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A COMPARISON OF THE ACCURACY OF SEVERAL CONTOUR PLOTS OF THE SÖHNSTETTEN TEST FIELD

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1. Introduction

1.1 Contour lines are the most important element for representing the configuration of the terrain in topographic maps. This applies above all to maps of medium to large scale between 1:2500 and 1:25 000. It is obvious that the development of topography is very closely connected with the development of contour-plotting techniques. If we look at the historic development of surveying and plotting techniques for contour representation in topographic maps, we can essentially recognize three different phases.

In the first phase, from the beginnings of topographic surveying in the early nineteenth century up to the early twentieth century, contour lines were obtained exclusively by plane-table or digital tacheometric surveys. In this classical method of topography, the ground was plotted with the aid of discrete characteristic points, and the contours were then interpolated either directly in the field or in the office.

After first applications in terrestrial photogrammetry, the second phase started in the 1930s with the use of aerial photogrammetry for contour plotting. The introduction of photogrammetric techniques for this purpose was a big step forward, because photogrammetry allows the contour lines to be measured and plotted directly in the form of lines. They no longer have to be interpolated between discrete points as in the past. This decisive advantage explains why ever since photogrammetric techniques have been used almost exclusively for the production or revision of topographic maps. They have relegated terrestrial topographic surveys almost completely to the background.

The present third phase is characterized by the desire further to increase the speed and economy of topographic surveys by means of automation. The progress made in electronics and computer technology gave decisive impulses to these endeavors in the late 60s. And it is interesting to note that general technological developments affect both the equipment and the working techniques employed. In photogrammetry, semi-automatic scanning systems allow height profiling in relatively and absolutely oriented models so that point-by-point digital contour plotting becomes possible in addition to the analog plotting of contour lines used up to that date. Terrestrial topographic surveys are made susceptible to automation by the introduction of self-recording electronic tacheometers and thus obtain a new lease on life.

Together with advanced computers, these new possibilities of acquiring, recording and storing data finally form the basis for the development of efficient computer programs for automatic contour plotting. The growing application of new automatic techniques of contour plotting also moves numerical methods into the foreground.

The automatic techniques cover the terrain first of all by measuring spot heights, similar to the conventional tacheometric techniques. It is here of no importance whether the height information is taken from a photogrammetric profile or point measurement or from a tacheometric survey. The contour lines are then obtained by numerical interpolation between the points measured (for which several different techniques and formulations can be used).

We thus have a situation that is basically similar to conventional tacheometric contour plotting.

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1.2 In the meantime, efficient program systems have become available for practical use at various organizations. These allow the automatic production of contour charts with cartographic quality (see references, Schut |1| and |2|).

Although the scientific interest in the problems of automatic contour plotting has recently increased, surprisingly little has become known about thorough practical investigations. Most of the papers published deal above all theoretically with detailed questions of the suitability and accuracy of interpolation formulas, or they report about new program developments (see Schut |1|). Thus, hardly any practical experience has up to now been available in respect of the accuracy, feasibility and economy of automatic contour-plotting techniques, just as direct comparison between advanced tacheometric and photogrammetric surveying and plotting methods have been lacking. In other words, there has hardly been any concrete information on questions that are of great interest especially to practical surveyors.

1.3 This is the reason why the Institute of Photogrammetry of Stuttgart University, which developed the SCOP[1] automatic program, decided to set up the Söhnstetten test field.

In order to allow a thorough study of the accuracy of automatic contour interpolation, the test field was repeatedly surveyed and plotted both tacheometrically and photogrammetrically, using conventional and more advanced techniques. As a result, information on the efficiency of automatic contour interpolation can be obtained by direct and comparative accuracy tests.

The present paper reports about first experience and results of the Söhnstetten test.

2. The Söhnstetten test field

2.1 Topographic conditions

The Söhnstetten test field in the Heidenheim area is situated in the Swabian Alb mountains and covers an area of approx. 0.9 x 1.7 km^2. It is very well-suited for studying large-scale contours because the open country hardly features any forests but a relatively large number of topographically interesting morphological details in a relatively small space. Elevation above sea level is between 580 m and 650 m with a maximum slope of 50 %. Outstanding topographic features are a marked wadi winding through the entire test field, a relatively flat, almost level plateau in the western part of the field as well as striking man-made structures, such as a dam with reservoir and a ski lift at the southern end of the area. The test field is primarily covered by typical moorland with junipers and is used agriculturally in the form of meadows and fields only partly on the plateau (see Annex 1).

2.2 Geodetic basis

As was mentioned at the beginning, the test field had been repeatedly surveyed both tacheometrically and photogrammetrically. The necessary horizontal control points and spot heights were obtained by extending the existing control.

The horizontal control network (Gauss-Krüger network) was extended by combined observations of direction and distance. The adjustment gave rms coordinate errors of < 3 cm for the pass points. The selected spot heights were tied into the vertical control network by double leveling. The rms error of heights is < 5 mm.

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[1] See references |2|, |3|, |4|, |5|, |6| and |7|.

2.3 Terrestrial topographic surveys

Table 1 lists the most important data of the different tacheometric surveys of the test field.

Type of survey	Area $\vert km^2 \vert$	Point interval [1] $\vert m \vert$	Survey points	1:2500 plotting
RegElta I (1975)	0.6	15	6100	manually and automatically with SCOP
RegElta II (1975)	0.31	25	1700	automatically with SCOP
Plane table (1974)	0.1	30 - 35	150	manually
Cadastral contour map (1925; digital tacheometry)	0.6	45	350	manually

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[1] applies to open terrain; partly lesser intervals in more difficult terrain.

Table 1 Terrestrial topographic surveys of Söhnstetten test field

In addition to the data in Table 1 it should be added that the RegElta survey I is used as a "nominal-status" survey for the different accuracy comparisons including the photogrammetric surveys. The terrain has therefore been covered in this survey in a rough gridform with a relatively small point interval of approx. 15 m. In addition, further points were observed along outstanding morphological lines (such as synclines, ridges or slope edges).

The high point density offered the additional possibility of reducing the number of points for a study of the effective point density on the accuracy of automatic contour interpolation. This work, which is still in progress, will not be discussed in greater detail here.

The RegElta II survey, which covered only part of the area, was included in the study as an independent survey because it can be used for a direct study of the effect of point density on contour accuracy.

The plan-table survey, which likewise covered only part of the area, allows a comparison between advanced techniques and the classical method of tacheometric surveying.

The official cadastral contour map at 1:2500 scale, finally, was used as an additional basis for an assessment of accuracy because it is the most accurate topographic map of Württemberg.

2.4 Photogrammetric surveys and plots

2.4.1 Signalization and photoflight

The Söhnstetten test field was flown with a Zeiss RMK A4 15/23 wide-angle camera at three different scales by Messrs. Geoplana of Rielingshausen in the spring of 1976. The most important flight data have been summarized in Table 2. The orientation of flight strips is illustrated in Fig. 1.

Date of flight	March 20, 1976
Aircraft	Cessna 180
Camera	Zeiss RMK A4 15/23
Focal length	153.19 mm
Photo scales	1:10 000, 1 model 1: 7 000, 3 models 1: 3 000, 14 models
Filter	B, light yellow
Film	Agfa Aviphot Pan 30
End lap	55 - 60 per cent

Table 2 Data of test-field flight

Control points were signalized by disks 20 cm x 20 cm in size. For the 1:3000 photo scale, the tie points were also signalized.

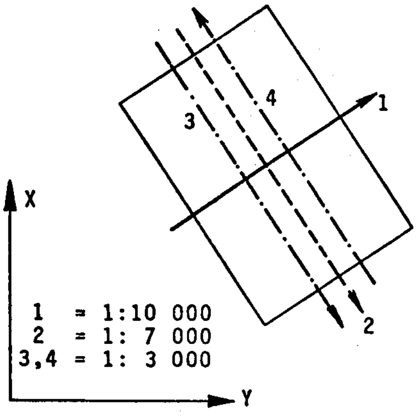


Fig. 1 Photoflight layout

2.4.2 Photogrammetric plotting

The photogrammetric plotting was performed at the Institute of Photogrammetry by Mr. Bettin. Only the 1:10 000 was, however, used for the test under discussion.

Photogrammetric plotting was performed in a Zeiss D-2 PLANIMAT equipped with an external EZ-3 tracing table and an ECOMAT-11 electronic recording unit with a DTM-1 accessory for semi-automatic acquisition of profile data. In order to allow several comparisons of accuracy to be made, the model of 1:10 000 photo scale was plotted by direct contouring and by profiling in three different versions.

The contour lines for photogrammetric profiling were computed automatically with the aid of the SCOP contour program.

General plotting data: Photo scale 1:10 000, model scale 1:5000, plotting scale 1:2500, contour interval 2.5 m. For further details regarding the different plotting versions, see Table 3.

Version	Profiling direction	Travel increment in |mm|1) x	y	z	Number of recordings	Plotting time2)	Computer time SCOP |SS|3)	Drafting time
1	x	3	3	1	8460	5 h 25 min.	614	2 h 45 min.4)
2	y	3	3	0	7580	4 h 24 min.	508	2 h 45 min.4)
3	y	6	6	0	1932	3 h 15 min.	391	2 h 45 min.4)
Direct contour plotting					-	11 h 00 min.	-	31 h 20 min.5)
Synclines, ridges, slope edges, etc.					11986)	6 h 00 min.7)	-	-

1) At model scale (1:5000); x,y,z in model-coordinate system.
2) Plus the time for relative orientation (40 min) and absolute orientation (2 h 50 min).
3) System seconds of CDC-6600 of data-processing center of Stuttgart University.
4) Scribing on Coragraph plotter (Cora IIB) by Messrs. Contraves.
5) Time for plotting the grid and control points 1 h 20 min; time for smoothing and scribing of contours 30 h.
6) Identical for all profile plots.
7) Preparations 3 h 35 min; measurement 2 h 25 min.

Table 3 Photogrammetric plotting of Söhnstetten test field

2.5 Experience with automatic data acquisition and plotting

2.5.1 Several papers |8|, |9| have been published regarding the use of the RegElta-14 self-recording electronic tacheometer for automatic contour generation. In the following, the results obtained with the RegElta-14 in the Söhnstetten test will therefore be mentioned only briefly.

In a survey with freely chosen instrument stations, an average of between approx. 200 points and approx. 600 points in open terrain were observed per day. With only 0.2 per cent of over 6000 observations, the number of errors was remarkably low. An inquiry with private companies confirmed these values, while official organizations (topographic and reallotment survey offices) did not yet have sufficient experience in the use of the RegElta-14 for topographic purposes |16|.

2.5.2 In the photogrammetric contouring techniques, a time comparison between direct contour plotting and profiling is of particular interest. Table 3 shows that for comparable contour quality pure plotting time is almost identical for analog and profile measurement (versions 1 and 2) if the time required for recording the structural and break-line points is included in the case of the profiling techniques. In view of previous time comparisons |5|, |10|, |11|, this result is rather surprising. It should be noted, however, that the terrain concerned here presented topographic difficulties and that the tentative value is based on only one model. It should also be noted that profiling of the model revealed an unexpectedly high loss of points, namely approx. 2 - 3 per cent. This large number of erroneous recordings is primarily due to the fact that the recording system did not yet work with the desired reliability. This was true above all for transfer of the data to magnetic tape.

For the automatic computation of contours with the aid of SCOP, an average of 2 - 3 runs were necessary up to final contour plotting. Table 3 gives an interesting comparison between computer times for automatic contour interpolation of the different photogrammetric profile measurements. A pronounced variation of computer time with the number of points is here evident. In general, computer time is also affected by the contour interval and the grid interval of the DTM.

3. Assessment of contour accuracy

3.1 When studying contour accuracy, we generally distinguish between geometric accuracy and morphological trueness of contours.

Geometric accuracy provides information on the absolute horizontal and vertical errors of the contours. In other words, it is an important measure of the measurability of a map, that is, its suitability for deriving absolute heights, level differences, etc.

By morphological trueness, on the other hand, we understand the accuracy with which the configuration of the terrain is reproduced by the contour image. Another term frequently used is relative contour accuracy.

For a general assessment of contour quality we thus have to make allowance for each of these errors. The usefulness of a contour plot will, of course, also be greatly influenced by the user requirements. This is why at large scales we are more interested in geometric accuracy, while morphological trueness only gains importance at ever smaller scales.

3.2 For a study of the contour plots available we now have to find a method suited for a thorough and comprehensive test of absolute and relative contour accuracy. The difficulty here is that according to all known theoretical suggestions there is no possibility of determining the two errors in a single study. We thus have to use separate and different methods for a study of geometrical and morphological accuracy of contour lines.

Absolute contour accuracy is normally determined by testing a contour chart point by point with the aid of separately observed reference points. Using Koppe's formula, the differences found at the reference points then give an rms heighting error that is a function of ground slope. If the reference points are chosen with a suitable distribution, this error offers the advantage that it is representative of the entire area, transparent and easy to interpret and, moreover, that it is well-suited for direct comparison - a factor that is of particular importance for the study we are concerned with here.

No uniform and generally accepted suggestions |4|, |12| have yet been made for testing morphological trueness. In some cases it has been tried to express this by means of errors of direction and curvature |12|, |13|, |14|, |15|. However, this approach has the disadvantage that the corresponding errors are not very descriptive of the quality of a contour plot and that they take a relatively large amount of work so that they will usually have to be limited to small parts of a map |8|, |12|. This is why in practice a visual comparison between two contour plots is frequently preferred to numerical methods of testing morphological trueness. Visual assessment is easy and allows a clear distinction to be made of contour quality precisely at the most interesting morphological features of the terrain.

Although it is not the primary objective of this paper to discuss the possibilities for adequate techniques of testing contour lines, some new possibilities for future tests of the accuracy of automatically generated contours will be outlined in the last section.

For better comparison, however, the results of the tests discussed here will be studied by the methods mentioned before. In other words, geometric accuracy will be computed by a comparison with independent reference points, while morphological trueness will be tested by visual comparison.

3.3 Absolute contour accuracy by comparison with reference points

Over 370 independent reference points arranged in 16 reference profiles were surveyed in the test field to check on the terrestrial topographic surveys. For a check of the photogrammetric contour surveys, an additional six profiles were chosen from the RegElta I survey so that in this case a total of 485 independent check points was available. The reference points were evenly distributed over the entire test field with special allowance for morphologically interesting features and thus allow a more or less representative assessment of the absolute heighting accuracy of the different contour plots (see Annex 1).

A check of the points observed with the aid of the RegElta revealed rms coordinate errors definitely below 5 cm in horizontal position and about 1 cm in height, exceeding 2.5 cm only in extreme cases. The reference points thus satisfy the necessary requirements for thorough testing in respect of quantity, distribution and accuracy.

The following procedure was used to test accuracy with the aid of reference points: the level differences h and slope α at the reference points were determined by interpolation between adjacent contours; the points were classified according to terrain categories and an rms heighting error $m_{h'} = \sqrt{|hh|/n}$ computed for each category; a curve $m_h = (a + b \tan\alpha)$ for the rms heighting error was determined by adjustment with compromising observations. Five different terrain categories were established for the present test, over which the reference points are distributed almost uniformly. The number of points in the different groups was used as a basis for weighting.

If the original, true errors h of the comparison points are used to compute an error curve instead of the rms heighting errors $m_{h'}$ for the different terrain categories, a systematic component of the heighting error varying with ground slope can be determined. If the number of points is sufficiently large - in the present case, this condition is satisfied with approximately 500 points - the mean of the true errors can be assumed to be zero with sufficient accuracy if it contains only accidental error components. Any other figure then is the systematic component of the rms heighting error.

This error is of particular interest for the photogrammetric contour plots because contact of the floating mark with the model surface and its guiding along the model features are influenced differently by various factors, such as ground slope, configuration of the terrain, lighting conditions, etc.

4. Results

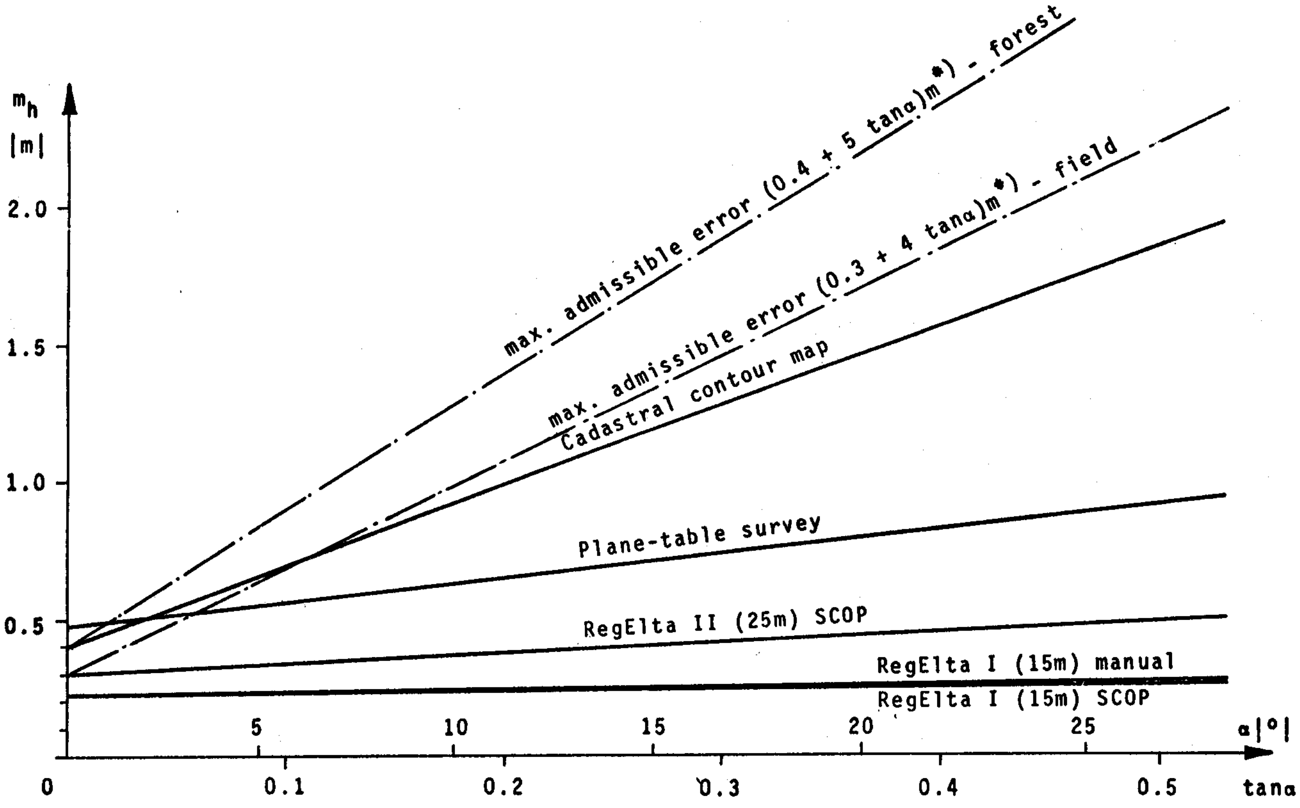
4.1 Absolute contour accuracy by comparison with reference points

The rms heighting errors of the contours from tacheometric surveys, obtained with the aid of reference points, are summarized in Table 4, those for the photogrammetric surveys in Table 5. Figures 2 and 3 show the results in graphical form.

In addition to the rms heighting error m_h and the mean errors of constants a and b, the tables also contain information on the mean ground slope α_s and the rms heighting error m_{hs} of the center of gravity of the error curve. Being the mean of a terrain category, this error provides valuable clues regarding the total error of a contour plot.

Survey / plot	Point interval |m|	Number of reference points	σ_s |°|	m_{hs} |m|	rms heighting error $m_h = (a + b \tan\alpha)$ |m|	σ_a |m|	σ_b |m|
RegElta I manual	15	373	15	0.26	$m_h = (0.22 + 0.15 \tan\alpha)$	0.03	0.09
RegElta I SCOP	15	369	15	0.25	$m_h = (0.22 + 0.13 \tan\alpha)$	0.02	0.07
RegElta II SCOP	25	145	17	0.43	$m_h = (0.30 + 0.42 \tan\alpha)$	0.13	0.39
Plane table manual	35	97	17	0.75	$m_h = (0.47 + 0.91 \tan\alpha)$	0.18	0.54
Cadastral contour map manual	45	371	15	1.16	$m_h = (0.40 + 2.99 \tan\alpha)$	0.23	0.79

Table 4 Absolute contour accuracy of tacheometric surveys of Söhnstetten test field

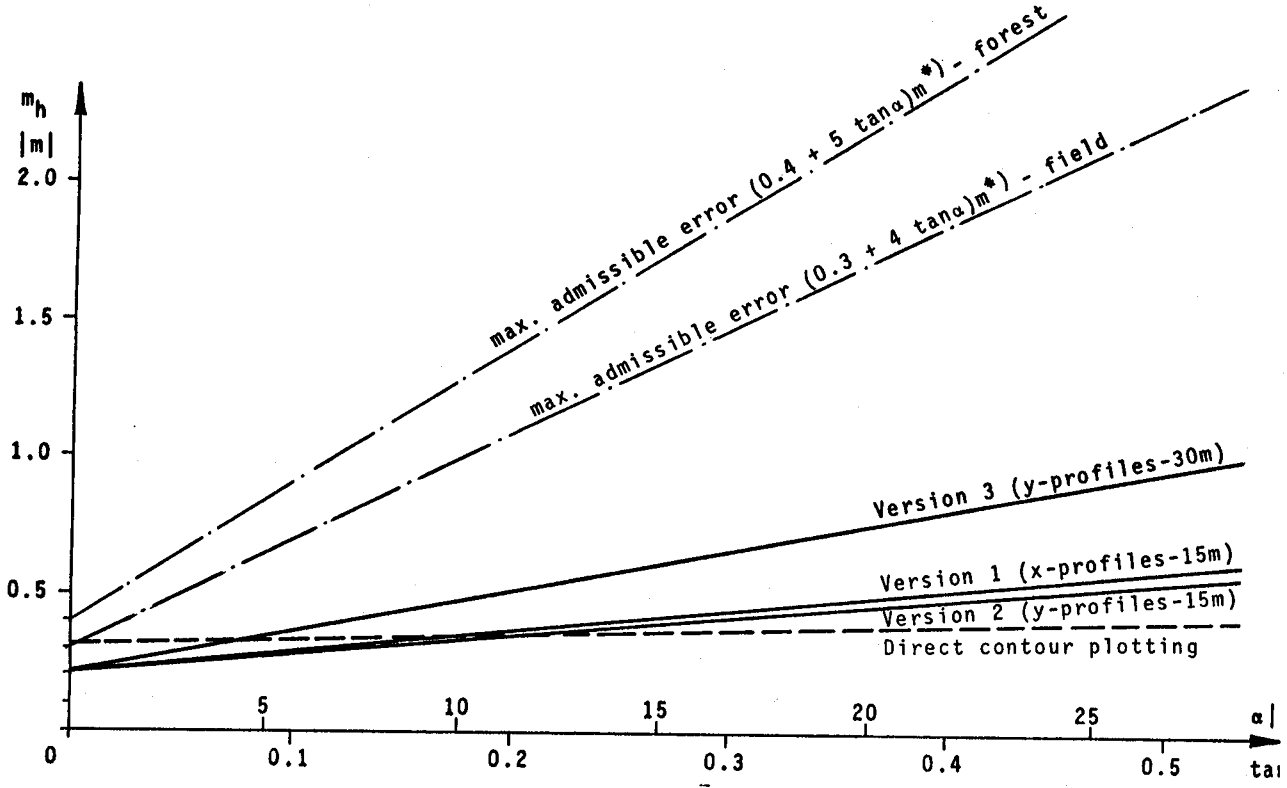


*) maximum admissible error applying to conditions in Baden-Württemberg

Fig. 2 Comparison between rms heighting errors of manually and automatically (SCOP) interpolated contours of tacheometric surveys

Measurement / plotting	Point interval $\|m\|$	Number of reference points	α_s $\|°\|$	m_{h_s} $\|m\|$	rms heighting error $m_h = (a + b \tan\alpha)$ $\|m\|$	σ_a $\|m\|$	σ_b $\|m\|$
Version 1 x-profiles SCOP	15	485	15	0.43	$m_h = (0.22 + 0.78 \tan\alpha)$	0.02	0.08
Version 2 y-profiles SCOP	15	485	15	0.40	$m_h = (0.21 + 0.72 \tan\alpha)$	0.04	0.15
Version 3 y-profiles SCOP	30	483	15	0.59	$m_h = (0.21 + 1.50 \tan\alpha)$	0.02	0.08
Direct contour plotting	-	485	15	0.37	$m_h = (0.32 + 0.21 \tan\alpha)$	0.02	0.07

Table 5 Absolute contour accuracy of photogrammetric surveys of Söhnstetten test field



*) **maximum admissible error applying to conditions in Baden-Württemberg**

Fig. 3 Comparison between rms heighting errors of direct contour plot and of contour lines generated by photogrammetric profiling and automatic interpolation with SCOP

4.2 Systematic heighting errors of photogrammetric contour plots

The systematic heighting errors of the different photogrammetric plotting versions are summarized in Table 6 and shown as a function of ground slope in Fig. 4. The number of reference points and the mean ground slope are the same as in Table 4 because computation of the two error curves differs only in the observations m_h' or h used.

Measurement / plotting	Point interval |m|	m_{h_s} |m|	Systematic heighting error $m_s = (a_s + b_s \tan\alpha)$ |m|	σ_{a_s} |m|	σ_{b_s} |m|
Version 1 x-profiles SCOP	15	0.18	$m_s = (0.12 + 0.22 \tan\alpha)$	0.05	0.17
Version 2 y-profiles SCOP	15	0.11	$m_s = (0.08 + 0.12 \tan\alpha)$	0.04	0.14
Version 3 y-profiles SCOP	30	0.15	$m_s = (0.20 - 0.19 \tan\alpha)$	0.07	0.22
Direct contour plotting	-	0.22	$m_s = (0.39 - 0.63 \tan\alpha)$	0.05	0.16

Table 6 Systematic heighting errors of photogrammetric contour plots

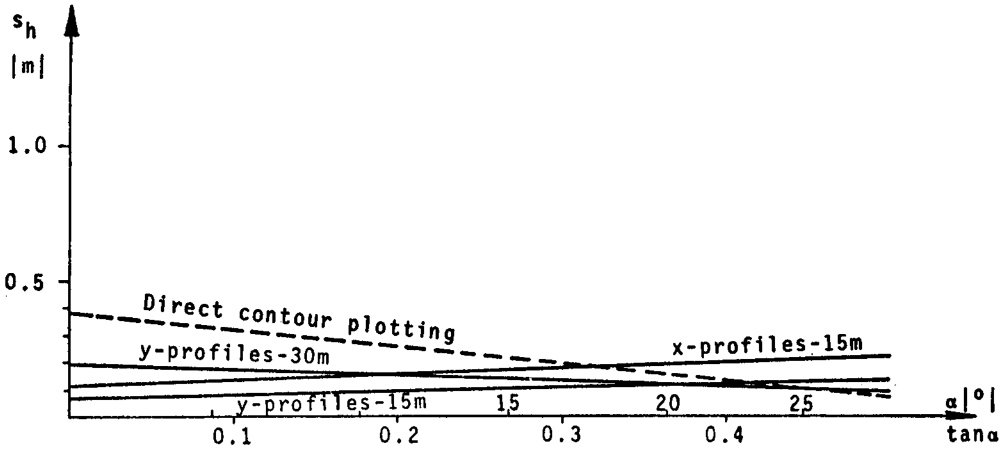


Fig. 4 Systematic heighting errors of photogrammetric contour plots, plotted against ground slope

Photogrammetrische Woche 1977
Institut für Photogrammetrie
Schriftenreihe, Heft 4, 1977

4.3 Visual comparison

As has been mentioned before, morphological trueness and general quality of the contours were assessed by visual comparison between two different contour charts. For this purpose, blueprints or color prints were made of the corresponding contour charts for the entire area suitable for comparison. The Stuttgart Topographic Survey was kind enough to help in preparing the color prints[1].

Table 7 briefly summarizes the number of comparisons made and also gives the purpose of each test.

Comparison	Contour plot I	Contour plot II	Prints used for comparison	Purpose of test
1	RegElta I (15m) manual	RegElta I (15m) SCOP	Color print	Checking automatic contour interpolation
2	RegElta I (15m) SCOP	RegElta II (25m) SCOP	Color print	Effect of point density on contour accuracy
3	RegElta I (15m) manual	Plane-table survey	Blueprint	Comparison between advanced survey technique and conventional method
4	RegElta I (15m) manual	Cadastral contour map	Color print	Comparison between test survey and official map
5	RegElta I (15m) manual	Direct contour plot	Color print	Comparison between terrestrial topographic survey and photogrammetry
6	Version 2 y-profiles (15m) SCOP	Direct contour plot	Color print	Comparison between analog contour plot with digital contour plot
7	Version 2 y-profiles (15m) SCOP	Version 1 x-profiles (15m) SCOP	Color print	Effect of profiling direction on contour accuracy
8	Version 2 y-profiles (15m) SCOP	Version 3 y-profiles (30m) SCOP	Color print	Effect of point density on contour accuracy

Table 7 Visual comparisons between contour lines for testing morphological trueness

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[1] The plans are listed in |17| and |18|. Annexes 2 and 3 show details of the different sample plots.

Photogrammetrische Woche 1977
Institut für Photogrammetrie
Schriftenreihe, Heft 4, 1977

5. Discussion of results

5.1 Contour accuracy of terrestrial topographic surveys

Fig. 1 shows that with one minor exception the absolute contour accuracy of the tacheometric surveys very clearly remains below the maximum admissible official error. Only the rms heighting error of the plane-table survey slightly exceeds the maximum admissible error in extremely flat terrain.

5.1.1 As was to be expected, the two plots based on the RegElta I survey and closely spaced points - manual interpolation and automatic contour interpolation with the aid of SCOP - are the most accurate. The rms heighting errors of either survey are identical and practically independent of ground slope. If allowance is made for the effect of terrain roughness and ground relief (if, for example, in very rough terrain minor relief or even small topographic features are no longer covered by the point interval or cannot be reproduced due to the contour interval), the rms heighting errors of manual and automatic interpolation may be considered to represent the maximum accuracy that can be attained with a point interval of 15 m and a contour interval of 2.5 m.

The equivalence of the manual and automatic contour plots based on the RegElta I survey is confirmed by a visual comparison. The two contour images agree extremely well even in their representation of minor features. Slight deviations can be recognized only at slope edges (roads, man-made structures) that can be reproduced more exactly by the manual technique. These minor differences are due to the fact that in the SCOP version used no rigorous allowance is yet made for break lines.

A study of the effect of point density on the accuracy of automatic contour interpolation revealed a minor but clearly visible increase in rms heighting error for the greater point interval of the RegElta II survey. Although the constant component of the rms heighting errors rises to 30 cm, its low dependence on ground slope remains almost constant.

If we compare the two automatic contour plots based on the RegElta surveys I and II, good agreement of contours becomes evident above all in terrain of uniform slope. The greater point interval results in a slightly more general representation of typical small features in rough terrain with pronounced slope, although this does not lead to higher vertical errors.

A mean point interval of 25 - 30 m (and even greater in areas of simple topographic structure) should be entirely sufficient for tacheometric surveys with the RegElta-14 and automatic plotting of contours even if higher requirements are made of accuracy.

5.1.2 The conventional tacheometric contour surveys - plane table and cadastral contour map - reveal a marked increase in rms heighting error as a function of ground slope. The error curves are much steeper, the dependence of the heighting error on slope, which is typical of tacheometric surveys being particularly pronounced in the case of the cadastral contour map (see Table 4 and Fig. 2). The rms values m_{hs} of the heighting errors come to 0.75 m for the plane-table survey and 1.16 m for the cadastral contour map 1).

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1) Allowance is here already made for a mean horizon shift of 0.27 m between the old and the new vertical system.

A visual comparison between the plane-table survey and the manual contour plot based on the RegElta I survey reveals considerable horizontal-position differences between the two although the representation of large characteristic features is in relatively good agreement. The deviations, which at some points reach the full contour interval of 2.5 m, occur above all in areas of great morphological variety and may be due, in addition, to the lesser accuracy of plane-table surveys in the case of steeper sights, to a partial exaggeration (higher generalization) of typical ground features during direct contour plotting in the field. The resulting horizontal-position errors of the contour lines lead to considerable heighting errors above all in rough terrain.

A comparison between the cadastral contour map and the manual "nominal-status" plot based on the RegElta I survey reveals similarly typical horizontal-position errors of the contours as in the plane-table survey. Due to the relatively large point interval (45 m) in the case of the cadastral contour map, which automatically results in greater generalization, the heighting errors in rougher terrain go up to 2 - 3 m.

5.1.3 Summarizing the results of the terrestrial topographic surveys, it may be said that the advanced techniques of automatic surveying and plotting are clearly superior to the conventional methods of plane-table and early numerical tacheometry. This is above all due to the advantages of data acquisition with self-recording electronic tacheometers which due to their longer range and faster measurement allow greater point densities and also higher measurement accuracy. Topographic surveys with the RegElta-14 therefore are characterized by high geometrical accuracy of automatically or manually plotted contours which - contrary to earlier tacheometric techniques - is only slightly affected by ground slope.

5.2 Contour accuracy of photogrammetric surveys

As is evident from the graphical representation of rms heighting errors in Fig. 3, the absolute contour accuracy of all photogrammetric surveys clearly remains within the official tolerance.

5.2.1 A more specific study of the results shows that the rms heighting error of the contours constructed from profiles has an identical constant component in each of the different versions. The error curves therefore only begin to differ with increasing ground slope. The versions based on a dense point grid (15 m) but different profiling directions differ only very slightly. However, the larger point spacing used in version 3 (30 m) makes the error curve noticeably steeper with increasing ground slope. The slope-dependent component of the rms heighting error increases by the factor 2.

The rms heighting error of the direct contour plot, however, reveals only slight dependence on ground slope.

A comparison between the rms heighting errors of directly and automatically plotted contours proves the superiority of conventional analog plotting in steep terrain, while profiling gives higher accuracy (except in version 3) in flat and rolling terrain with up to about 20 per cent slope.

If in addition we take a look at the total errors m_{hs} of the different photogrammetric contour plots, a slight superiority of direct contour plotting will likewise be noticed, which is primarily due to the slight dependence of the rms heighting error on ground slope.

5.2.2 An analysis of systematic heighting errors provides interesting additional information on the absolute contour accuracy of the different photogrammetric surveys. (In the error curves in Fig. 4, computes from true errors, positive values indicate that the floating mark was positioned above the model surface.)

The course of error curves for direct contour plotting very clearly confirms their well-known uncertainty in flat terrain. The relatively high systematic heighting error in this type of terrain shows that the floating mark here was constantly kept too high above the surface. It is true, however, that this systematic setting error goes down very markedly as ground slope increases.

The automatic contour plotting of version 1 (x-profiles) and of version 2 (y-profiles) reveals a clearly different course of error curves for the systematic heighting error. As is obvious from Fig. 4, the values for flat terrain are relatively small, while in version 2 their magnitude is almost in the order of terrain roughness, and unlike in direct contour plotting they slightly increase with ground slope. The systematic errors of x-profiles, which are mostly perpendicular to the contours, are clearly higher than those for comparable y-profiles (see Table 6, Fig. 4). This may also be assumed to be the reason why version 2 gives slightly better absolute accuracy.

5.2.3 For an overall assessment of the contours obtained by photogrammetric methods, four selected visual comparisons were made, as is evident from Table 7.

A comparison between the automatic contour plots of version 1 (x-profiles) and version 2 (y-profiles)[1] indicates good agreement of ground representation, except for minor variations in the case of more pronounced relief. This seems to indicate that the profiling direction has only a minor effect on the representation of geomorphological details. The advantage expected for version 1, namely that profiling perpendicular to the slope direction would result in better coverage of the configuration of the terrain, did not materialize. On the contrary, it is precisely this version which in rough terrain produces a slight waveform of contours as a function of profile direction and profile width in spite of filtration of a systematic profiling error.

A direct comparison between the automatically generated contours of versions 2 and 3 - in either case y-profiles with point intervals of 15 m or 30 m - reveals a pronounced dependence of automatic contour interpolation on point density. The differences between these two contour representations above all in areas of great morphological variety are greater than would at first have been expected from the difference between rms heighting errors. Due to the greater point interval and the largely accidental distribution of profile points, important information for the representation of typical terrain features is lost and cannot be offset by additional measurements at break lines and special structures (which, incidentally, is identical in the two versions). The missing information results in a clearly visible smoothing of the contour image in which characteristic small features are largely lacking, while larger morphologically interesting features are reproduced only incompletely or not at all. This applies above all to terrain with many morphological features, since the effect of point density naturally is much less in relatively open or uniformly sloping terrain so that in these cases fairly good agreement can be found between the contour plots of versions 2 and 3. Altogether, however, the representation of version 3 will hardly satisfy more exacting cartographic requirements, in spite of its relatively good geometric accuracy.

Checking the automatically generated contours of version 2 (y-profiles, 15 m) against direct contour plotting, fairly good agreement between the two techniques can be found. Apart from minor systematic variations of contours in flat terrain, slight but typical variations can be noticed in isolated cases

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[1] See Annex 3

(small features and slope edges), which for the aforementioned reasons are reproduced partly smoothed or incompletely by automatic interpolation. It should be added, however, that the direct contour plot shows isolated features of topographic interest (such as roads, buildings, cuts) with slight exaggeration, as is likewise obvious when comparing the manual plot of the RegElta survey[1] visually with the direct contour plot. Otherwise, the two contour images of the direct photogrammetric contour survey and the tacheometric ground survey using the RegElta are practically identical, with the exception of small systematic variations in flat terrain.

5.2.4 In general, the numerical and visual check of the photogrammetric contour surveys allows the conclusion that with sufficient point density (for instance 15 m for 1:2500 scale) the automatic generation of contours from photographic profiles gives almost the same results as direct contour plotting. Automatically interpolated contours offer certain advantages in flat and slightly sloping terrain due to their higher absolute accuracy and noticeably smaller systematic heighting errors. The geometrical accuracy of the automatically generated contours does reveal a certain dependence on ground slope, however, which increases noticeably if the point interval is increased and finally results in a superiority of analog plotting in rough terrain. Even more than geometrical accuracy, morphological trueness is affected by point density in automatic contour plotting. This holds above all for terrain with a great variety of features.

Although the results of profile plotting in the case of the Söhnstetten test do not yet allow any final conclusions regarding the question of optimum point density for automatic contour interpolation, which up to now has hardly been studied, there are a few interesting clues. It has been found, for example, that a suitably tight-meshed square grid gives a generally satisfactory contour accuracy. However, if the relationship between the number of points and computer time is taken into consideration together with the fact that a greater point interval in relatively simple terrain has only a minor effect on morphological trueness, a rectangular selection of profile points should be preferable. In this case, relatively large meshes may be chosen, for example for incremental recording in the profiling direction, to which additional points may be added if need be. The lateral spacing of profiles, on the other hand, should be fairly close in order not to lose too much information between the profiles. For the aforementioned reasons, the use of a square grid with greater point intervals seems to make little sense for topographic applications.

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1) See Annex 2

6. Conclusions

The Söhnstetten test was intended to provide information on present capabilities of automatic contour interpolation, based on various accuracy tests.

The results of the extensive investigation confirm an altogether high efficiency of the different acquisition and plotting techniques for automatic contour generation.

This applies above all to terrestrial topographic surveys where the use of new automatic acquisition and plotting methods undoubtedly brought the greatest step forward. Topographic surveys with self-recording electronic tacheometers are primarily characterized by small errors in data acquisition and high geometric accuracy of contours combined with only minor dependence on ground slope. They are thus clearly superior to the conventional tacheometric methods.

The photogrammetric techniques offer advantages for automatically generated, profile-based contours in flat and slightly sloping terrain, while conventional analog plotting is at a slight advantage in more steeply sloping terrain and in the representation of topographic details. When discussing the pros and cons of the two photogrammetric plotting techniques, it is therefore not only their economy but primarily their use that is of decisive importance: the question of whether a contour chart is to be employed for civil-engineering or topographic purposes.

The results of the Söhnstetten test also provided information on the most desirable objectives of future investigations of automatic contour interpolation:

1. More than anything else, the question of optimum point density should be studied by theoretical and practical investigation.
2. The use of electronic computers for automatic contour interpolation also opens up new possibilities for checking contour accuracy. Thus, the true errors h for computation of absolute contour accuracy can be directly determined in the DTM by the SCOP program and need no longer be taken graphically from a contour chart. There is another possibility for comparing two digital contour plots: computing a so-called "digital differential model" from the differences of grid heights of the DTM and plotting it in the form of isolines. This allows quick determination of the magnitude and distribution of the heighting errors in two different map sheets. Both these possibilities have already been used to great advantage in other investigations in connection with the Söhnstetten test field.
3. A practical investigation of the accuracy of automatic contour interpolation should be extended by a similar test to cover also the small-scale area where generalization is an additional influence.

May I finally thank Dipl.-Ing. S. Heege and Messrs. W. Massa, G. Rieger as well as G. Waizenegger for their assistance in these tests.

Literatur

|1| Schut, G.H.: Review of interpolation methods for digital terrain models. Invited paper, Kommission III, ISP-Kongreß Helsinki 1976.

|2| CAD-Bericht 11: Das digitale Geländemodell (DGM), Gesellschaft für Kernforschung Karlsruhe, September 1970, 270 S.

|3| Kraus, K.: Ein digitales Geländemodell - Theorie und Anwendungsmöglichkeiten. Numerische Photogrammetrie, Sammlung Wichmann, Neue Folge, Band 5 (1973), S. 225-253.

|4| Kraus, K.: Weitere Entwicklungen und Anwendungen der digitalen Höhenlinienkartierung und des digitalen Geländemodells. Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, 1 (1976), S. 147-157.

|5| Stanger, W.: Das Stuttgarter Höhenlinienprogramm - Beschreibung und Ergebnisse. Numerische Photogrammetrie, Sammlung Wichmann, Neue Folge, Band 5 (1973), S. 255-282.

|6| Stanger, W.: Erfahrungen mit dem Stuttgarter Höhenlinienprogramm. Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, 1 (1976), S. 113-130.

|7| Aßmus, E.: Die Behandlung geomorphologischer Strukturen im Stuttgarter Höhenlinienprogramm. Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, 1 (1976), S. 131-146.

|8| Kraus, K.: Rationalisierung der tachymetrischen Geländeaufnahme und Automatisierung der Weiterverarbeitung zur großmaßstäbigen Karte. AVN (1973), S. 2-15.

|9| Stache, B.: Ein Beitrag zur Automation der Herstellung großmaßstäbiger topographischer Karten durch elektronische Tachymetrie. Wissenschaftliche Arbeiten der Technischen Universität Hannover, 58 (1974).

|10| Kraus, K.: Anwendungsmöglichkeiten eines digital gesteuerten Differentialumbildegerätes. Geowissenschaftliche Mitteilungen der Universität Wien, 8 (1976), S. 1-21.

|11| Jacobsen, K.: Profilweise Höhenmessung für die Deutsche Grundkarte (DGK 5). BuL (1974) S. 131-133.

|12| Finsterwalder, R.: Zur Beurteilung der Geländedarstellung in topographischen Karten. Schriftenreihe der Societé Francaise de Photogramétrie, Bulletin N° 57, Paris 1974, S. 9-16.

|13| Lindig, G.: Neue Methoden der Schichtlinienprüfung. ZfV (1956) S. 244-251 und 296-303.

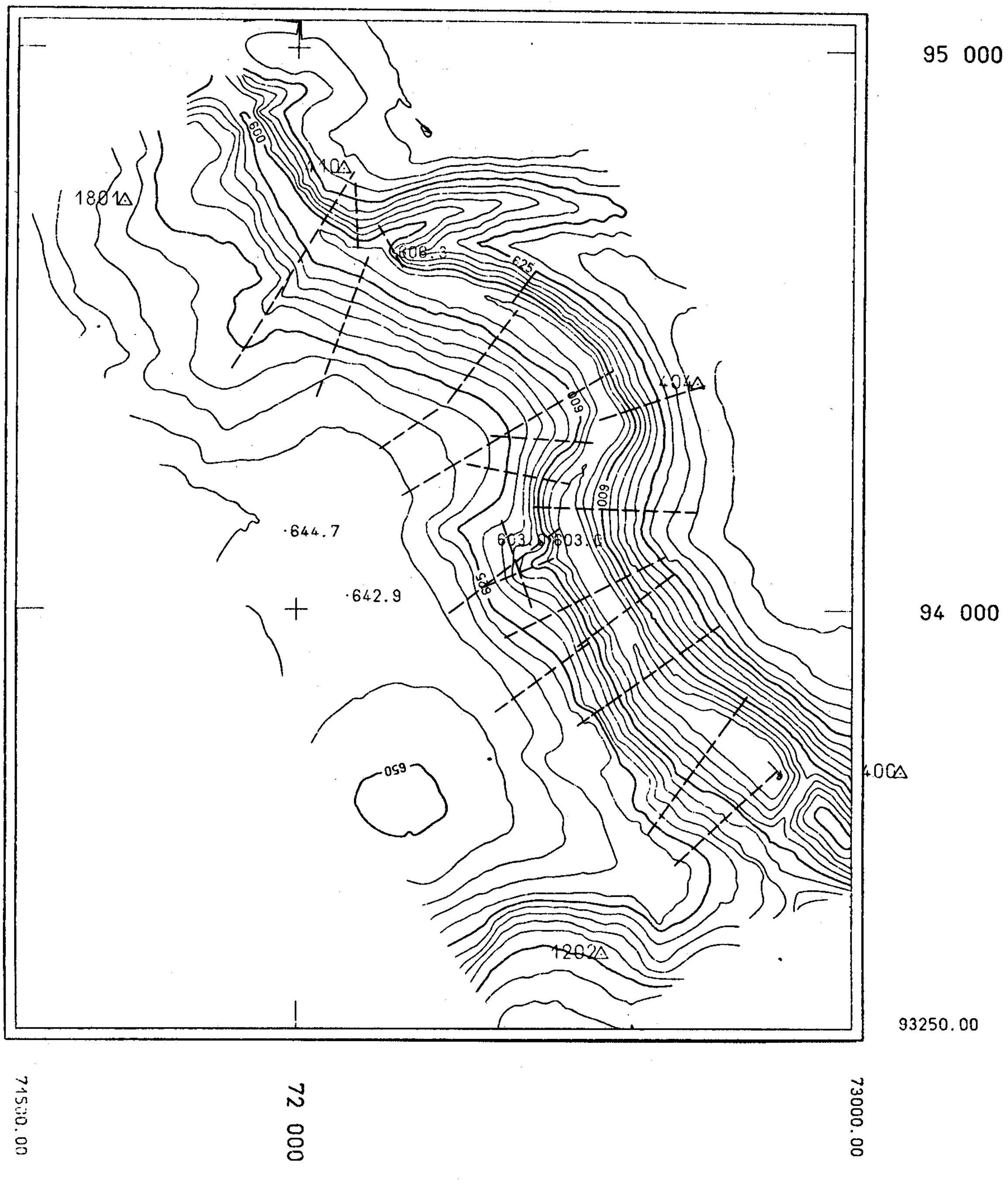
|14| Appelt, G.: Kontinuierliche Formfehleruntersuchung von topographischen Karten. München (1962) Veröff. DGK Reihe C, Nr. 54.

|15| Finsterwalder, R.: Photogrammetrische Höhenschichtlinien. ZfV (1957) S. 203-209.

|16| Heege, S. / Massa, W. / Rieger, G. / Waizenegger, G.: Aufnahme eines digitalen Geländemodells. Studienarbeit am Institut für Photogrammetrie der Universität Stuttgart, (1976) (nicht veröffentlicht).

|17| Massa, W. / Waizenegger, G.: Vergleichende Untersuchungen zur Genauigkeit der automatischen Höhenlinieninterpolation. Diplomarbeit am Institut für Photogrammetrie der Universität Stuttgart, 1977.

|18| Heege, S. / Rieger, G.: Untersuchungen zur Genauigkeit photogrammetrischer und digitaler Höhenlinien. Diplomarbeit am Institut für Photogrammetrie der Universität Stuttgart, 1977.



SÖHNSTETTEN TEST FIELD

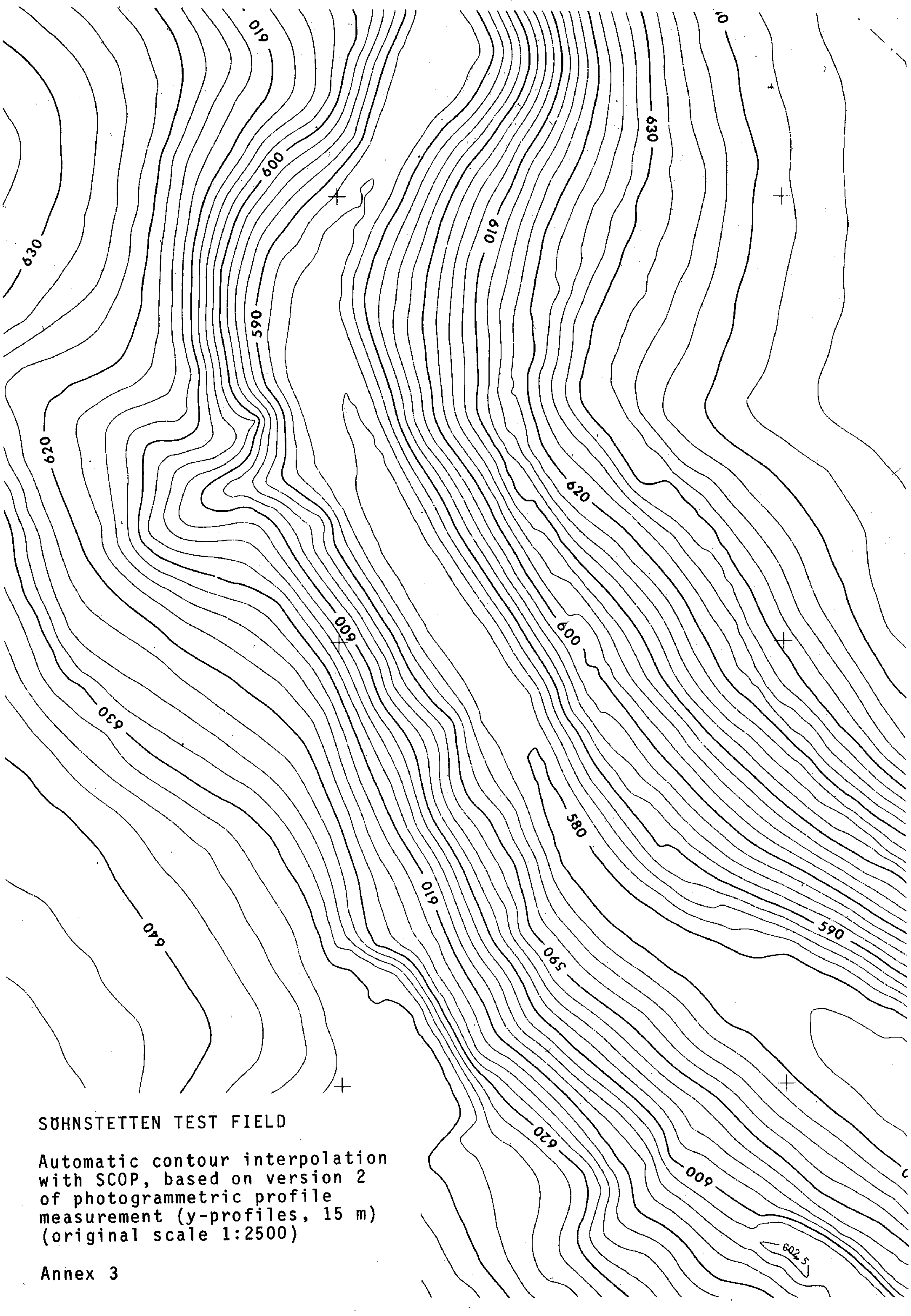
General view of test area
and check profiles

Annex 1

SÖHNSTETTEN TEST FIELD

RegElta I survey (15 m), manual
contour interpolation
(original scale 1:2500)

Annex 2



SÖHNSTETTEN TEST FIELD

Automatic contour interpolation
with SCOP, based on version 2
of photogrammetric profile
measurement (y-profiles, 15 m)
(original scale 1:2500)

Annex 3

Photogrammetrische Woche 1977
Institut für Photogrammetrie
Schriftenreihe, Heft 4, 1977

Abstract

The Söhnstetten test field was set up by the Institute of Photogrammetry of Stuttgart University as a basis for a thorough study of the accuracy of automatic contour interpolation with the aid of the Stuttgart SCOP contour program. The test field is about 0.9 x 1.7 km² in size. A Zeiss RegElta-14 electronic tacheometer was used for repeated ground surveys of the relatively difficult terrain. In addition, wide-angle aerial photography was flown at a scale of 1:10 000.

A total of ten different contour plots at 1:2500 scale are available (four tacheometric and four photogrammetric surveys). These allow a very thorough test of contour accuracy.

In a first step, the absolute heighting accuracy of the different contour plots was computed with the aid of independent check profiles. A direct comparison between the results of conventional and advanced techniques then provided conclusive information on the capability of present-day digital contour plotting. Another comparison between the results of tacheometric and photogrammetric surveys finally completed the accuracy test.

The paper presents the results of these investigations both numerically and graphically. The tests generally confirm the high efficiency of automatic contour interpolation. In addition, some isolated results provide interesting clues for future investigations in this field.

Zusammenfassung

Das Testgebiet Söhnstetten wurde vom Institut für Photogrammetrie eingerichtet, um gezielte Untersuchungen über die Genauigkeitsleistung der automatischen Höhenlinieninterpolation mit dem Stuttgarter Höhenlinienprogramm SCOP anstellen zu können.
Das ca. 0.9 x 1.7 km² große, topographisch relativ schwierige Gelände wurde mehrfach tachymetrisch mit dem RegElta-14 aufgenommen und zusätzlich mit einer WW-Kammer im Maßstab 1:10 000 beflogen.

Insgesamt liegen 10 verschiedene Höhenlinienauswertungen im Maßstab 1:2500 vor (4 tachymetrisch, 4 photogrammetrisch). Damit ist eine umfassende und durchgreifende Überprüfung der Höhenliniengenauigkeit möglich.

Zunächst wird für sämtliche Höhenlinienauswertungen mit Hilfe unabhängig gemessener Kontrollprofile die absolute Höhengenauigkeit berechnet. Ein direkter Vergleich zwischen den Ergebnissen der konventionellen und modernen Verfahren gibt Aufschluß über den gegenwärtigen Leistungsstand der digitalen Höhenlinienkartierung. Ein weiterer Vergleich zwischen den Ergebnissen der Tachymetrie und Photogrammetrie vervollständigt schließlich die Genauigkeitsuntersuchungen.

Die Ergebnisse der Untersuchung werden zahlenmäßig und in graphischer Form dargestellt und diskutiert. Die Untersuchungen bestätigen insgesamt die hohe Leistungsfähigkeit der automatischen Höhenlinieninterpolation. Aus einzelnen Ergebnissen ergeben sich auch interessante Hinweise für zukünftige Untersuchungen zu diesem Thema.

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Résumé

L'Institut de Photogrammétrie de l'Universität de Stuttgart a préparé le terrain de test de Söhnstetten, afin de pouvoir étudier la précision obtenue avec le programme SCOP pour l'interpolation automatique des courbes de niveau.

Le terrain de Söhnstetten a une configuration topographique difficile et couvre une superficie d'environ 0.9 x 1.7 km Il a été levé plusieurs fois avec le Tachéomètre enregistreur électronique RegElta-14, ainsi qu'avec une chambre aérophotogrammétrique grand-angulaire à l'échelle 1:10 000.

Dix restitutions différentes de courbes de niveau ont été exécutées à l'échelle 1:2500 (4 restitutions tachéométriques et 4 restitutions photogrammétriques) et permettent ainsi un examen minutieux de leur précision.

La précision altimétrique absolue a été tout d'abord calculée pour les dix restitutions, au moyen de profils de contrôle mesurés indépendamment les uns des autres. La comparaison directe entre les résultats des méthodes conventionnelles et des méthodes modernes renseigne sur le rendement actuel de la restitution numérique des courbes de niveau. Une autre comparaison entre le résultats de la restitution tachéométrique et celui de la restitution photogrammétrique complète utilement l'analyse de la précision.

Les valeurs fournies par les comparaisons sont représentées sous une forme numérique et sous une forme graphique, en vue de leur discussion. En conclusion, l'étude ne peut que confirmer la haute précision de l'interpolation numérique des courbes de niveau. Certains résultats donnent des informations intéressantes pour des études ultérieures portant sur le même thème.

Resumen

El Instituto de Fotogrametría ha preparado la región de ensayo "Söhnstetten" para analizar sistemáticamente la exactitud lograda en la interpolación automática de curvas de nivel con ayuda del programa de curvas de nivel SCOP, desarrollado en Stuttgart. De este terreno topográficamente bastante difícil, cuya extensión es de 0.9 km x 1.7 km, se han hecho varios levantamientos taquimétricos con ayuda del RegElta-14, y adicionalmente se lo ha fotografiado con una cámara granangular en la escala de 1:10 000.

En total se dispone de diez restituciones altimétricas con curvas de nivel en la escala de 1:2500 (4 taquimétricas y 4 fotogramétricas), lo que permite verificar amplia y eficazmente la exactitud de las curvas de nivel.

Para todas las restituciones de esta índole se calcula en primer lugar la exactitud altimétrica absoluta con ayuda de perfiles de control, levantados de manera independiente. La comparación directa de los resultados obtenidos por métodos convensionales y modernos informa acerca de la capacidad actual de la restitución altimétrica digital. Otra comparación entre los resultados obtenidos por vía taquimétrica y fotogramétrica completa los análisis de exactitud.

Los resultados del análisis se representan digital y gráficamente y se discuten. Todos los análisis confirman la alta capacidat de la interpolación automática de curvas de nivel. Algunos resultados específicos abren interesantes perspectivas con respecto a análisis futuros relacionados con este tema.

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