THE EFFICIENCY OF THE TOPOMAT-B AND TOPOCART-D/ ORTHOPHOT-E DIFFERENTIAL RECTIFICATION SYSTEMS FROM JENA

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In the following a report is given on the fields of application, the functional properties and the efficiency of the differential rectification systems as well as the appropriate software from JENA.

1. TOPOMAT B - An equipment system for automating differential rectification

1.1. Applicabilities of TOPOMAT B

Due to the efficient units combined in the equipment the TOPOMAT automatic stereoplotting system is highly versatile in its application. The main units are the TOPOCART stereoplotter in modified form, the ORTHOPHOT D differential rectifier, the OROMAT image correlator, the 900 x 1200 EA-F precision coordinatograph and the cross slope corrector. An electronic coordinate recording instrument may be connected as additional unit so as to increase the range of application.

The major case of application for TOPOMAT B is the on-line differential rectification with automatic height tracking.

Typical of the TOPOMAT system is a second photo carrier pair which is moved by the mechanical calculator of the TOPOMAT simultaneously with the visually viewed photopair. Only the OROMAT electronic image correlator uses this second photopair for both information acquisition and motor-driven control of the z coordinate from the correlation result. The basic objective of this constructive solution with the double photo carrier system is to reach the unrestricted use of the equipment system for the production of colour and false-colour orthophotos.

The technical data of the modified TOPOCART plotter and ORTHOPHOT D differential rectifier determine the application ranges of TOPOCART B.

In the automatic restitution of aerial photographs and terrestrial-photogrammetric photographs with the image correlator some requirements connected with the correlation technique must, however, be taken into consideration. These requirements especially refer to a sufficient and suitable information structure in the photographs as well as the kind and height of terrain discontinuities (buildings, trees, forests, breaking edges etc.), which generally cause restrictions at larger map scales.

The results of this restitution are for example:

- orthophotos and digital height models as data base for TOPAS, which with the CONT program and the DZT 90 x 120 is capable of automatically producing a contour line map,
- graphical representation of profiles,
- digital height models for off-line orthophotography (DETO program of the TOPAS program system).

1.2. Functional characteristics of TOPOMAT B

Given homologous image areas the electronic correlation circuit checks the video signals of the left and right photographs for x parallaxes which represent themselves in the video signals as phase shift between two similar signal sequences and, in dependence on these phase shifts, it controls the electrical z drive in the stereoplotter so that the ascertained x parallax becomes zero by the relative shift of the images owing to the z change. For the video signal acquisition the OROMAT uses a light spot scanning system with two cathode-ray tubes and two photomultipliers.

The possible scanning raster sizes referred to the image are 2 mm x 1 mm, 3 mm x 2 mm and 4 mm x 4 mm. The video signals to be correlated are digitized after signal shaping by 3 band passes with different transmission ranges, so that the correlation electronics merely processes digital signals. The digital hardware correlation enables fast and reproducible solutions capable of being readily handled in the process technology. Furthermore, the OROMAT has a series of automatic functions for adapting the system to the different conditions in the photographs. These automatic functions refer for example to the function parameters scanning raster size, correlation frequency range and y scanning speed which can be selected by the operator. The automatic functions correct the performed settings in accordance with the situation and simplify the operation.

A new and important functional unit in TOPOMAT B is the automatic y residual parallax correction in the image correlation system. The task of this unit is to guarantee y residual parallaxes of less than $\pm$ 0.04 mm referred to the image in the second photo carrier pair. The device for the automatic y residual parallax correction is designed so that it still compensates y residual parallaxes up to about $\pm$ 0.15 mm referred to the image plane. From this results the important advantage that the demands on the optimum y parallax-free orientation of the photographs are decisively alleviated. When the p_y correction is switched off, the y residual parallax qualitatively indicated on a measuring instrument is available for supporting the orientation process in the rear image pair.

A technique for reducing the correlation failures involves, however, a qualitatively new function in TOPOMAT B.

The technique assumes the possibility that during the brief correlation loss the height tracking can be traced back to the previous neighbouring profile. This technique is implemented with a profile store. This functional unit allows the acquisition of a control voltage Δz for height tracking in a correlation loss as well as of the terrain cross slope information $\tan \alpha_y$ and controls the automatic switching between correlator and storage operation. The automatic consideration of the x step width in the terrain cross slope ascertainment avoids additional operational efforts.
The realized profile storage unit positively influences the automatic restitution in several respects. Besides the drastic reduction of the manual operations another advantage is that the terrain cross slope can be ascertained in on-line operation and directly serves for activating the cross slope corrector for ORTHOPHOT D.
Especially for recording a digital height model the output of an additional information has been provided which permits of marking the recorded z coordinates during profile storage guided tracking.

1.3. Efficiency of the TOPOMAT B system under practical aspects

For automatic restitution each stereomodel must be available in duplicate. On conclusion of the manual relative and absolute orientation kappa need merely be transferred to the rear photocarriers. After the start of the fully automatic profile scanning, restitution of the model area is performed within the ranges limited by the x and y end positions.
The main advantages of the TOPOMAT B automatic stereoplotting system are the relief of the operator and especially the high speed of the plotting procedure. The y scanning speed lies typically at 4 to 8 mm/s in the image depending on the terrain shape.
Another important performance parameter is the height measuring accuracy of the system which is of importance for the position accuracy of the orthophoto as well as for a digital height model. In judging the height measuring accuracy it has to be considered that an electronic image correlator having not the intelligence of an operator, keeps the floating measuring mark always on the visible surface and that through the areal extension of the scanning raster a flattening (smoothing) of small topographic terrain forms (tops of hills, bottoms of valleys) occurs. Several typical investigations performed without automatic y residual parallax elimination and without profile storage showed the following results /2/.
For a stereomodel with m_b = 1:27 000 the mean value of the relative height error with automatic profile scanning was about $\pm$ 0.6 ‰ of the flying height. These data of the height measuring accuracy are for the reasons given to be considered as general orientation values.

Practical experiences in the automatic plotting from different image material with the profile store show that one succeeds in drastically reducing the number of correlation failures. The number of the remaining correlation failures per stereomodel lies between 0 and about 5 depending on the image material and the terrain shape.

In on-line differential rectification with terrain cross slope correction the mismatches in the orthophoto as they occur in the case of terrain cross slope are on an average reduced by a factor of 3. This process requires an offset (eccentric) slit diaphragm, so that the maximally possible x step width in this technique is 8 mm.
The simple operation of the instrument system does not set standards of qualification going far beyond those of photogrammetric plotting. The large range of application and the high working productivity characterize the TOPOMAT B equipment system as a universal system which to a particular degree meets the requirement of automation and economy.

2. TOPOCART D - ORTHOPHOT E, an equipment system for on- and off-line differential rectification

2.1. Design and applicabilities

The equipment system has been designed in the building block fashion. It consists of the TOPOCART D stereoplotter, ORTHOPHOT E differential rectifier and a drawing table. Through the incorporated Cross Slope Corrector E terrain cross slope is simultaneously taken into consideration in on-line rectification.
The Cross Slope Corrector E has been designed as electronic analogue computer and ascertains the swing angle and the magnification correction for the optical image transfer system in differential rectification under consideration of the terrain cross slope. The ascertained values are fed into the correction regulating circuits on the Schmidt prism for image rotation and on the magnification system for scale correction. In this way the system errors of differential rectification (double imagery , gaps and mismatches) are corrected in the orthophoto. Hence, rectification can be made with larger slit width and working productivity considerably be increased.
An even more universal equipment system is achieved, when an additional digital control unit with an appropriate input/output periphery is connected. It is then possible to carry out double model orthophoto productions and repetitive rectifications in off-line operation. Thanks to this expansion capability on the basis of the quantity-produced TOPOCART D stereoplotter an extremely efficient and economic equipment system has been implemented for the restitution of normal, wide and super-wide-angle photographs.
The TOPOCART D - ORTHOPHOT E equipment system is suitable for the orthophoto production as well as the universal graphical and numerical restitution of photographs of all scales.

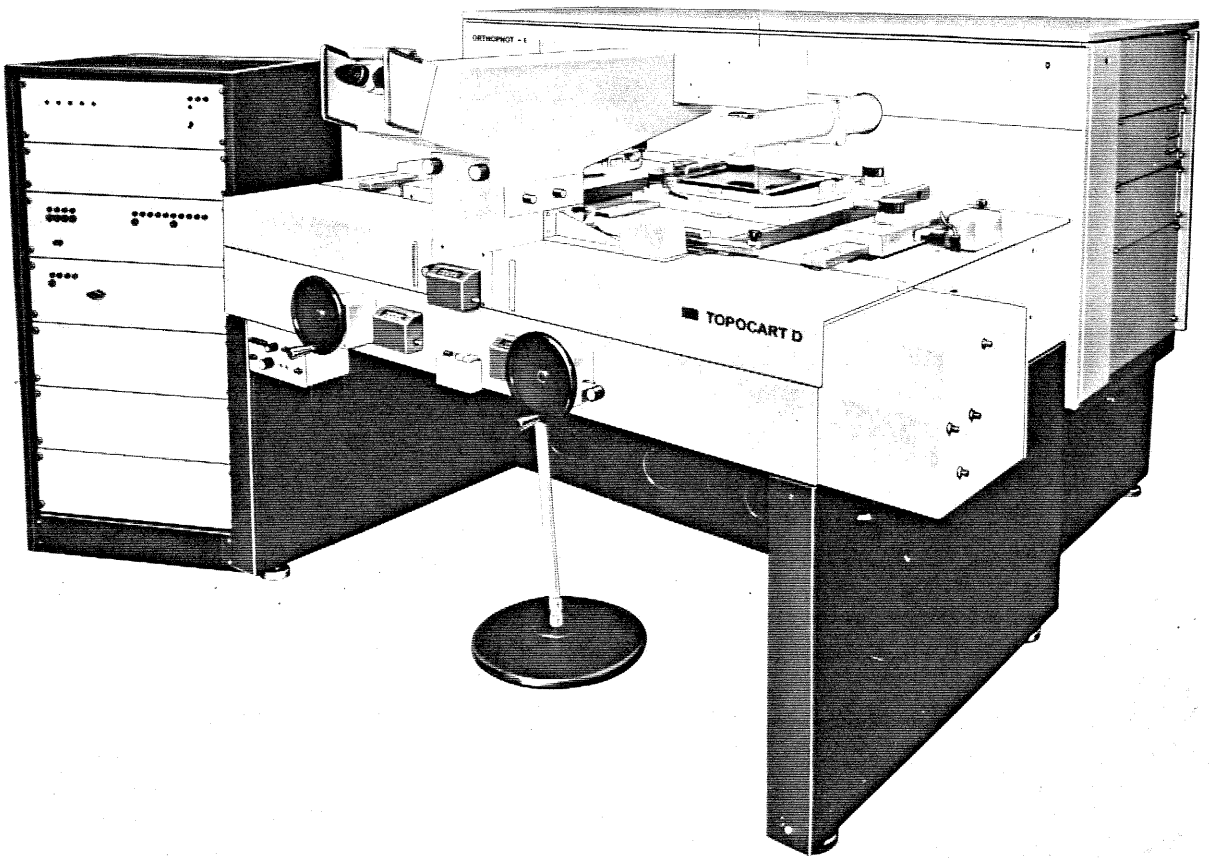


Fig. 1 TOPOJART D - ORTHOPHOT E

Possibilities of application are:
- Orthophoto production with and without terrain cross slope correction.
- Off-line double model orthophoto production with and without terrain cross slope correction (use of efficient software packages for data editing for automatic off-line control of the differential rectification process and contour line representation; BEST, DETO and CONT programs of the TOPAS program package).
- Production of stereoorthophotos in on- or off-line rectification (using the DETO program).
- Restitution of terrestrial photographs (e.g. façades of buildings).
- Digital restitutions (digital height models).
- Analogue stereomapping.

In the TOPOCART D - ORTHOPHOT E equipment system on-line differential rectification has a central position; compared with the off-line principle it has several merits, such as
- higher accuracy (through continuous acquisition of the terrain height instead of discrete storage and reconstruction of the terrain profiles),
- fast production of orthophotos (the orthophoto is already exposed during model profiling), and
- low amount of organisation.

These advantages offer the equipment user a highly economic technology which is in particular of importance in the production of large-scale maps for projecting work.

2.2. Functional characteristics and efficiency

The upgrade of the TOPOCART D - ORTHOPHOT E equipment system resulted in the extension of the applicabilities, improvement of the operating comfort and increase of accuracy. Important novel features compared with the preceding systems are:
- Integration of a cross slope corrector with digital profile storage unit into the equipment system. In scanning a y-z profile the z value ascertained via a counter is compared with the z value digitally stored under the same y address in the previous y-z profile; from this is obtained the terrain cross slope information $\tan \alpha$.
- Concentration of all necessary operating elements of the ORTHOPHOT E on a console close to the operator.
- Optimization of the plotting speed with large magnifications from the image to the orthophoto. The fixation of the particular optimum speed range is automatically made at the beginning of restitution with the reset button.
- Improvement of the illuminating system for the image projection by providing a rotating eccentric mirror behind the halogen lamp.
- Increase of accuracy in the plotting procedure through the modified arrangement of the halogen lamp for the left image illumination (in this way heating of the photographs is avoided).
- Omission of the graphical drop-line representation with the Orograph for manual contour line scanning. The calculation and graphical representation of contour lines

are made with the CONT program of the TOPAS program package and the DZT 90 x 120.

- Provision of an additional digital output for the direct connection of a digital drawing table (e.g. DZT 90x120) or of an electronic recording instrument (e.g. COORDIMETER H).

The functional characteristics of the preceding instruments of ORTHOPHOT E were retained. These characteristics also largely apply to TOPOMAT B.
Because of the consideration of the terrain cross slope in on-line differential rectification orthophotos are produced in less time with a better visual impression of the orthophotos.
The mismatches remaining at the slit edges with use of the cross slope corrector are reduced by the factor of 3 compared with the operating mode without cross slope correction.

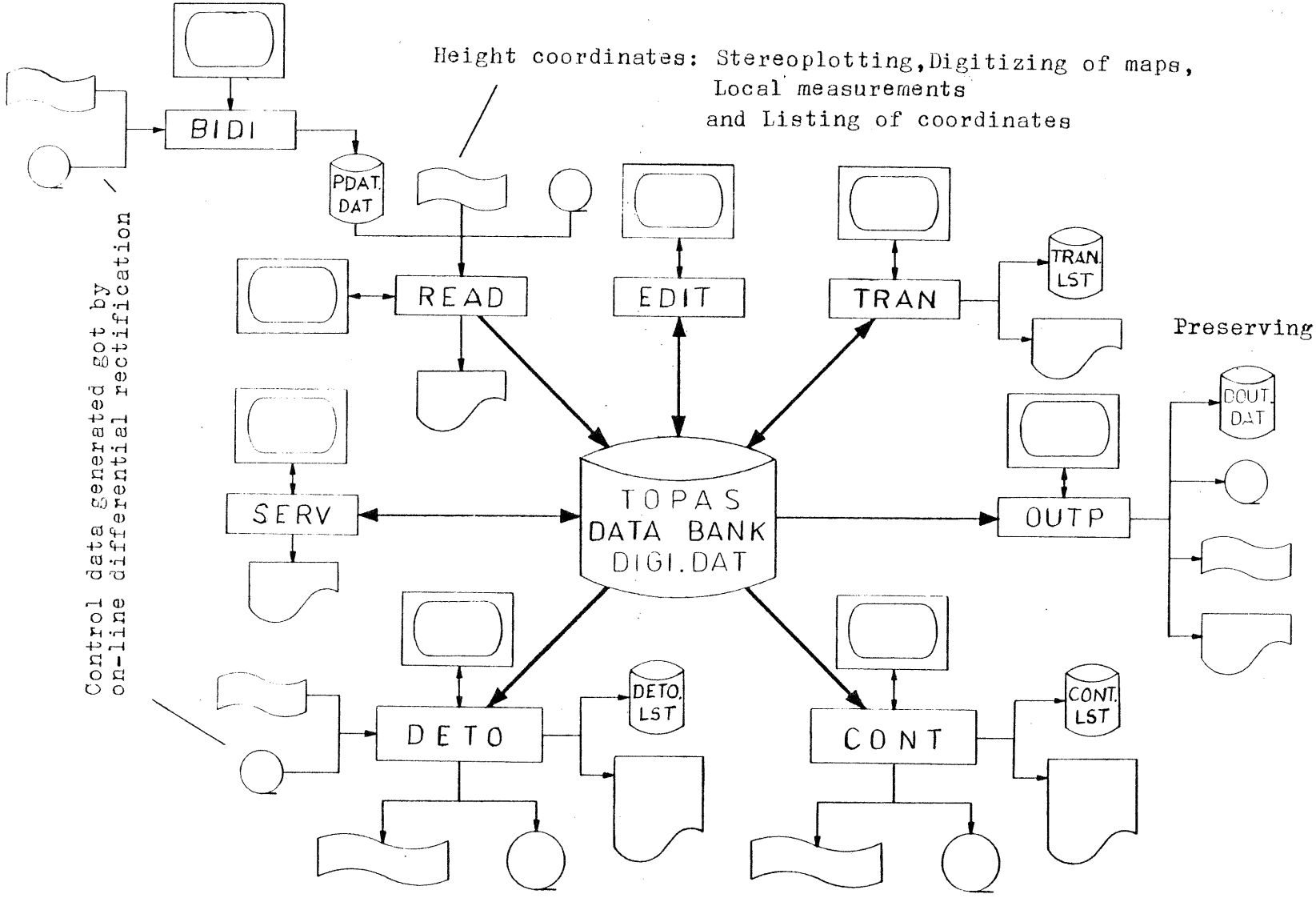
Since further accessories can be connected the equipment system is flexible and expandable. For stereoorthophoto production the tilt calculator's transformation gear is connected between ORTHOPHOT and TOPOCART.
Simultaneously with the manual or automatic z guidance the x model coordinate is shifted by the tilt calculator in dependence on the b_x/z base ratio. This shift corresponds to artificial horizontal parallaxes in the stereomate.
By connecting a digital control unit with an input-output periphery to the equipment system this becomes also applicable for off-line differential rectification. The control data for the automatic control of the rectification process are ascertained by the programs BEST (from profile data gained with on-line rectification) and DETO (from digital terrain models).

3. TOPAS - program system for the automatic differential rectification with TOPOCART/ORTHOPHOT

3.1. Structure and applicabilities

The program package TOPAS (TOPOCART-ORTHOPHOT program system for analytical control data calculation) serves for the calculation of control data for an off-line differential rectification process and for the automatic contour line drawing from digitally stored height data of the terrain to be mapped. It is written in FORTRAN IV and designed for minicomputer with a usable main storage capacity of 64 Kbyte.

TOPAS consists of the DETO, CONT, BIDI programs and the data bank modules (SERV, READ, OUTP, TRAN, EDIT) required for the generation and updating of the data bank.
Basis for the calculation of off-line control data are files of the TOPAS data bank, which contain the digital height model of the working area (Fig. 2).
The primary data required for the generation of the TOPAS data bank can be derived from the following sources:
- Stereoplotting from photographs with digital recording (profiles, contour-lines, single points arranged in an array or irregularly).



Control data for the automatic Orthophoto- and/or Stereomate production with TOPOCART-ORTHOPHOT equipment System

Control data for DZT 90 x 120 representation of contour lines

Fig. 2 TOPAS program system - data flow

- Digitization of existing maps (contour lines, single points arranged in an array or irregularly).
- Local measurements (terrain points arranged in an array or irregularly).
- Coordinate lists (filed digital height models).

3.2. DETO program

The DETO program serves for the calculation of control data for the off-line differential rectification with the TOPOCART-ORTHOPHOT equipment system with digital control unit, cross slope corrector and I/O periphery. Apart from z data for the automatic height tracking it also calculates data on the terrain cross slope on the basis of a digital height model, which is stored in various files of the TOPAS data bank.
In addition to the control data for the production of an orthophoto the control data for the production of a stereomate can simultaneously be produced for the same photo. The latter can also be calculated without the use of the digital height model stored in the data bank on the basis of profile data for the appropriate orthophoto (which were an outcome of on-line differential rectification).

The interpolation of the individual grid points at the distance Δy per profile is performed by the method of the gliding tilted plane.
The major performance parameters of the DETO program are:
- Calculation of data for the cross slope corrector for correcting the influence of the terrain cross slope in orthophoto production, so that especially in hilly terrain a considerable increase in working productivity is achieved by a larger profile spacing.
- Double model orthophoto productions, so that only every 2nd model in the TOPOCART must be oriented.
- Repetition of restitutions
- Automatic reduction of the given slit width or y step width (if the minimum has not yet been reached) in the case of too large terrain cross slopes.
- Inspection for gross errors of the measuring values intended to be used for the interpolation of the profile points; faulty points are not used for interpolation.

3.3. CONT program

Since orthophotos must frequently be complemented by contour lines, a program has been elaborated, which calculates control data for the automatic drawing of contour lines on the DZT 90 x 120. In one program run the CONT program calculates up to maximally 100 contour lines with constant contour line spacing. As with the DETO program, basis are the files of the TOPAS data bank which in their sum must cover the map sheet to be drawn.
The interpolation of the individual grid points is performed analogously to DETO by the method of the gliding tilted plane. The interpolation of the reference points of the

individual contour lines is carried out linearly in triangles, which are formed by diagonals of the grid meshes. Result of the program runs are the drawing table coordinates of the curve lines including the appertaining instructions for lifting and lowering the drawing tools of the DZT 90 x 120.
The major performance parameters of the program are:
- Reduction and filtering of the interpolated reference points of the contour lines.
- Calculation of an analytic curve interpolation.
- Curvature analysis of the grid meshes for ascertaining unsteady areas (dams, river valleys etc.).
- Drawing of the main contour lines with a second tool (intensified line in scribing) with statement of the height numbers optionally either outside or inside the map sheet.
- Mapping of the control points lying inside the map sheet with statement of the control point number for the purpose of a later orientation with respect to the orthophoto or representation of a planimetric situation.
- Mapping of the grid crosses lying inside the map sheet.

3.4. BIDI program

The BIDI program serves for the generation of model coordinates from profile data gained in on-line differential rectification with the TOPOCART-ORTHOPHOT equipment system, digital control unit and an input/output periphery. It links the model coordinates of the control points measured on the TOPOCART stereoplotter with the profile data obtained in on-line differential rectification (meander-shaped model scanning).
The systematic scanning errors contained in the profile data are corrected by curvature-dependent longitudinal and transverse smoothing. The model coordinates produced with BIDI can subsequently be read in with the READ module into the TOPAS data bank and further processed with DETO or CONT.

3.5. Data bank modules

The data bank modules (SERV, READ, OUTP, TRAN, EDIT) are auxiliary programs, which serve for the generation, updating and editing of the TOPAS data bank. The combined action of the modules with the DETO and CONT programs is obvious from Fig. 1.
After initializing the data bank DIGI.DAT with SERV the primary data can be read in with the READ module into the data bank. The OUTP module is used for control printouts of data bank files and for filing purposes. Any necessary corrections (insertions, deletions or changes) of these files in the data bank are made possible by EDIT. The TRAN program transforms the files into the ground coordinate system (coordinate system for DETO and CONT programs), with the position transformation being performed as a plane similarity transformation and an arithmetic levelling being the base for the height transformation.
Further terms for considering a model distortion or x or y bending may be added.

4. BEST - automatic differential rectification with a simplified program

In addition to the TOPAS program package which calculates control data for the differential rectification process from digital height models with arbitrary point arrangement, a simple program has been developed which processes the profile data obtained from on-line differential rectification with digital control unit. The BEST program is written in FORTRAN IV and elaborated for minicomputer with 64 kbyte main storage capacity.
The BEST minicomputer program allows the utilization of the off-line differential rectification (cross-slope correction, double model orthophoto production, repetitive rectification) in a simplified process, which is based on the TOPOCART/ORTHOPHOT system combination with digital control and cross slope correction. Input data are used which are recorded with the digital control unit in the output mode on data carriers in order to calculate control data for the off-line rectification process. The control data calculated with BEST have the same record format as the control records calculated with TOPAS (three-digit smoothed model height data: three-digit tangent data information on the terrain cross slope).
ORTHOPHOT D-300 offers the possibility to limit the length of each profile individually by a button so as to rectify only those parts of the model being of interest, for instance, for routes or map revisions.
Therefore, the BEST program can also handle profiles of different lengths. If for one profile point only one or no neighbouring point at all is found by this, the calculation of the terrain cross slope is performed by simplified formulas and model smoothing is dispensed with.
Differential rectifications performed with cross slope corrector result not only in a better image quality through the elimination of systematic errors but have also the essential advantage that they can be carried out with at least the double slit width as compared to differential rectifications without cross slope correction. As is evident, this way of rectification benefits the economy of orthophoto production quite considerably. Furthermore, control data for the same model area and the same model scale can be used as often as is desired, so that a special data bank with files is generated for the particular map sheets.
The BEST program belongs to the standard equipment of the digital control unit.

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Summary

The upgraded TOPOMAT B automatic stereoplotting system with increased efficiency is specially distinguished by a wider field of application for the image correlator (larger image scales), by the relief of the operator during model scanning as well as by an improved quality of orthophotos due to the cross-slope corrector in on-line operation.

In the TOPOCART-ORTHOPHOT system the principal method is the on-line differential rectification, whose advantages compared with the off-line mode offer users a highly economical technique especially in the production of large scale maps for projection purposes. Cross-slope correction is likewise accomplished during the on-line rectification process.

The extension of the TOPOCART-ORTHOPHOT system by the digital control unit and input-output peripherals enables double model orthophoto production and repetitive restitution in off-line operation. For this mode efficient software packets are available for calculating control data for the automatic rectification process and the contour line representation of digital terrain models.

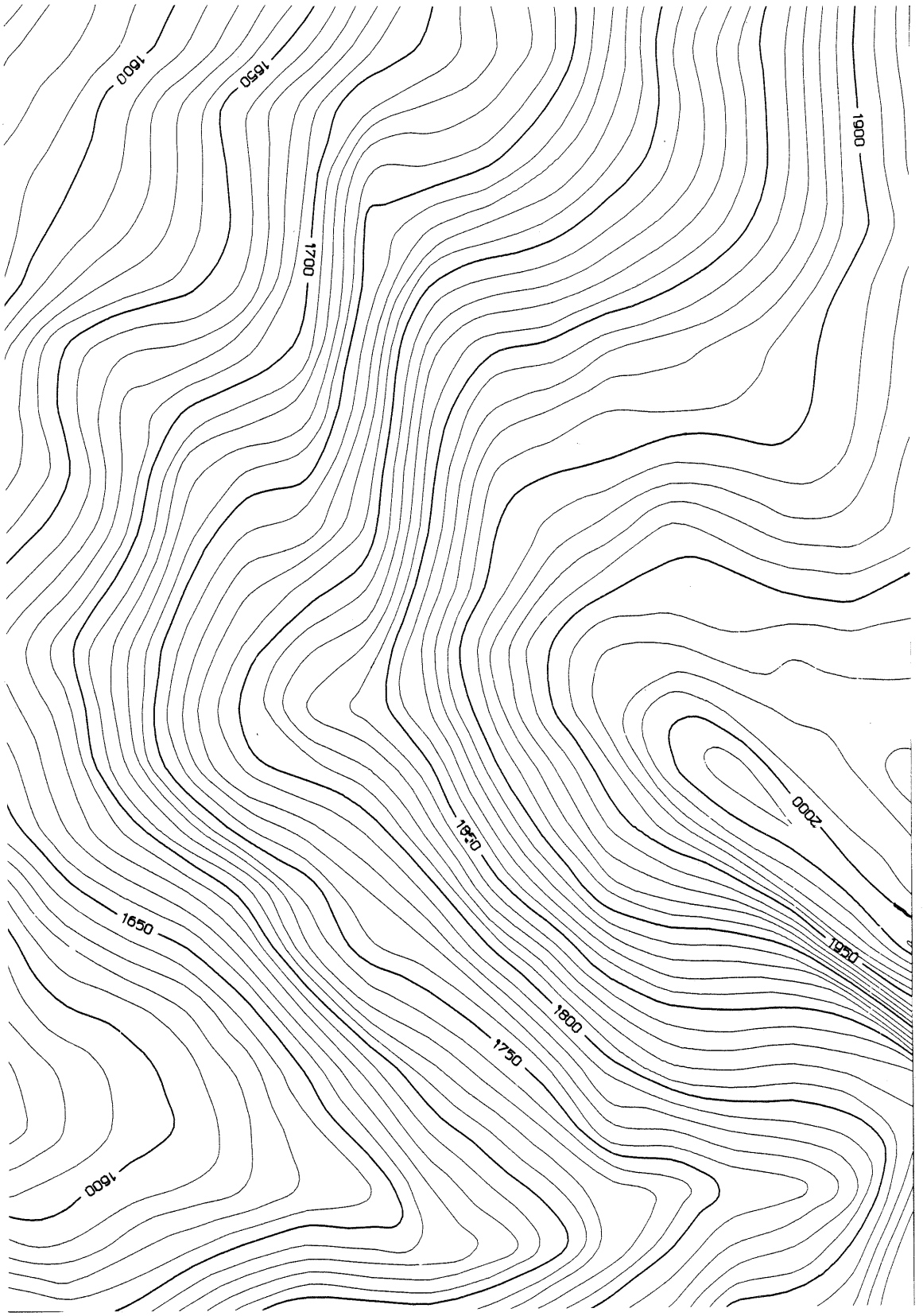

Fig. 3 Contour line plan