COMPARISON OF TWO METHODS FOR DERIVING SKELETON LINES OF TERRAIN

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ABSTRACT:

Skeleton lines of terrain, i.e. ridge and valley lines are essential features on topographic maps. A skeleton line is the one with minimum slope among the slope lines. Slope lines are the lines of the steepest slope. Skeleton lines are used for a wide range of aims, e.g. emphasizing land forms, generation of high fidelity digital terrain models, terrain generalization, determining characteristic points of contours, etc. There are several methods for derivation of skeleton lines from contours and digital elevation models (DEMs). The primary objective of this study is to compare the results obtained by two different methods. Firstly, the skeleton lines are derived with respect to the algorithm developed by Aumann et al. (1991) using the contours generated from the height points of the DEM in addition to the characteristic points of the terrain. After that, the algorithm developed by Chang et al. (1998) for derivation of the skeleton lines from only the height points of the DEM is used. The results are compared with the skeleton lines of the terrain drawn by the operator in the stereo models of the area. For comparison, some cartographic and geomorphologic properties of contours and skeleton lines (i.e. numbers, locations and lengths of skeleton lines, and relationships between the contours and the skeleton lines) are used as the measurements. As a result, the skeleton lines derived from contours are more satisfactory than that are derived from DEM.

1. INTRODUCTION

Contours are the most important tools for representing relief forms on topographic maps with their geometries, i.e. locations and heights. They are defined as the intersections between the terrain surface and the leveling surfaces. A leveling surface contains the points of which heights are the same.

Skeleton lines of terrain, i.e. ridge and valley lines could be defined as the common paths of the steepest slope lines. In other words, they are specific steepest slope lines. A steepest slope line means the path traced along the steepest slope directions (Figure 1).

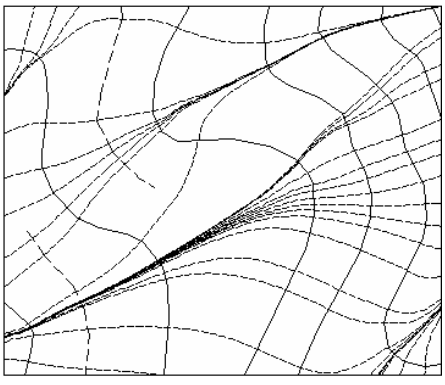

Figure 1. Contours (solid and long dashed lines) and the steepest slope lines (short dashed lines)

Aumann et al. (1991) describes the skeleton lines with the steepest slope lines as "… the skeleton line is the one with minimum slope among the steepest slope lines in the surrounding, thus also the longest one…" According to Finsterwalder (1986), it is mentioned that the valley lines are the rain water collectors, i.e. the lines connecting the lowest points of the valleys, and the ridge lines are the rain water separators, i.e. the lines connecting the highest points of the ridges, in cartography literatures. From the aspect of cartography, the coherent relationships between the contours and the skeleton lines could be expressed that they cross each other at right angle.

Skeleton lines are used for (1) emphasizing the land forms such as ridge, valley, and pass represented by contours, (2) giving some specific information to the users, e.g. mountain climbers use ridge lines as the paths with minimum slope leading to the tops of hills, (3) determining the borders between light and shadow in a hill-shading process, (4) deciding the political borders, (5) generation of high fidelity digital terrain models, (6) terrain generalization, (7) determining characteristic points of contours, etc. (Gökgöz, 1999).

Actually, skeleton lines (especially ridge lines) are usually not contained in topographic maps explicitly. Nevertheless, certain land forms such as ridges and valleys find their expression in contours and digital elevation models, and the skeleton lines can be derived.

2. DERIVATION OF SKELETON LINES FROM CONTOURS USING STEEPEST SLOPE VECTORS

In the first section, skeleton lines are defined as the common paths of the steepest slope lines. According to this definition, it is possible to trace enough number of steepest slope lines all over the area, and their common paths are determined as the skeleton lines, but a lot of time is required for this process. However, regions of the skeleton lines are already most probably known, i.e. there are their clues. Therefore, there is no need to trace too many steepest slope lines all over the area in fact. Skeleton lines, each of them is also a steepest slope line, could be traced directly. In the following, a method developed by Aumann et al. (1991) is described.

Firstly, it is necessary to obtain an optimum triangulated irregular network (TIN) of contours. Since the contours in form of 'polyline' are the primary data only (Figure 2), it must be taken care of intersections between contours and triangle edges. Such an optimum TIN could be obtained by constrained Delaunay triangulation. However, it is hardly to gain a satisfactory result in this case. Horizontal triangles of which vertices have same height may occur in the TIN. They lead to an incorrect description of terrain surface from the aspect of modeling. On the other hand, they are the important clues, i.e. they mark the regions of skeleton lines, because they occur where the land forms chance considerably. The areas of horizontal triangles are called critical areas. Skeleton lines are derived in the critical areas (Figure 3).

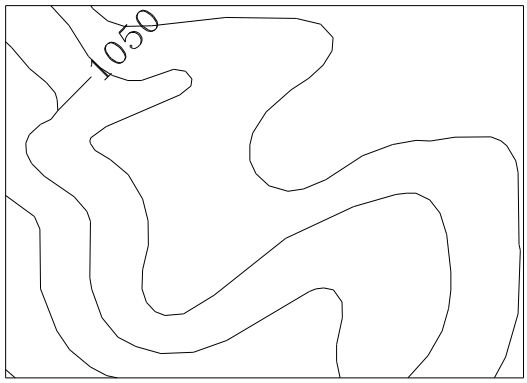

Figure 2. Contours

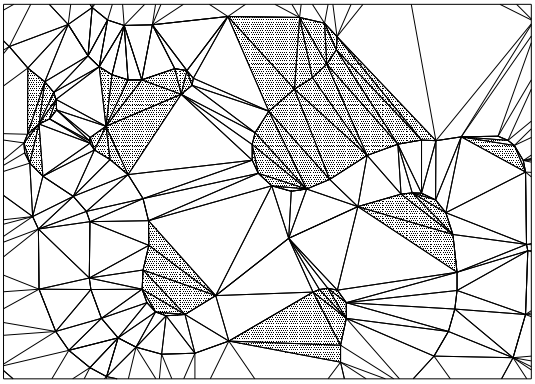

Figure 3. Critical areas of horizontal triangles in TIN

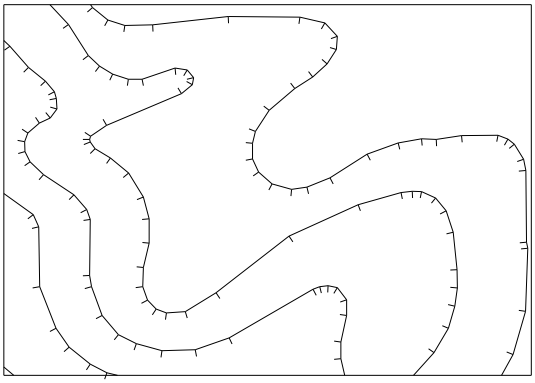

Figure 4. Steepest slope vectors at contour points

Types of the skeleton lines to be derived are determined in accordance with the steepest slope vectors at contour points (Figure 4). A steepest slope vector at a contour point is assumed as the bisector unit vector. It means the bisector between two consecutive contour segments at the contour point.

It is formerly decided that the bisectors are determined whether lower or higher side of the contours. All bisectors are computed at the same side of the contours. For instance, if all the bisectors are computed at lower sides and they indicate each other in a critical area, the skeleton line to be derived in that area is a valley line.

Skeleton lines are derived by tracing process. It starts with selection of the beginning point of the skeleton line to be derived. A point on the highest contour in the critical area of horizontal triangles is selected as the beginning point, if the skeleton line to be derived is a valley line. Otherwise, i.e. if it is a ridge line, the lowest point in the critical area is selected as the beginning point. A beginning point is the one that yields the longest steepest slope line in the critical area. After that, beginning from this point, a series of vector are computed consecutively. These vectors are called skeleton line vectors. Length and direction of a skeleton line vector is one unit and steepest slope direction respectively. The value of one unit is calculated with the following formula.

$$SL = 0.1 \times MP \tag{1}$$

Here, *MP* is the arithmetic mean of all contour segments (Aumann, 1994). Direction of a skeleton line vector is computed with the followings:

- Directions of the steepest slope vectors at the vertices of the triangle containing the beginning point of the skeleton line vector
- *x* and *y* components of the steepest slope vector
- *x* and *y* components of the skeleton line vector direction by means of linear interpolation with the *x* and *y* components of the steepest slope vectors at the vertices of the triangle (Figure 5).

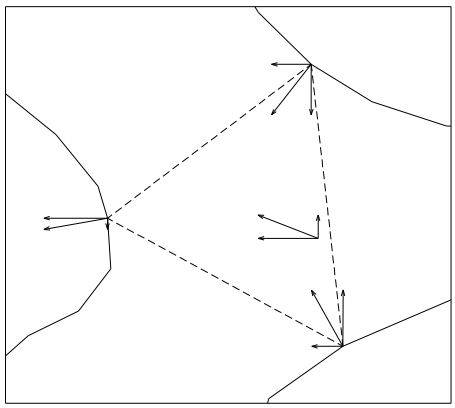

Figure 5. Components (*x*, *y*) of the steepest slope vectors

Tracing process for a skeleton line is finished when it is reached to end of the critical region (Figure 6). Finally, it is assigned heights to the skeleton line points by means of linear interpolation using the related contour elevations.

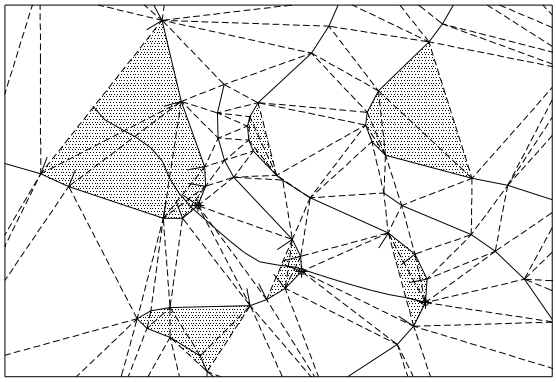

Figure 6. A skeleton line derived in a critical area

3. DERIVATION OF SKELETON LINES FROM DIGITAL ELEVATION MODELS USING THE PROFILE RECOGNITION AND POLYGON-BREAKING ALGORITHM

Chang et al. (1998) has proposed Profile Recognition and Polygon Breaking Algorithm (PPA) for derivation of skeleton lines from DEMs. The algorithm consists of five procedures as follows:

3.1 Target Recognition

The recognition is done with an algorithm that is termed the Profile Recognition. All the points that can be recognized as part of a ridge shape along a profile with limited length are taken as ridge targets (Figure 7).

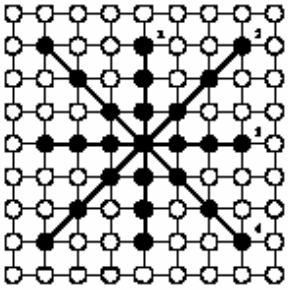

Figure 7. Four profiles with the lengths of seven points

The algorithm first takes the current processed point as the centre of the profile. If it can find at least one point lower than the central one on both sides of the profile, the central point is taken as a ridge target. Furthermore, the profile is switched from N-S, NE-SW- E-W to NW-SE to check whether the point is a target or not.

This is a relatively loose recognition process compared to traditional shape recognition because, even if a point is not a local high along any direction, it still is possible to accept it as a ridge target. For example, if a profile length equal to 7 points with elevations of 1, 2, 3, 4, 3, 2 and 1, then not only is the central point with elevation of 4 recognized, but so are its two closest neighbors. If, on the other hand, the user takes a profile length equal to 3, the profile recognition is reduced to a pure shape recognition. It is suggested that profile length is selected to be a length just long enough to recognize the possible ambiguous targets on the map.

3.2 Target Connection

Once target recognition has been accomplished, every two neighboring target points are connected into a segment. For this program, in a 9-point girdded cell, the central point has eight neighbors which are memorized as number 1 for the northern point through number 8 for the other points in a clockwise direction. Under this approach, many diagonal connections cross each other and make many new junction points which are not located on the gridded nodes. When such a situation occurs, the process automatically gets rid of the less important segments; for example, in a ridge search case, the segment with lower elevation is eliminated (Figure 8).

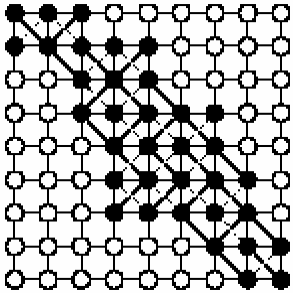

Figure 8. Target connection

3.3 Segment Check-Out

After the processes of target recognition and connection, it is guaranteed that all possible axes confirmed within the connected segment groups. In this process, the unfavored segments are cautiously eliminated one by one without breaking the continuity of the lines. Firstly a repeated procedure called Polygon Breaking is applied in order to check the closed polygon and eliminate the least important segment within each polygon until no closed polygon of any size remains (Figure 9).

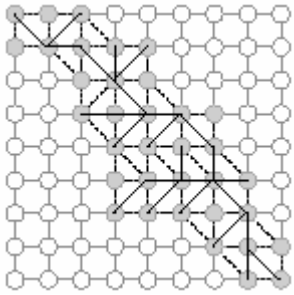

Figure 9. Polygon breaking

The relative importance of the segment is determined by the elevation; for instance, in the case of ridge depicting, the segment with lower elevation is less important than segments with higher elevation. After this process, the remaining lines become pure dendritic patterns all the axes are represented by continuous segment groups with many branches instead of a belt of closed polygons. The tracing tour starts from one end of the weakest segment which has not been checked previously. When the tracing tour comes back to either end of this segment, the

tracing stops. Because the possible polygons to include the segment may exist in both sides of it, the tracing process is executed in both clockwise and counter-clockwise directions. After polygon breaking, many short branches remain besides the axes. Therefore, at this stage called Branch Reduction, all the branches are reduced a length of half of the profile length (Figure 10). The actions taken for this process are: (1) all the end-points are located, (2) the connections of those end-points are eliminated, and (3) round = round + 1; if the round is less than the (profile length) / 2; step (1) is repeated.

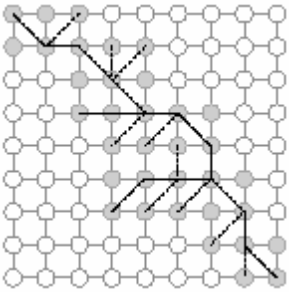

Figure 10. Branch reduction

3.4 Line Smoothing

This process simply takes the position weighting average of the target and its connected neighbors as its new position (Figure 11). The weight of each target is a value proportional to elevation for ridges, inversely proportional to elevation for valleys. The weight of each target is a value proportional to its elevation in the ridge case or inversely proportional to its elevation in the valley case. Because the new position is an average of the neighboring points and itself, the shifting distance is never more than a grid interval.

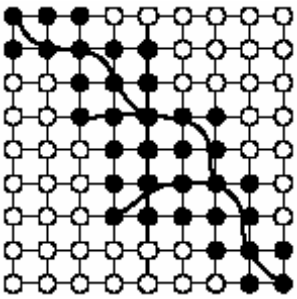

Figure 11. Line smoothing

3.5 The Valley Axes Case

When the target lines are the valley axes, the PPA program simply reverses the topography prior to the recognition procedures.

The program is straightforward to use because only the target type and the length of profile recognition need to be defined by the user. Once the data and these two parameters are given, the program can be left to run on its own.

4. EXPERIMENTAL TESTING

Experimental testing is realized for comparing the methods developed for deriving the skeleton lines from contours and DEMs. Firstly, skeleton lines are derived from contours (Figure 12), which are generated from the height points of the DEM (Figure 13) in addition to the characteristic points of the terrain, in accordance with the method developed by Aumann et al. (1991). The DEM covers an area of 650 m x 500 m in a map of Turkey at scale 1:5000 (Figure 12). The height points are 10 meters apart and the DEM consists of 51 rows and 66 columns. After that, the algorithm developed by Chang et al. (1998) for derivation of the skeleton lines from the height points of the DEM is applied. In this study, as the length of profile, it is not assigned any value. In other words, all points are assumed as the target points. It should also be noted that two methods uses the same data in fact, because the contours are also generated from the height points of the DEM.

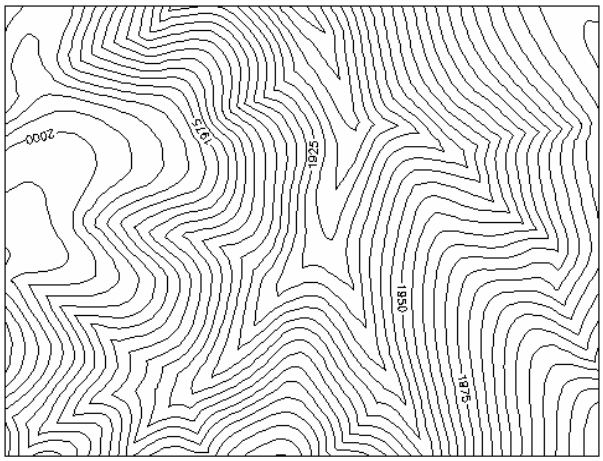

Figure 12. Contours generated from the height points of the DEM in addition to the characteristic points of the terrain

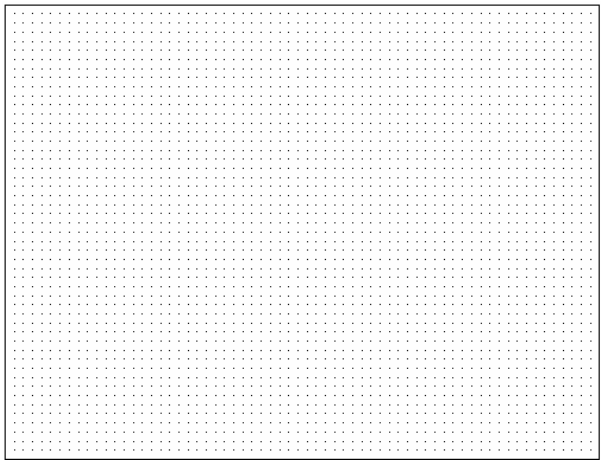

Figure 13. Height points of the DEM

Figure 14 shows the skeleton lines drawn by the operator in the stereo model. The results of the derivation process, i.e. derived skeleton lines in accordance with the methods developed by Aumann et al. (1991) and Chang et al. (1998) (right hand side), are represented in Figure 15 and 16 respectively.

The results of the derivation processes are compared with the valley lines of the terrain produced by the operator from the stereo models of the area, because the operator has drawn the valley lines only as it is usual. However, the methods are able to derive both valley and ridge lines.

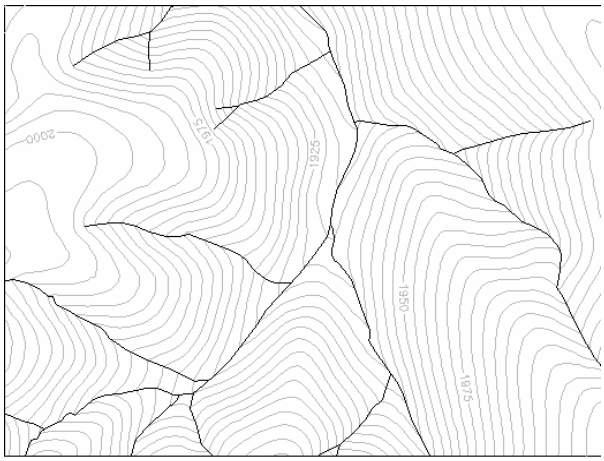

Figure 14. Valley lines drawn by the operator in the stereo model

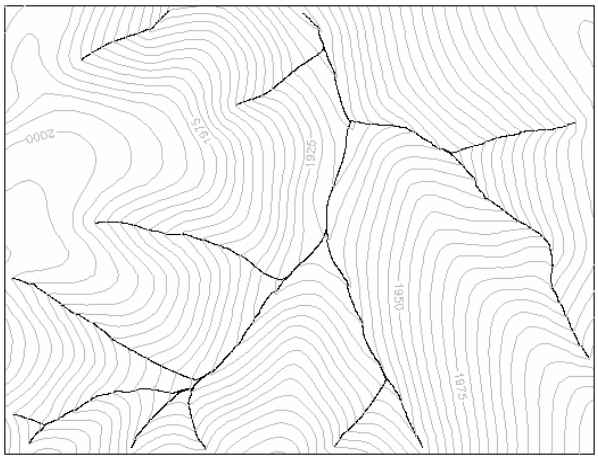

Figure 15. Valley lines derived from the contours

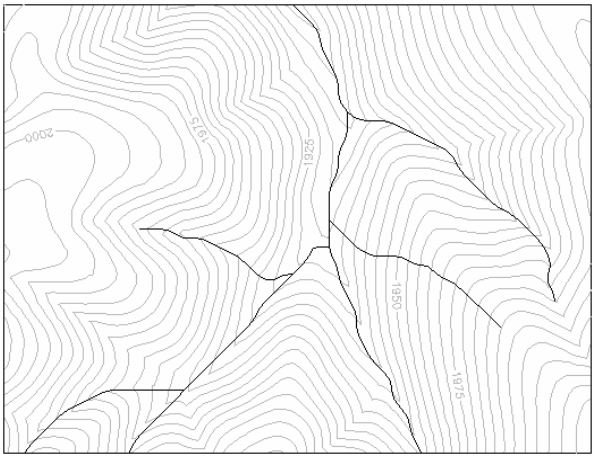

Figure 16. Valley lines derived from the DEM

For comparison, some measurements related to cartographic and geomorphologic properties of contours and skeleton lines (i.e. numbers, locations and lengths of skeleton lines, and coherent relationships between the contours and the skeleton lines) are used.

In comparison with the valley lines drawn by the operator, the valley lines derived from the DEM are quite different. All valley lines to be expected are not derived. However, an unexpected valley line appears. Lengths of some valley lines are shorter. The relationships between the contours and the valley lines are not good, i.e. the valley lines do not cross the contours at right angle. On the other hand, the valley lines derived from the contours are quite similar to that are drawn by the operator from the same aspects. Number of valley lines is almost same except three small branches. They appear in the same regions. Their lengths are almost equal. They are also satisfactory with respect to the relationships between them and the contours.

5. CONCLUSIONS

In this study, two methods developed for deriving skeleton lines of terrain from contours and DEMs are compared in accordance with the results obtained from the same data set. The results of the first method developed by Aumann et al. (1991) are more satisfactory than the second method developed by Chang et al. (1998) from several aspects such as numbers, lengths and locations of the skeleton lines and the relationships between the contours and the skeleton lines. However, it should be noted that this evaluation is not true for every case; because the second method has a parameter (i.e. length of profile) and thus different results can be obtained if different values are assigned to it.

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