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A PROGRAM FOR PROGRESSIVE SAMPLING FOR THE ZEISS PLANICOMP

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Introduction and Survey

A program for computer-supported data acquisition with the Zeiss Planicomp analytical plotting system is presented in this paper. This program enables digital elevation model measurement with point densities matched to the terrain conditions and precision requirements. The progressive grid point densification method was introduced by MAKAROVIC under the name "Progressive Sampling" /1/. Contributions from other authors are published in /2/, /3/, /4/.

In the photogrammetric model, break lines and a wide-mesh basic grid are measured first. Then the second height difference is computed at the grid points taking into account the break lines, and compared with a threshold value. If the second height difference at a grid point is below the threshold, no further measurement is made in this area, but if it exceeds the threshold, the basic grid is locally densified to half the original mesh size. Then second height difference analysis is repeated and the net is locally densified again if necessary. The floating mark is prepositioned to the densification points in plan and elevation. If break lines are measured beforehand and the size of the basic grid is judiciously selected, two densification steps are generally sufficient.

The presented program is the data acquisition component of the HIFI software package (Height Interpolation with Finite Elements). The HIFI-P version serves to interpolate a grid-type DEM with a grid size corresponding to the smallest point distance. Output of digital profiles for controlling the Zeiss Z 2 Orthocomp analytical orthoprojector is optional /5/. The fully configured HIFI-PC version enables digital contour lines of desired equidistance to be computed /6/.

Hardware Considerations

The presented program was developed for the C 100 Planicomp analytical plotting system on behalf of Carl Zeiss. It was written in Fortran for the Hewlett-Packard HP 1000 minicomputer. With the RTE IV-B operating system and the C 100 Planicomp, it requires 128 K words. Other versions are available for the new Planicomp systems (C 120, C 130) with the RTE A and RTE A.1 operating systems.

Like all other Planicomp application programs, this program can be controlled at the photogrammetric panel. It has B level priority and can be called at the panel using the name B075 /7/.

Data Acquisition with the Presented Program

Parameter Input

This program is controlled interactively by answering, at the operator control panel, the questions displayed at the terminal. The following entries are required:

- First, a decision is required on whether existing elevation measurement data is to be used.
  If yes, the existing grid is used as the basic grid and is densified locally. The area boundaries and the mesh size are derived from the data file. If the area is to be measured again from scratch, its size can be defined by digitizing three points in the photogrammetric model or by entering coordinates.

- Then a decision has to be taken on whether break lines are to be used.
  Sudden slope variations (break lines) occurring in the terrain are used for second difference computation at the grid points. Using them generally results in a considerable saving in densification points. The break lines have to be measured and stored in a file before nominal grid point measurement.

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- Finally the measurement precision required for the digital elevation model has to be entered.
  Using this value the second difference threshold can be selected so that the point density meets the project requirements.

Selecting and Measuring the Basic Grid

The mesh size selected for the basic grid should reflect the required minimum point density and the number of densification steps. In practice, the minimum point spacing is often given by the project. In an orthophoto project, for example, the selected orthoprojector slit width may be the decisive factor, but the point density can also be specified by the operator or determined by means of a separate analysis method /4/, /8/.

The program allows for two densification steps, and the mesh size is halved in each step. The reason for this can best be illustrated by means of an example: An area of the size of one sheet of the Bavarian Topographical Map (about 2400 m x 2400 m) is to be measured with a given minimum point spacing (e. g. 20 m). A 20 m grid requires 121 x 121 = 14641 points. The terrain conditions require such a dense grid only in some subareas. Measurement with a wide basic grid and local densification to 20 m allows much time to be saved compared to measurement of the whole 20 m grid. Table 1 shows the number of points in various basic grids for differing numbers of densification steps.

Grid Mesh (m)	Number of Grid Points	Number of Densification Steps	Percentage of Full Grid
160	16 x 16 = 256	3	1.8
80	31 x 31 = 961	2	6.6
40	61 x 61 = 3721	1	25.4
20	121 x 121 = 14641	0	100.0

Table 1: Number of Grid Measurement Points

It can easily be seen that the maximum possible saving in measurement time becomes small when more than two densification steps are used (less than 5 % of the total measurement time). On the other hand, the risk of bad second difference determination and insufficient densification increases when the basic grid size is doubled /9/. This risk is minimized by restricting the program to two densification steps. The basic grid size then is the quadruple of the minimum grid size.

When break lines are used, they have to be edited for later second difference computation at the grid points in parallel with measuring - or reading - the basic grid. This is necessary to minimize the computing and disk access times during densification, i. e. to avoid delays during densification point measurement.

Processing of Patches

For local densification of the basic grid, the overall area is subdivided in patches of approximately eyepiece image size. Measured points and break lines are shown in plan on the graphics CRT screen to allow the operator to check that the whole area has been measured.

Each patch is processed completely with up to two densification steps. The patches are measured in a back-and-forth sequence so that adjacent patches can be reached in the shortest possible time.

Adjacent patches overlap to ensure uniform data acquisition. This allows densification points measured in one patch to be used for second difference computation in another patch. Appropriate safeguards have been provided to prevent points located in overlap areas from being measured twice.

The floating mark is prepositioned to the densification points in plan and elevation. The elevation is interpolated linearly from adjacent grid or break line points and increased slightly so that the operator can set the floating mark from above.

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If ground visibility is restricted by trees or houses, deviating from the preset planimetric points is possible. Entering a code allows "collecting" near-by points for representative elevation determination. Measurement can be interrupted whenever a patch has been completed with the possibility to continue at next program call with the next sequential patch by entering a code. The location of the patch being measured in the overall area is displayed on the graphics CRT screen.

Local Grid Densification

The second height difference computed from three successive points is used for grid densification (formula 1). It is computed for the X and Y directions and is compared with a threshold value.

At break lines, outside points must not be used for this computation. Instead of adjacent grid points (P1 and/or P3 in formula 1), break line points are used in this case. Not using break line points generally results in unnecessary grid densification.

$$K = |(Z_2 - Z_1) - (Z_3 - Z_2)| \qquad (1)$$

Z_1 Z_2 Z_3 heights of P_1 P_2 P_3

If one of the second height differences computed for a grid point exceeds the threshold, a grid with half the basic mesh size is used in this area. This densification is restricted to the immediate neighborhood of the point and may result in up to 8 more points having to be measured in the next step. The number of points actually to be measured depends on the densification required for adjacent points and on the location of the break lines.

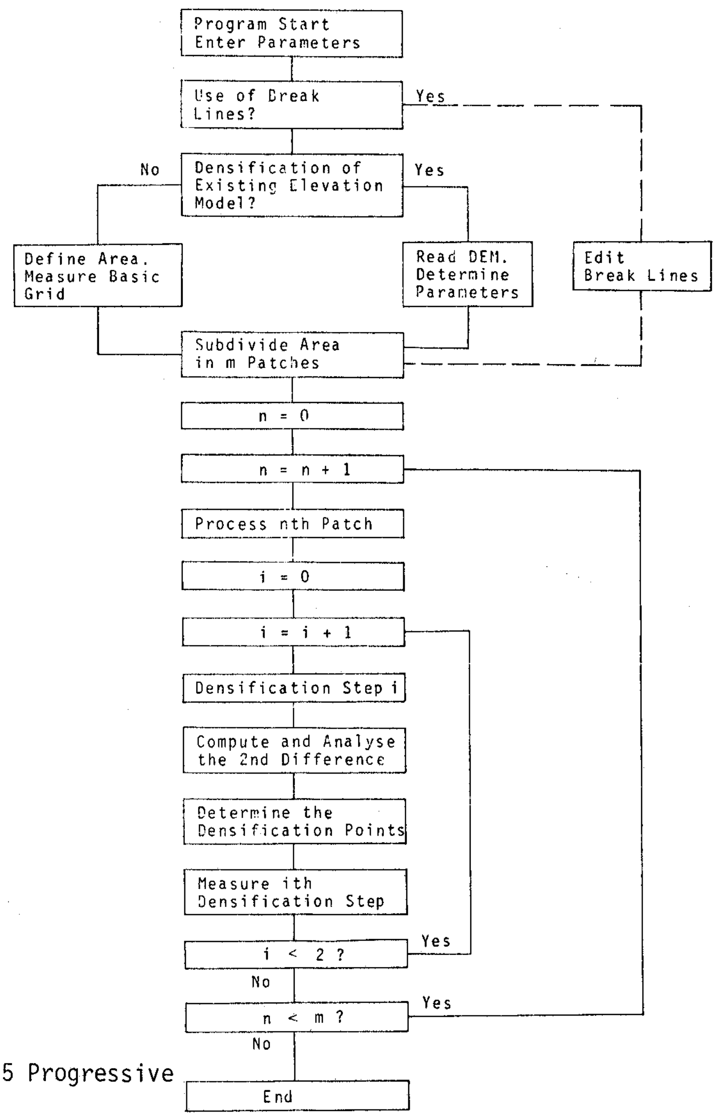

Fig. 1 :

Flowcharts of the B075 Progressive Sampling Program

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Typical Applications

Two projects with differing objectives which were processed with this program are described in the following. The data of the "Donauwörth" model was to be used for generating digital contour lines with an equidistance of 2.5 m, while the "Nordheim" project data was to be used for the derivation of orthophoto profiles controlling the Zeiss Z 2 Orthocomp orthoprojector.

"Donauwörth" Project

Material: 1 dual model (photo scale 1:14 400, Zeiss RMK 15/23) covering topographical map N.W. 28-31 (scale 1:5 000). Size of overall area: 2400 x 2340 m^2

Data acquisition:
- Recording of break lines
- Measurement of a basic grid with a mesh size of 80 m and local densification to 40 m and 20 m respectively

Operator: M. Spindler

Further processing:
- Interpolation of a DEM with a 20 m grid for the whole area (14157 unknowns) with the HIFI-P Program
- Derivation of digital contour lines from the DEM with the HIFI-C program
- Scale 1:5 000 plotting of the computed contour lines with the DZ 7 digital tracing table

Figs. 2 to 4 show the plots of the recorded break lines, the measured points and the digital countour lines.

Time required for data acquisition:

- Preparations and orientation with the C 100 Planicomp, recording of the break lines (1108 points)		3.5 hours
- Measurement of the basic grid and of the densification points (4141 points)		3.5 hours
	Total	7.0 hours

Measuring the whole 20 m grid (14157 points) takes about 11.5 hours, and the total time requirement is about 15 hours. Using the progressive sampling method saves about 55 % of the total time.

"Nordheim" Project

Material: 1 dual model (photo scale 1:5 000, Zeiss RMK 15/23) covering one sheet of the scale 1:2 000 map used by the Land Consolidation Department of Munich. Size of the overall area: 700 m x 700 m.

Data acquisition:
- Local densification of a 64 m basic grid to a 32 m and 16 m grid respectively

The minimum point spacing of 16 m was selected for orthophoto production with an 8 mm wide slit. Recording break lines could be dispensed with in this area of the project. Since a 16 m grid already existed for this area, measurement was simulated with the program. The basic grid and the densification points were extracted from the 16 m grid.

Further processing:
A digital elevation model with a 16 m grid was interpolated from the data with the HIFI-P program, and the control profiles for orthophoto production were derived from this model. To represent the processed area, digital contour lines were computed with the HIFI-C program and plotted with the DZ 7 digital tracing table (Fig. 6). Fig. 5 shows the location of the grid points.

Time required for data acquisition:

- Preparation and orientation with the C 100 Planicomp		2.5 hours
- Measurement of the basic grid and of the densification points (569 points)		0.5 hours (estimate)
	Total	3.0 hours

Measuring the whole 16 m grid (2025 points) takes about 2.0 hours. The saving is 1/3 of the total time and 75 % of the point measurement time in this case.

Finally, the control profiles required for orthophoto production were computed from the full grid with the HIFI-P program. The differences between control profiles obtained from different data were then computed at the profile points. The RMS deviation was 0.15 m. In the present example, control profiles for orthophoto production can be obtained with 28 % of the full grid without incurring a significant loss of precision.

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Abstract

A program for the photogrammetric measurement of digital elevation models by the progressive sampling method is presented. It is written in Fortran and runs on the Zeiss Planicomp analytical plotting system.

Measured terrain edges and a wide basic grid are used to decide where grid densification is required. Analysis and densification of the measured data are performed in steps, with the mesh size being halved each time. For processing, sub-areas are formed whose size is matched to the field of view. Grid points to be measured are positioned planimetrically and set approximately in elevation. Delays noticeable to the operator do not occur. The result is a grid with variable mesh size whose point density is matched to terrain conditions and to the required precision.

This program expands the HIFI program system for height interpolation with finite elements and the data acquisition sector.

The precision and cost-effectiveness potential of the method is demonstrated by examples.

EIN PROGRAMM FÜR PROGRESSIVE SAMPLING AM ZEISS PLANICOMP

Zusammenfassung

Vorgestellt wird ein Programm zur photogrammetrischen Messung digitaler Höhenmodelle nach der Methode des "Progressive Sampling". Es ist in FORTRAN geschrieben und läuft als On-Line-Programm in Verbindung mit dem analytischen Stereoauswertesystem Zeiss Planicomp.

Aus gemessenen Geländekanten und einem groben Basisgitter wird ermittelt, in welchen Bereichen ein dichteres Gitter erforderlich ist. Analyse und Verdichtung der gemessenen Daten erfolgen stufenweise, wobei die Gitterweite jeweils halbiert wird. Zur Bearbeitung werden Teilgebiete gebildet, deren Größe dem Gesichtsfeld angepaßt ist. Zu messende Rasterpunkte werden nach der Lage und näherungsweise nach der Höhe angesteuert. Spürbare Wartezeiten für den Operateur bestehen nicht. Als Ergebnis wird ein Gitter variabler Maschenweite erhalten, dessen Punktdichte der Geländeform und der erforderlichen Genauigkeit angepaßt ist.

Mit dem vorgestellten Programm wird das Programmsystem HIFI (Höheninterpolation mit finiten Elementen) um die Datenerfassungskomponente erweitert.

An Beispielen wird die Leistungsfähigkeit der Methode hinsichtlich Genauigkeit und Wirtschaftlichkeit demonstriert.

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PROGRAMME D'ACQUISITION PROGRESSIVE DES DONNEES AVEC LE PLANICOMP

Résumé

L'objet de l'exposé est un programme déstiné à la mesure photogrammétrique de modèles altimétrique digitaux selon une méthode d'acquisition progressive des données, dite "Progressive Sampling". Ce programme écrit en FORTRAN est exécuté en on-line par le système de stéréorestitution analytique PLANICOMP de Zeiss.

Partant des ruptures de terrain et d'un réseau de base à larges mailles, le programme détermine les zones qui nécessitent un réseau plus serré. L'analyse et la concentration des données mesurées se font par échelons, les mailles du réseau étant à chaque fois réduite de moitié. Pour le traitement des données, le programme extrait des fragments de modèles dont la dimension est adaptée à celle du champ visuel. Le repère de mesure est positionné sur les points de réseau à mesurer selon les coordonnées planimétriques et de façon approximée en hauteur. Ces opérations ont lieu sans aucun temps d'attente pour l'opérateur. Le résultat est un réseau avec des mailles de largeur variable dont la densité des points est adaptée à la topographie du terrain et à la précision recherchée.

Ce programme complète le logiciel HIFI (Interpolation altimétrique avec éléments finits) en ce sens qu'il y ajoute l'acquisition des données.

Des exemples démontrent la performance de cette méthode quant à la précision et à la rentabilité.

UN PROGRAMA PARA EL MUESTRO PROGRESIVO PARA EL PLANICOMP

Resumen

Se presenta un programa para la medición fotogramétrica de modelos digitales del terreno por el método del muestro progresivo. Está escrito en FORTRAN y funciona como programa on-line en el sistema estereorrestituidor analítico Zeiss Planicomp.

A base de cantos medidos del terreno y una cuadrícula básica muy amplia se determina dónde se requiere una cuadrícula más densa. El análisis y la densificación se llevan a cabo en etapas, durante las cuales se divide cada vez por mitad el ancho de la malla. Para el procesamiento se delimitan áreas parciales cuya extensión está adaptada a la del campo visual. Los puntos de la cuadrícula que se desean medir se posicionan planimétricamente y en altura en forma aproximada. El operador no deberá contar con tiempos significantes de espera. Como resultado, se obtiene una cuadrícula de anchos de malla variable, cuya densidad de puntos depende de la topografía del terreno y de la precisión requerida. El programa presentado amplia el sistema de programas HIFI (interpolación de altura con elementos finitos) por el aspecto de la recopilación de datos.

Con ayuda de ejemplos, se demuestra la capacidad del método bajo los aspectos de la precisión y economicidad.

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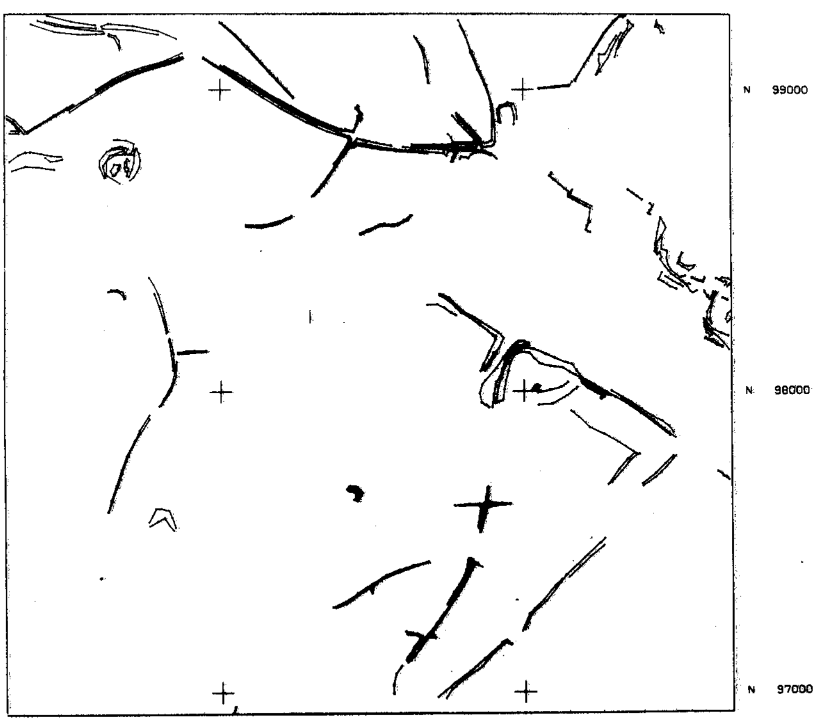

Fig. 2 :

Recorded break lines, Donauwörth project (reduction)

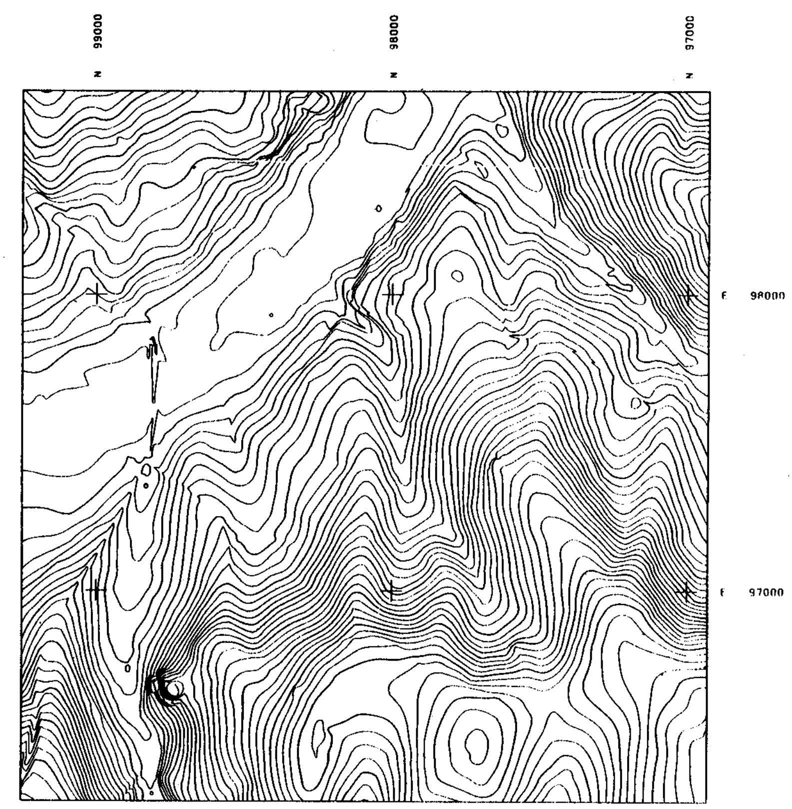

Fig. 4 : Digital contour lines, Donauwörth project (reduction)

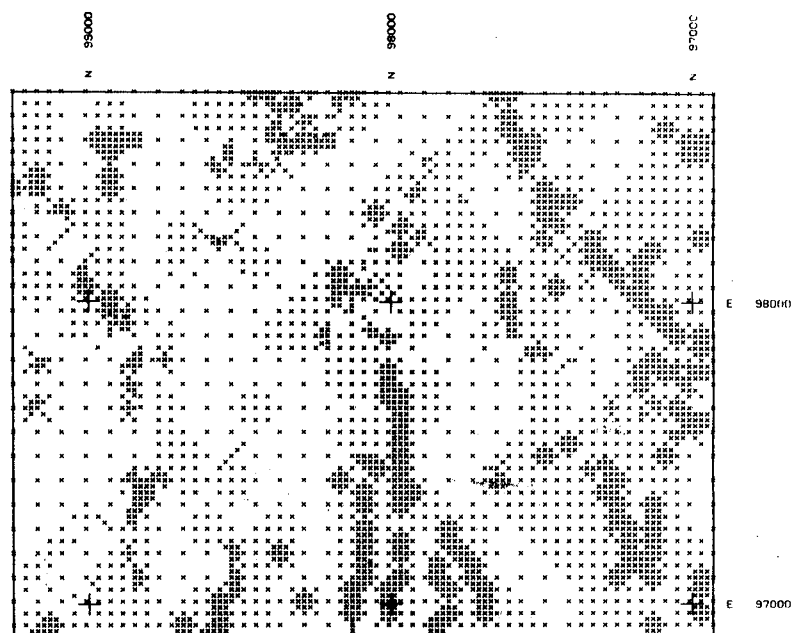

Fig. 3 : Measured points, Donauwörth project (reduction)

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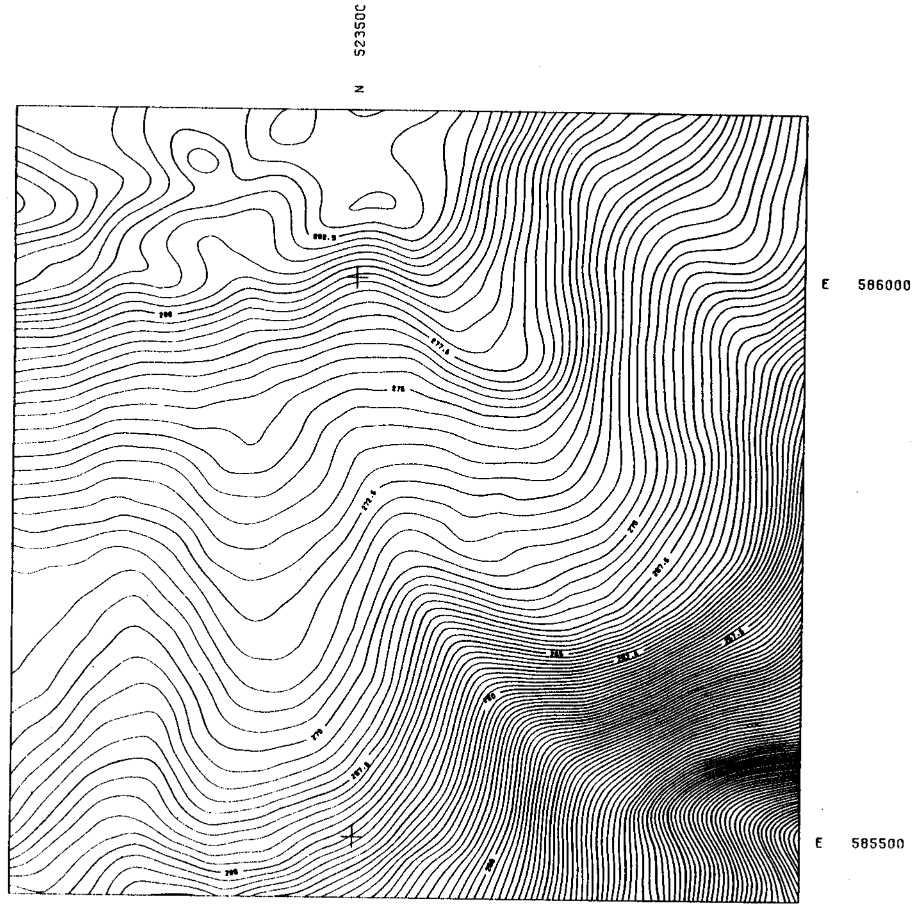

Fig. 6 : Digital contour lines, Nordheim project (reduction)

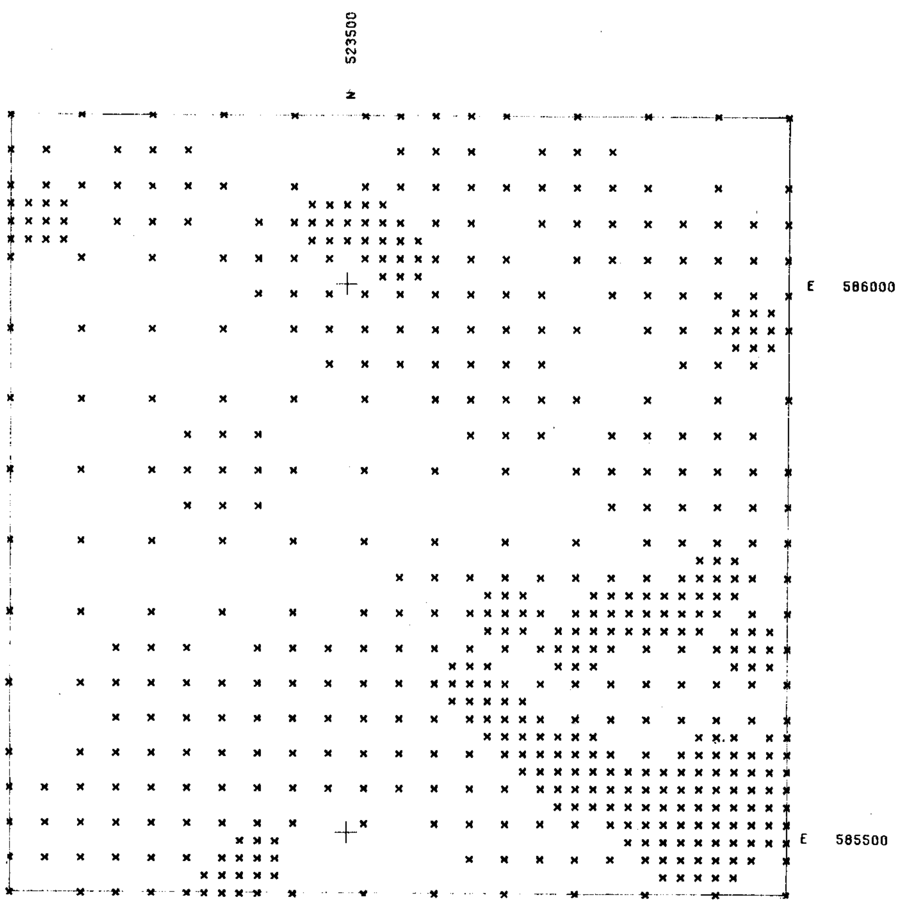

Fig. 5 : Measured points, Nordheim project (reduction)