Presented Paper to Commission III, 15th ISPRS Congress, Rio de Janeiro, 1984

A DIGITAL ELEVATION MODEL FEATURING VARYING GRID SIZE

André Köstli and Emil Wild

Summary: A DEM structure is introduced, which allows an adaption of the grid size to local features. Its efficiency is discussed with regard to selected methods of data acquisition, in particular progressive sampling.

In high accuracy DEM computation and storage, the trade-off between computing expense and quality is reduced. Practical application will result in higher accuracy in areas with a more detailed topographic structure without affecting the overall performance.

1. General Philosophy

The development of data acquisition methods and data processing systems are interdependent processes promoted by the actual state of the art in science and technology. Considering the field of Digital Elevation Models (DEM) various levels have been run through, and further developments can be foreseen which will reduce the costs of data acquisition and processing for a DEM with a desired accuracy.

In photogrammetry DEM activities started on the basis of recorded profiles or grid points. The sampling of additional terrain lines was soon recognized as essential for more sophisticated DEM applications. Nowadays computer supported analytical plotters allow a more efficient sampling using algorithms to find out optimal point density (progressive sampling / Makarovic /3/, Reinhardt /4/). In the future digital image processing may lead to the automatic recognition of special terrain features like edges, which until now are selected manually.

Related to the data acquisition there was the parallel development of software for off-line DEM computation. First versions were restricted to input and processing of simple reference points (e.g. points along profiles, contours or arbitrarily distributed) and were more or less specialised (e.g. to derivate contours from orthophoto profiles or vice versa). Now there exist general purpose program systems that can handle more complex data structures (break lines, form lines, highs and lows) and make available tools for an increasing number of DEM applications.

Considering the actual performance of data acquisition methods and available data processing systems there is no doubt that at present projects can be carried out with today's hardware facilities. Anyway the reduction of computer expense has to be envisaged considering the actual trend of the design of data processing systems: mainframes are to be replaced by networks with distributed intelligence or by low-cost micro computers.

The step of progressive sampling in data acquisition has had the logical conclusion of introducing a varying grid size into the DEM structure used by the program package SCOP (Kraus /2/). The varying grid size avoids the densification of an intentionally reduced amount of data and it allows the direct transfer of the progressive sampling grid with the additional lines into a corresponding DEM. For other data acquisition methods like digitised contours, profiles and irregularly distributed points the grid size of the DEM can be adapted locally to the terrain features.

The improvement of the DEM structure results in a reduction of computing time and storage needs without affecting the accuracy. Especially applications accessing the DEM have considerably reduced expense.

2. The structure of the DEM

The DEM that is constructed and used by SCOP is stored essentially as z-values of a rectangular grid, where the grid lines run parallel with the coordinate axes of the reference system. In addition three different types of lines can be intermeshed with this grid:

- border lines to flag areas which are of no interest
- break lines to represent edges
- form lines to describe other characteristic shapes in the terrain.

To complete the grid by these line structures has the effect of an infinite densification of the grid along the lines, if they are strictly interpreted by the DEM algorithms.

Grid heights and intermeshed lines are organized and stored in so called computing units (CU). A CU is a rectangular area of constant size all over the DEM. The margins of the CU's must match grid lines. Within one CU the grid width is constant.

The DEM consists of an arbitrary number of CU's organized as a matrix. It covers an area that is handled in one computer run, therefore the size is restricted by computing time and disc storage. If locally no height information is available, the corresponding matrix elements are inactive.

A basic grid size is selected for each DEM. The grid size for each CU can be recursively doubled according to the requirements of point density or terrain features.

3. Selection of the local grid width

DEM applications call for certain accuracy specifications. DEM theory leads to the criterion of a height accuracy, which is mainly a function of grid width, curvature and slope (Ackermann /1/). To achieve a constant height accuracy, grid width must be decreased in steep or hilly areas.

For an automated selection of the grid size the sampled data must be analyzed. Obviously there are two cases to be distinguished.

- Point density is a significant sign for the terrain features, because during data acquisition there was a feedback between sampling algorithms and local shapes. Grid width is obtained from point density. In case of progressive sampling DEM grid and measured grid can be unified.
- Point density is not necessarily a sign for the terrain feature. Data acquisition was carried out for example by profiling or contouring. For instance in the common overlap of photogrammetric models a higher point density results regardless of the terrain. Therefore, in a first step the function representing the terrain surface must be predicted within a CU. This provides in a second step knowledge about curvatures and tilts which enables grid width enlargement. This can be interpreted as a regressive sampling method for grid enlargement.

4. The efficiency of the DEM

The efficiency of the DEM structure is investigated in respect to quality, data management and computation time. In general, efficiency means the best ratio between quality and expense; in high accuracy DEM computation it aims at no loss of previously acquired information with the lowest possible cost.

4.1 Quality

The achievable accuracy of the DEM is restricted by the fidelity of the representation of the terrain surface by the sampled points. To reach this accuracy, DEM computation algorithms must use the complete available information and interprete it correctly. SCOP considers the usual point groups when the DEM is built up by prediction without or with filtering or by directly storing measured grid points. Varying information density is adapted to in the DEM by varying grid size and the additional intermeshed lines.

If the application programs can make use of it, this leads to the following improvements:

a) Contour derivation:
   - Form lines ensure the exact run at characteristic terrain lines
   - Break lines cause angles in the contours; impossible intersections between the contours and the break lines of an embankment are avoided.
   - Border lines allow contours to be omitted.
   - Correct run of the contours around highs and lows.

b) Slope map derivation (isolines of constant slope) (Stanger /6/):
   - Break lines become discontinuities; that means that all slope lines between the values to the left and right of the break line have the location of the break line.

c) Perspective representation:
   - In addition to the grid mesh, line information can be plotted too.

d) Single point or profile interpolation:
   - All height information (grid, lines, highs and lows) can be considered; points in areas excluded by border lines must be (or may not be, as an option) omitted.

4.2 Data Management

Today DEM's can be seen as an autonomous product similar to contour maps. This leads to certain requirements in respect to the handling and storage of DEM data:

a) access optimization: excerpts of a DEM must be retrieved quickly when only small areas of large DEM's are of interest, but also easy sequential access to the CU's must be provided when processing large areas e.g. for contouring.
b) storage optimization: minimizing the amount of disc storage means to reduce hardware costs.
c) transportability between different data processing systems: access and storage optimization require computer dependent data management; therefore utilities are required to transform these data into a computer independent form and vice versa.
d) DEM manipulation: replacement of areas in case of changed height information saves the expense of recomputing the whole DEM.

Not all of these items have been realized in an optimal way in SCOP; however data reduction achieved by the step from constant to varying grid width does a good job with regard to less storage and faster access.

4.3 Computing Time

DEM computations can still be considered as time consuming when high accuracy interpolation methods are used. For many interpolation methods this is almost independent of the number of grid points. However the direct storage of grid data corresponding to the DEM grid and chaining up additional lines is very fast. In case of progressive sampling data the direct storage can only be achieved by the varying grid size of the DEM.

Computing time effects of varying grid width are more important in DEM applications. In most cases the computing time depends linearly on the number of grid points, in perspective representations this is also true for the plotting time.

5. Demonstration example

The test area of Soehnstetten (Schilcher /5/) was investigated using the new facility of varying grid width. Some results are presented here and in the appendix.

The data acquisition was done with aerial photographs of 1:10 000. The landscape of the test area can be described as a plateau, which is cut by a valley. There were measured 554 profile points, while the profile distance was 30 m. The profile points were completed by 305 break line points, 244 form line points and 3 highs or lows.

In a first step a DEM was computed by using a constant grid width of 7.5 m. The data and the derived contours with an interval of 2.5 m are shown in appendix 1. A perspective representation of the DEM is given in appendix 2. In a second step the facility of the varying grid size was used, allowing larger grid sizes of 15 m and 30 m. The DEM grid and the derived contours are shown in appendix 3 and the perspective representation of the DEM in appendix 4. It can be recognized that in the valley area the dense grid width is kept, in the plateau area the grid size is increased to 15 m and 30 m, respectively.

5.1 Computing time comparison

The computations were done on a Harris H100 minicomputer and the following computing times have been recorded:

a) DEM computation for
   - constant grid width: 7918 grid points, 274 CPU seconds
   - varying grid width: 4064 grid points, 254 CPU seconds

   The varying grid size has an effect of about 7% reduction of computing time. The direct storage of corresponding progressive sampling data (about 4000 measured grid points and 650 additional points) is expected to take only about 70 CPU seconds.

b) Derivation of contours using the DEM of
   - constant grid width: 6904 contour points, 100 CPU seconds
   - varying grid width: 5921 contour points, 88 CPU seconds

   Only 12% computing time is saved by the varying grid size because most of the contours run through the steep areas, where the dense grid is used.

c) Perspective representation
   Computing- and plotting time for
   - constant grid width: 242 CPU sec, 207 min plotting time (DZ6)
   - varying grid width: 144 CPU sec, 125 min plotting time (DZ6)

   In both computing- and plotting time a considerable reduction of about 40% is gained.

5.2 Storage of the DEM

The reduction of the grid points from 7918 to 4064 means a 49% saving of storage.

5.3 Quality

Comparing the two plots of the contours there is nearly no difference between them. In flat areas with the large grid width the contours are somewhat smoother, what is anyhow desired for cartographic applications. An additional investigation with check points has shown that there is no difference in standard nor maximum deviation (58 cm / 184 cm) for both the constant grid width and the varying grid width.

6. Performance and future ideas about SCOP

In this paper actual trends and aspects of DEM computation and application have been summarized, as contemplated by the staff engaged in SCOP development.

All application programs use the DEM structure with the varying grid size and the intermeshed lines. Only the perspective representation program cannot yet plot the additional lines, for the time being.
There is available also a utility to transform computer dependent DEM's from one computer system to another. Implemented are the transformations between IBM, Harris and HP1000 systems, which have word lengths of 32, 24 and 16 bit, respectively.

Facilities under work are access optimization and further storage minimization of the DEM as a prerequisite for the following new features:
- perspective representation including lines
- manipulation of DEM's
- combination of DEM's at the same location (e.g. to compute cut and fill volumes)
- combination of adjacent DEM's (e.g. to compute a contour map across the margins of two or four neighboured DEM's)

References

/1/ Ackermann, F.: The Accuracy of Digital Height Models.
37. Photogrammetrische Woche 1979, Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Heft 6, 1980.

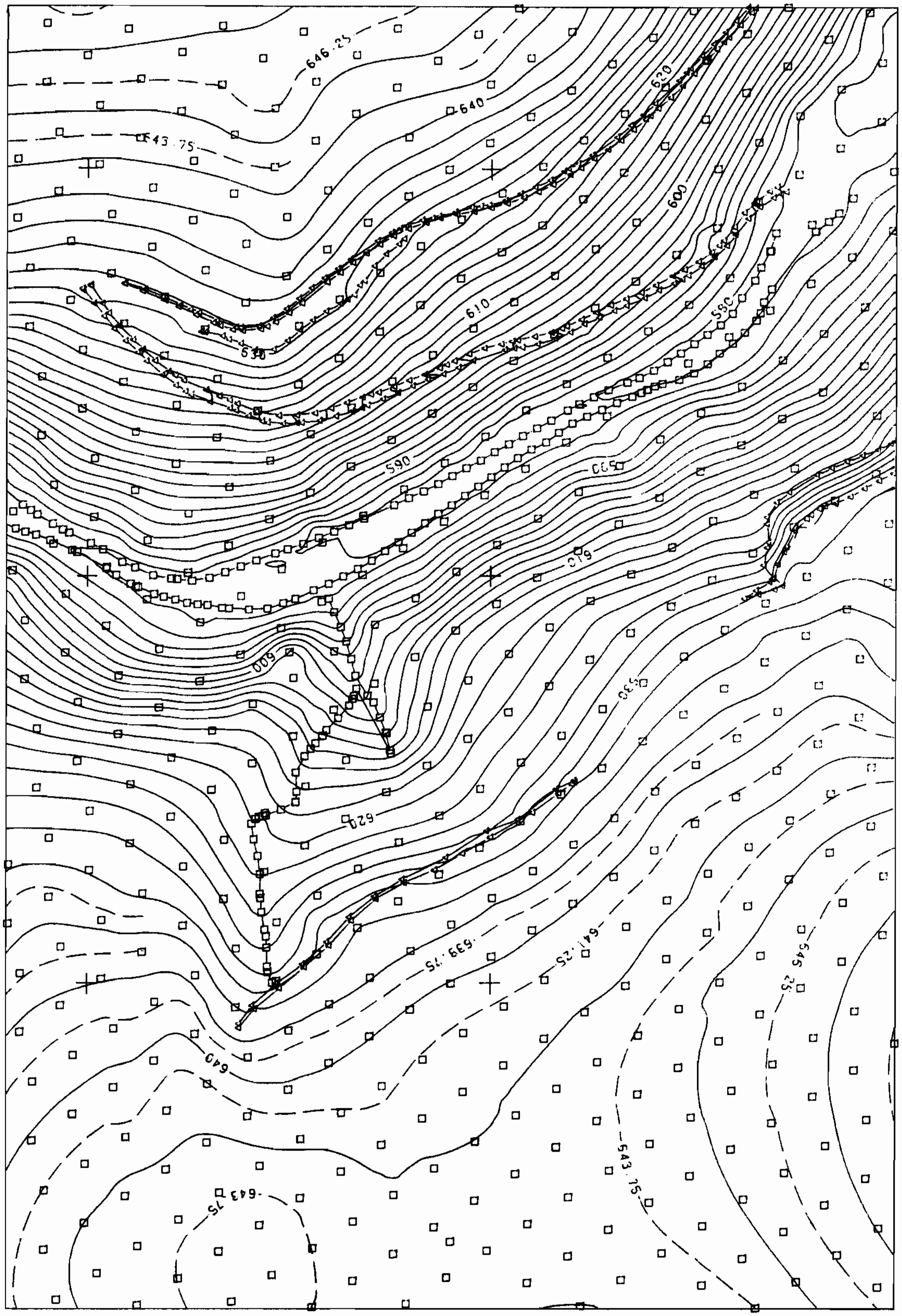
/2/ Kraus, K.: Digital Elevation Models: Users Aspects
38. Photogrammetrische Woche 1981, Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Heft 8, 1982.

/3/ Makarovic, B.: Progressive Sampling for Digital Terrain Models.
ITC-Journal 1973-3

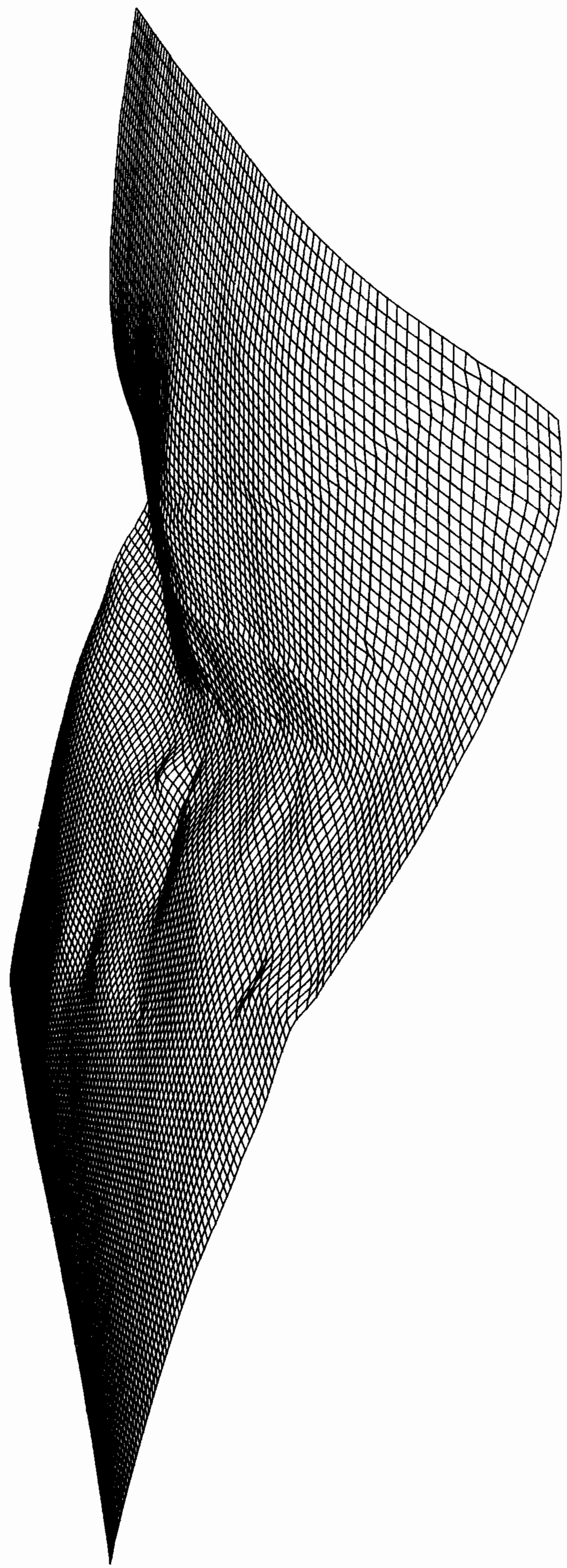
/4/ Reinhardt, W.: A program for progressive sampling with the Zeiss Planicomp.
39. Photogrammetrische Woche 1983, Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Heft 9, 1984.

/5/ Schilcher, M.: A comparison of the accuracy of several contour plots of the Soehnstetten test field.
36. Photogrammetrische Woche 1977, Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Heft 4, P. 29-50, 1977.

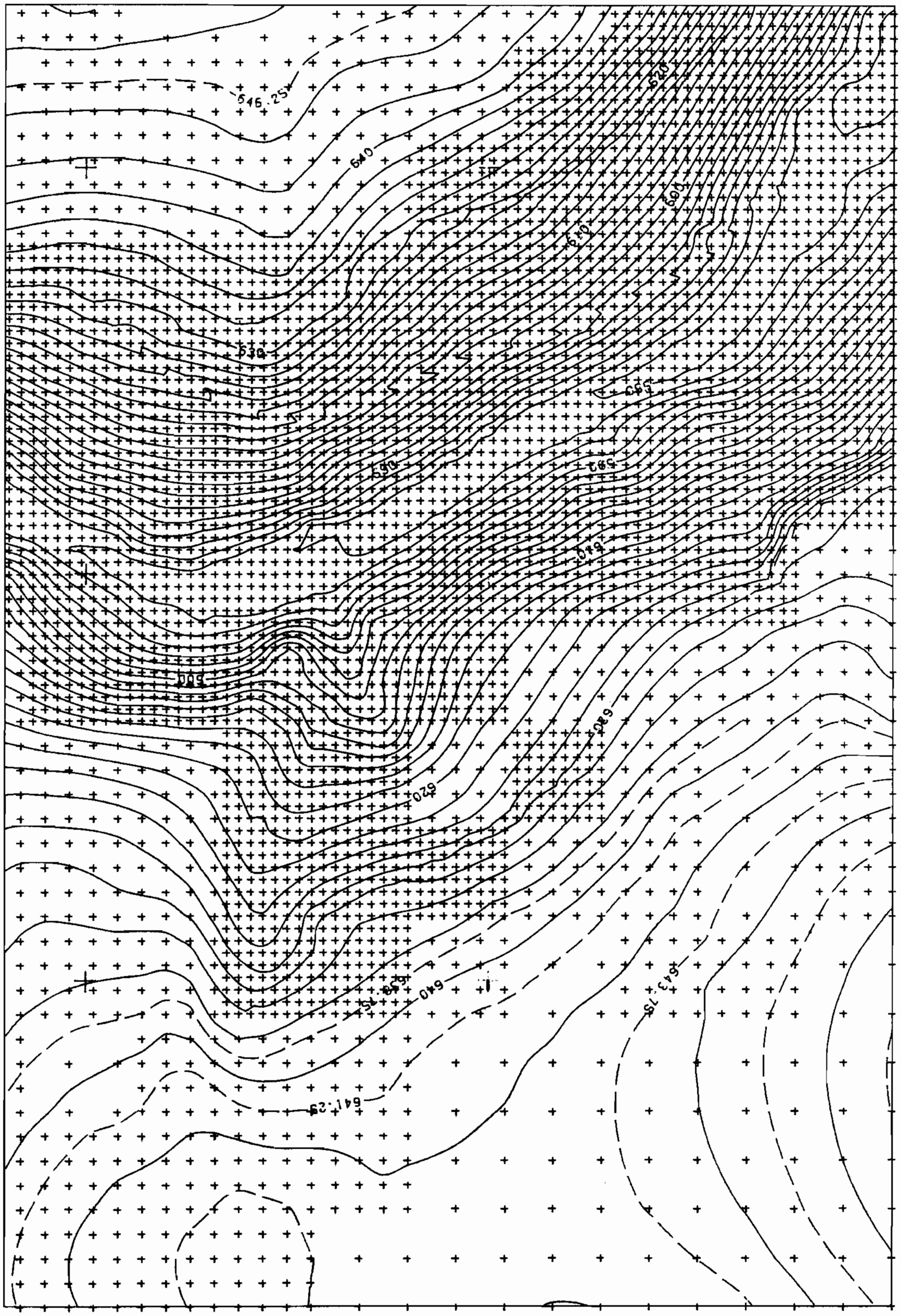
/6/ Stanger, W.: Automatische Herstellung einer Gefällstufenkarte
Sociêtê Francaise de Photogrammetrie, Bulletin No. 57, P. 34-41, 1975.



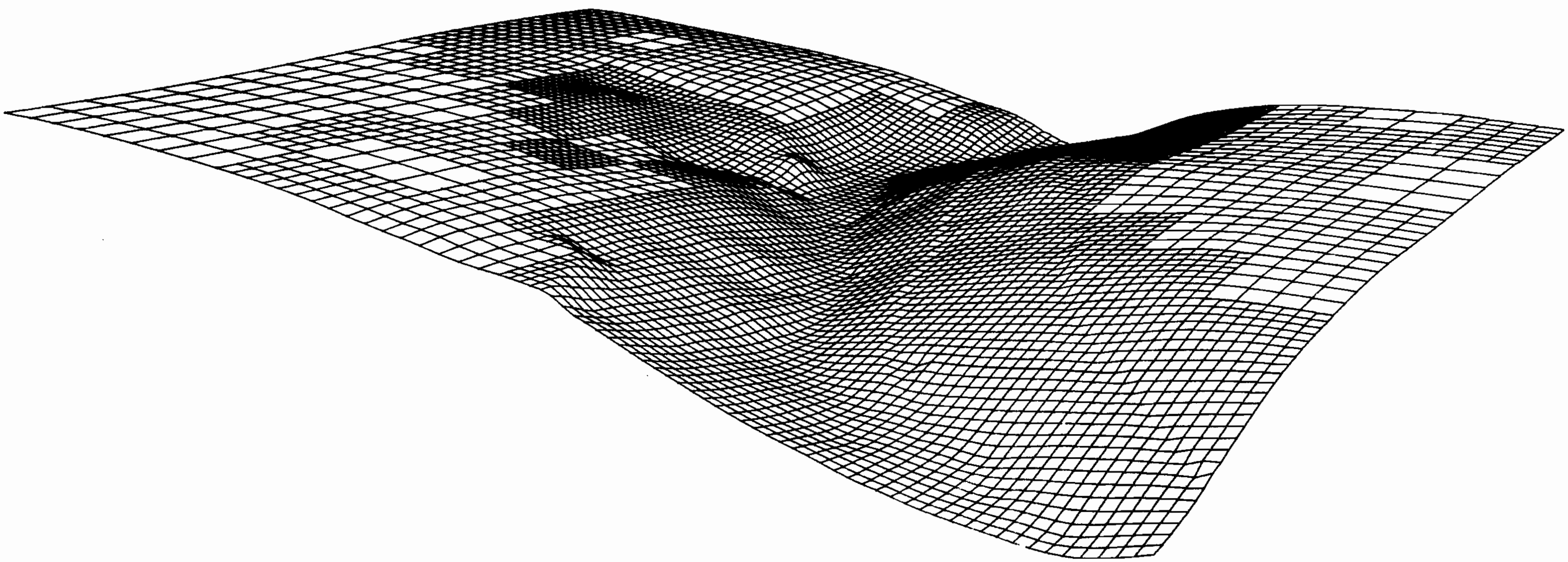
Appendix 1.   Original data and contours derived from DEM with constant grid size.



Appendix 2. Perspective representation of DEM with constant grid size.



Appendix 3. DEM grid of varying grid size and derived contours.



Appendix 4. Perspective representation of DEM with varying grid size.