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Geometrical Quality of Stereo-Orthophotos Produced from Automatic Image Correlation Data

Stereo-orthophoto derived terrain heights were compared with those obtained by automatic image correlation and by manual stereo compilation.

INTRODUCTION

THE GESTALT PHOTO MAPPER GPM II was modified by Gestalt International Limited, under an unsolicited proposal program managed by the Forest Management Institute (FMI), to allow production of stereo-orthophotos. The GPM II is particularly suited for simultaneous production of orthophotos and stereomates because the instrument is equipped with two image transfer systems and printing units (Crawley, 1974). In the conventional mode of operation, one of these units is used for recording the orthophoto image, while the other one is used for on-line recording of contour lines. By sacrificing the possibility for on-line contour printing, it was possible to convert the instrument to enable simultaneous recording of the orthophoto and stereomate images. Contour lines are plotted in an off-line mode of operation from the recorded terrain data on a computer controlled plotting table.

The use of identical height data for the production of the orthophoto and the stereomate, or a simultaneous production process, is important in view of the height accuracy of the stereo-orthophoto pair (Collins, 1968). This was demonstrated for manually operated orthophoto systems (Collins and van Wijk, 1976). In the case of the GPM II system, this would mean that errors in the automatic correlation, such as caused by vertical terrain discontinuities, would only partially affect the height accuracy of the stereo-orthophotos produced on this system.

In this paper experimental results are presented, which were obtained from various stereo-orthophotographs produced on the GPM II system. The height accuracy of the stereo-orthophotos, as compared with the Digital Terrain Model (DTM), is evaluated.

KEY WORDS: **Automation; Correlation; Gestalt photomapper; Images; Stereo-orthophotos; Terrain**
ABSTRACT: The geometrical quality of stereo-orthophotos, produced on the Gestalt Photo Mapper II by automatic image correlation, is analyzed. The terrain heights measured in these stereo-orthophotos are compared with the DTM obtained from the same automatic image correlation data and with corresponding information derived from the original photographs by conventional photogrammetric techniques. The experimental results refer to various terrain types. The effect of vertical terrain features, such as trees and buildings, on the accuracy of the automatic image correlation process and the stereo-orthophoto is evaluated.
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TEST MATERIAL

The experiments are based on three stereo

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overlaps of photographs at scales 1:15 000, 1:10 000, and 1:16 000 respectively of the Sudbury, Ripon, and Tandil test areas (Table 1). The photographs of the Sudbury and Ripon areas were taken with a Wild RC8 wide-angle reseau camera. The photographs of the Tandil area were taken with a Wild RC5 wide-angle camera.

The Sudbury test area consists of a mainly bare and rocky landscape with vegetation in the form of bush and shrubs restricted to the lower areas. It contains a dense net of targeted control points with X, Y, and Z coordinates determined by precise surveying. The Ripon area, used in the ISP Orthophoto Experiment (Blachut and van Wijk, 1976), is mainly a farming area with open fields, farm buildings, and a few forested sections. The Tandil area also offers a combination of open country, forests, and built-up areas. This area was previously used for a large-scale mapping experiment by the Pan-American Institute for Geography and History. The control for the Tandil and Ripon photos was densified photogrammetrically. In the Tandil area well-defined terrain details served as reference for the photogrammetrically determined check points, while for the Ripon area the reseau crosses in the photo, from which the orthophoto was produced, were used for this purpose. Similarly, for the Sudbury test area the photogrammetrically determined ground elevations corresponding to the reseau marks in one of the photos, were used as additional elevation check points. Reseau marks that coincided with trees or buildings were omitted from the analysis.

In experiments, such as the present one, where photogrammetrically determined coordinates can serve as a basis for the accuracy evaluation, the use of reseau marks offer certain advantages. They offer a dense net of approximately 200 points in a regular stereo overlap, they can be identified easily and represent the different terrain forms in the model, such as flat areas, slopes, gulleys, etc. This is not usually the case with targeted control points, such as in the Sudbury area, which because of survey and targeting requirements are in most cases located in relatively flat and horizontal areas on tops of hills. A reseau mark, in addition, does not form a stereoscopic target and consequently does not affect the image correlation favourably (human controlled or automatic). The results obtained from the reseau marks are, therefore, more representative of the actual terrain surface than those obtained from the targeted control points.

The x-parallax in the stereomates was generated as a linear function of the terrain height according to the average base/height ratio. For the Sudbury and Ripon test models, additional stereo-orthophoto pairs were produced with a vertical exaggeration of approximately 57 percent. Collins (1970) suggested the use of a logarithmic function to improve the stereo-orthophoto height accuracy. The degree of improvement would depend on the terrain height differences within the stereomodel and on the magnitude of the correlation or profiling errors. The International Orthophoto Experiment (Blachut and van Wijk, 1976) indicated that for the GPM system the correlation errors for the terrain surface, in the vicinity of vertical terrain features such as buildings and trees, could amount to 0.4 mm at the scale of the original photos (1:10 000). Even for such an excessive height error, the differences between x-parallaxes, generated by the linear and logarithmic approximations of the parallax equation, would not exceed 0.01 mm at photoscale for the terrain height differences in the models used in this experiment. The logarithmic x-parallax/height function would, therefore, not have improved the vertical accuracy obtained in the present experiment.

TABLE 1. MATERIAL USED IN THE EXPERIMENT

Test area	Scale of photos and stereo-orthophotos	Average flying height	Terrain elevation differences	Average base/height ratio	Px/h	Type of Control
Sudbury	1:15,000	2,280 m	55 m	0.645	0.645 1.014	targets & reseau
Ripon	1:10,000	1,520 m	80 m	0.671	0.671 1.057	reseau
Tandil	1:16,000	2,430 m	130 m	0.583	0.583	terrain details

Experimental Results

Single Points

The stereo-orthophotos produced on the GPM are at original photo scale and a stereocomparator could, therefore, be used for the analysis. It is interesting to note that, after the orthophoto and stereomate have been properly aligned on the image carriers by means of rotational and Δy adjustment, a stereoscopic model, virtually free of y-parallaxes, can be observed in an instrument of the stereocomparator type.

The RMS values of the y-parallaxes in the different stereo-orthophoto pairs were calculated after a numerical adjustment to eliminate the influence of small errors in the alignment of the stereo-orthophotos on the image carriers. They were found to be within the range

$$m_{\Delta y} = 0.010 - 0.015 \text{ mm.}$$

The x, y, Δx, and Δy values were recorded for the check points in the stereo-orthophotos. The measured x-parallaxes were converted into heights, at orthophoto scale, using the appropriate x-parallax/height ratio. The stereo-orthophoto xyz coordinates were then transformed into the control coordinate system by linear conformal transformation. Standard errors calculated from the residuals are listed in Table 2.

It is seen from Table 2 that the standard elevation errors for the reseau marks generally exceed those for the targets and the terrain details. Since the reseau marks do not appear stereoscopically in the stereo-orthophotos, their height information refers to the actual terrain surface which, in certain cases, does not offer the same pointing accuracy as the stereoscopically well-defined ground targets and terrain details.

For the Sudbury test area, which is practically free of higher vegetation, the same accuracy was obtained for the two stereo-orthophoto models produced without and with vertical exaggeration. This indicates that the automatic correlation process is very reliable for this type of terrain. Also, for the checkpoints located in the open fields of the Ripon area, no significant differences in the standard height errors were detected for the stereo-orthophotos without and with vertical

Table 2. Standard Errors in Stereo-Orthophotos

Test Area	Orthophoto Scale	px/h	Type of Control	At orthophoto scale m_p μm	m_z μm	m_z ‰ H	Number of points
Sudbury	1:15,000	0.645	targets, open areas	60	42	0.28	101
			reseau, open areas	—	55	0.36	130
Sudbury	1:15,000	1.014	targets, open areas	57	43	0.28	98
			reseau, open areas	—	55	0.36	124
Ripon	1:10,000	0.671	reseau, open areas	50	51	0.34	36
			reseau	61			21
			near vert. objects		51	0.34	30
Ripon	1:10,000	1.057	reseau, open areas	48	47	0.31	36
			reseau,	56			21
			near vert. objects		96	0.63	30
Tandil	1:16,000	0.583	points in open areas	51	30	0.20	56
			points near vert. objects	84	41	0.27	26

exaggeration. For check points located near vertical terrain objects in the Ripon model the standard height error, determined for the stereo-orthophotos produced with vertical exaggeration, was considerably larger than for the Ripon model without vertical exaggeration. Vertical exaggeration should, therefore, not be used in areas where image correlation errors due to terrain discontinuities could occur.

The results for the Tandil stereo-orthophotos are generally slightly better than those obtained for the targeted control points in the Sudbury test area.

TERRAIN PROFILES

The quality of three-dimensional terrain representation by stereo-orthophotos is also demonstrated by terrain profiles measured in the Tandil model. Four profiles, including

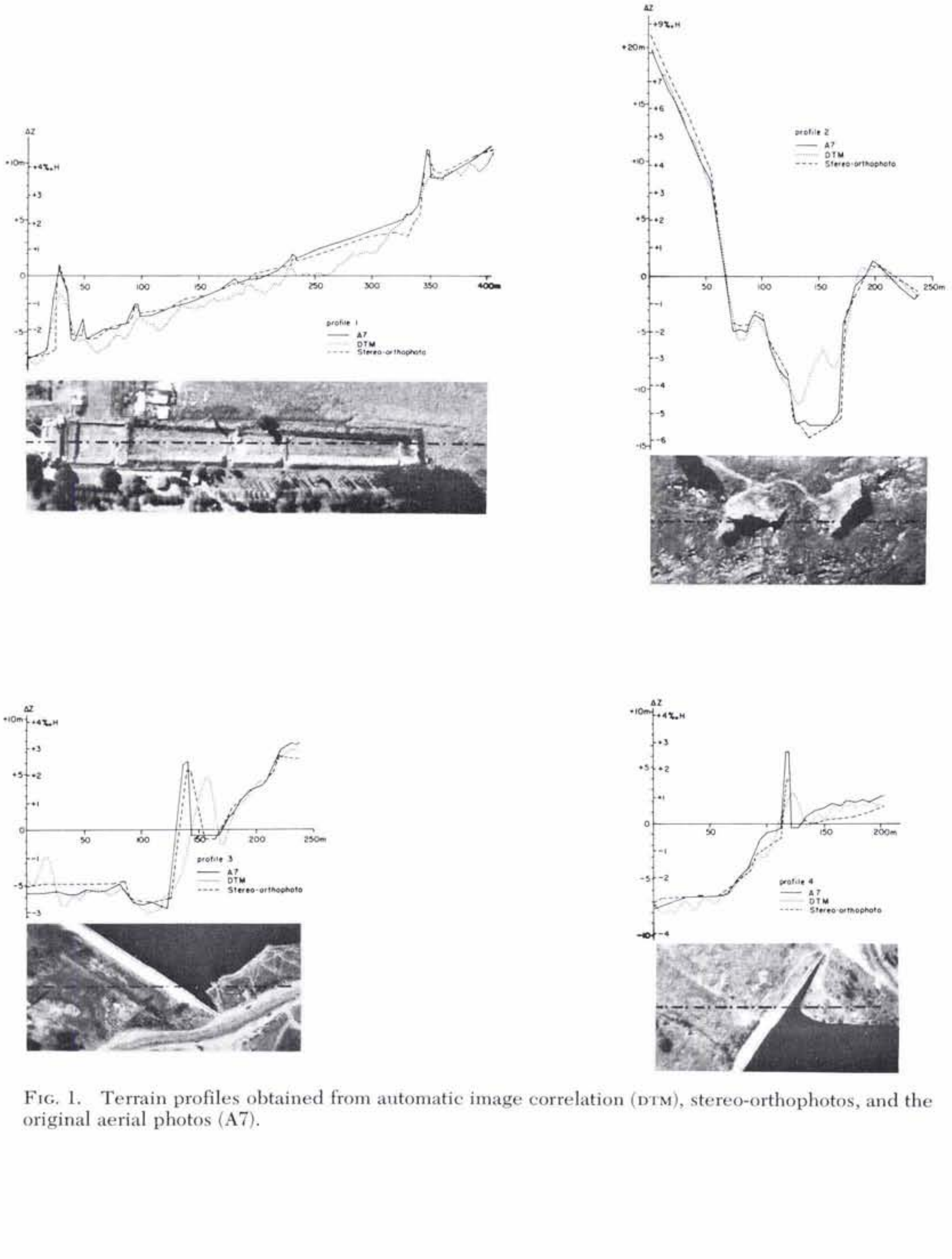

FIG. 1. Terrain profiles obtained from automatic image correlation (DTM), stereo-orthophotos, and the original aerial photos (A7).

terrain discontinuities such as a power dam and excavations, were selected. They were measured in the stereo-orthophotos, in the original photos, and also derived from the DTM. The profile data were transformed to the ground coordinate system using a linear conformal transformation based on the *xyz* coordinates of the end points of the profiles (a total of eight points).

The profile measurements in the stereo-orthophotos and the original photos included the characteristic terrain points of the profiles. The average distance between measured profile points is 8 m (0.5 mm at photoscale). The profile points, derived from the DTM, are regularly spaced at an average distance of 2.5 m (0.16 mm at photoscale).

It is seen in Figure 1 that the results obtained from the automatic image correlation data (DTM) contain some excessive height errors, particularly for the earth dams (profile 1), the shaded area of the pit (profile 2), and the hydro dam (profiles 3 and 4). Systematic errors, as large as 2.5 per thousand of the flying height (or 0.4 mm at the scale of photographs) are revealed for these terrain features. It is interesting to note that these correlation errors affect the stereo-orthophoto height data only by a limited amount. The systematic affect in the height errors of the DTM in profile 1 could have been reduced if more points had been used for the transformation of the DTM profiles to the ground control system.

The excessive planimetric error in the DTM for the hydro dam in profile 3 was probably caused by poor image correlation for the water surface adjacent to the dam. A correlation error results in a radial displacement of the orthophoto image with respect to the principal point. Since the image of the dam is approximately in line with the principal point of the photo used for the orthophoto production, the effect of the correlation error for the dam is not revealed by the stereo-orthophoto profile.

When excluding the systematic height errors in the DTM, the standard height errors, derived for the profiles by comparing the DTM and the stereo-orthophoto heights with the A7 heights, are

- for the stereo-orthophotos 0.26 per thousand of the flying height; and
- for the DTM (systematic errors excluded) 0.32 per thousand of the flying height.

The height determined on the A7 was assumed to be free of error.

CONTOUR LINES

The results for the stereo-orthophoto discussed above in this chapter suggest a possible use of stereo-orthophotos in editing and correction of contour lines which are computed and plotted from the automatic image correlation data. The advantage in using the stereo-orthophotos for this purpose is the simplicity of the equipment which could be used, such as the NRC Stereocompiler shown in Figure 2 (Blachut, 1971). Also, the time saved in using stereo-orthophotos as compared with the original photos will be appreciable as the result of the simple orientation procedure needed to set up a stereo model in the Stereocompiler.

The stereo-orthophotos of the Tandil area were used to evaluate the quality of manually plotted contour lines from stereo-orthophotos. The original GPM orthophotos were photographically enlarged by a factor of 4 to the scale 1:4 000. Contours were plotted at a contour interval of 5 m on the NRC Stereocompiler, on an A7 from the original photographs, and plotted automatically from the automatic image correlation data. Examples of these contours and the corresponding orthophoto image are shown in Figure 3 for a small section of the test area.

The superior quality of terrain presentation for the forested areas by the Stereocompiler contours, as compared with the automatic image correlation contours, is evident from Figure 3. The Stereocompiler contours also indicate a good agreement with the A7 contours and offer a similar amount of detail.

The graphical accuracy of the automatic image correlation contours and the Stereocompiler contours was checked for the Tandil overlap by comparing their elevation with the corresponding values in the A7

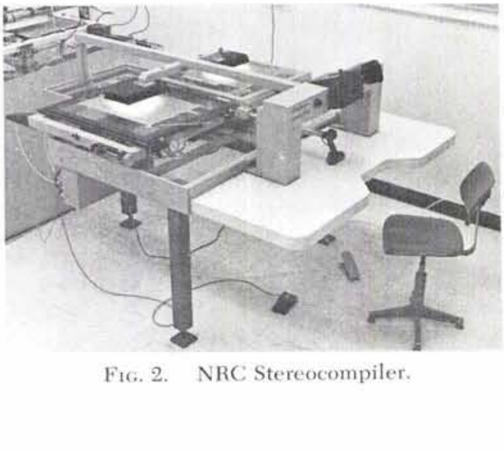

FIG. 2. NRC Stereocompiler.

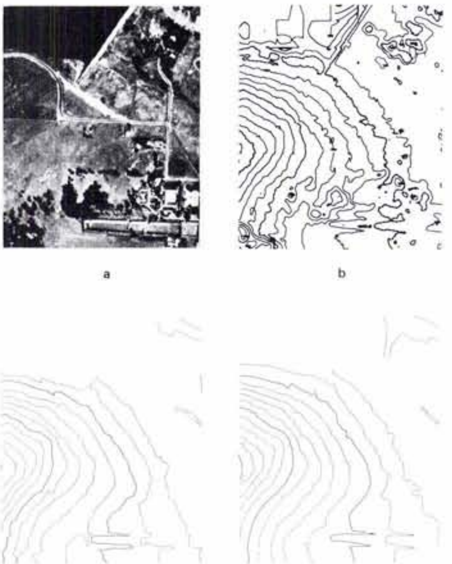

FIG. 3. (a) Orthophoto image; (b) contours generated from automatic image correlation data; (c) contours plotted on the Stereocompiler from stereo-orthophotos; (d) contours plotted on the A7 from the original photos.

stereomodel. Systematic errors of up to 8 per thousand of the flying height were detected for the forested and built-up areas in the automatic image correlation contours. When eliminating these systematic errors in the calculation of standard errors, the following values were obtained for approximately 250 check points along the contour lines in the two maps:

- for the Stereocompiler contours 0.45 per thousand of the flying height; and
- for the automatic image contours (systematic errors excluded) 0.51 per thousand of the flying height.

The result obtained for the Stereocompiler contours included open fields as well as forested and built-up areas. No systematic errors were removed in comparing the Stereocompiler contours with the A7 contours.

CONCLUSIONS

The height accuracy of the GPM II stereo-orthophotos used in this experiment was found to be in the range 0.2 - 0.4 per thousand of the flying height (RMS value) when x-parallaxes in the stereomate were generated according to the average base/height ratio of the original photos. Generally this accuracy was better than that of the DTM derived from the same automatic image correlation data on which the production of the stereo-orthophotos was based. This conforms with the theory of the stereo-orthophoto technique which states that correlation errors have a reduced effect on the height accuracy of stereo-orthophotos if they are identical for the orthophoto and the stereomate (Collins, 1968). This is the case for the simultaneous production process in the GPM II apart from possible instrumental inaccuracies in the image carriage position control for the two individual printing units.

A requirement for obtaining a satisfactory height accuracy and a correct representation of small terrain details is that the orthophoto and the stereomate are produced from the two different photos of the stereopair. The x-parallaxes should be generated in the stereo-orthophotos according to the base/height ratio of the original photopair and vertical exaggeration is generally not recommended, particularly in cases where correlation errors due to vertical terrain features are expected. A linear x-parallax/height ratio for the stereo-orthophotos was found to be satisfactory for the terrain conditions encountered in this experiment.

The stereo-orthophotos, after proper alignment on two parallel image carriers, were found to be virtually free of y-parallaxes. Values ranging between 0.010 and 0.015 mm (RMS value at the scale of original photographs) were found. This confirms that simple equipment can be used to form a stereoscopic model from stereo-orthophotos for photo interpretation, measuring, and mapping purposes.

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