

# GENERATION OF HIGH FIDELITY DIGITAL TERRAIN MODELS FROM CONTOURS

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### ABSTRACT

Generating a digital terrain model (DTM) from a given set of contours has particular importance due to the wide availability of contour maps. To generate a high fidelity DTM at first a sufficient data preparation of the resource data is necessary. In this paper the required steps for the data preparation, especially the automatical derivation of skeleton lines from the given contour set, are shortly described. Three approaches for generating a high fidelity DTM using the given contours and the derived data are presented. The high fidelity DTM can be based on a triangulated irregular network (TIN) or a regular grid. Practical examples are presented. The results demonstrate the efficiency of the proposed methods.

**Key words:** digital terrain model, contours, geomorphological information, TIN-structure, grid-structure.

### 1. INTRODUCTION

The digital terrain model (DTM) has been subject of research and development for more than three decades. In the last years there is a tendency to generate countrywide high fidelity DTMs. In this context contour maps, which are available in many cases with good accuracy, attach importance for DTM generation (Leberl et al, 1984; Clarke et al, 1982). To generate a high fidelity DTM at first a sufficient data preparation is necessary. In this paper the required steps for the data preparation, especially the automatical derivation of skeleton lines from the given contour set, are shortly described. Three approaches for generating a high fidelity DTM using the

given contours and the derived data are presented. The efficiency of the proposed methods is demonstrated using practical examples.

### 2. DATA PREPARATION

The recording of the contour data set is to be done either by photogrammetric stereo measurement or by digitization of existing contour maps. The digitization proceeds either manually, semiautomatically or automatically (Lichtner, 1987; Giebels/Weber, 1982; Yang, 1990). After the data acquisition the data preparation is necessary to generate high fidelity DTMs. First of all the gross errors have to be eliminated (Aumann et al, 1992). Afterwards the data set has often to be thinned out by special algorithms without losing essential information to obtain a proper data density for the further DTM generation (Bässmann /Besslich, 1989).

For generating DTMs from a given contour set, geomorphological information in form of skeleton lines, i.e. ridge and drainage lines, is of essential importance. Existing contour maps contain these lines implicitly. To extract this information automatically from the given contour set two approaches have been developed at Technical University Munich.

The first method is based on raster data processing techniques. Treating the given contour set as a graph, medial axes are computed by means of suitable algorithms. Parts of the medial axes, i.e. those between two parts of the same contour line, are picked out, connected and used as the approximate skeleton lines (Aumann et al, 1991; Tang, 1991).

The second method is a vector-based approach, which will be summarized shortly in the following. A more detailed presentation is given in (Aumann et al, 1991).

The automatic derivation of skeleton lines from a given contour set is based on the use of aspect information. At each contour line point aspect information, e.g. the direction of the slope line, can be calculated as the unit vector of the bisector of the angle formed by two adjacent polygon sections. For calculating the aspect vectors in the area between two contour lines an interpolation is necessary. In our case a triangulated irregular network (TIN) is used for interpolation. This means that all contour line points are triangulated by a proper triangulation method e.g. a constrained Delaunay triangulation (Reinhardt, 1990). With the help of the aspect information slope lines can be calculated.

The computation of skeleton lines is restricted to areas, where they most probably occur. These areas show up in the TIN in the form of horizontal triangles (fig. 1). In these areas a skeleton line is found as the slope line of minimum slope and thus as the longest one among the slope lines in the surrounding. In fig. 2 the automatically derived skeleton lines are shown as thin lines.

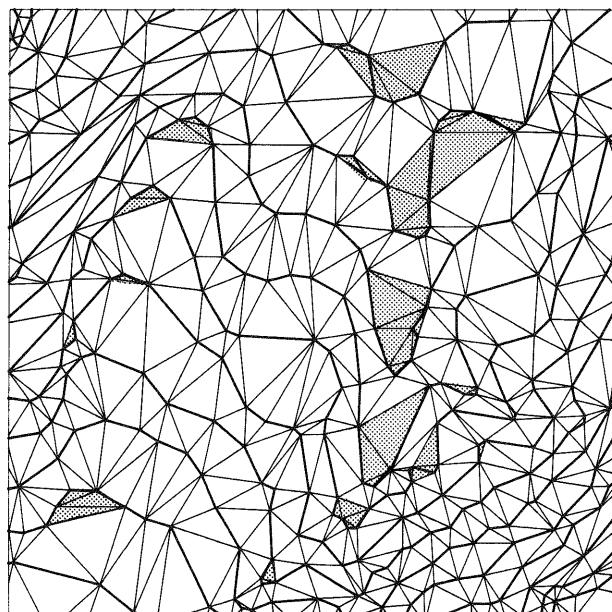


Fig. 1: Contour lines (thick lines) and the resulting TIN.  
The grey areas represent horizontal triangles.

A lot of tests of the approach using practical data have shown, that the method is robust. The treatment of big areas is possible by partitioning the whole area. Prob-

lems in the border regions can be avoided by choosing suitable overlaps.

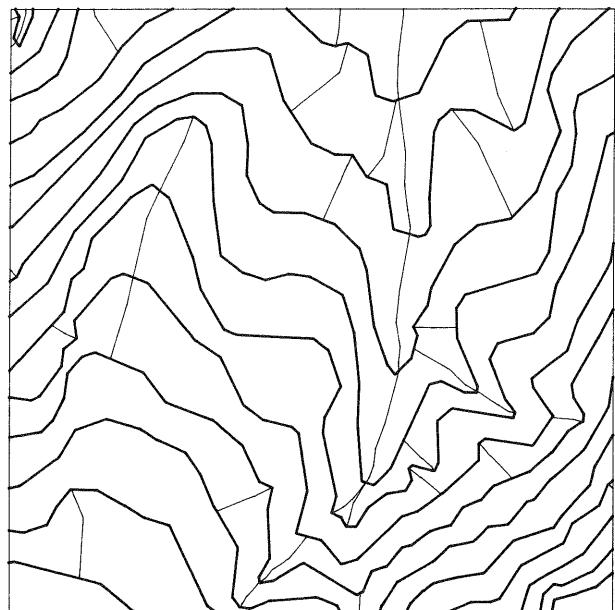


Fig. 2: Contour lines with automatically derived skeleton lines (thin lines).

### 3. DTM-GENERATION

When generating a DTM from a given set of contours, undesirable artificial terraces usually appear along ridges and valleys, e.g. in the areas, which show up in the TIN in the form of horizontal triangles (see fig.1).

To avoid these problems the skeleton lines derived from the contours have to be used as additional information in the DTM generation.

There are different concepts for DTM generation, leading to a TIN-DTM, a grid-DTM or a hybrid grid/TIN-DTM (Ebner, 1991). In the following three approaches for generating a high fidelity DTM are presented.

#### 3.1 TIN - DTM

To generate a DTM based on a TIN-structure, the contour line points must be triangulated by a proper method e.g. a constrained Delaunay triangulation. To generate a high fidelity TIN-DTM the skeleton lines have to be considered, too. The result of the TIN - based DTM can be illustrated by the contours derived from the DTM (see fig. 3). The derived contours include the original

ones exactly. The high quality of the surface description is represented by the intermediate contours (thin lines in fig.3). Artificial terraces are avoided completely. Moreover, irregularly distributed contour lines do not cause any problems. The shaded relief representation shown in fig. 4 demonstrates, that the TIN-DTM is of high fidelity but not smoothed.

The data organisation of a TIN based DTM is rather complicated, especially if countrywide DTMs have to be generated.

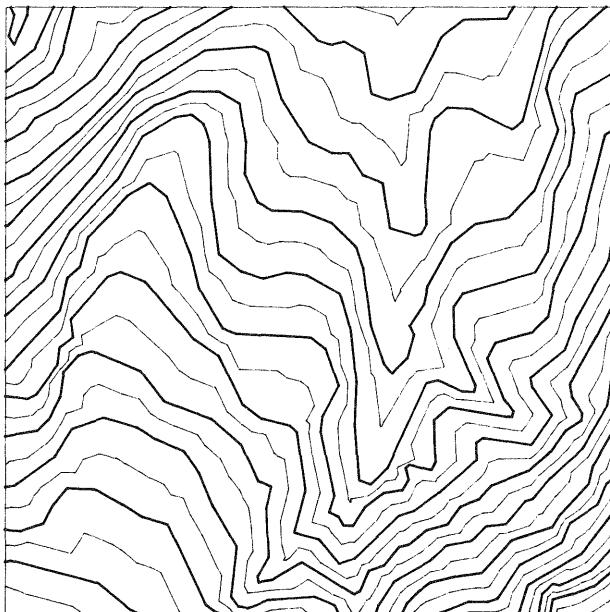


Fig. 3: Contour lines derived from a TIN-DTM. The thin lines represent the intermediate contours.

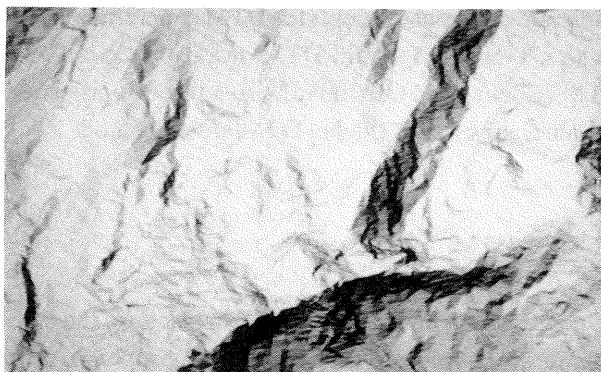


Fig. 4: Shaded relief representation derived from a TIN-DTM.

### 3.2 "Simple" grid-DTM

An essential advantage of a grid-DTM in contrast to a TIN-DTM is the simple data organisation, especially for large DTMs. The grid-DTM is well suited for data management within a data base and allows for quick data access.

To combine the advantages of both the TIN-DTM and the grid-DTM, a "simple" grid-DTM is generated by interpolating the DTM grid points directly from the TIN. The contour lines derived from such a "simple" grid-DTM are shown in fig. 5. They are nearly the same as the ones, derived from the TIN-DTM (fig. 3). The "simple" grid-DTM allows the reconstruction of the original contours nearly exactly. Artificial terraces are avoided and problems because of irregularly distributed reference data do not occur. The TIN, which is needed for the interpolation, can be calculated in subareas with suitable overlaps.

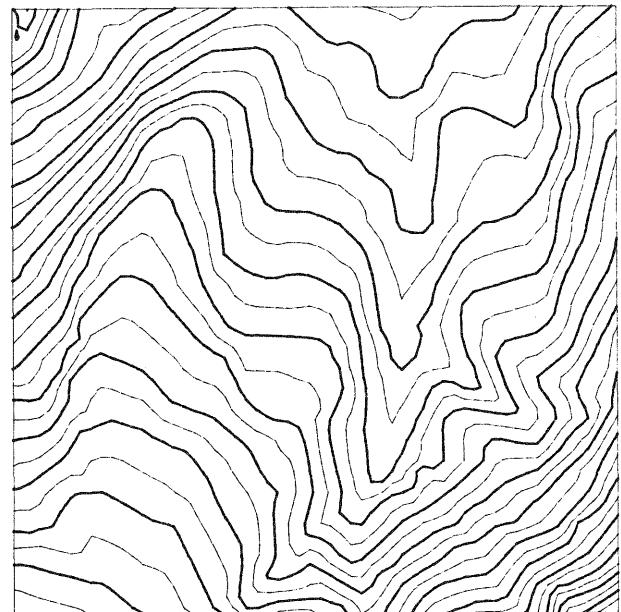


Fig. 5: Contour lines derived from a "simple" grid-DTM. The thin lines represent the intermediate contours.

### 3.3 Smoothed grid-DTM

Generating a smoothed grid-DTM by means of finite elements has proven to be very suitable (Ebner/Reiß, 1978; Reiß, 1986). A high fidelity smoothed DTM can be generated, if the contours and the additional skeleton

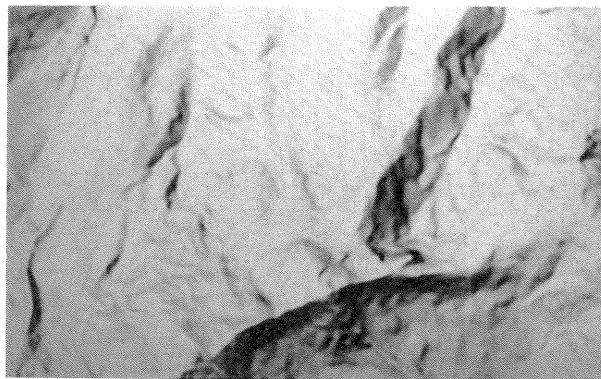


Fig. 6a: Shaded relief representation derived from a smoothed "simple" grid-DTM.

lines are used. A hybrid grid/TIN data structure mentioned above is not necessary in this case. To avoid problems caused by irregularly distributed contour lines, grid points, interpolated from the "simple" grid-DTM, can be used as additional reference data (Aumann et al, 1992).

To minimize the effort for DTM generation, a direct smoothing of the "simple" grid-DTM with the method of finite elements was investigated. The smoothed "simple" grid-DTM and the smoothed grid-DTM are illustrated by shaded relief representations in fig. 6. As one can see, both methods lead to similar results. Therefore, the smoothed "simple" grid-DTM can be considered as an attractive alternative.

#### 4. CONCLUSION

The skeleton lines, derived automatically by the method shown in chapter 2, supply the additional geomorphological information for DTM generation. All three methods shown in chapter 3 are able to generate a high fidelity DTM. The requirement to generate countrywide DTMs leads to the conclusion that the TIN-DTM (chapter 3.1) is less useful than the grid-DTM because of the complicated data structure. The "simple" grid-DTM (chapter 3.2) is generated by interpolating the DTM grid points directly from the TIN. Therefore, the quality is comparable with the one of the TIN-DTM. Using the method of finite elements, either a smoothed grid-DTM or a smoothed "simple" grid-DTM (chapter 3.3) can be generated.

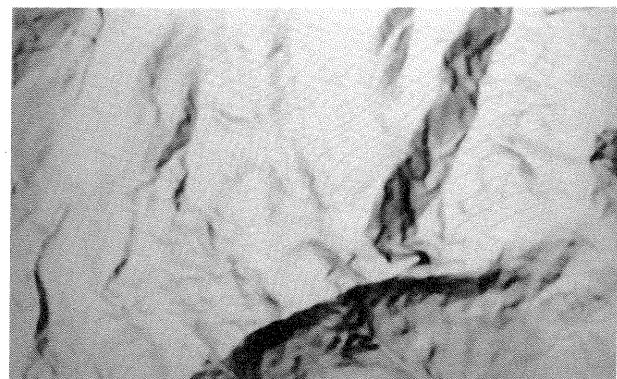


Fig. 6b: Shaded relief representation derived from a smoothed grid-DTM.

Finally, fig. 7 shows the contour lines derived from a smoothed "simple" grid-DTM. The intermediate contour lines (thin lines) again demonstrate the high quality of the surface description. The example (2,5km\*1,5km) was calculated automatically and no interactive work was needed.

#### REFERENCES

- Aumann G., Ebner, H., Tang, L., 1991: Automatic derivation of skeleton lines from digitized contours. ISPRS Journal of Photogrammetry and Remote Sensing, 46, 259-268.
- Aumann, G., Eder, K., Pfannenstein, A., Würländer, R., 1992: Primary data Analysis and Preparation for DTM Generation. In preparation for XVII ISPRS Congress, Washington.
- Bässmann, H., Besslich, Ph.W., 1989: Konturorientierte Verfahren in der digitalen Bildverarbeitung. Springer-Verlag Berlin Heidelberg, New York London Paris Tokyo.
- Clarke, A.L., Grün, A., Loon, J.C., 1982: The Application of Contour Data for Generating High Fidelity Grid Digital Elevation Models. Proceedings Auto-Carto 5, 213-222.
- Ebner, H., Reiβ, P., 1978: Height interpolation by the Method of Finite Elements. Nachrichten aus dem Karten- und Vermessungswesen. Reihe II, Heft 36, 79-94.

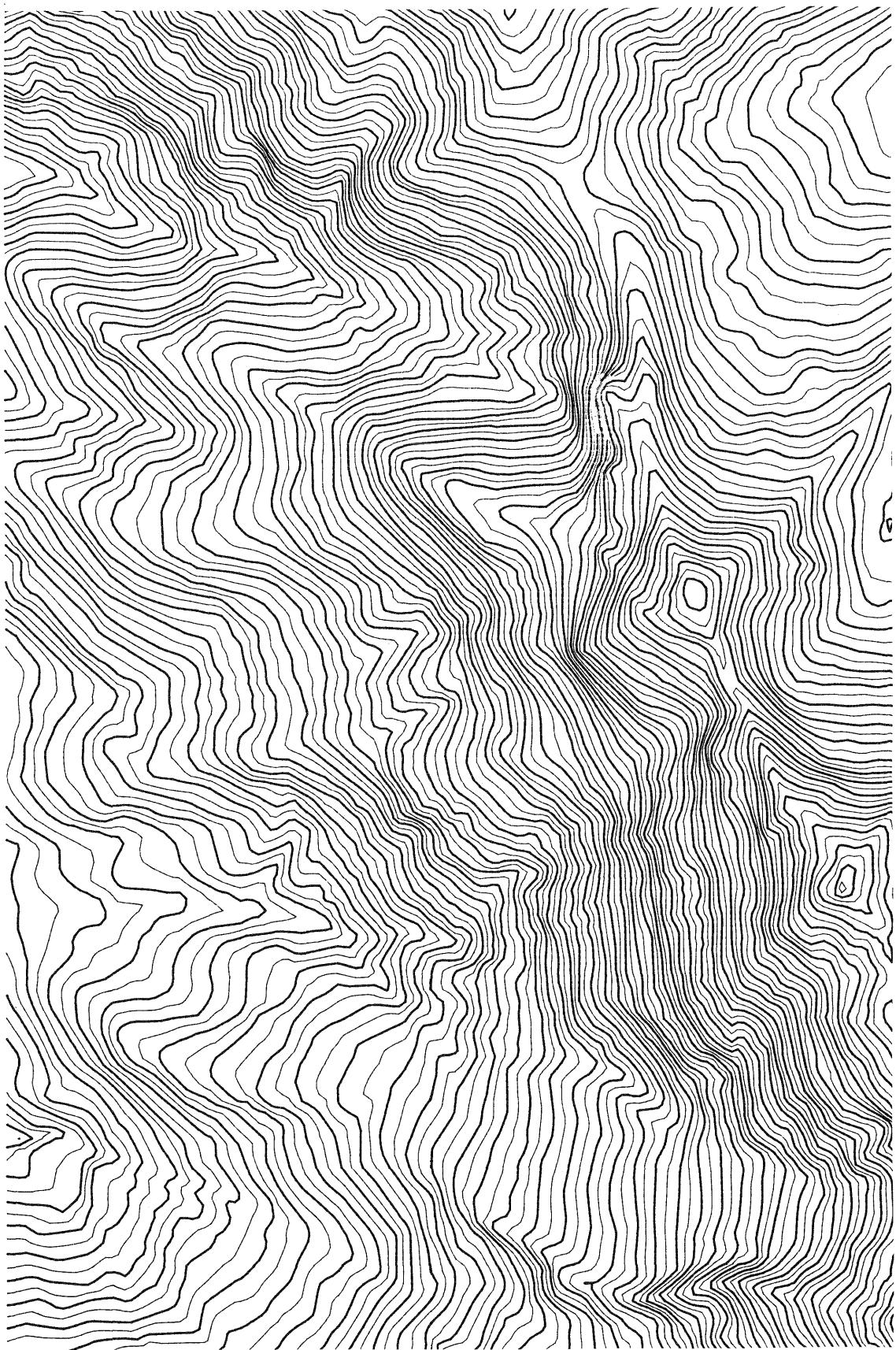


Fig. 7: Contour lines derived from a smoothed "simple" grid-DTM. The thin lines represent intermediate contours.

Ebner, H., 1991: Digital Terrain Models - New Requirements and Fields of Use. Geodetical Info Magazine, Volume 5, Number 6, 31-33.

Giebels, M., Weber, W., 1982: Höhenliniendigitalisierung nach Verfahren der Raster-Datenverarbeitung. Nachrichten aus dem Karten- und Vermessungswesen, Reihe I, Heft 88, 61-75.

Leberl, F., Glänzer, S., Beer, M., 1984: Herstellung sehr dichter Höhenraster aus digitalisierten Schichtenlinien. Zeitschrift für Vermessungswesen, Heft 1, 27-33.

Lichtner, W., 1987: RAVEL - Ein Programm zur Raster-Vektor-Transformation. Kartographische Nachrichten, Heft 2, 63-68.

Reinhardt, W., 1991: Interaktiver Aufbau hochqualitativer digitaler Geländemodelle an photogrammetrischen Stereosystemen. Deutsche Geodätische Kommission, Reihe C, Heft 381.

Reiß, P., 1985: Aufbau digitaler Höhenmodelle auf der Grundlage einfacher finiter Elemente. Deutsche geodätische Kommission, Reihe C, Heft 315.

Tang, L., 1991: Einsatz der Rasterdatenverarbeitung zum Aufbau digitaler Geländemodelle. Mitteilungen der Technischen Universität Graz, Folge 73.

Weber, W., 1982: Raster-Datenverarbeitung in der Kartographie. Nachrichten aus dem Karten- und Vermessungswesen, Reihe I, Heft 88.

Yang, J., 1990: Automatische Erfassung der Höhenlinienfolien mit Verfahren der Mustererkennung. Nachrichten aus dem Karten- und Vermessungswesen, Reihe I, Heft 105, 197-206.