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HIGH QUALITY DTMS FROM CONTOURLINES BY KNOWLEDGE-BASED CLASSIFICATION OF PROBLEM REGIONS

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ABSTRACT

Contourline maps are increasingly used to generate DTMs (Digital Terrain Models). That's, because in most countries such maps are existing, covering the whole area in different scales, thus representing a cheap source of data. Unfortunately, DTMs from digitized contourlines can have certain quality draw-backs. At our Institute a program has been developed to improve the quality of the results. This is done by extracting the important topographic features (ridges, summits, saddles, drainage lines and valleys) and calculating points and lines as additional input.

From the original contourlines a TIN (Triangular Irregular Network) is created. This TIN can immediately be used to calculate additional points to improve the data distribution. Furthermore, the triangulation is used to analyze the contourlines and to detect relevant topographic features. This analysis is a knowledge-based classification of problem regions by the use of rules. A classified topographic feature yields calculation of additional points and lines. Thus the main topographic features are revealed. The method has been developed especially for contourline data, but can be extended for other kinds of input data without effort. The developed program performs as a preprocessing module for SCOP[2] .

The proposed method has been tested with various input data. These examples are presented and discussed in the second part of the paper, including an outlook on further developments.

1 INTRODUCTION

For the generation of large-area, or even country-wide, DTMs the data capturing process is the most time and cost consuming part. Therefore, it would be preferable to use existing data. One possible source of data are contourline maps. These maps have been measured in the last decades and cover in most countries the whole area in different scales. That's the reason why, esp. federal agencies have started to digitize these maps and to use these lines as input data for the generation of DTMs (about digitization of lines - manually and by scanning - cf. [Aumann94]).

Unfortunately, the calculated results have certain draw-backs in quality. This is due to:

- the inhomogeneous data distribution: areas with nearly no points vary with areas of high point density (see Fig. 1-1, cf. [Weibel91], p272f). This is problematic especially for grid-based DTMs.
- the loss of characteristic topographic features (ridges, summits, saddles, drainage lines and valleys) during the generation of the DTM. But, exactly these features determine the quality of a DTM.

Contourline maps contain a lot of topographic information, but part of it is contained implicitly and therefore is not easily accessible. E.g. a hill will be flattened during the process of DTM generation, unless a spot-height has explicitly been measured. Similarly, a ridge or a drainage line may disappear without a formline, indicating this topographic feature (s. Fig. 1-2).

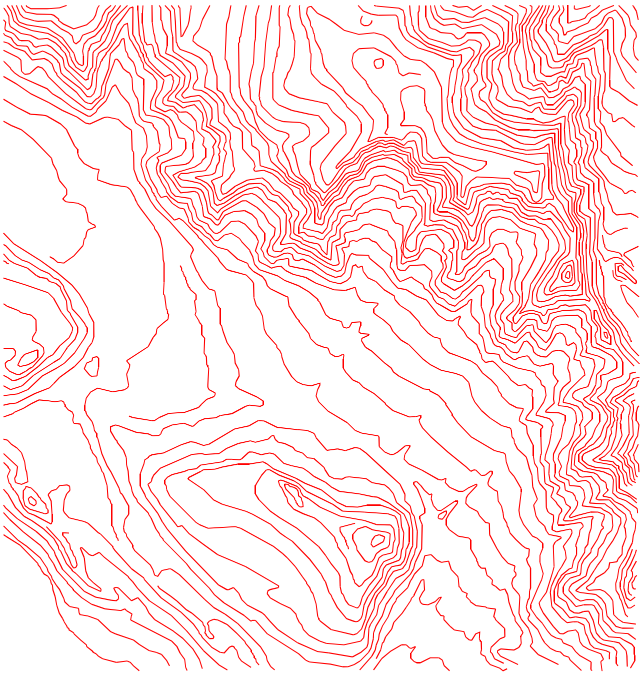

Fig. 1-1: Digitized contour lines in scale 1:25.000; Swiss Federal Office of Topography.

[2] SCOP is a DTM package, developed by the Inst. f. Photogrammetry a. Remote Sensing and INPHO GmbH, Stuttgart

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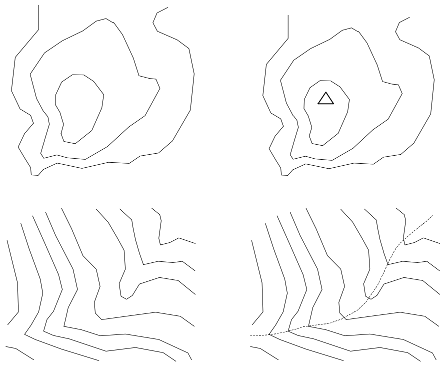


Fig. 1-2: Topographic features: hill and ridge. Without explicit information these may be flattened during DTM generation. To preserve these features, a spot-height for the hill and a formline for the ridge has to be calculated.

Various attempts have been made to develop algorithms, that calculate additional points and lines to gain a better data distribution and to reduce the loss of topographic characteristics. Some of these approaches may be intoduced: In [Clarke82] linear or cubic interpolation along straight lines (predefined directions or direction of steepest slope) is used to calculate additional points between the lines. In [Peng96] the contourlines will be triangulated and for each flat region - a region with only horizontal triangles - a line segment will be calculated, using linear interpolation within profiles. [Christensen87] also uses a TIN and only adapts the Delaunay criteria for the triangulation of contourline data. [Aumann94] uses the aspect information in the points of the contourlines. These aspect vectors are used to calculate the skeleton lines. Aumann generates these lines in flat regions, but also tries to connect the line segments, so to gain longer skeleton lines. A rather particular approach is the one of [Mark86], who uses knowledge about the processes which have formed the surface, to calculate intermediate contourlines. But this method should only be applied to fluvially-eroded surfaces.

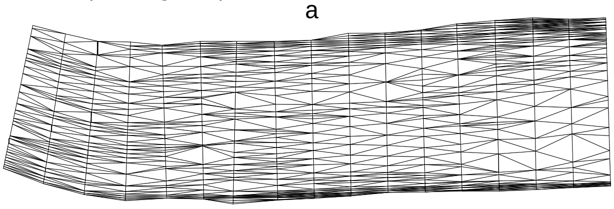
Many algorithms (esp. in GIS-environments) deal with the direct generation of gridded DTMs using contourlines in raster-format. This task is not part of our method, for completeness some approaches: [Aumann90], [Fukue90], [Takagi96] and also [Mark86].

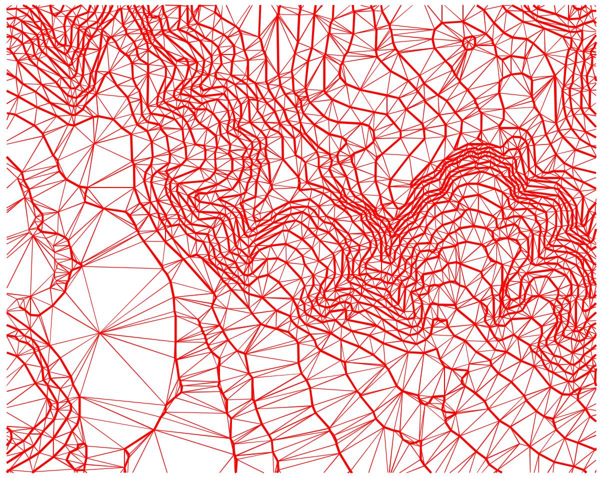
2 HIGH QUALITY DTMS FROM CONTOURLINES BY KNOWLEDGE-BASED CLASSIFICATION OF PROBLEM REGIONS

2.1 Triangulation

As it is stated in [Weibel91, p274], triangle based DTMs offer more flexibility in regard of inhomogeneous data distribution: "TINs are able to reflect adequately the variable density of data points and the roughness of terrain" (see Fig. 2-1).

a





b

Fig. 2-1: Triangulation of a) profile data and b) contourline data. The connection between two subsequent points of a line performs as a constraint edge of the triangulation.

The triangles are stretching over the gaps where no points exist. Immediately, the triangulation can be used, to calculate additional points, regularly or irregularly spaced (see Fig. 2-2, cf. [Aumann94], p 82f) - These points will be used as additional input for conventional DTM generation.

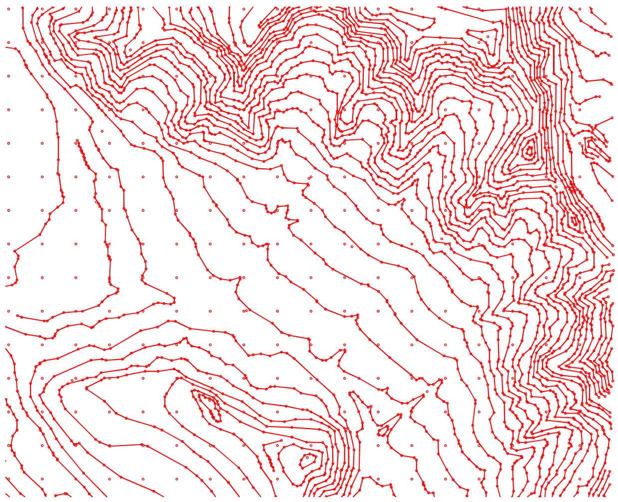


Fig. 2-2: Additional points to improve the data distribution.

Furthermore, a triangulation is optimal for a local analysis of the data, because it represents the local topology (neighbourhood relations) between points, edges and lines. Therefore, it is possible to detect situations where topographic information is hidden, to analyze it and to calculate additional points. Hidden information means: here exists a topographic feature, like a hill, but without an explicit point or line this feature may get lost during conventional DTM-generation (see Fig. 1-2).

The algorithm for triangulation, used in our approach, is a 3D-algorithm to triangulate 3D-surfaces (see [Heitzinger96]), because it is part of a concept for a real three-dimensional DTM (see chapter 3.1).

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2.2 Classification of problem regions

Let us call a situation with hidden topographic information a problem region. The goal is to detect these regions, to determine the spatial extension and neighbourhood relations and to classify the region - i.e. to determine the type of the region. In our approach this is done like that: The triangulation is scanned for suspicious triangles. A strong indicator for a problem region is a horizontal triangle. Another one would be a sharp bend in a contourline.

Fig 2-3: Problem region: initial triangle marked black and region gray; horizontal triangles are hatched.

Fig. 2-3 shows a part of a ridge, where the initial horizontal triangle is marked black. The classification continues with the determination of the spatial extension and the type of the detected region (in Fig. 2-3 an elementary ridge).

A very important characteristic of topographic features - esp. ridges and drainage lines - is that they do not consist of only one element, but many connected elements. Therefore, in the next step of the classification, possible neighbours of a classified region are searched. The sampling of the candidates will be done by a local analysis in the neighbourhood of the region. These candidates will also be classified, resulting in a set of connected regions, representing e.g. a whole ridge (s. Fig. 2-4). The different regions can be of different type. On the other hand, often larger, complex regions occur. These are decomposed into elementary connected regions (Fig. 2-5).

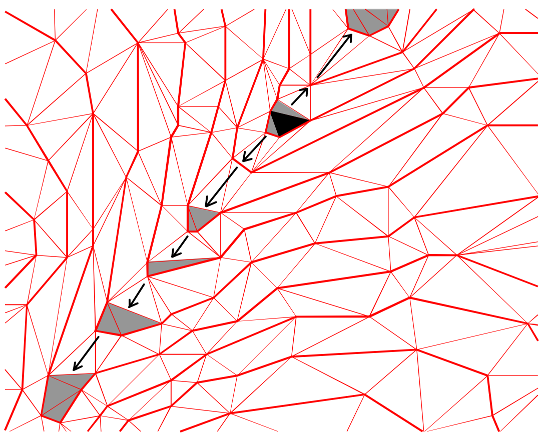

Fig. 2-4: Ridge elements connected to a whole ridge.

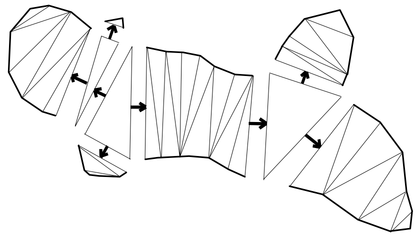

Fig 2-5: A complex hill is decomposed into elementary regions.

The problem regions are modelled as objects (in the sense of OOP - Object Orientated Programming), which are structured hierarchically (see Fig. 2-6). The nodes of the tree represent intermediate and the leaves final types of regions. During the classification the problem region moves from the root to one of the leaves. The object hierarchy can easily be altered and extended for new types of problem regions. It has been tried to incorporate the knowledge of a topographic expert, when determining the type of a region. The representation of this knowledge, as well as the concept of the classification itself, are taken from expert systems. More about basic concepts of classification and knowledge representation in [Puppe93].

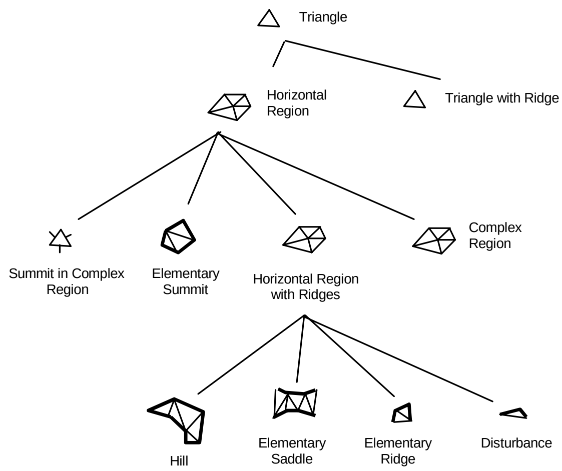

Fig. 2-6: Object hierarchy of problem regions.

2.3 Rules

The way of knowledge representation in our approach is the usage of rules. The rules ask questions about the problem regions. The answer distinguishes between different types of regions. The action part of the rule can be the final determination of the type, investigation of further parameters (like sampling of neighbours) or, mostly, another rule.

<u>Example</u>:

```
Rule4.Evaluate(Triangle Data)
{ if( Data.Contourline_closed() )
  { Data.NewType(hill);
    SendMsgToRule( 5, Data);
  }
  else
  { SendMsgToRule( 6, Data);
  };
};
```

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The function `SendMsgToRule()` passes the problem Region `Data` on to the next rule, whose identifier is the first parameter of this function.

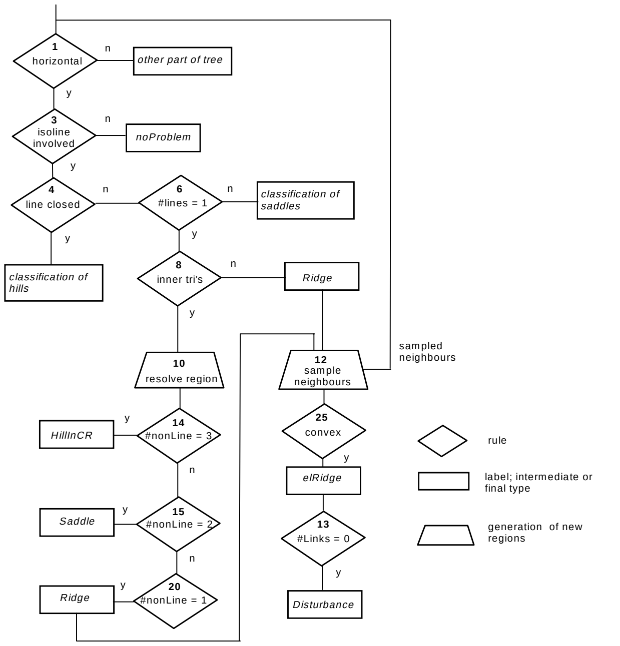

Fig. 2-7: Rules for the classification of ridges.

The rules are objects for themselves, which are structured hierarchically in a tree. The communication between different rules is performed with the usage of messages. Again, this concept allows effortless alteration: rules can be abandoned or new rules for new regions can be appended. Fig 2-7 shows a part of the actual tree which is responsible for the classification of ridges.

2.4 Calculation

At the classified problem region it is now possible to establish this topographic feature. That can be done by alteration of the triangulation or by calculation of additional points and lines. In our method local, second degree polynomial interpolation is used to calculate the x-, y- and z-coordinates of the additional points. Fig 2-8 shows the result of the example above. The calculated line has already been inserted in the triangulation.Due to the object-orientated approach, the algorithms of calculation can be exchanged without affecting the classification.

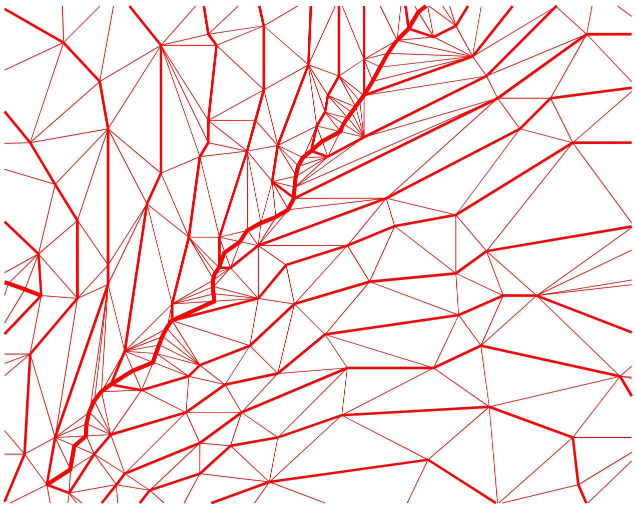

Fig. 2-8: A formline calculated for the whole ridge.

3 PRACTICAL EXAMPLES

3.1 The program

At our Institute a 3D-TIN is currently in development. As a first spin-off, the triangulation has been used to realize the presented concept. The program performs as a preprocessing module for SCOP. It can be used to calculate point heights in a regular grid by linear interpolation inside a triangle. Additionally, the topographic features can be extracted.

3.2 Profile data, example TULLN

Across the river Danube, near Tulln (Lower Austria), depth-profiles have been measured. The mean point distance within a profile is ca. 2.5m and the distance between two profiles is about 100m. The points have been triangulated and the heights in a regular grid have been calculated.

This data set does not include contourlines, but it is an excellent example for an inhomogeneous data distribution. Probably not many DTM-programs can produce a correct surface from this data.

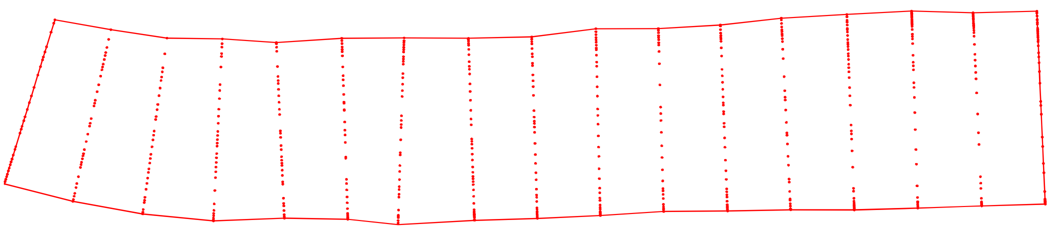

Fig. 3-1: The input data of example TULLN.

The quality of the derived contourlines has been tested by comparison with the manually derived contourlines. This test did not reveal any major differences. In this example no topographic features have been extracted, but it is imaginable to introduce hydrodynamic knowledge about the river-bed. In this way, e.g. the main stream-line could be calculated and used as additional input.

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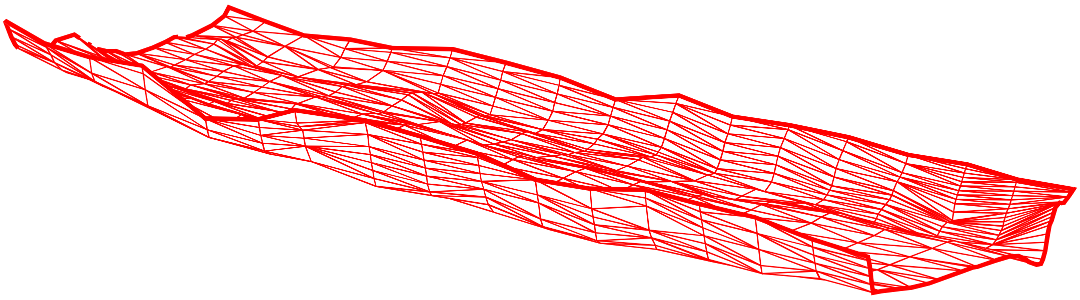

Fig. 3-2: The triangulated surface (heights magnified ten times).

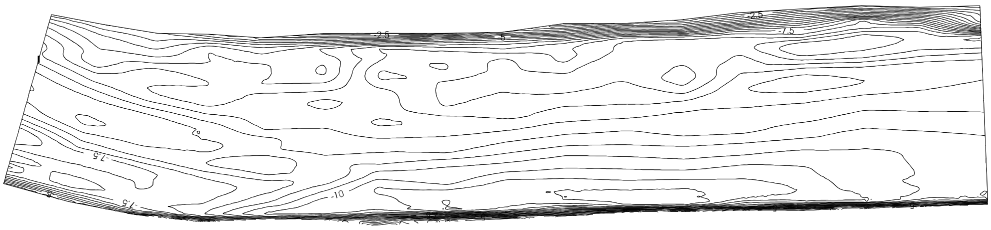

Fig. 3-3: The derived contourlines.

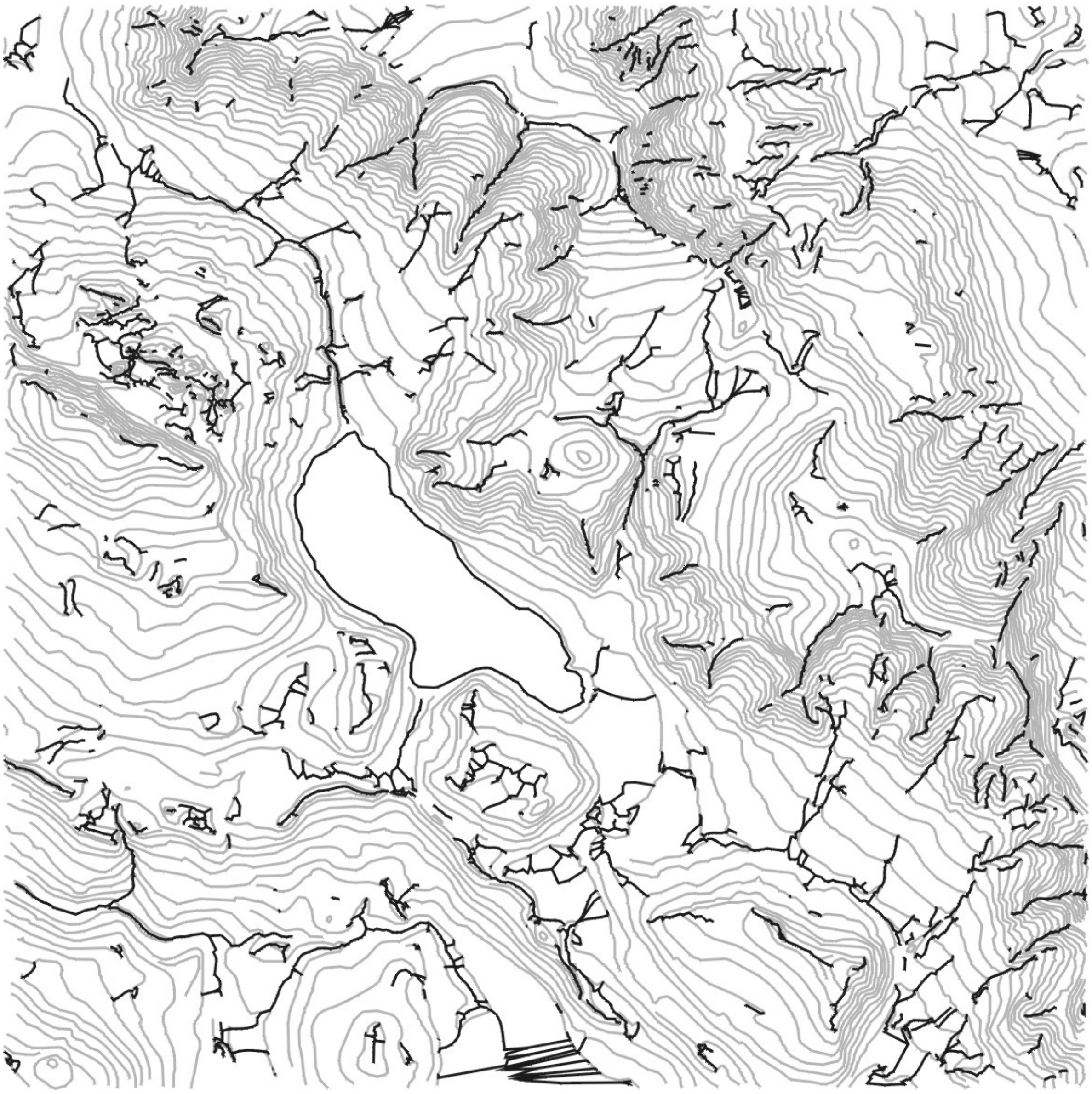

Fig. 3-4: Original contourlines (gray) of example ALBIS, together with derived lines and spot-heights.

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3.3 Contourline data, example ALBIS

At the Swiss Federal Office of Topography contourlines in the scale 1:25 000 has been digitized. The presented example is a set with 18.449 points. The data has been triangulated and the topographic features have been extracted. Fig. 3-4 shows the original lines (gray lines) overlaid with the extracted lines and spots.

Using the triangulation, the heights of a grid (50 x 50m) have been calculated. Together with the original lines and the extracted lines (as formlines) a DTM has been created with SCOP. Fig. 3-5 shows the original lines in gray and the derived contourlines overlaid in black. For serious judgement of the result, intermediate contourlines have been drawn, to show the shape of the surface between the original lines. Major differences only occur in flat areas, but in these areas contourlines are always a weak description of the surface (small changes in height result in big changes of the ground coordinates).

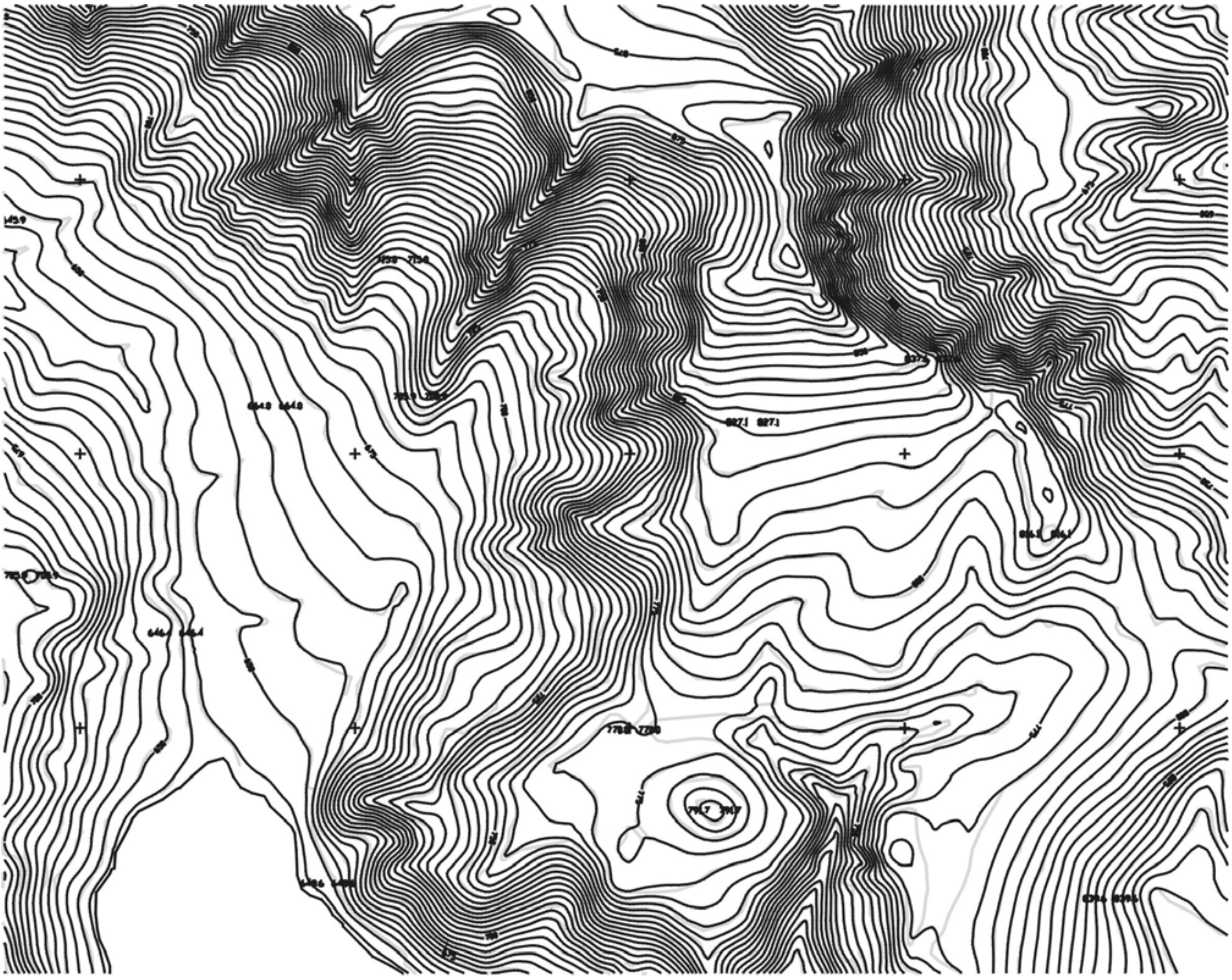

Fig. 3-5: Derived contourlines (black, with intermediate lines) with original contourlines (gray)

The main problem of this data set is not the generation of a DTM. The task is, to calculate a DTM which contains as much topographic details as possible and which preserves the characteristics of the terrain. For the purpose of comparison, a DTM has been created using only the original contourline data. The next images (Fig. 3-6 to Fig. 3-8) show details of the result without extracted features (left side) in comparison with the corresponding area of the DTM containing the extracted features (on the right side).

Each example shows a part of the whole data set, where interesting topographic details are included. The results without extracted features show a significant loss of these details, whereas the improved DTM preserves the important characteristics.

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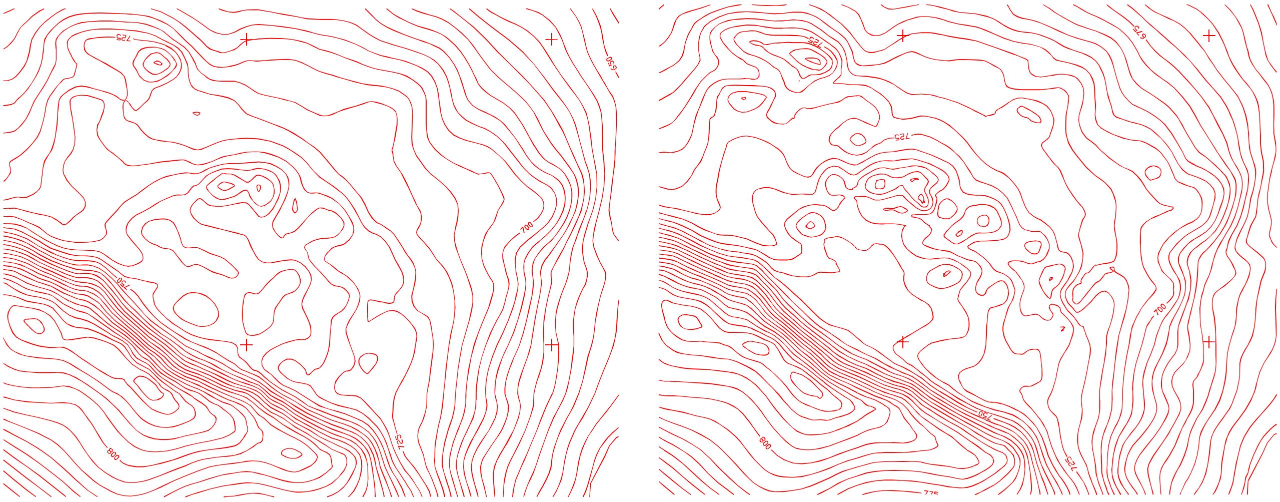

Fig. 3-6: Left: derived contourlines from DTM without additional input. Right: DTM with additional input

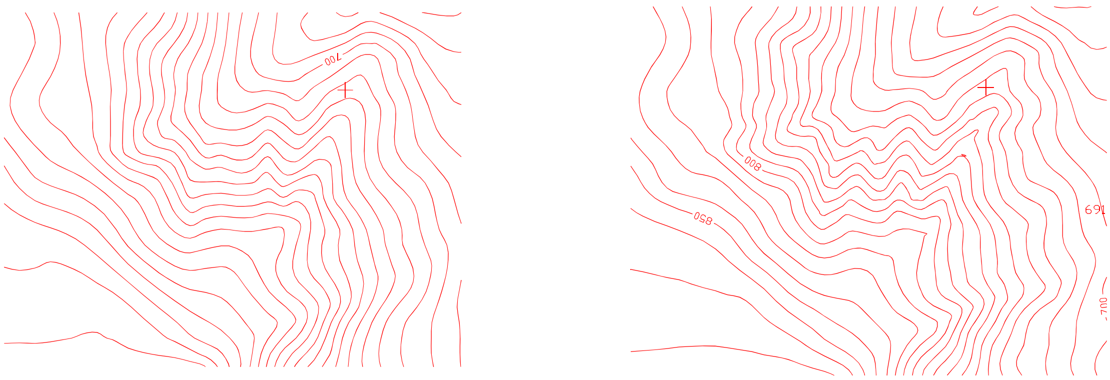

Fig. 3-7: Left: derived contourlines from DTM without additional input. Right: DTM with additional input

Fig. 3-8: Left: derived contourlines from DTM without additional input. Right: DTM with additional input

4 DISCUSSION AND OUTLOOK

The presented method is a very thorough and general approach to extract feature lines from contour data. Experience shows that it is not sufficient to apply only one method - some of them are presented in chapter 1 -, but it is necessary to analyze the current situation and choose an appropriate method of calculation. For this purpose it has been tried to include the knowledge of a topographic expert for the derivation of the main topographic characteristics.

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The whole concept is flexible and extendible. By introducing new rules and new types of problem regions, the method can be used for other kinds of data than contourlines. E.g. for river-beds hydrodynamic knowledge about the surface could be included.

The examples show, that it is possible to increase the quality of the generated DTM. Nevertheless, there is enough room for improvements:

- Ridges: at ridge elements it may be necessary to calculate the vertex of the ridge as the point of maximum curvature on the contourline.
- Connectivity of ridges: calculate longer lines, even if there is a line between, without a clear sign of a ridge.
- Significance of extracted lines: with further rules it should be possible, to distinguish between significant lines (or side-branches of lines) and non-significant ones. The task is, to avoid results as can be seen at the bottom of Fig. 3-4.
- Lines: to improve the quality of the calculated lines, it will be necessary to smooth the lines (Fig. 2-8 immediately reveals the necessity for smoothing). It is planned, to utilize the three-dimensional adjustment of line nets, using cubic, parametric polynomials, which has been presented in [Halmer96]. This method allows the adjustment of all three coordinates, independently of the coordinate system.
- Linetype: Presently, the calculated lines are inserted as formlines. For some ridges it would be better to introduce a breakline. With one additional rule it could be distinguished between sharp ridges (breakline) and smooth ridges (formline).
- Calculation: other forms of calculation than 2nd degree polynomials may be preferable. But all methods have to be local ones.
- Inclusion of 2D-lines, such as rivers, which are nothing more than ground-projections of breaklines or formlines.

5 ACKNOWLEDGEMENTS

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