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Experimental Investigation into the Accuracy of Contouring from DTM*

The results confirm that digital contouring is equivalent to results from direct photogrammetric contouring or from ground surveys.

(Abstract appears on following page)

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Introduction

Digital terrain models have been developed and studied for more than 20 years. The development has revealed the significance of several main aspects, such as data-acquisition, interpolation methods, computer programs, accuracy, and applications. Those aspects are interrelated, which may explain why no unique system has yet evolved.

Among the various applications, the use of DTMs for mapping and cartography has been given serious attention only recently, in particular, the digital derivation of high quality contour lines from DTMs of according quality. Such applications are especially demanding, in view of the high quality and accuracy requirements in standard mapping. It is desirable, however, to develop and to investigate such applications, in relation to the general trend to automation in cartography.

It may be briefly recalled that the systems for digital derivation of contour lines from DTMs start from the basic assumption that the heights of a sufficient number of terrain points have been measured, either by ground survey or by photogrammetric techniques. (Evidently, different specifications regarding the accuracy and distribution of such terrain points—random, triangular or grid pattern, along profiles, singular points—can lead to different procedures.) The terrain points are supposed to represent the terrain surface sufficiently. From them a digital terrain model is derived by digital computation. The DTM consists of derived heights associated with a set of points which may have the same horizontal location as the originally measured points. Often, however, a new set is chosen, according to a preestablished pattern, such as a regular grid. Thus, the DTM computations consist of the interpolation of the height values for a set of points the locations of which are given. (It is very obvious that there is a great number of possibilities for different interpolation methods and operational features, hence the variety of existing DTM systems.) The density of the new set of points is usually different from the originally measured terrain points,

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ABSTRACT: *Results of an experimental investigation on the accuracy of DTM-interpolation of digitally derived contours are presented. The test area "Soehnstetten" was precisely surveyed by electronic tacheometry, including a number of check profiles. Also a plane table survey was available, and a state base map at 1:2,500 scale. For photogrammetric restitution, wide angle photography at a photo-scale of 1:10,000 was used.*

The accuracy of conventional contouring (contour interval 2.5 m) as obtained by manual interpolation of tacheometric surveys, by plane table, and by direct photogrammetric plotting is compared. The main part deals with the accuracy of DTMs and contours as obtained through digital interpolation, in this case with the SCOP-program. It refers to input data from photogrammetric profiling and from ground survey by electronic tacheometry.

The results confirm that digital contouring is equivalent to results from direct photogrammetric contouring or from ground surveys.

it can be larger or smaller. From the DTM finally the controur lines are derived, represented by (dense) strings of points of equal height, respectively. With adequate rules for sequentially connecting the points on a contour line by more or less simple curves, the final contour lines can be edited and plotted off-line with an automatic plotter or drawing table.

The accuracy and quality of such contour lines depends on a number of parameters. They relate first to the data acquisition: density, distribution, and quality of measured points, including representation of special morphological features (break lines, etc.). The parameters relate second to data processing: interpolation principle and special operational features of the program (filtering, etc.).

The interaction of various parameters and the great number of possible operations make the accuracy of the resulting contour plots and the capability of digital contouring methods a highly complex matter. In fact, little is known about the quality of DTM-derived contour lines. Up to now attention has been focused mainly on the questions of interpolation methods and on the development of computer programs. Although the basic capabilities have been demonstrated, the influence of data acquisition on the quality of the derived contour lines remains to be investigated thoroughly. Also, the specifications for adequate data acquisition have not yet been worked out.

This paper reports about an experimental investigation into the accuracy of DTM interpolation and of derived contours, for different cases of data acquisition.[1] In view of the many parameters involved, it can only be considered a preliminary pilot study. The restitutions refer to a controlled test area; hence, absolute accuracy results can be quoted. Several survey methods are compared, and some variations of profiling are studied. The tests demonstrate that high quality contours can be obtained.

Throughout the tests the SCOP program for the interpolation of DTMs and of contour lines has been used.[5] It can handle variable input and allows filtering of the data; the derived DTM forms a regular grid of points. In this paper, neither the program nor the interpolation method is the subject of investigation. It has been the tool only, the properties of which made it convenient to execute the various variations. For the computations the Control Data Cyber 74 at the Stuttgart University Computing Center was used. The contour sheets were plotted on the Contraves automatic drawing table DC 2 of the Landesvermessungsamt-Baden-Württemberg, the cooperation of which is greatly appreciated.

THE SOEHNSTETTEN TEST AREA: DATA ACQUISITION, AND REVIEW OF EXPERIMENTS

All experiments refer to the test area "Soehnstetten." It extends approximately 0.9 km × 1.7 km in a northwest-southeast direction and is located on the jurassic plateau of the Suebian Alb, near the village of Soehnstetten, about 60 km east of Stuttgart. The elevations range between 580 m and 650 m above sea level. The main feature is a dry valley winding through the area, with rather steep slopes (up to 50 percent) on both sides, gradually merging into the somewhat hilly plateau. The valley is closed by a dam built some years ago for flood protection. The area has a variety of small morphological features which make it most suited for lage scale contour tests. The appropriate map scale is 1:2,500, with a 2.5 m contour interval. The area is mostly open, covered with grassland, heath, and junipers. Some patches are covered by bushes or trees.

In 1975, a tacheometric ground survey of a part (0.6 km^2) of the test area was made by a group of graduate students,* with a Zeiss Reg Elta electronic tacheometer. The survey was based on a network densification. The area was covered by a grid of about 6,100 surveyed terrain points. They have an average spacing of 15 m in the terrain (less dense in flat parts, more dense in difficult parts of the area). Their internal relative precision can be estimated to be about 2 cm or better. The tacheometric ground survey (here referred to as Reg Elta 1) constitutes the reference survey for all subsequent tests. Contour lines were derived from it by conventional manual interpolation and by automatic interpolation with the SCOP program.

Together with the tacheometric ground survey 22 terrain profiles were determined. They spread over the whole test area, and have been selected to represent special and average terrain conditions and to allow significant checks for the accuracy of the derived contour lines. The check profiles, or rather the 485 included check points, served only for testing the accuracy of derived contour lines. Consequently, they were not used for the actual interpolation of contour lines.

For a part of the area a second tacheometric survey (Reg Elta 2) was made, comprising about 1,700 points, at an average spacing of 25 m.

In addition, a manual contour plot happened to be available, established by a plane table survey in 1974. The plot covers only a small part of the area. It is based on about 150 surveyed points of 30 to 35 m average spacing. The plane table survey was made by a senior staff member in connection with students' exercises. It must be considered experimental as plane tables are normally not used any more.

Finally, the area in question is mapped in the official 1:2,500 scale base map of the state of Baden-Württemberg. The contour sheet has been mapped in 1925, based on conventional tacheometry (about 350 points, average spacing 45 m). The contour lines with intervals of 2.5 m, 5 m, and 10 m were derived by manual interpolation. They are much more generalized than the contour lines of any of the presented tests.

The test area is covered by aerial photography, flown in spring 1976, with a wide angel camera Zeiss RMK 15/23, by the Geoplana Company. The available photo coverage is one stereo-model at the photo scale 1:10,000, one strip with three models at 1:7,000, and two strips with seven models each at 1:3,000. All photogrammetric restitutions referred to in this paper have been made with the 1:10,000 scale photography. The control points for absolute orientation are signalized and located in the four corners of the model. They are sufficiently accurate not to cause any consideration.

For the photogrammetric restitution the Zeiss Planimat D 2 of the Institute of Photogrammetry was used, operated by R. Bettin. The model scale was always 1:5,000, and the map scale was 1:2,500 (for direct contouring).

First, a contour plot was mapped, with 2.5 m contour interval, by conventional direct contouring in the stereo-model. From the original contour manuscript a fair drawing was derived by manual scribing, which implied some generalization of the contour lines in the usual way. This edited contour sheet was used for the test.

The main part of the photogrammetric investigation refers to different (nonautomatic) modes of scanning the stereomodel. The model was scanned in seven different versions, of which three were thoroughly investigated (see Table 1). The versions are distinguished by different spacings and directions of the scan lines. The average speed of profiling was about 1 mm/sec in the model (scale 1:5,000) or 5 m/sec in the terrain.

Photogrammetric scanning of the stereomodel along parallel profiles at given intervals runs the risk of missing special terrain features. Therefore, a number of structural lines and spot heights were measured, to be considered in the interpolation, in addition to the regular scan lines. The total number of additional points was about 1,200.

In addition to the main program of investigation, a direct contour plot and profile restitutions were also made with the Zeiss Planitop F 2, a small stereo-plotter with free hand movement, which can be connected with an Ecomat for data registration. The Planitop restitutions will be touched upon only briefly.

The scanning of the model gives an original observed DTM with an approximate grid

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TABLE 1. PHOTOGRAMMETRIC DATA ACQUISITION

Version	scan direction	scan increments x	y	recorded points	instrument time	computing time syst. sec. CDC Cyber 74	plotting time Contraves Coragraph DC 2B
Precision plotter Planimat D 2 (model scale 1:5000)							
1	x	15 m	15 m	8460	$5^{h}25^{min}$	614	$2^{h}45^{min}$
2	y	15 m	15 m	7580	$4^{h}24^{min}$	508	$2^{h}45^{min}$
3	y	30 m	30 m	1932	$3^{h}15^{min}$	391	$2^{h}45^{min}$
	additional points (break lines etc.)			1198	$6^{h}00^{min}$		
4	direct contouring				$11^{h}00^{min}$		$31^{h}20^{min}$ (manual)
Topographic Plotter Planitop F 2 (model scale 1:10 000)							
5	y	15 m	15 m	7114	$4^{h}20^{min}$	356	$2^{h}45^{min}$
	additional points			1150	$2^{h}00^{min}$		
6	direct contouring				$4^{h}30^{min}$		$\sim 1^{h}30^{min}$ (automatic)

pattern of points. From those points and the additional observed points a denser DTM of a regular grid of points is interpolated with the SCOP program. The regular DTM grid was chosen to have points every 5 m in the terrain, which amounts to a total number of more than 70,000 interpolated DTM points. (The width of the interpolated DTM grid represents another parameter which has deliberately been kept constant in this particular series of tests, in order to reduce the number of cases to be studied.) Finally, from the regular DTM grid the contour lines are derived and plotted.

The assessment of the derived contour lines was done in two ways:

First, the contour plots were superimposed and compared with regard to general

TABLE 2. ACCURACY RESULTS, DERIVED FROM CHECK PROFILES

Survey/plot	observed grid / profile	RMS height error	standard height error $m_h = (a + b \tan \alpha)$ m |m|
Ground Survey			
Reg Elta 1 manual	15 m	0.26 m	$m_h = 0.22 + 0.15 \tan \alpha$
Reg Elta 1 SCOP	15 m	0.25 m	$m_h = 0.22 + 0.13 \tan \alpha$
Reg Elta 2 SCOP	25 m	0.43 m	$m_h = 0.30 + 0.42 \tan \alpha$
Plane table manual	35 m	0.75 m	$m_h = 0.47 + 0.91 \tan \alpha$
State Base Map	45 m	1.16 m	$m_h = 0.40 + 2.99 \tan \alpha$
Planimat			
Version 1 SCOP	15 m/x	0.43 m	$m_h = 0.22 + 0.78 \tan \alpha$
Version 2 SCOP	15 m/y	0.40 m	$m_h = 0.21 + 0.72 \tan \alpha$
Version 3 SCOP	30 m/y	0.59 m	$m_h = 0.21 + 1.50 \tan \alpha$
Version 4 direct contouring		0.37 m	$m_h = 0.32 + 0.21 \tan \alpha$
Planitop			
Version 5 SCOP	15 m/y	0.64 m	$m_h = 0.50 + 0.54 \tan \alpha$
Version 6 direct contouring		0.48 m	$m_h = 0.43 + 0.17 \tan \alpha$

agreement and to the representation of local features. Unfortunately, the superposition of various sheets cannot be shown in print.

Second, the absolute accuracy of the contour lines was determined from the check profiles. In the conventional way the true height errors at the check points were determined and the resulting accuracies expressed as linear functions of the terrain slope.

In this paper 11 different contour plots are investigated, as listed in Table 2. The tests can be divided into two main groups, according to data acquisition (by ground survey or by photogrammetry). Within the photogrammetric data acquisition the main point of interest is the contour quality as obtainable by profiling, in comparison with direct contouring, as will be elaborated below.

Some Observations on Data Acquisition and Data Processing

Before discussing the accuracy results of the tests, some additional information is given which may be of interest.

The tacheometric ground survey (Reg Elta 1) proceeded in the field at an average rate of 42 terrain points/hour, or 450 points/day (10.5^h/day). It took 13 working days to survey the total number of 6,000 points, at an average spacing of 15 m. The automatic plotting of the surveyed points and their heights required 10^h; thereafter, another 80^h were needed for the manual interpolation of the contour lines.

In Table 1 some figures are given about the time requirements of the photogrammetric data acquisition. For completion it is added that the relative orientation of the model took 40 min, and the absolute orientation, $2^h\,50^{min}$. The latter time is rather high; it may be explained by a number of checks and precise orientation of the map sheet.

The profiling of the models by the operator required between $3^h\,15^{min}$ and $5^h\,25^{min}$, depending on density and direction. The average scanning speed was kept constant at about 1 mm/sec in the stereo-model (1:5,000) or 5 m/sec in the terrain. In version 1 about 8,400 profile points were recorded. The measurement of the additional 1,200 points (spot heights, structural lines, or special features) required $2^h\,25^{min}$ at the instrument, after $3^h\,35^{min}$ preparation time with a stereoscope. The time needed for the additional points is rather high. It could and should be reduced considerably. By comparison the direct photogrammetric plotting of contour lines required 11^h, to which 30^h for scribing and editing of the fair drawing have to be added, apart from an additional $1^h\,20^{min}$ for preparing the map sheet (grid, control points).

The data acquisition with the Planitop plotter operated under somewhat different conditions. The model scale was 1:10,000, and the direct contouring was digitally recorded (at 1 mm = 10 m steps in x and y) and subsequently plotted with the Contraves DC 2 automatic drawing table, at a map scale of 1:2,500. Only contours of 5 m interval were plotted. The direct contouring required $4^h\,30^{min}$ instrument time (free hand movement) which corresponds to an average speed of 0.75 mm/sec at 1:10,000 or 7.5 m/sec in the terrain. Almost the same time was needed for scanning the model along profiles 1.5 mm apart (at 1:10,000, $\hat{=}$ 15 m in the terrain), for the subsequent computation of DTM and contour lines of 2.5 m interval: $4^h\,20^{min}$ for scanning plus 2^h for structural and break lines.

The computing time required for the interpolation of the DTM and the contour lines depends naturally very much on the number of observed terrain points to be handled and on the density of the computed DTM grid. For version 1 (8,460 + 1,200 terrain points) the total computation required 614 system seconds on the CDC Cyber 74 computer. The major percentage of the computing time went into the interpolation of the about 70,000 DTM grid points, whereas the derivation of the contour lines from the 5 m grid used up only about 120 system seconds in all cases.

For the interpolation of the DTM by the method of linear prediction a value of 8 cm for filtering noise was applied. The effect is a certain smoothing of the final contour lines. The filter value was kept constant for the tests in question.

The plotting of the computed and edited contour lines with the Contraves DC 2 automatic plotting table required in all cases about $2^h\,45^{min}$.

Results

As direct results of the various restitutions, scribed contour plots are available. Some examples are displayed in Figures 1 to 9, which cover only a small section of the actual map sheets. Unfortunately it is not possible to print here the full size sheets, nor can the various 2-color overlays be reproduced which have been printed for easy comparison of the different contour plots.

The quality assessment of the results must consider two different aspects: Besides the absolute accuracy of contour lines, the quality of a contour map is especially judged by the fidelity which small details and fine morphological features are represented in the contour lines. Unfortunately, there is considerable disagreement among cartographers as to what extent such details are to be demanded. Also, there are no clear objective criteria with which to describe or to measure the morphological fidelity of contour lines. Here, we shall first assess the overall picture of the contour plots and attempt comparisons by mutual super-position of the plots. The discussion is subdivided into the terrestrial and the photogrammetric mode of data acquisition.

The tacheometric ground survey (Reg Elta 1), based on a dense 15 m grid of terrain points, represents here the optimum contour lines (Figures 1 and 2). They appear sufficiently and agreeably generalized, but they display all morphological features. The 15 m grid (6 mm in the map) represents an unusually high density of surveyed points, which would normally not be applied in practice.

The first essential statement concerns the comparison of the manual interpolation of contour lines with the automatic interpolation: Both contour plots are virtually identical. For most parts of the test area there are no differences beyond graphical drawing precision. Slight differences in a few places remain within 10 percent of the contour interval. There are very few details with some deviation between contour lines, which can all be explained. For instance, an abandoned overgrown field path was considered in the manual interpolation without having been surveyed in the data.

The SCOP interpolation of the independent Reg Elta 2 tacheometric survey, based on a 25 m grid, shows the effect of a less dense survey of terrain points (Figure 3). The overlay with the SCOP contours of the Reg Elta 1 survey demonstrates that both plots are still almost identical. Especially in the slope areas virtually no differences are visible. It is only in the flat areas where the contours based on the 25 m grid appear somewhat

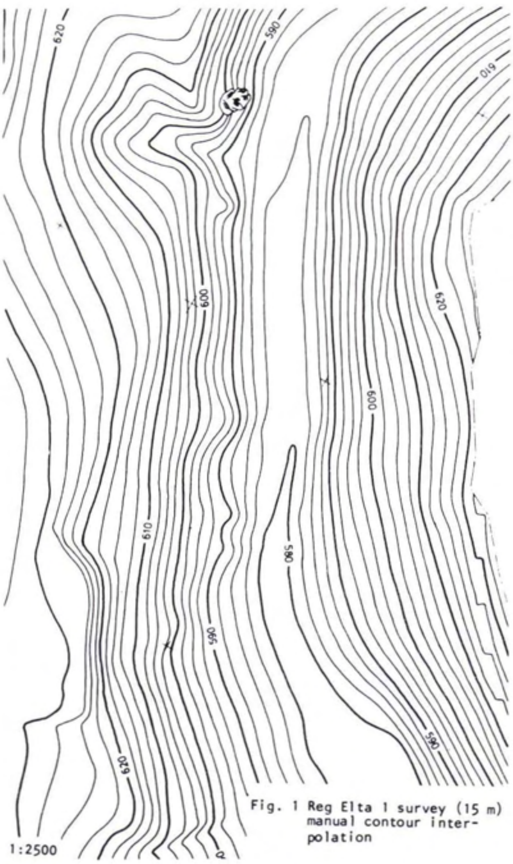

FIG. 1. Reg Elta 1 survey (15 m), manual contour interpolation.

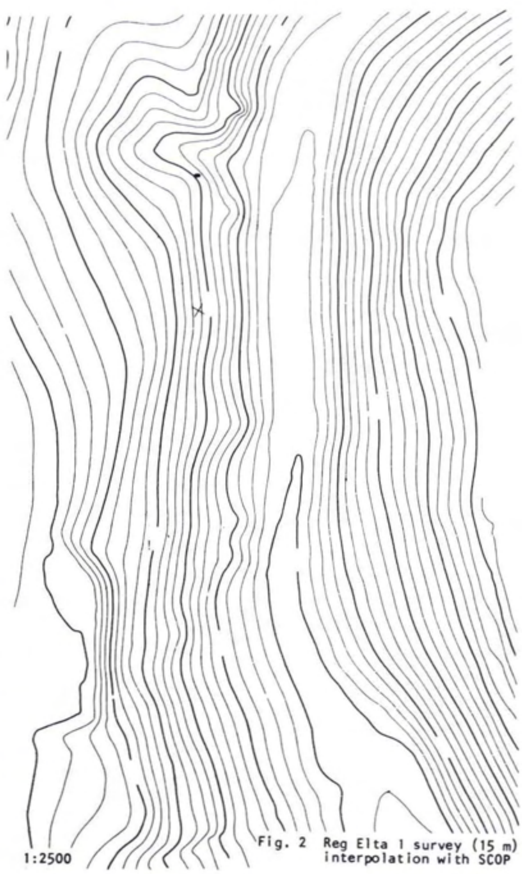

FIG. 2. Reg Elta 1 survey (15 m), interpolation with SCOP.

smoother. Also, small features of less than 25 m extension tend to be lost. Nevertheless, the appearance of the plot qualify the contour lines as highly acceptable.

The plane table contour lines have in general about the same appearance as the Reg Elta 2 version, and the same degree of smoothness. They are based on considerably less surveyed points. The morphological features are considered and sketched directly in the terrain. It is this admittedly subjective evaluation in the terrain which can give a plane table survey high quality, depending on the experience and skill of the field surveyor.

Compared with contours derived from such detailed field surveys, the official state base map shows contour lines which are much more generalized (Figure 4). In the area in question the contour intervals vary between 2.5 m, 5 m, and 10 m. Thus implicitly reduced quality specifications are indicated which agrees with the lesser number of surveyed terrain points at 45 m average spacing (18 mm at the map scale). Small morphological features and high frequencies must be lost. It should be recalled, however, that the 1:2,500 base map, which is available for the whole state, is considered a sufficient general purpose large scale map of general high quality.

Turning to the photogrammetric data acquisition, let us first consider the result of the conventional direct contouring (with Planimat, version 4, see Figure 5). It is not surprising that the directly plotted contours, although generalized to some degree by the process of manual editing, show more details than any other test. However, the contour lines may be considered to appear still slightly too irregular. Additional smoothing might have been appropriate. The direct plotting also shows more morphological features symbolized (breaks, rocks, etc.) than any other plot. The overall agreement with the Reg Elta 1 version is very good.

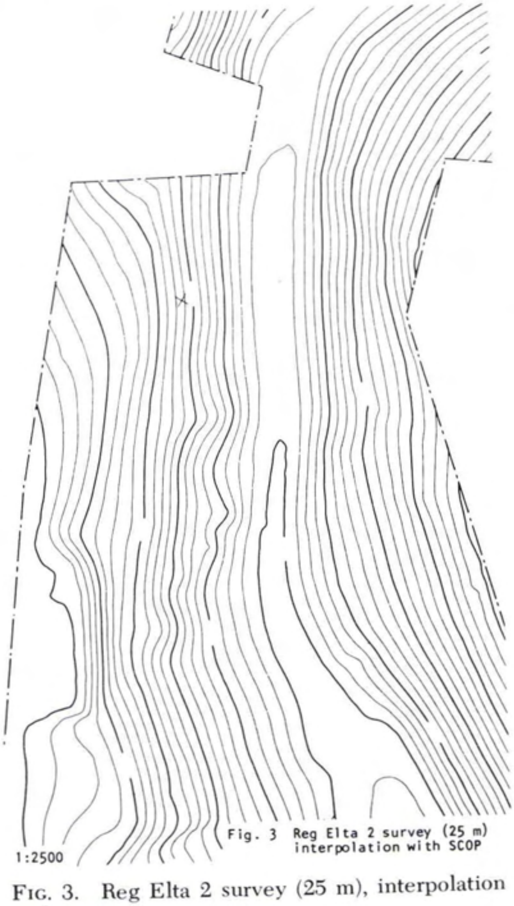

FIG. 3. Reg Elta 2 survey (25 m), interpolation with SCOP.

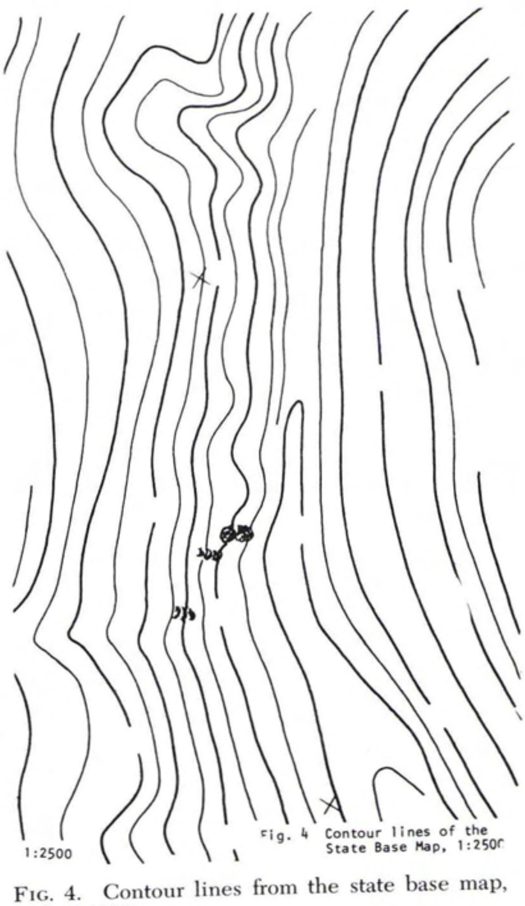

FIG. 4. Contour lines from the state base map, scale 1:2500.

If we now compare the versions based on scanning of stereo-models, we can first observe that the influence of the scan-direction is practically negligible. Versions 1 and 2 with scanning in the x- and in y-directions, respectively, both referring to a 15 m grid of terrain points, differ very little from each other. The differences concern features of less than 15 m extension. Scanning along or across the major slope direction has evidently no significant overall influence.

Both contour plots of versions 1 and 2 (Figure 6) are in good agreement with the directly plotted contours and with the Reg Elta 1 result. Due to the scanning errors of the flying measuring mark, an additional smoothing effect of about 20 to 30 cm becomes noticeable. Therefore, the total result is about equivalent with the Reg Elta 2 version with a 25 m grid. The explanation is that the residual roughness of the terrain merges with the scanning errors, both effects being noise effects in the first instance. The scanning errors decrease the effective density of the surveyed points (here from 15 m to 25 m). Hence, frequencies or details of less than 20 m or 25 m tend to be suppressed. In flat areas some systematic scanning errors seem to be effective. The contour lines show some noticeable systematic deviations against the directly plotted contours. The deviations remain, however, within 25 percent of the contour interval. In the slope areas the contour lines agree perfectly.

By comparison, the scanning version 3 generalizes and smoothes the contour lines even more (Figure 7). The 25 m grid of observed points, together with scanning errors on the order of 20 to 30 cm, decrease the effective density of points to perhaps 30 or 40 m. Local morphological features below that magnitude of extension, which is 12 to 16 mm in the map, tend not to be resolved by the derived contour lines. Local ridges of that dimension are suppressed. Nevertheless, the contours of version 3 are for really

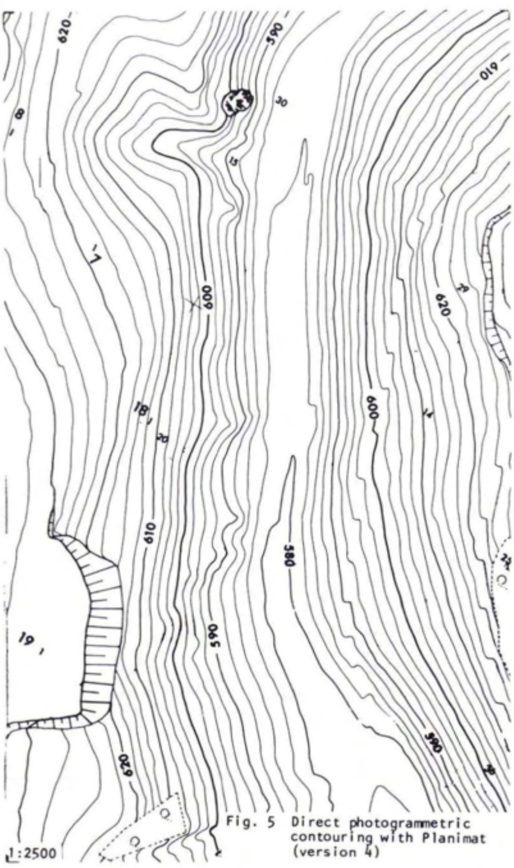

FIG. 5. Direct photogrammetric contouring with the Planimat (version 4).

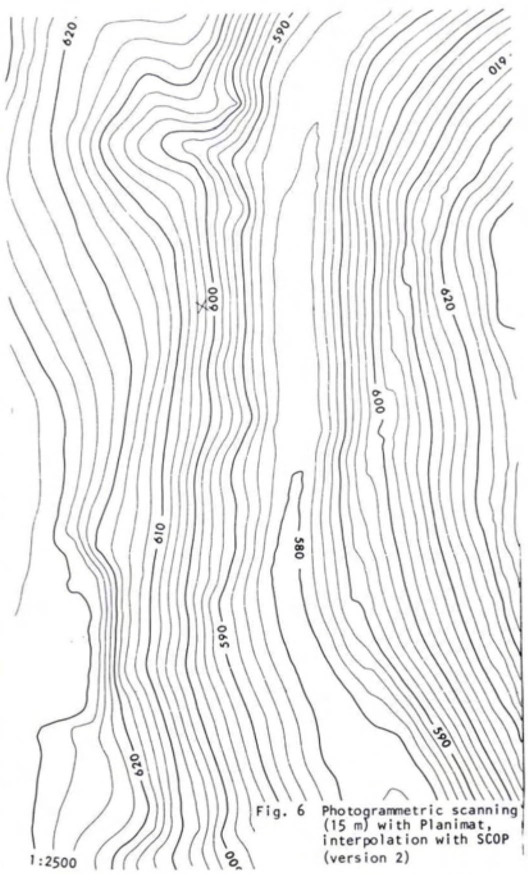

FIG. 6. Photogrammetric scanning (15 m) with the Planimat, interpolation with SCOP (version 2).

most applications still very well acceptable. They are still much more detailed than the contours of the official state base map.

The evaluation of the Planitop restitutions (versions 5 and 6) leads to a very similar conclusion. The interpolated contour lines appear rather smooth, because of the smaller model scale and the rather high scanning speed. The directly plotted contours appear somewhat irregular, obviously because of the enlargement ratio of 4:1 between model and map. Also, a tendency for systematic errors becomes apparent, which will be discussed below.

Turning now to the absolute height accuracies of the DTMs and contour plots, as derived from the check profiles, we refer to Table 2 and to Figures 10, 11, and 12. The investigations confirm in general the judgements just derived from the visual inspection and comparison of the contour plots.

The Reg Elta 1 tacheometric survey gives, with an average height accuracy of 26 cm for the manual interpolation of contour lines, the best result of all test versions. The equivalence of manual and automatic interpolation is confirmed. Very remarkable is the fact that there is no apparent dependence on slope. The obtained absolute height errors of 25 cm represent the residual roughness of the terrain when interpolating between points 15 m apart.

With the SCOP interpolation of the Reg Elta 2 tacheometric survey, based on a 25 m grid of terrain points, the absolute height errors increase to the average value of 43 cm. Also a slight dependence on the slope of the terrain creeps in. Both effects are to be expected with reduced density of surveyed points.

Quite surprisingly, the accuracy of the plane table contours falls off considerably, to an RMS height error of 75 cm and a marked dependency on slope. The same tendency is continued in the contour lines of the state base map which refers to a further reduced density of points.

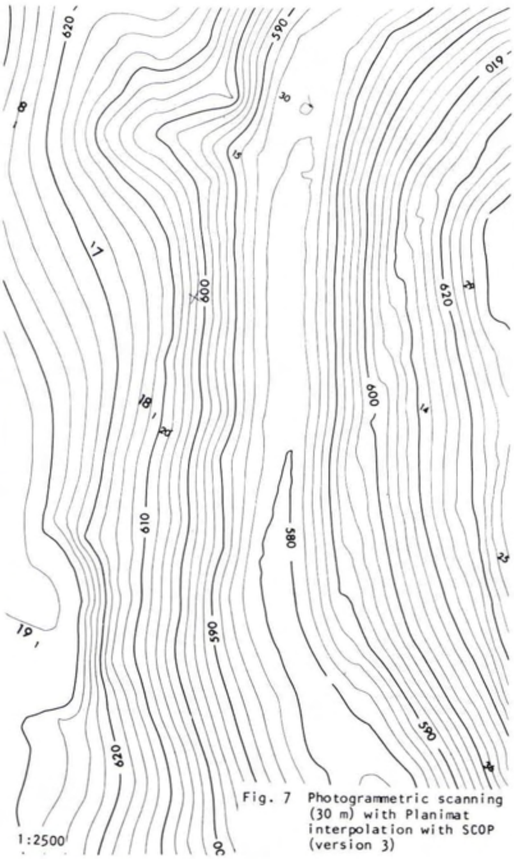

FIG. 7. Photogrammetric scanning (30 m) with the Planimat, interpolation with SCOP (version 3).

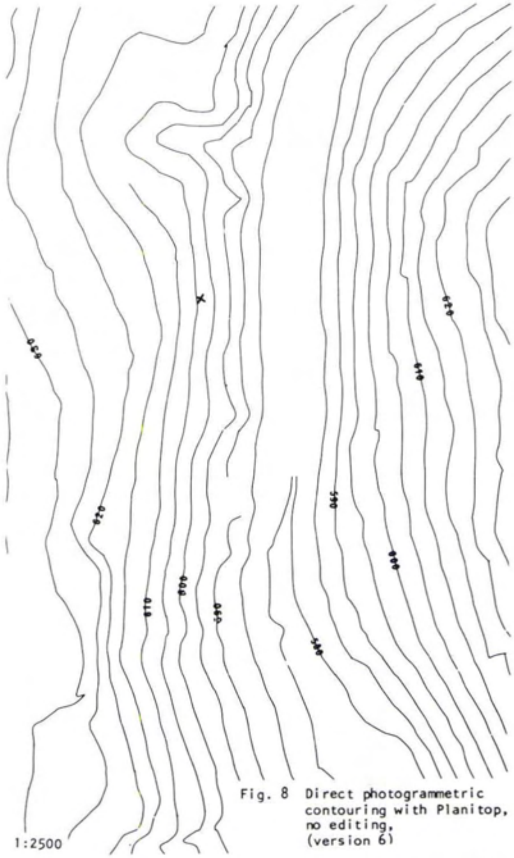

FIG. 8. Direct photogrammetric contouring with the Planitop, no editing (version 6).

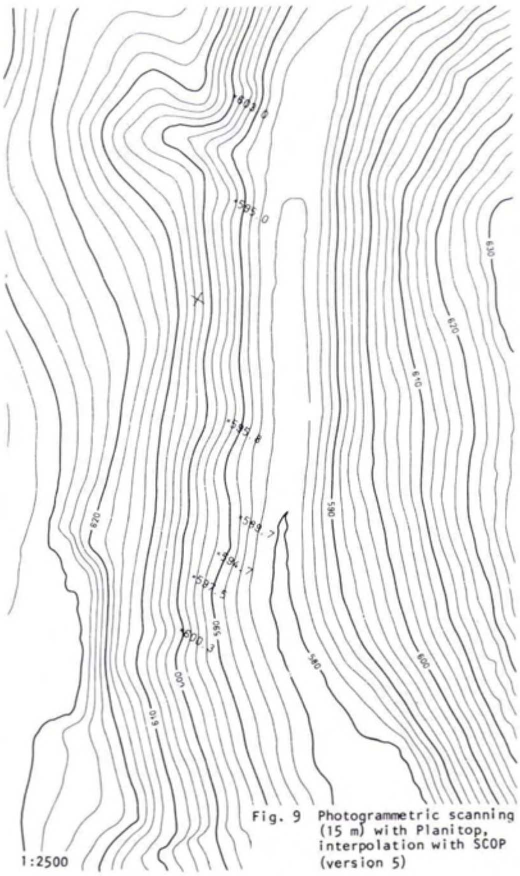

FIG. 9. Photogrammetric scanning (15 m) with the Planitop, interpolation with SCOP (version 5).

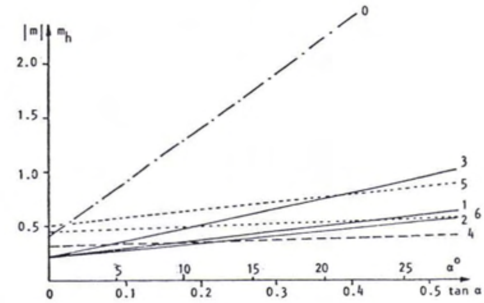

FIG. 11. Height accuracy of contour lines from photogrammetric data acquisition, as a function of terrain slope.

0 official tolerance (0.4 + tan α) m.
1: version 1, 15 m x-scanning, Planimat; SCOP.
2: version 2, 15 m y-scanning, Planimat; SCOP.
3: version 3, 30 m y-scanning, Planimat; SCOP.
4: version 4, direct contouring, Planimat.
5: version 5, 15 m y-scanning, Planitop; SCOP.
6: version 6, direct contouring, Planitop.

The investigation into the absolute accuracy of the photogrammetrically derived contour lines confirms the general assessment which was obtained from the visual inspection of the contour plots.

The test versions 1 and 2 (photogrammetric scanning of a 15 m grid in x- and in y-direction) agree very closely. Their RMS height errors of 43 cm and 40 cm, respectively, coincide with the value of 43 cm of the Reg Elta 2 version (25 m grid), a result which has been concluded above from the discussion of the scanning error effects. Also, the slight slope dependency is apparent.

In the version 3, based on scanned profiles 30 m apart, the stated trend continues reaching an RMS height error of 59 cm and stronger slope dependency. Flat areas, however, are hardly affected by the reduced density of points, as is apparent from the constant term of 21 cm.

The directly plotted contours have with a 37 cm (0,24‰ of h) RMS height error a good overall accuracy, in addition to the good representation of small morphological features. It is to be pointed out that the absolute height accuracy of the contours is almost independent of slope (within the range tested).

By comparison, the accuracy of the contour lines plotted directly from the Planitop falls somewhat off, reaching an RMS value of 48 cm, while the slope dependency remains

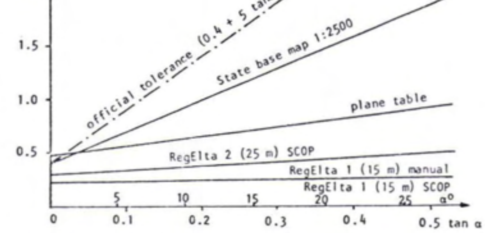

FIG. 10. Height accuracy of contour lines from terrestrial surveys, as a function of terrain slope.

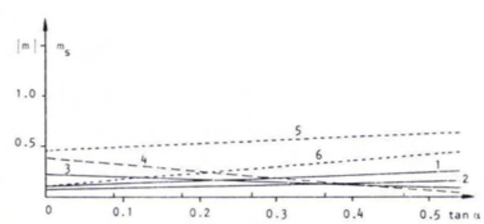

FIG. 12. Systematic height errors of contour lines from photogrammetric data acquisition, as a function of terrain slope (see Figure 11 for legend).

TABLE 3. SYSTEMATIC HEIGHT ERRORS OF THE PHOTOGRAMMETRICALLY DERIVED CONTOUR LINES

Survey/plot	observed grid / profile	RMS value of syst. height errors	quadratic syst. height errors $m_s = (a_s + b_s \tan \alpha)\ m$ $\|m\|$
Planimat			
Version 1 SCOP	15 m/x	0.18 m	$m_s = 0.12 + 0.22 \tan \alpha$
Version 2 SCOP	15 m/y	0.11 m	$m_s = 0.08 + 0.12 \tan \alpha$
Version 3 SCOP	30 m/y	0.15 m	$m_s = 0.20 - 0.19 \tan \alpha$
Version 4 direct contouring		0.22 m	$m_s = 0.39 - 0.63 \tan \alpha$
Planitop			
Version 5 SCOP	15 m/y	0.56 m	$m_s = 0.45 + 0.40 \tan \alpha$
Version 6 direct contouring		0.26 m	$m_s = 0.12 + 0.55 \tan \alpha$

low. An explanation may be the enlargement ratio of 4:1 from model to map, mentioned earlier. By contrast, the version 5 of 15 m scan profiles of the Planitop reached with an RMS value of 64 cm unexpectedly large height errors, combined with a moderate slope dependency. The result is caused by considerable systematic height errors, see next paragraph.

The accuracy investigation was extended to a detailed analysis of systematic height errors of the contour lines, systematic errors being defined by the deviations from expectation zero. It turned out that all photogrammetric restitutions have systematic height errors to some extent, as summarized in Table 3 and Figure 12. The scan versions of the Planimat restitutions are very little affected by systematic errors. The overall contributions of them amount to RMS values between 11 cm (version 2) and 18 cm (version 1). There is only marginal dependence on terrain slope. The direct contouring with the Planimat contained systematic height errors of 22 cm average magnitude. They are particularly conspicuous in the flat areas, reaching there a magnitude of 39 cm.

The results of the Planitop restitutions behave quite differently with regard to systematic errors. The different measuring conditions have been referred to earlier. Here the scanning procedure seems to be liable to considerable systematic errors, accounting for 56 cm of the total RMS height error of 64 cm. The systematic errors are slope-dependent to some extent. The systematic error effects seem not to be caused by instrumental errors but rather by some features inherent to the observational circumstances of scanning. We are investigating the case, considering also the Fertsch-effect. By comparison, direct contouring with the Planitop has systematic errors of considerably smaller magnitude, although they exceed the Planimat values and show different slope dependency. Obviously the question of systematic errors of conventional photogrammetric contouring should be given more attention.

Summarizing the test results presented here, it may be stated that the high accuracy capability of digital contour interpolation has been demonstrated. It has been confirmed that contour lines of high cartographic quality can be obtained.

It has also been shown that the resulting accuracy depends to a great extent on the appropriate data acquisition, in fact more than on anything else. There seems to be simple, in first approximation, linear relationships between contour accuracy and average density of recorded terrain points. Direct contouring fits into the relationship, corresponding to certain fictitious point densities. Research has to be continued in order to establish practicable rules.

The tests have confirmed further that uniform density of points is not the ideal distribution. The density of terrain points should be effectively adapted to the terrain features to be represented by contours. Rules should be worked out with which the required results can be guaranteed. Unfortunately, there is a major theoretical obstacle. Indisputable solutions are prevented as long as no objective criteria are specified concerning the required fidelity with which local terrain features are to be represented by contour lines. Cartographers are urgently requested to establish such criteria.

References

1. Schilcher, M.: A comparison of the accuracy of several contour plots of the Söhnstetten test field. Photogrammetric Week 1977; Schriftenreihe des Instituts für Photogrammetrie, Universität Stuttgart, Heft 4, 1977.
2. Massa, W., and G. Waizenegger: *Vergleichende Untersuchungen zur Genauigkeit der automatischen Höhenlinieninterpolation.* Diplomarbeit am Institut für Photogrammetrie der Universität Stuttgart, 1977.
3. Heege, S., and G. Rieger: *Untersuchungen zur Genauigkeit photogrammetrischer und digitaler Höhenlinien.* Diplomarbeit am Institut für Photogrammetrie der Universität Stuttgart, 1977.
4. Schut, G. H.: *Review of interpolation methods for digital terrain models.* Invited paper, Comm. III, ISP Congress Helsinki 1976.
5. Kraus, K.: Ein digitales Geländemodell—Theorie und Anwendungsmöglichkeiten. *Numerische Photogrammetrie,* Sammlung Wichmann, Neue Folge, Band 5 (1973).
6. Stanger, W.: Das Stuttgarter Höhenlinienprogramm Beschreibung und Ergebnisse. *Numerische Photogrammetrie,* Sammlung Wichmann, Neue Folge, Band 5 (1973).
7. Stanger, W.: Erfahrungen mit dem Stuttgarter Höhenlinienprogramm. *Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart,* 1 (1976).
8. Aßmus, E.: Die Behandlung geomorphologischer Strukturen im Stuttgarter Höhenlinienprogramm. *Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart,* 1 (1976).

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