Karl Kraus
Institut für Photogrammetrie der Technischen Universität
Vienna, Austria

Rectification of Multispectral Scanner Imagery*

Rectification is accomplished first by interpolating image points to map points and then by transforming the remainder of the imagery based on the parameters of that interpolation.

Introduction

In remote sensing, multispectral line-scanning systems are of particular importance. They permit the simultaneous recording of the radiation properties of the scanned surface of the Earth in various spectral ranges. The radiation intensities are first recorded in analog form on magnetic tape and may then be transformed into photographic images by means of special reproduction equipment. Thus, photographic images may be produced for each particular spectral range and also for combinations of various spectral ranges.

These images have not been widely used, however, because of their poor geometric properties. On the one hand, they cannot be immediately related to existing topographic and thematic maps and, on the other, it is impossible to fit adjoining strips together without gaps.

In view of this situation, the rectification of multispectral scanner (MSS) images is one of the most important problems to be solved in remote sensing. For ERTS MSS photos with their small deformations such rectification has in principle been achieved, e.g., by IBM (Bernstein, 1974). Undistorted MSS photos taken from an aeroplane have so far not come to the attention of the author. According to a report by Konecny (1975) this problem is being dealt with at Hannover Technical University and at Purdue University, USA.

Interesting proposals have been published concerning particular aspects of the rectification problem. Various authors (Baehr, 1975; Baker, Marks, and Mikhail, 1975; Derenyi, 1974; Leberl, 1971a) have elaborated methods for determining the deformations of MSS photos by means of formulas on the basis of reference points. Further, Leberl (1971b) has stated general ideas for a rectification of MSS photos.

After the presentation of the new digitally-controlled orthophoto system developed by Wild Heerbrugg Ltd. (Stewardson, 1974; Poelzleitner, 1975), the author saw the possibility of rectifying MSS photos by means of a combination of available equipment. The process begins in a stereocomparator, in which the image deformations are measured in discrete points and recorded on a digital data carrier. These data are processed by a computer program which produces as output, on magnetic tape, the data required to drive the orthophoto projector (Wild Avioplan OR 1). The transformation in the Avioplan OR 1 is carried out by a direct optical method. The entire process of this digitally controlled, optical differential rectification of MSS images will be described in the following paragraphs by means of a practical example.

Data for the Example

The example is taken from a set of MSS images made by order of the government of Lower Austria to document the drainage conditions in the Marchfeld area. The flight, performed by a Pilatus Porter of the Austrian Federal Bureau of Standards and Surveys, was carried out at an altitude of h = 3350 m. A Daedalus scanner, DEI 1250 of Spacetec Ltd., Vienna, with a total aperture of $2\Theta = 77°$, was used. This scanner simultaneously registers radiation intensities in 11 channels in the spectral range from 0.38 to 14.0 μm. The transformation of magnetic tape recordings into photographic images was per-

* This article was originally published in German as "Die Entzerrung von Multispektralbildern" in ***Bildmessung und Luftbildwesen,*** Issue No. 4, 1975. Reproduced by permission of Herbert Wichmann Verlag, Karlsruhe, West Germany.

formed by a Daedalus printer, DEI 616, of Spacetec Ltd. This equipment produces film strips 120 mm wide (b = 120 mm). In this connection, so-called roll and panoramic corrections are applied, i.e., the lateral inclination of the plane is compensated, and the angular velocity of the recording cathode ray flying spot is varied so as to prevent distortions within a profile, 120 mm in length, provided the terrain is horizontal. From those data the following approximate picture scale number results:

$$m_b = \frac{2h \tan \theta}{b} = \frac{2 \cdot 3350 \cdot \tan 38°.5}{0.120} = 44\,000$$

PRINCIPLES OF THE METHOD

The distortions of the MSS images obtained by means of the line-by-line recording and reproduction system—disregarding errors arising in the equipment—are due to:

- Longitudinal tilt and swing of the scanner,
- Y- and Z-deviations of the aircraft from the pre-determined horizontal flight line,
- varying flying speeds, and
- variations in ground altitudes.

Since the line of flight, longitudinal tilt, and swing are unknowns varying in time, these parameters as in photogrammetry, can be determined only from control points. The correspondingly modified collinearity relations are established for the scanned profile strips and then certain simplifications relative to the flight parameters to be determined are introduced (Konecny, 1972).

A different procedure for the evaluation of MSS images consists in regarding the distortions in the MSS photo as being essentially independent of the flight parameters and, starting with the distortions at the control points, determining the rectification of the remaining image points by means of interpolation.

Baker, Marks, and Mikhail (1975) were able to prove that, with the same number of control points, the interpolation method yields better results than does the method analogous to that used in photogrammetry. Thus, it can be taken for granted that the differential rectification of MSS imagery based on the interpolation method is of a high level of accuracy.

COMPARATOR MEASUREMENT

The determination of control-point coordinates and of distortions at the control points can be done with a stereocomparator. For the Marchfeld example, a topographic map, scale 1:50 000, was placed in the left picture carrier of the Wild STK 1, and an MSS picture, photographically reduced to about the same size, was placed in the right picture carrier.

Of the various spectral ranges, the strip of channel 11 was chosen. The grey tones of that strip, it should be noted, closely resemble a classical black-and-white aerial photo.

Because the operator is able to observe both the MSS image and the map in the stereocomparator simultaneously, he is thus able to select, comparatively easily, identical points. The double images also enable him

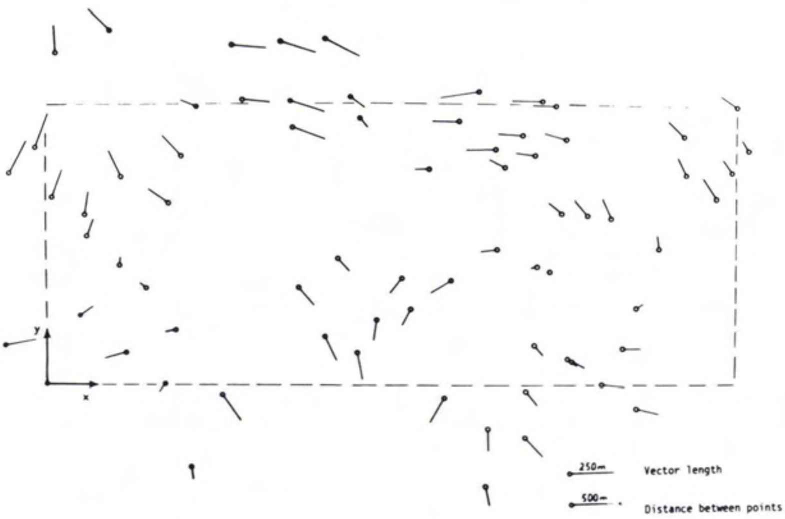

FIG. 1. Distortions of the MSS image in the 74 control points.

to vary the control-point density in relation to local distortions. In this example, 74 control points were measured in this way (Figure 1) and recorded on a digital data carrier.

DATA PROCESSING

For differential rectification of the MSS image, the next step is to transfer the distortions at the control points to a square reference grid. In principle, the parallaxes of the comparator measurements, which are identical with the distortions of the MSS image relative to the topographic map, can be introduced into the interpolation method as reference values. Because the entire image may be rotated and its scale varied in the Wild Avioplan OR 1 (Stewardson, 1974), the reference values measured originally are reduced by the values derived by means of a similarity transformation before being rectified differentially. Such a reduction is achieved by carrying out a Helmert transformation with the picture coordinates of the topographic map and of the MSS image. Figure 1 shows the residual deformation vectors after the Helmert transformation (reference values for the subsequent interpolation). The mean square values in the *X*- and *Y*-directions are—

$$\sqrt{V_{1,x}} = \pm 86 \text{ m} \qquad \sqrt{V_{1,y}} = \pm 72 \text{ m}$$

Where V_1 = variances of residual deformation vectors.

In principle, various interpolation methods are suitable for the transfer of distortions from the control points to a square reference grid. Because the author possesses a computer program, QINT, for "Linear Least-Squares Interpolation" (Kraus, 1972), and other authors have achieved good results with this statistical interpolation (prediction) method (Baehr, 1975; Schut, 1974), it was applied to this example.

The statistical analysis of the reference values (Kraus, 1972) resulted in the following covariance functions in terms of distance *d*:

$$C_x(d) = 0.990\, V_{1,x} e^{-(0.0012\, d)^2}\;;$$
$$C_y(d) = 0.985\, V_{1,y} e^{-(0.0008\, d)^2}$$

The linear least-squares interpolation, on the basis of these covariance functions, led to the vectors shown in Figure 2.

DIFFERENTIAL RECTIFICATION

The result of the interpolation outlined above may be interpreted: In the MSS image the coordinates of points arranged in "traverses" are known; they correspond to points in the topographic map equidistant from each other along parallel linear profiles. In order to obtain a non-distorted MSS picture, the MSS image must be differentially transformed so as to produce a square grid in the transformed MSS picture in place of the previous "traverse" net.

The new, digitally controlled Wild Avioplan OR 1 (Stewardson, 1974) works on this principle. It obtains the computed "traverse" coordinates, computed in the CYBER 74 of the Technical University of Vienna, of the original MSS image on magnetic tape. A small process computer, forming part of the Avioplan OR 1, controls a Dove prism and a zoom lens for the desired scan-by-scan transformation.

The result, with the 1:50 000 topographic map superimposed, is shown in Figure 3. The transformation was done in 13 scans parallel to the *Y*-axis. In general, good correspondence was achieved between the map and the transformed MSS image. The dis-

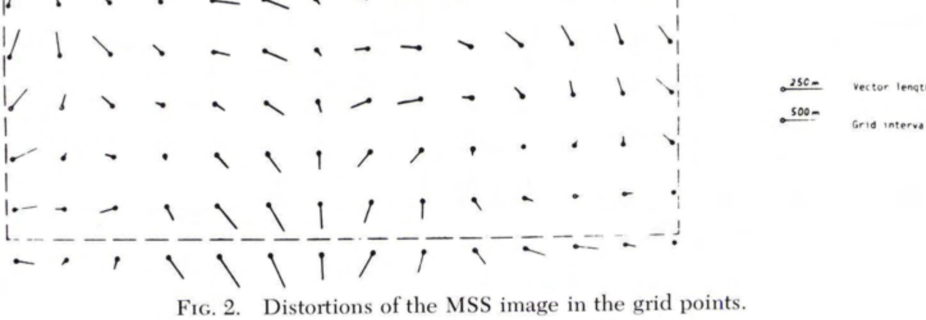

FIG. 2. Distortions of the MSS image in the grid points.

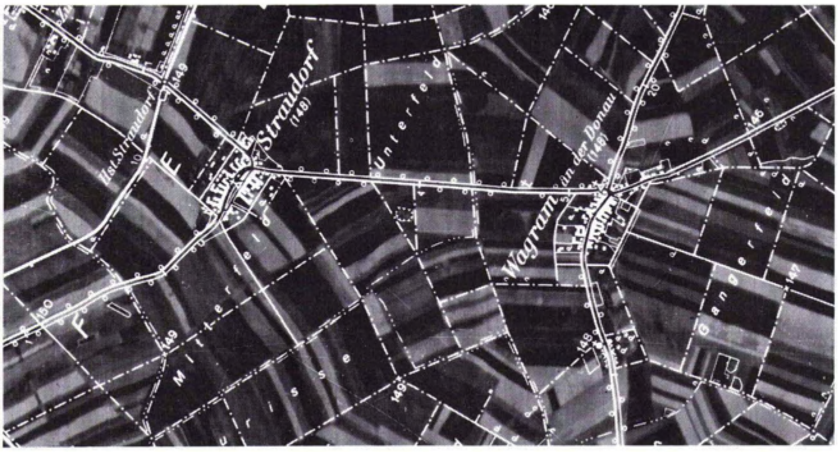

FIG. 3. Superimposed 1:50 000 scale topographic map and rectified MSS image.

crepancies still present as Figure 2 shows are due to the inadequate number and distribution of control points in those areas. It is important to note that only the differentially rectified MSS image, coinciding with the map, permits a completely accurate reference of the information in the MSS image to the parcels of land, which is what the government of Lower Austria was concerned with when it ordered the survey in the Marchfeld to be made.

The tape with the data for the differential rectification of the MSS image reproduced by channel 11 may subsequently be used for the transformation of the MSS images reproduced by other channels. The measuring and computing work for one ground section has thus only to be done once in order to rectify the various MSS images of one flight automatically.

FURTHER POSSIBILITIES

The procedure described by means of the example of the Marchfeld may be expanded in various directions. Instead of a topographic map, generally speaking an orthophoto is more suitable as a reference basis. In the examination of the orthophoto and the MSS image in the stereocomparator, control points can be selected more easily. Particularly ideal conditions are created if the MSS images and aerial photos are taken during the same flight and orthophotos are then first produced from those aerial photos.

The geometrical quality of the rectified MSS images may be enhanced and the number of control points to be measured in the comparator may be reduced if the sensor is mounted on a stabilized platform in the aircraft. Such stabilization is particularly important for the swing, κ (rotation about the x-axis) (Leberl, 1971b).

The accuracy of linear least-squares interpolation and, thus, also of differential rectification may be increased by separating the determinist trend before interpolation proper. Various components may feature as trend:

- The (usually) greatly different scale of MSS photos in the two coordinate directions (affine transformation instead of the Helmert transformation used so far.
- The image displacements perpendicular to the flight direction due to height differences in the ground. Heights might be taken from a digital terrain model that would result as a by-product during the orthophoto production already mentioned (Kraus, 1975).
- Inclusion of the camera stations and the other external orientation elements of an aerial photo block which might be taken during the MSS flight. The coordinates of the camera stations and the three rotation angles of the pictures would be obtained as a result of a block adjustment.

The rectification procedure presented and the further possibilities indicated may be extensively applied to the rectification of radar images.

SUMMARY

A versatile use of MSS imagery requires its rectification. In this paper a rectification procedure is presented which functions as follows: The distorted MSS imagery is placed in the right- and an orthophoto or a line map in the left-hand side of a stereocomparator. The image deformations are then measured in discrete points and interpolated for a square reference grid by using

a medium-size computer. The interpolated grid values are stored on magnetic tape which serves as the input for the control unit of the differential rectifier Wild Avioplan OR 1.

ACKNOWLEDGMENTS

My thanks are due to Dipl. Ing. Dr. techn. G. Stolitzka, Professor, Agricultural University of Vienna, for suggesting this paper. Dipl. Phys. M. Sartori, manager of Spacetec Ltd., Vienna, and the members of the government of Lower Austria kindly assisted in organizing interdisciplinary cooperation. Further, my thanks are due to Wild Heerbrugg Ltd., who carried out the differential rectification in the prototype of their Avioplan OR 1 on November 18, 1974. My assistants, Dipl. Ing. Dr. G. Otepka and Mr. J. Tschannerl, worked on the example.

REFERENCES

Baehr, H. P., 1975. Interpolation and Filtering of ERTS-Imagery, *Bildmessung und Luftbildwesen* 43: 28-29.

Baker, J. R., G. W. Marks, E. M. Mikhail, 1975. Analysis of digital multispectral scanner (MSS) data, *Bildmessung und Luftbildwesen,* 43: 22-27.

Bernstein, R. 1974. Digital Image Processing of the ERTS-Data. XIV.FIG-Congress in Washington, Commission 5, Publication Nr. 510.1.

Derenyi, E. 1974. Planimetric Accuracy of Infrared Line Scan Imagery. *Canadian Surveyor,* 28: 247-254.

Konecny, G. 1972. Geometrische Probleme der Fernerkundung. *Bildmessung und Luftbildwesen,* 40: 162-172.

__________. 1975. Approach and Status of Geometric Restitution for Remote Sensing Imagery. *Bildmessung und Luftbildwesen,* 43: 2-11.

Kraus, K. 1972. Interpolation nach kleinsten Quadraten in der Photogrammetrie. *Bildmessung und Luftbildwesen,* 40: 3-8.

Kraus, K. 1975. Erfahrungen mit einem digitalen Geländemodell. *Mitteilungen der geodätischen Institute der TH Graz,* Folge 18: 177-186.

Leberl, F. 1971a. Metric Properties of Imagery Produced by Sidelooking Airborne Radar and Infrared Linescan Systems. ITC-Series A, No. 50, 124-151.

__________. 1971b. Vorschläge zur instrumentellen Entzerrung von Abbildungen mit Seitwärts-Radar (SLAR) und Infrarot-Linienabtastsystemen (IRLS), *Bildmessung und Luftbildwesen,* 39: 85-90.

Poelzleitner, F. 1975. Orthophotoherstellung mittels Bildkoordinaten im Universalorthophotosystem, *Zeitschrift für Vermessungswesen* 100: 42-47.

Schut, G. H. 1974. Two Interpolation Methods, *Photogrammetric Engineering* 40: 1447-1453.

Stewardson, P. B. 1974. Ein neues universelles Orthophotosystem. *Schweizer, Zeitschrift für Vermessungswesen,* Fachblatt 2/74, Juni 1974.

Forthcoming Articles

Gene L. Brothers and *Ernest B. Fish,* Image Enhancement for Vegetative Pattern Change Analysis.
J. Fleming, Exploiting the Variability of Aerochrome Infrared Film.
Dr. Robert W. Johnson, Mapping of Chlorophyll *a* Distributions in Coastal Zones.
Dr. V. Kratky, Reflexive Prediction and Digital Terrain Modelling.
Clifford J. Mugnier, Analytical Rectification Using Artificial Points.
Dr. Charles K. Paul, Internationalization of Remote Sensing Technology.
John P. Snyder, The Space Oblique Mercator Projection.
Dr. Hartmut Ziemann, A Coordinate System for Aerial Frame Photography.