The DTM-System TASH in an Interactive Environment

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INTRODUCTION

For 20 years already, the Institute of Cartography (IfK) at Hannover University, has been engaged in the development of Digital Terrain Models (DTM). The results of research and investigations are the foundation of the program system TASH, the Topographic Evaluation System of Hannover University.

This paper deals with the description of several methods of surface interpolation, which are carried out in TASH. The paper also contents the results of practical experience which were made by application of these methods to datasets of different density and structure.

Furthermore the recent work of the IfK in connecting the DTM- software package with Interactive Graphic Systems (IGS) is explained by a number of examples and projects.

The Authors of this paper will discuss the different methods for DTM-modeling which are carried out in TASH giving some advices in which cases which method will guarantee best results.
A review in the wide field of IGS is given by a number of examples.

1. CONCEPT OF THE TASH-SOFTWAREPACKAGE

The digital terrain model recently has established itself in various disciplines of surveying. Its spatially referenced components give diverse information for photogrammetrical, cartographic -topographical and geotechnical systems.

The developed methods which are carried out in TASH approximate the relief by using grid or triangulation algorithms.
The choice of methods for surface-modeling - square grid with local triangulation or triangulated irregular network (TIN) - largely depends on the data point's structure and distribution.

1.1 Structure of Input-Data

The TASH-System uses a three dimensional (x_i, y_i, z_i) data set. Data may be regularly or irregularly spaced, and its source may be widely varied. The data may be measured in the field by terrestric methods, photogrammetrically measured, echo sounded or digitized (manually or automatic)
A program element prepares the data and select from the input data for
- breaklines
- lines of ridges and valleys
- no data areas
- geological faults
- spot heights
- grid and plot boundary

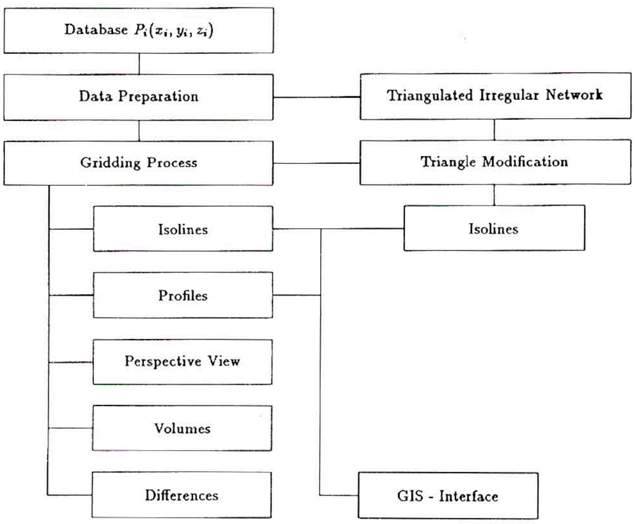


Fig. 1.1-1 - Modules of TASH.

Once these preparations have been completed, two methods are available for further processings: the regular square grid method and the triangulation method (Fig. 1.1-1).

The gridding module determines a square grid which represents the terrain surface. The grid is orientated northwards, taking into account the morphological terrain lines. The calculation of the grid points follows the principle of smooth polynomial surfaces as described in chapter 2.1

1.2 Range of Performance

The program derives isolines, differences, volumes, perspective views and profiles out of the grid. The isoline positions are determined by linear interpolation between the grid nodes. Where terrain lines such as ridge or valley lines run through a grid square, a local triangulation follows, on condition that these terrain lines form the fixed point boundary of the triangulation net. The isolines' positions are then determined by linear interpolation along the triangles' edges.

Where measurements were made in various epochs, a digital difference model is formed by substraction from a reference DTM. The DTMs then have to overlap partially or completely, and the grid intersections must have identical plane coordinates in both DTMs. The volume calculations are done by the prism method. The program works within a given perimeter by adding up single volume elements across a defined surface to give a total volume.

A threedimensional view can be derived from the grid, where non- visible lines are suppressed. The user specifies the viewer's position.
An infinite number of profiles may be calculated and displayed from the DTM considering the original data set in areas with breaklines and local triangulations.

The first step of the triangulation process follows the algorithm given by Delaunay's method. In a second step the triangles are modified to convert given line structures into triangle sides (Buziek 1990/1). Isolines may then be derived directly by linear interpolation along the triangle's sides.
The triangulation net however may be converted into a regular grid. The grid nodes heights are determined by the calculation of the spatial intersection from a straight perpendicular line through the grid nodes' position and the spatial plane of the triangle (Buziek 1990/2). This derived DTM may then be used as the base for further processing.

The link to a IGS is made by interfacing the data. Data files are created by calculation of isolines, perspective views and profiles, which are then entered into the IGS-Software for further processing.

2. METHODS OF TERRAIN MODELING

2.1 The Gridding Process

The grid module calculates a regular square grid in the ground plane (x, y) from the input data set. To derive the digital terrain model, the height of every grid point has to be calculated.
The program uses the method of Moving Surfaces whereby the terrain around each grid points is approximated by a fitted surface. The equation of the surface is generated by an adjustement. Its parameter gives the height of the grid point itself. The selection of reference points is made by partitioning the area around a grid point into eight octants and choosing a certain number of closest points of each octant. The following four mathematical functions are available to obtain the optimal results for different relief features (Kruse, 1987):

1. Elliptic surface:

$$z_i = a_1 + a_2 * x_i + a_3 * y_i + a_4 * x_i * y_i + + a_5 * x_i^2 + a_6 * y_i^2 \quad (2.1 - 1)$$

2. Hyperbolic Surface:

$$z_i = a_1 + a_2 * x_i + a_3 * y_i + a_4 * x_i * y_i \quad (2.1 - 2)$$

3. Oblique plane:

$$z_i = a_1 + a_2 * x_i + a_3 * y_i \quad (2.1 - 3)$$

4. Horizontal plane:

$$z_i = a_1 \quad (2.1 - 4)$$

A certain function can be chosen either by the user or automatically by the program. In the latter case the elliptic surface is calculated first. The standard deviation derived from the difference between the height of the reference points and the surface is compared with a given value. If it is not accepted, the next function will be used and so on.
Sometimes smoothing of DTM is desirable for certain applications. This can be achieved simply by calculating the average of a number of neighbouring grid points. If there are breaklines or geological faults in the area, a module deletes the terrain points that are behind these lines otherwise, the polynomial surface would be fitted in a wrong manner.

It is possible to define topographic structures like ridge, valley and breaklines in the data set, this morphologic skeleton must be considered in the square grid. This is necessary to model the terrain morphologically and geometrically correct. So, if there are terrain lines in the data set, a local triangulation is done in the areas with complex topography to connect these lines with the grid nodes.

2.2 The Construction and Modification of a TIN

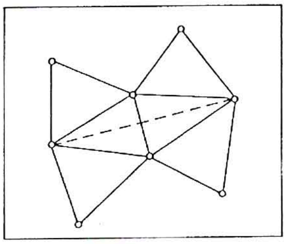
Traditional triangulation methods are often used to construct digital terrain models. These algorithms however are not able to take linear terrain features into accout during the triangulation process. Instead of this a method has been dveloped at the IfK to transform the triangles without manipulating the data points, as the important structural information for the terrain's morphologically correct representation is contained within the triangulation network.
With TASH's expansion to triangulation, the user is given the possibility of applying an optimal method for terrain modeling in the case of linear distributed point fields (e.g.digitized contourlines). The triangulation network's transformation into a regular grid system allows all of TASH's modules to be used.

2.2.1 Delaunay's Triangulation Scheme

The data firstly is restructured to ensure good computing times. The data points for each section can be found quickly by applying them to individual reference grids. This method is also known also "Divide and Conquer" - technique. Since the triangulation is only completed when the point field is surrounded by a convex hull, one of the hull's individual sides may be used as the starting side for the triangulation at the beginning of the process.
The aim is to form the first triangle using the starting side. Only those points, in direct vicinity of the starting side are applied to the starting side's reference grid. A minimum diameter circle is calculated through these three points using Delaunay criterium. The triangulation net is stored in a structure similar to the structure described by Elfick (1979), which also allows an adjacency relationship analysis. This process is repeated for each of the triangles' side until the convex hull is reached and the network is completed. The starting sides' purpose is then taken over by the other sides.

2.2.2 Modification of the Delaunay Triangulation

The linear structuring however is contained in the network only if the Delaunay criterium is satisfied for each of them. The theoretical sides are formed in a post-process algorithm, so that the algorithm's efficiency is not reduced.



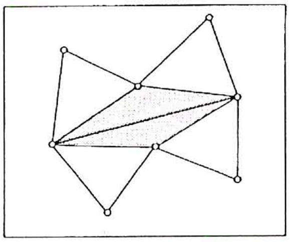


Fig. 2.2.2-1 - Direct changing of a common side.

The dotted line in figure 2.2.2-1 could not be produced. If this vertex is given by two points in neighbouring triangles, a changing of the common triangle side is possible. Therefore a convex hull must be given by the couple of triangles. In this trivial case the theoretical side is formed in one step of changing the common side. We call it the direct changing of common sides.
If the connection to be made between points can not be formed by a unique redefinition of triangles (Fig. 2.2.2-2), then all those triangles crossed by the line still to be

formed must be defined like this. Once this is done, these lines are combined in convex pairs, of which the diagonals may be exchanged. This process may be iterated until two neighbouring triangles contain the theoretical side.

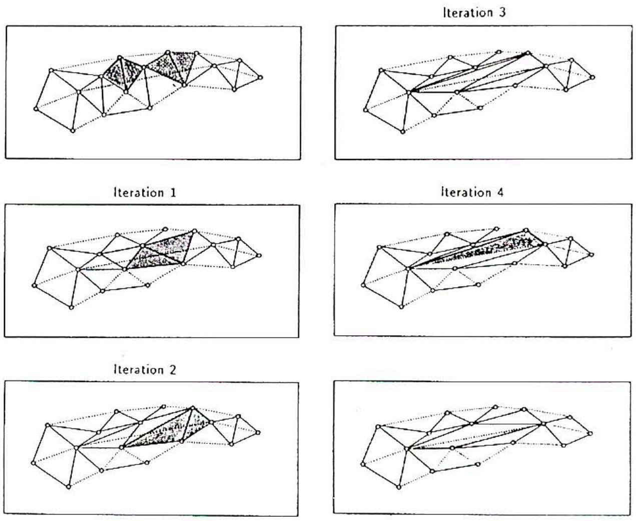


Fig. 2.2.2-2 - Iterative changing of common sides.

This then has provisionally formed all the linear structures. A final step of removing incorrectly existing plateaus is necessary to produce an optimal TIN. This starts from a similarly defined starting triangle equally following the above described triangle redefinition method. Figure 2.2.2-3 show certain steps of the algorithm to avoid non-realistic plateaus. The result of this post-process-algorithms is a so called modified TIN (MTIN).

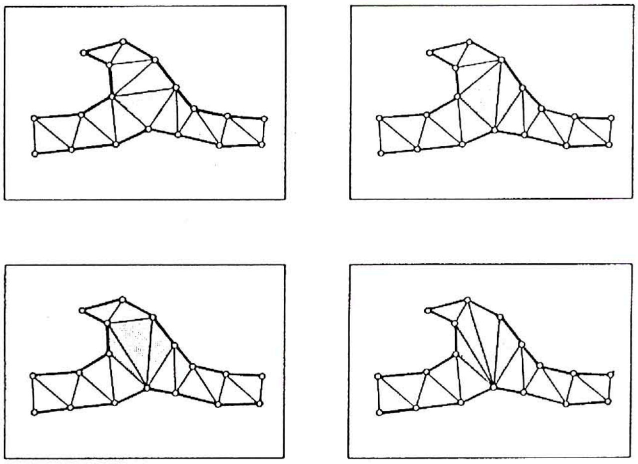


Fig. 2.2.2-3 - Avoidance of non-realistic plateaus.

The isolines in figure 2.2.2-4 show the need for special attention to be given to linear structures.

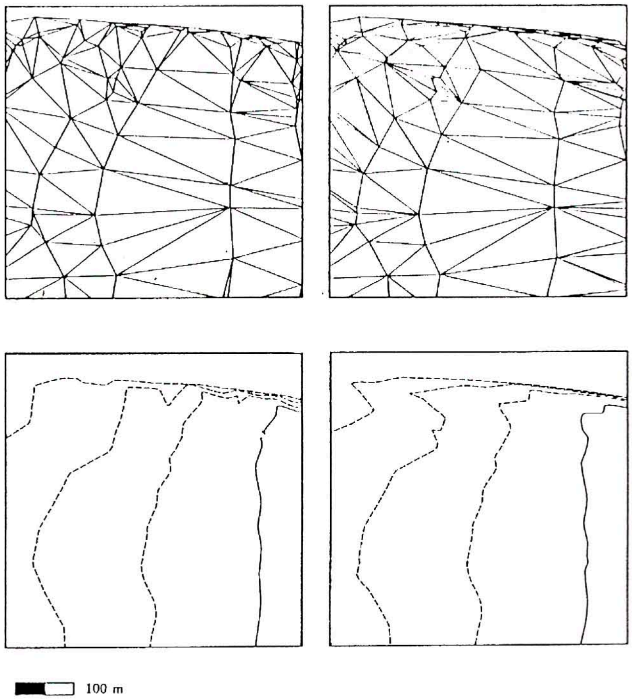


Fig. 2.2.2-4 - Isolines derived from a TIN and MTIN.

3. THE CONNECTION, OF DTM AND IGS

The TASH DTM-package is connected to an IGS system. This gives it a further set of tools for processing the project. In this way all the IGS' processing methods may also be used. Statistical analysis as well as editing of isolines are possible. The DTM's isolines may need editing for one of the following reasons:

- The DTM is calculated without reference to the topographic situation. In a simultaneous display of isolines and reality, the automatically placed contour values may be placed inconveniently. They may be overwrite features e.g. roads, paths or houses.
  With the aid of IGS' editing functions, these contour values may be shifted.
- If not all houses are defined as non-data areas, this may be done interactively on the IGS.

The TASH program system is connected to the IGS by means of interfacing the data. In the calculation of isolines or profiles, TASH forms a data file which the IGS can store. In the IGS GRIPS (Graphical Interactive Program System, developed by Kohns and Poppenhager, Neuenkirchen, FRG), TASH forms a user selectable concept, such as all isolines may be selected individually or in groups for further processing. TASH transfers the contour values as text.

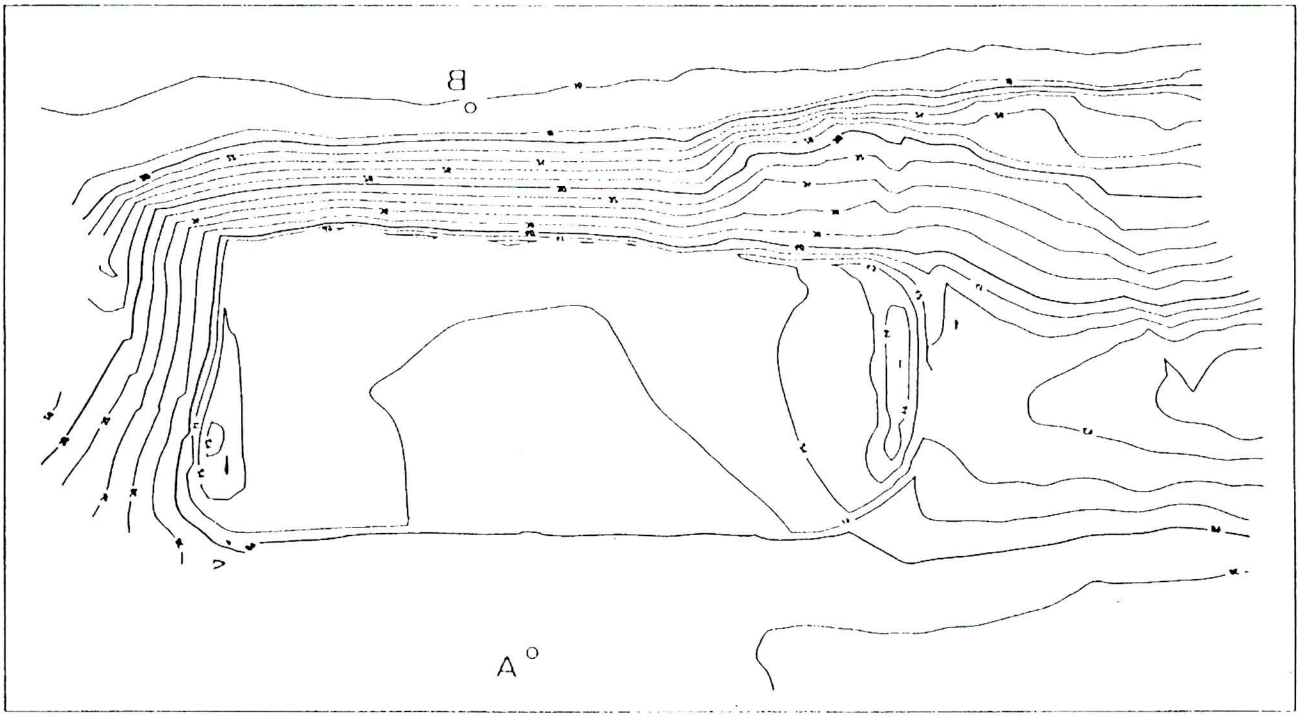


Fig. 4.1 - Contourlines.

Breaklines, ridge and valley lines, non-data areas and geological faults are stored in special levels. All the information may be selected and edited individually.

4. RESULT AND EXAMPLES

The DTM's main product is a contour plot. Figure 4-1 shows a prehistoric fortification in lower Saxony, FRG. The DTM was calculated using the square grid method. The contours have been derived taking into account breaklines, ridge and valley lines. The contour values were automatically placed with their foot pointing downhill. A profile was calculated (Fig. 4-2) from point A to B. An input of the profile's endpoints as well as the step lenght along the profile is necessary. The profile's intersections with breaklines, ridge and valley lines are calculated automatically. The connection to the IGS is also possible by using the profile element. This gives further possibilities for labelling and introducing additional design data into the project.

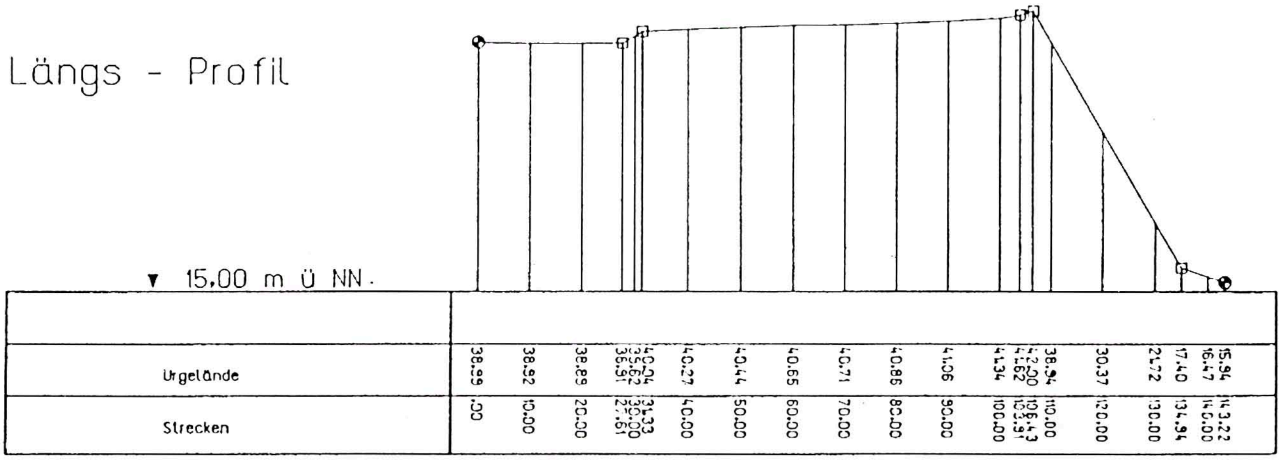


Fig. 4.2 - Cross section.

A perspektive view was derived from the DTM's grid in figure 4-3. This view's main purpose is presentation of the terrain. Furthermore it simplifies an interpretation of the relief.

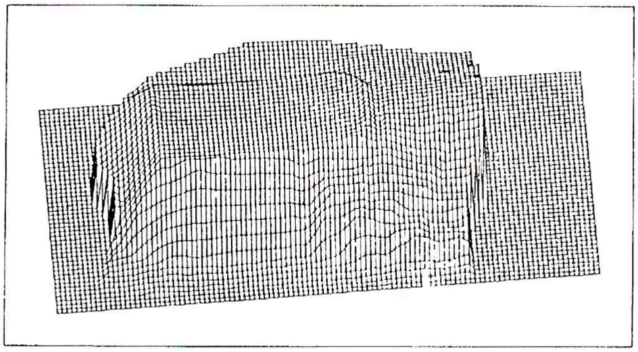


Fig. 4.3 - Perspective view.

This view has been calculated using the hidden-line technique, in which the viewer's position may be freely specified.

TASH can also display differences. A further possibility is the calculation of water table maps (Höper and Kruse 1979, Höper 1983). A water table map shows the differences between the earth's surface and the water table's depth. The DTM lends itself to topographical or photogrammetrical measurements.

The data for calculating the water table DTM is taken from water level gauge observations. A DTM is calculated for both, the water table observations as well as for the topography. The water table's height is then calculated by subtracting each grid point's water table depth form its corresponding topographic height.

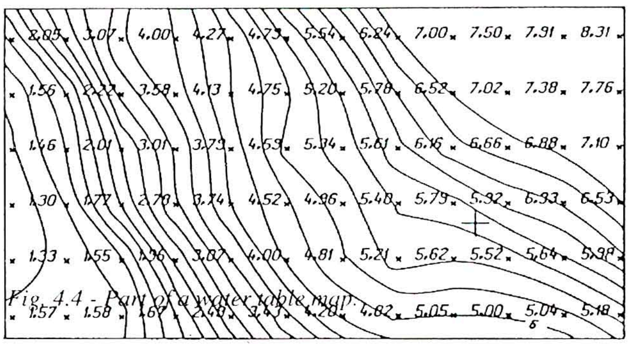


Fig. 4.4 - Part of a water table map.

Figure 4-4 shows lines of equal depth as well as the numerical difference for each point, to help the user's individual interpretation needs. Figure 4-5 shows an extract from a plan which was adapted to suit planning purposes. The site for the DTM was measured with an electronic tacheometer, and had been entered into both systems TASH as well as the system GRIPS' digital planimetric model (DPM). After the DTM using TASH had been calculated, the contour plot was taken for processing the DPM using GRIPS. The result is a combination of DPM and DTM.

CONCLUSIONS

Interactive Graphic Systems (IGS) are presently able to take up and process a large amount of interdisciplinary information. The user is presented with a choice of tools for manipulation, simulation and analysis. DTMs supply the height component or its derived applications from largerly spatial data. A synthesis of digital terrain models and geo-information systems is not only sensible, but a logical consequence and result of developments in computer assisted cartography.

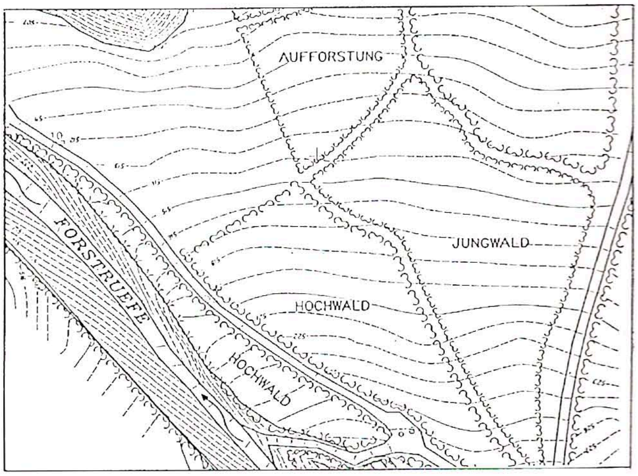


Fig. 4.5 - Combination of DPM and DTM using IGS tools.

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