South and Central America, and Australia (Seige et.al., 1993).

MOMS-02 is a push-broom scanner type three-line digital CCD-camera with three panchromatic channels (fore, nadir and aft). The high resolution nadir channel has a ground resolution of 4.5 m, the two stereo channels and the four multispectral (nadir) channels furnish 13.5 m. Depending on the selected mode, swath widths of 37 and 78 km are obtained. For further details see (Seige et.al., 1993). With its along-track stereo capability (Fig. 1), MOMS-02 distinguishes favorably from SPOT's across-track stereo configuration, the reason being that stereo imagery is captured practically simultaneously on the same orbit.

The responsibilty of analysing and processing the image data collected during the experimental mission lies within a German research team, the photogrammetry part of which is being coordinated through the Institute of Photogrammetry at Stuttgart University. A preliminary account of the work performed by this group is given in (Dorrer, 1994). While the main goal consists in developing automated methods for the extraction of 3D terrain and topographic object information by purely digital image processing techniques, we have been consistently pursuing the analytical photogrammetric way. Obviously, the majority of work in photogrammetric practice is being carried out in analog/analytical fashion and will certainly continue to do so for the next decade.

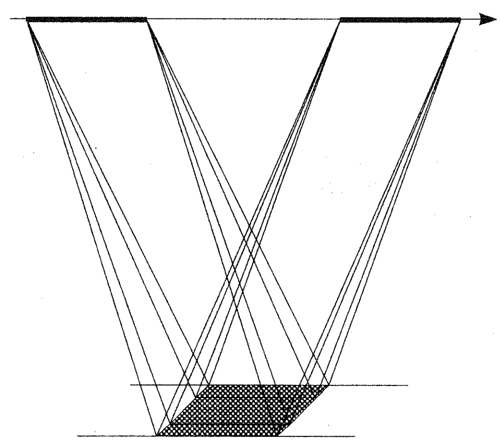

Figure 1: Along-track MOMS-02 stereo configuration

KINEMATIC MODEL ORIENTATION

Unlike the static geometric orientation of conventional perspective frame photography, the orientation of scanned imagery is a kinematic process and must, therefore, be described accordingly. Although the ultimate goal for future missions would be a precision onboard position and attitude determination, e.g. by means of kinematic GPS combined with INS, this has not been the case with MOMS-02. Consequently, investigations into indirect solutions to the kinematic orientation problem have been carried out. (Kornus et al., 1995) and others treated the problem from the general photogrammetric triangulation point of view by extending to several longer strips and using all three-line images. We have restricted our work to single stereo scenes formed by the two fore and aft stereo channels. As the spatial movement of the camera over relatively short segments may be assumed reasonably deterministic and stable, orbit and attitude has been modelled by simply describing the six orientation parameters as second or third degree polynomials in time. The functional approach to kinematic interior and exterior orientation and the theory behind the photogrammetric adjustment and stochastic model of the utilized constrained collinearity equations is described in detail in (Dorrer et al., 1995a).

We developed a program package, denoted *ORIMOMS*, written in C, which enables the determination of kinematic exterior orientation of a MOMS-02 stereo scene from measured image coordinates of a sufficiently large number of tie and ground control points (Dorrer et al., 1995a). *ORIMOMS* is imported in Zeiss' Planicomp analytical plotter data base management software PHOCUS and may thus be called within *MOMS* (see next section), but can also be utilized as standalone version. It identifies the type of spheroidal map coordinates (e.g. UTM) of the given ground control and performs a transformation to a topocentric cartesian system local to the current stereo scene. On a SGI R4000, processing time for *ORIMOMS* with some 100 model points requires less than 30 seconds. Experience so far shows that in order to minimize model parallax, tie points must be selected in insufficiently controlled areas. This is mainly caused by high correlation between some of the orientation parameters and could be relaxed by employing a different functional model.

INTEGRATION IN PLANICOMP-PHOCUS

Analytical stereorestitution of MOMS-02 hardcopy images with analytical plotters is supposed to function under the same basic software system used for the compilation of "normal" metric frame photogrammetry underlying perspective geometry. A software package, denoted *MOMS*, has been developed enabling precision 3D-restitution of MOMS-02 stereo scenes on the Planicomp P-series analytical plotters of Zeiss. Basis is a real-time program module running in background mode under VMS on VAXstation or UNIX on Silicon Graphics Indigo as host. Considering the typical kinematic imaging geometry for linear array sensors, *MOMS* has been rigorously integrated in the latest version of the photogrammetric restitution software system PHOCUS (Fig. 2).

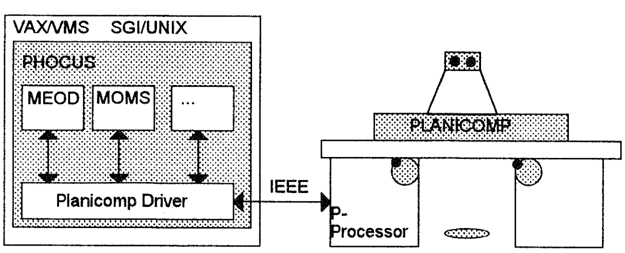

Figure 2: Experimental *MOMS* software integration into PHOCUS environment.

Several necessary or useful interactive functions are available, e.g. determination of interior orientation; determination of exterior (absolute) orientation via the program *ORIMOMS*, unless already known from external sources; semi-automated mono- or stereoscopic measurement of image points; 3D-measurement of model points and contours; transformation of object coordinates between different mapping systems (presently UTM, Gauss-Krüger, Spheroidal, Geocentric, Topocentric). The influence of earth curvature on elevation contour lines as well as geometric nonlinearities of the individual CCD-lines (Dorrer, et.al., 1995c) may be considered by realtime corrections within *MOMS*.

Since the size of analog pictures on the Planicomp stages is limited to 230 by 230 mm, particular emphasis must be placed on a simple way of extracting specifically defined stereo measurement scenes from the original image data format. For this reason, a separate, interactive program package, *MOMS_GIID*, running under UNIX and VMS on workstations equipped with X11-libraries, has been developed. It contains several useful functions permitting direct on-line access to line and frame header information of the image data, e.g. image roaming and zooming, simple image enhancement, specification of individual stereo scene formats, image data output for the production of hardcopies on a precision filmwriter, etc.

For a detailled description of the main features of the entire software package see (Dorrer et al., 1995b)

ACCURACY POTENTIAL OF 3D-MEASUREMENT

In essence, two larger experiments were performed with data taken over the Andes in Bolivia (orbit 115) and the Out-Backs in Australia (orbit 75b). All image and stereomodel measurements were carried out in a Planicomp P2 analytical plotter on diapositives with 40 mikron pixel size yielding 1:337,500 image scales for channel 6/7 stereoscenes (ground resolution 13.5 m). The diapositives were produced on a Cirrus LC-3000 Laser filmwriter at GAF Image Processing Services. While ground control for the Bolivia scene could only be derived from an old 1:50,000 topographic map, the Australia scene was fully controlled by over 50 GPS-determined ground points with sub-decimeter accuracy (Fraser et al., 1996). Therefore, trustworthy accuracy assessment results, to be discussed in the sequel, could only be expected from the Australia scene.

The Australia scene covers a fairly flat and featureless terrain in the Lake Nash/Georgina River area of the southeast Northern Territory. Maximum elevation differences are below 80m. Even though ground control was referred to man-made features, e.g. corners of small dam sites, intersections of country roads or fence lines, centers of water holes, point identification in the imagery turned out to be nontrivial. See also (Fraser et al., 1996) for details. Stereoscopic interpretation and identification proved extremely helpful, and must be strongly recommended for future work. In the course of determining the kinematic exterior orientation with *ORIMOMS*, 7 control points had to be rejected for obvious gross errors. Some of these could be corrected due to misinterpretation and were reconsidered. Together with 41 measured tie points, the rather strong datum resulted in an absolutely parallax-free stereomodel.

In order to obtain an objective indication of the overall accuracy of the adjusted object points, several tests with varying numbers of control points were performed. For each test, unused control was entered as tie point information in the orientation adjustment and could therefore be considered as check points. The diagram in Fig. 3 exhibits the attained check point rms-errors vs. the number of control points used. Obviously, the rms-errors increase with decreasing number of control points, which my be an indication of still unmodelled residual systematic errors. The rather constant distribution of the planimetric rms-errors for tests with higher control density suggests an influence of a constant error due to misinterpretation on the ground or in the imagery. Indeed, as (Fraser et al., 1996) report, such errors in the order of 1-2 pixels cannot be discounted in matching a feature on the ground with its imaged position due mostly to changes of the terrain surface in the time span between image acquisition (1993) and ground survey (1994 and 1995). The vertical rms-values seem not to be influenced significantly by interpretation errors. This can be deduced from Fig. 3 and from the fact that, due to the flat terrain, the vertical measurement error is independent of the planimetric residual error.

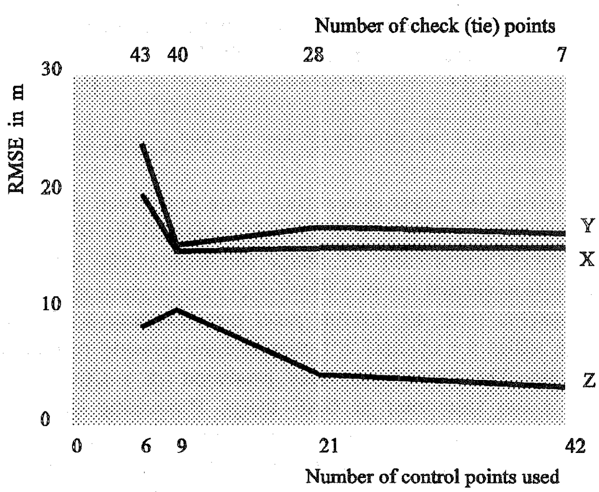

Figure 3. RMSE vs. number of control points (Australia scene)

If the rms-error, μ , is assumed to be related to the number of control points, n, and to a constant interpretation error, μ_I, according to

$$\mu^2 = \mu_I^2 + \mu_0^2 + (k/n)^2 ,$$

then, assuming the vertical interpretation error to be zero and the ratio $k/\mu_0 = const.$ for all three coordinates, the following empirical relations in units of m were deduced

$$\mu^2_{X,Y,Z} = \begin{pmatrix}14.0\\14.3\\0\end{pmatrix}^2 + \begin{pmatrix}4.7\\6.1\\3.6\end{pmatrix}^2 + \frac{1}{n^2}\begin{pmatrix}72.8\\97.6\\57.3\end{pmatrix}^2 .$$

The estimated planimetric interpretation rms-errors in the order of 14 m seem consistent with the previous statements. Without it and provided 9 control points are available, realistic measurement rms-errors of 9m, 12m and 7m may be expected for the X-, Y- and Z-coordinates, respectively. The values would drop to 7m, 9m and 5m, respectively, if 15 control points were used. As these error values represent somewhat absolute quantities, a truly remarkable result, indeed. It shows that stereophotogrammetric measurements achieve sub-pixel accuracies, particularly in height.

The high accuracy potential for elevations derived from MOMS-02 stereomodels was confirmed by independent stereophotogrammetric measurements along a GPS-controlled DTM evaluation profile. This profile, situated in the western part of the Australia scene, is identified by over 16km of a fence line clearly visible in the imagery and was established during the 1995 field survey (Fraser et al., 1996). In a preliminary investigation, ten reference points established along the fence line, were measured repeatedly (five times each) in the Planicomp in due course of the profile measurement. Fig. 4 exhibits the differences between the photogrammetric heights and the surveyed control elevations. Notice the vertical scale of 2m vs. the 500m in horizontal direction. Several conclusions may be drawn. First, internal precision is in the range of 1.2–3.0m standard deviation. Then, external accuracy is biased by unmodelled systematics, e.g. model deformation or datum problems, and influenced by interpretation errors. In the analyzed test data, rms-errors lie in the range of 4.0–9.0m. Finally, if an obvious linear trend is removed, the remaining rms-values decrease to a range of 2.0–5.0m. A detailled investigation of the entire height profile will be given elsewhere.

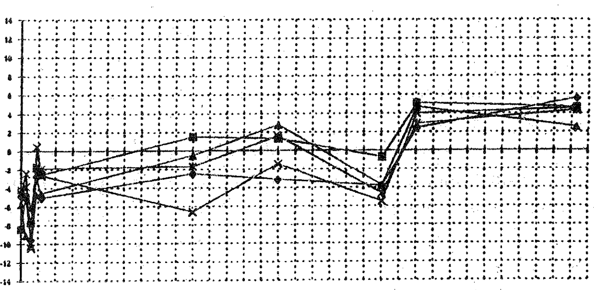

Figure 4. Height differences (in m) at ten reference points along DTM evaluation profile

EXPERIMENTAL STEREOPLOTTING

The rather surprising high elevation accuracy could be reproduced in a first attempt to generate a "conventional" elevation contour map. In an area covering 20km by 15km near the center of the Australia scene (see Fig. 5 as part of the backward looking image) and exhibiting relatively rough topography with elevations up to 50m, contour lines with 10m equidistance were measured on the analytical plotter. After some familiarization with the rather small image scale, the human stereooperator, until then only acquainted with aerial photography, has found it increasingly easy to generate the contour lines shown in Fig. 6. Continuous lines represent contours with 10m interval, dotted lines with 5m. Notice that adjacent

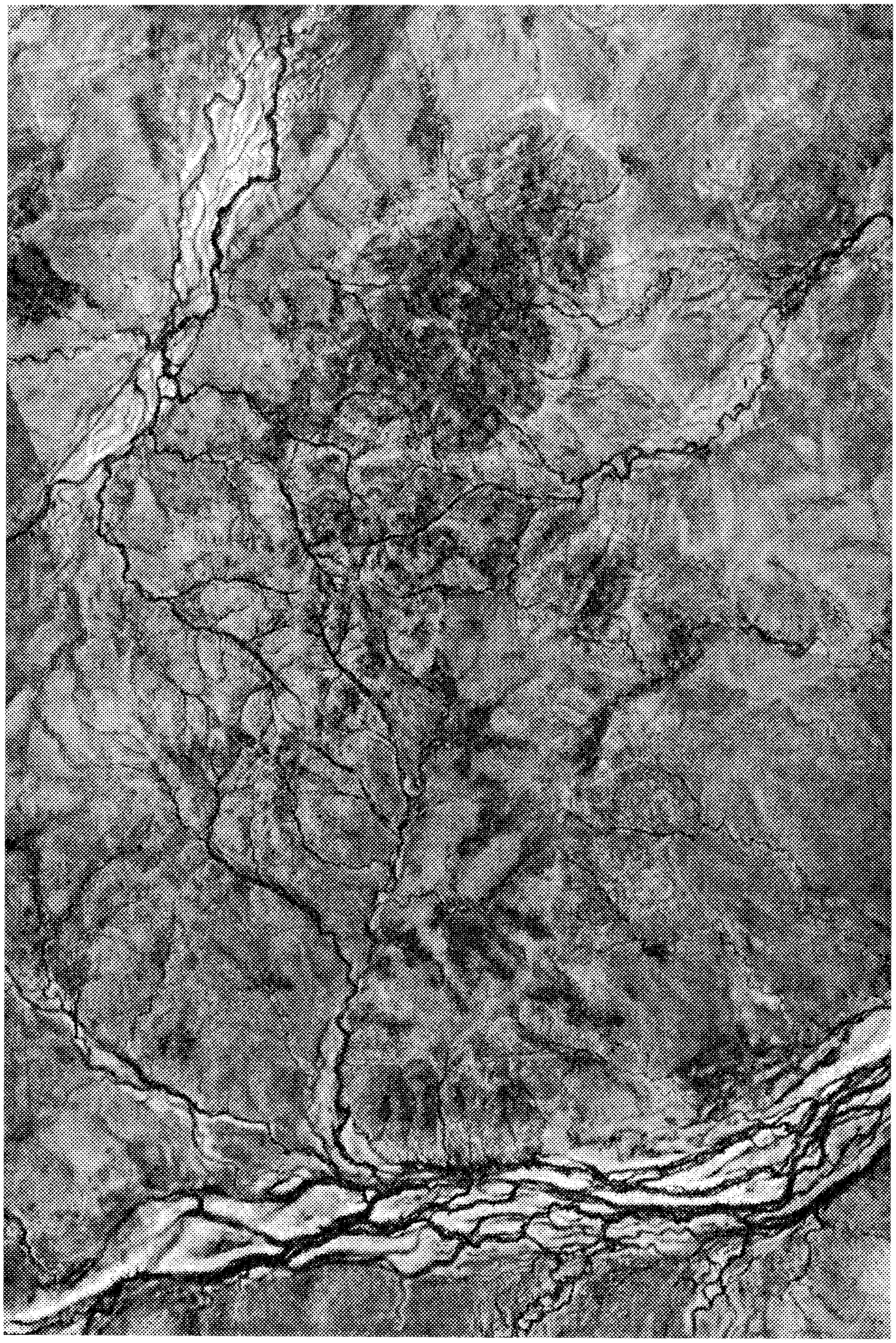

Figure 5. Central part of the backward looking MOMS-02 image of the Australian testfield covering the contour plot in Fig. 6

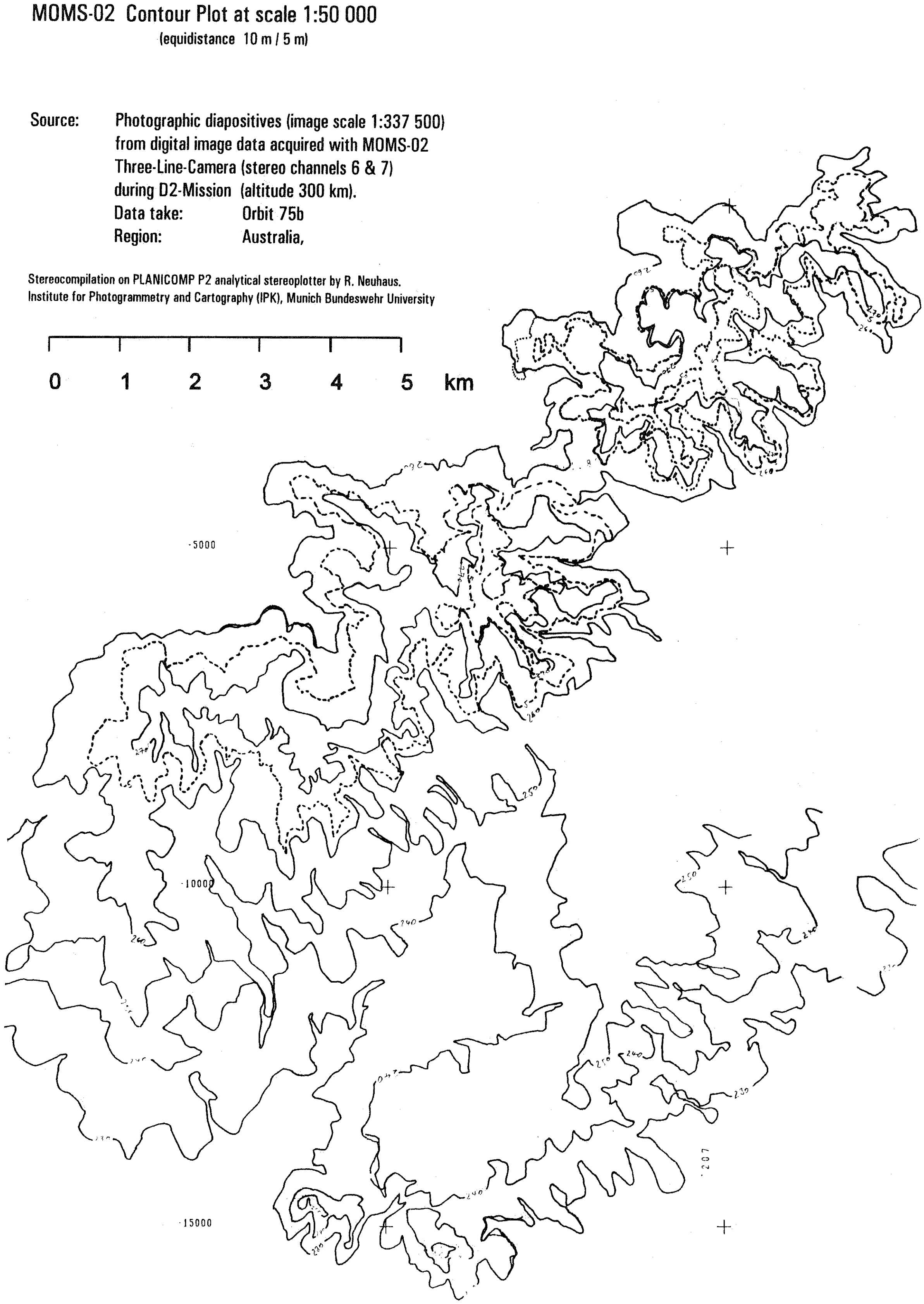

Figure 6. Experimental elevation contour plot with 10m (5m) interval (Australia scene)

lines never cross and seldom touch each other. Inspection of some of these regions revealed steep escarpments and cliff-like slopes on both sides of numerous short ravines, hence indirectly verifying these situations. It is indeed a surprise that quality 5-m-contour lines can be measured from stereo imagery with 13.5m ground resolution. This might be seen as evidence for a still higher degree of inner consistency in the order of some 2m standard deviation in height.

The Bolivia scene covers an extremely rugged, highly mountaineous terrain of the central part of the Andes in the Rio San Juan Del Oro region close to the border of Argentina. For this scene, where ground control could only be derived from an old 1:50,000 topographic map, identifying suitable and clear control features both on the map and the imagery turned out to be a major problem. Planimetric features on the map could only be identified with an accuracy in the range of 10m to 30m. By virtue of the stereo capability, vertical control could be identified and measured within a few meters. Therefore, clearly visible spot heights, particularly mountain peaks, are extremely well suited for vertical control. This is one of the advantages of stereophotogrammetry. In this way, 41 control points could be identified. Their digitized map coordinates with estimated standard deviations in the order of 0.1mm had to be transformed from the original UTM grid to a scene-local topocentric cartesian system. Together with 57 measured tie points, *ORIMOMS* succeeded in producing a parallax-free stereomodel despite the relatively weak datum. Encouraged by the good results obtained from the Australia stereo scene, we decided to demonstrate the feasibility of measuring contour lines in mountaineous terrain. In an area covering some 10km by 25km and with elevation differences in the order of some 700m, contour lines with 20m interval were measured. The final plot in Fig. 7 shows a typical Andean north-south running mountain ridge with a few peaks up to 4,300m altitude, steep slopes facing west and moderate easterly slopes towards a flat depression. Captured under PHOCUS, the data base consists of some 400 individual objects encompassing 255,000 coordinates and requires 2.5 MByte disc space. Visual comparison with the contours in the topographic map mostly showed good agreement.

CONCLUSIONS AND FUTURE ASPECTS

With the presented system, extensive topographic mapping by means of spaceborne three-line stereo imagery is near at hand. Map scales of 1:50,000 or larger can be produced by conventional analytical photogrammetry from 1:350,000 image scale. Although stereocompilation of analog photoproducts derived from digital image data may be considered an "anachronism", nevertheless, its high potential for "conventional" mapping and map revision is obvious – at least as long as purely digital photogrammetric solutions are still immature or too expensive for practical work. *MOMS* is ready for photogrammetric production expecting stereo image data to be acquired on the MIR-Station and made available during the joint Russian-German MOMS-2P Priroda-Mission beginning in August 1996

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Figure 7. Experimental elevation contour plot with 20m contour interval (Bolivia scene)