AUTOMATIC EXTRACTION OF TERRAIN SKELETON LINES FROM DIGITAL ELEVATION MODELS

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ABSTRACT:

Terrain skeleton lines, among the most significant elements of topographical maps, are the valley lines that connect the deepest points of valleys, and the ridge lines that connect the highest points of ridges. In order to obtain correct and enough information about land forms from a topographical map, skeleton lines have to be considered and portrayed together with contours. Their extraction has a great importance in the different areas. They can be gathered from contours, digital elevation models (DEMs) or digital images automatically besides land surveying or photogrammetric stereomodels. In this study, a program called 'RidgeValleyAxisPicker' written for extracting ridge and valley lines from DEMs is used. It is based on the algorithm of Profile Recognition and Polygon Breaking (PPA) developed by Chang, et al. (1998). 'RidgeValleyAxisPicker' differs with PPA from two aspects: (1) profiles are not used in target recognition step and thus all height points are considered as targets, (2) branch reduction process is performed iteratively. All of the DEM points in 10 meter grid distance that are used in the case study are automatically collected from a stereomodel for a map at the scale 1: 5000. At the end of the study, the results are compared with the original topographic maps at the same scale from several aspects. In conclusion, although the method described in this paper for automatic extraction of terrain skeleton lines from DEMs can be working with huge amount of data quite rapidly, there are some cartographic problems on the extracted lines.

1. INTRODUCTION

Terrain skeleton lines, among the most significant elements of topographical maps, are the valley lines that connect the deepest points of valleys, and the ridge lines that connect the highest points of ridges. Terrain skeleton lines, i.e. valley and ridge lines are very important and inseparable part of topographical maps. In order to obtain correct and enough information about land forms from a topographical map, skeleton lines have to be considered and portrayed together with contours. Some of the land form structures (e.g. hills, pikes, ridges, valleys etc.) become more readable by adding terrain skeleton lines in a topographical map which can only be represented with contours.

Besides skeleton lines are obtained from land surveying or photogrammetric methods, they can be extracted from elevation data automatically. While producing skeleton lines for a topographical map in any of the known ways (geodetic surveys, photogrammetric surveys and automatic extraction cartographically) care must always be taken, that skeleton lines must reflect the characteristics of terrain and the contour lines bend precisely on them (Yoeli, 1984).

Extraction of terrain skeleton lines has a great importance in the different areas where topographical maps are used such as hydrological applications, military applications, generalization studies, determination of political borders, discovery of the steepest slope path for hiking and mountain climbing, relief representation and determination of soil or rock type of a land. Drainage networks, i.e. valley lines, can also form a vital element in geographic information systems for land systems analysis and resource management in hydrology (Mark, 1984). Therefore, many scientists have studied on extracting drainage networks from elevation data in order to determine water resources and solve hydrological problems (Seemuller, 1988; Meisels et al., 1995). The location and density of drainage gullies are important in determining the accessibility of terrain for military applications. Moreover, the geometric structure of the drainage network gives a clue for soil or rock type of a land (Seemuller, 1988). Geomorphological structures are essential for the computer-assisted terrain generalization studies and information about them (i.e. valley and ridge lines) can be extracted analytically from the source digital terrain model (Weibel, 1992).

Topographical maps which indicate continuous elevations by contours and structural lines are also very important for mountaineers. They usually prefer to walk along the ridge side of the mountains to protect themselves from the high avalanche dangers while climbing to summit. In addition, some of the terrain skeleton lines can be political border for different countries. For example, neighbouring countries usually accept that rivers can be as a political border.

Extracting information from many types of two-dimensional data is very important for a lot of interpreters. They generally have to develop a line-drawing process to identify the features. However, in most situations, such automatic processes have not been widely accepted and the task of line drawing still is done manually. According to Chang et al. (1998) the main reason for this is that the human interpreter can consider data trends within a wide spatial range more effectively than most automatic algorithms suggested to date.

In this study, some of the terrain forms depending on elevation data for deriving topographical map information have been investigated. Then, an automatic line extraction algorithm coded firstly in FORTRAN by Chang et al. (1988) with the name PPA program have used for extracting the terrain skeleton lines by expending the effect of the branch reduction step. The algorithm is prepared to demonstrate the feasibility of digital elevation models and computer programming techniques in automation for extracting ridge and valley line systems of topographical relief. Finally, some of automatic valley line extraction results have compared with a topographical map which is drawn by a human operator from photogrammetric stereomodel.

2. FORMS OF DTM AND DEM DATA SETS

The terrain surface model is most commonly described either as a DEM, or as a digital terrain model (DTM) in literature. The form of DEM is defined as a regular two dimensional array of heights sampled above some datum that describes a surface. The other description of DEM is regular gridded matrix representation of the continuous variation of relief over space. On the other hand, the form of DTM contains elevation information with the addition of some explicit coding of the surface characteristics such as breaks in slope, drainage divides etc. Examples of DTMs include the triangulated irregular network (TIN), digital contours with form lines, and the richline model of Douglas that uses ridge, valley and form lines to define an elevation model (Wood, 1996).

The points of DTM or DEM data set can systematically be collected using four different methods according to geometric disposition of the heights points on terrain surface (Figure 1).

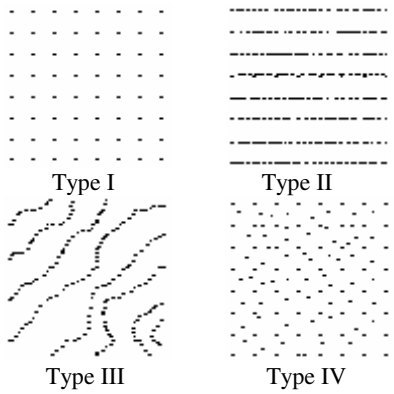

Figure 1. Height points data sets (Yoeli, 1984)

Type I: Regular distances height points are ordered with squared grid as a DEM,
Type II: Irregular distances height points are distributed along the equidistant parallel profiles,
Type III: Horizontal arrays of equal height points,
Type IV: Randomly distributed height points.

The height points in Type I can be collected manually or automatically from photogrammetric stereo models. The height points in Type II can be collected manually where the slope is changed along the equidistant parallel profiles from photogrammetric stereo models. The height points in Type III can be collected manually along the equal horizontal heights from photogrammetric stereo models or along the contours by digitizing from hardcopy topographical maps. The height points in Type IV can be collected where the slope is changed from photogrammetric stereo models or land surveying.

Adequate logics for the analytical search of skeleton lines of the relief can, in principle, be formulated for all four types of DTMs and there is no need to transform the Types II, III, IV, if initially so given, into a DTM of Type I by interpolating a secondary DTM superimposed on the original points (Yoeli, 1984). For example, Aumann et al. (1991) and Tang (1992) are derived skeleton lines from digitized contours to generate high quality DTMs. Their data set is like Type III which is acquired from the contour maps. On the other hand, the simple matrix form of elevation values as Type I is the most efficient data to be able to processing with programming language. Due to its easy integration within a geographic information system (GIS) environment, the use of gridded matrix representation of the continuous variation of relief, which means DEM according to Wood (1996), has become widespread (Figure 1, Type I). For the availability of gridded matrix representation, most scientists have used DEM form in order to extract the terrain skeleton lines in their studies (Yoeli, 1984; Wood, 1996; Chang, et al., 1998).

3. AUTOMATIC EXTRACTION OF TERRAIN SKELETON LINES FROM DEMs USING 'RIDGEVALLEYAXISPICKER' PROGRAM

The basis of the PPA algorithm is written by Chang in Visual Basic in three steps; target recognition, polygon breaking and branch reduction. After the three steps, the program produce smoothed or non-smoothed skeleton line segment coordinates in a text file. Figure 2 shows the steps of the program.

The main difference of the 'RidgeValleyAxisPicker' program from the original PPA program has been appeared on profile recognition in target recognition step. There is no profile in 'RidgeValleyAxisPicker' program and all height points are target. Another difference is in branch reduction step. Because half of the profile length is unknown, there is no rule how many segments have been deleted for any branches in the step.

In the study, the effect of branch reduction step of the 'RidgeValleyAxisPicker' program is modified by deleting branches iteratively to obtain more suitable skeleton lines to the land form.

3.1 Target Recognition

Target recognition procedure is carried out in 'ConnectAll' and 'SortSegment' subroutines in the 'RidgeValleyAxisPicker' program. Both of the subroutines start automatically. Firstly, 'ConnectAll' ties all of the DEM points which have elevation values, that means points are upper than sea level, with line segments. Secondly, 'SortSegment' sorts all of the segments according to their weights which are calculated by total elevation value of two points of a segment. Briefly, all of the DEM points, upper than sea level, are selected as target and tied with line segments, before the segments are sorted in target recognition step (Figure 3).

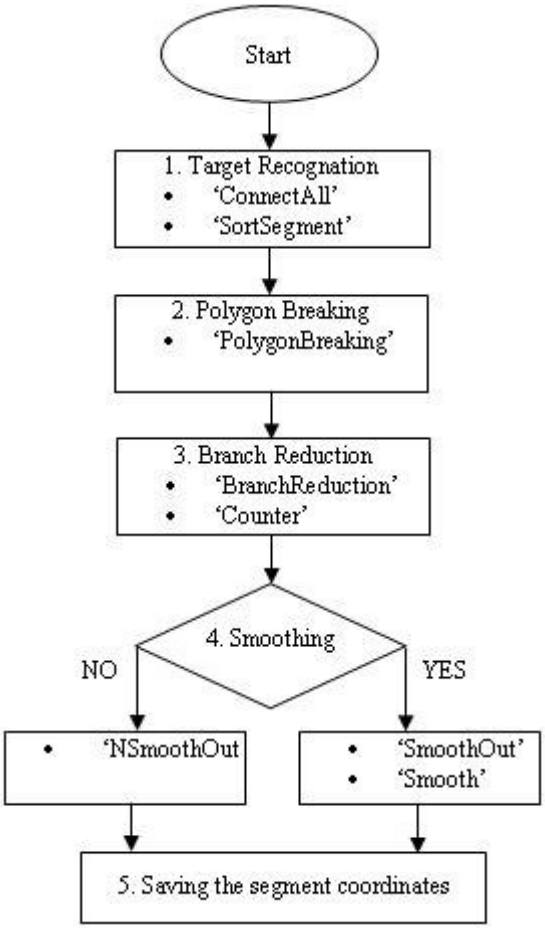

Figure 2. The flowchart of 'RidgeValleyAxisPicker' program

3.2 Polygon Breaking

Terrain skeleton lines are like a network structure and never closed polygon according to Chang et al. (1998). On the other hand, after the 'ConnectAll' subroutine, line segments are closed structure in Figure 3. In order to solve closed polygon and obtain a network structure, it is applied the 'PolygonBreaking' subroutine to the sorted segments after the target recognition step automatically. The polygon breaking is a repeated procedure to check the closed polygon and eliminate the least important segment within each polygon until no closed polygon of any size remains (Figure 4). The importance of the segments is determined by their weight related to elevation value relatively. For example, for ridge depiction, the segment with lower elevation is less important than segments with higher elevation.

3.3 Branch Reduction

In order to extract more accurate skeleton lines, the effect of the branch reduction step is modified in this study compared to previous study of Chang et al. (1998). For this purpose, short segments that do not reflect to terrain characteristic are deleted iteratively in order to obtain proper branches that are same as the terrain skeleton lines for topographical map (Figure 5).

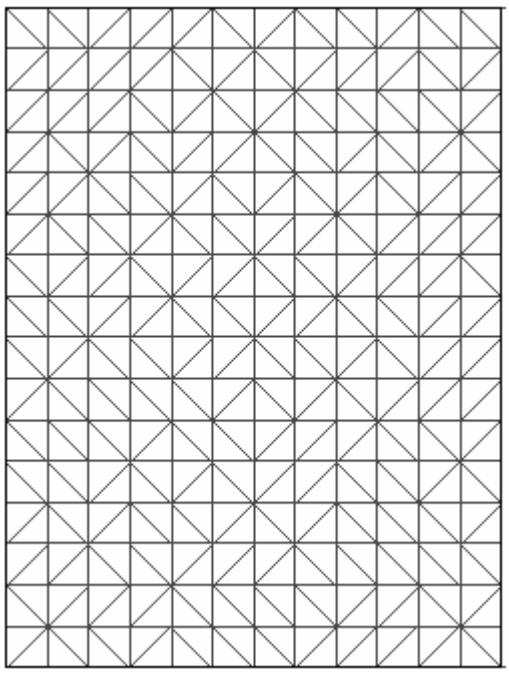

Figure 3*. Connected points and sorted segments at scale 1: 5000

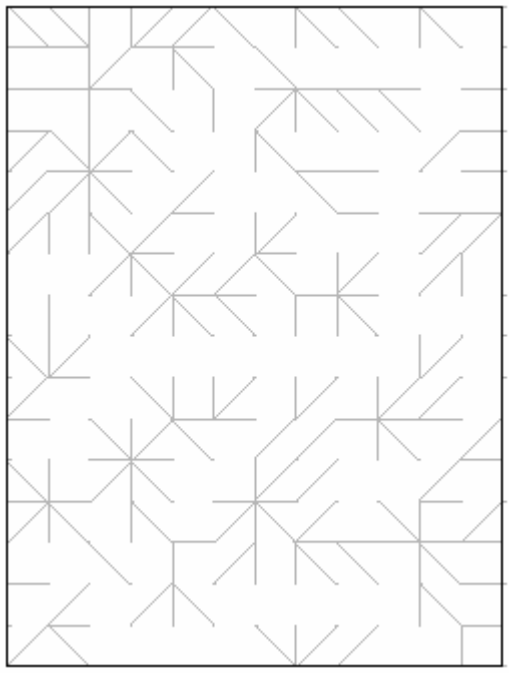

Figure 4. Solved closed polygons and new segments at scale 1: 5000

Short branches to be deleted are determined in accordance with the threshold value depending on the grid distance and map scale. In order to obtain the proper branches, 'BranchReduction' and 'Counter' subroutines are used in 'RidgeValleyAxisPicker' program. 'Counter' subroutine calculates branch lengths from end points to the node points.

* 20m. grid distance used because of the easy showing segments characteristics

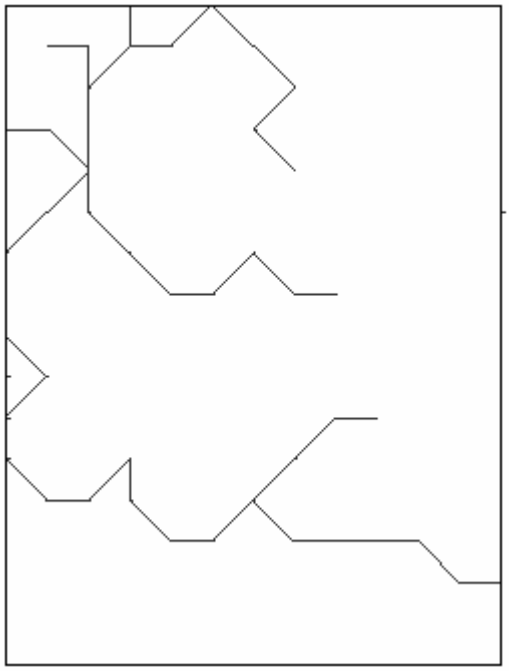

Figure 5. Reduced branches at scale 1: 5000

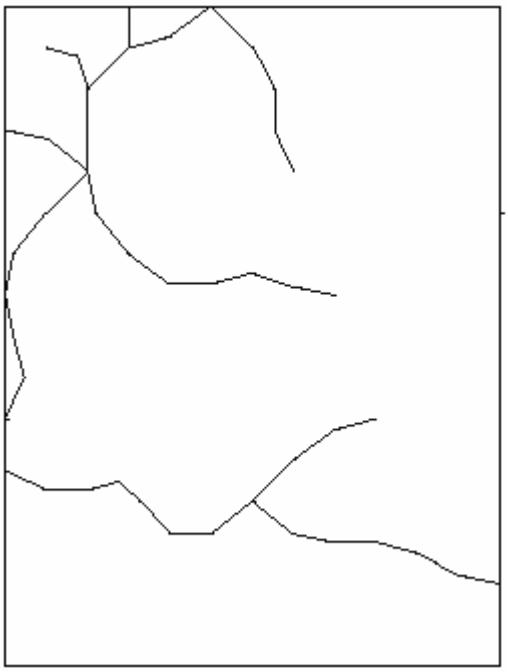

Figure 6. Smoothed branches at scale 1: 5000

In the first step, after the processing of 'Counter' subroutine calculated branches lengths are sent to 'BranchReduction' subroutine. The branches of one segment are deleted. In the second step, 'Counter' subroutine are repeated and it calculates new lengths of branches, then 'BranchReduction' subroutine deletes branches if they are one or two segment in length. This process is repeated until any branches that are shorter than the threshold value do not remain.

After the process, segment coordinates can be saved in a text file as the points of terrain skeleton lines. On the other hand, all the following segments groups are not smooth enough for map representation. They indicate sharp turnings that rarely occurred in land forms. To solve the problem, line smoothing step is added to 'RidgeValleyAxisPicker' program.

3.4 Line Smoothing

The process can result in targets moving to positions that better match the line trend. Because the new position is an average of the neighboring points and itself, the shifting distance is never more than a grid interval. In this way, the process does not violate the information provided by the gridded data set (Chang, et al., 1998). Figure 6 shows the results of line smoothing of lines in Figure 5.

4. CASE STUDY

In case study, 'RidgeValleyAxisPicker' has been used to extract terrain skeleton lines. All of the DEM points are automatically collected from a stereomodel in 10 meter grid distance for the map at the scale 1: 5000 (Figure 7). The points are saved in a text file with their row and column numbers (i.e. grid coordinates) and their elevations. Grid coordinates are obtained from land coordinates by means of a transformation.

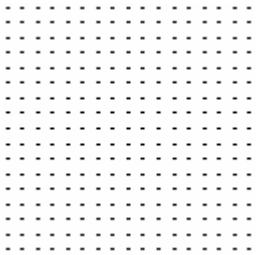

Figure 7. 10m gridded DEM points sample at the scale 1: 5 000

Figure 8 shows the extracted and the smoothed ridge and valley line results of the 'RidgeValleyAxisPicker' program for the whole study area.

Although the method for automatic extraction of terrain skeleton lines can be working with a huge amount of data quite rapidly, there are some cartographic problems on the extracted lines. The results of 'RidgeValleyAxisPicker' program are evaluated with the harmony of extracted skeleton lines and contours. Figure 9 shows the result of digitized valley lines for the same topographical map. The valley lines are only demonstrated in these examples, because ridge lines are not usually digitized for topographical maps.

The numbers of the digitized valley lines and the program results are different because of the effect of branch reduction step. Some short valley lines are reduced and not demonstrated in Figure 8 as a result of branch reduction step. However, there are some unexpected valley lines on hill sides and no valley line in valley region.

Moreover, the extracted and smoothed valley lines do not bend precisely on contours. Figure 10 shows this condition clearly. Many of the extracted valley lines are not entirely appropriate to contours.

Finally, some extracted valley lines are shorter than digitized lines.

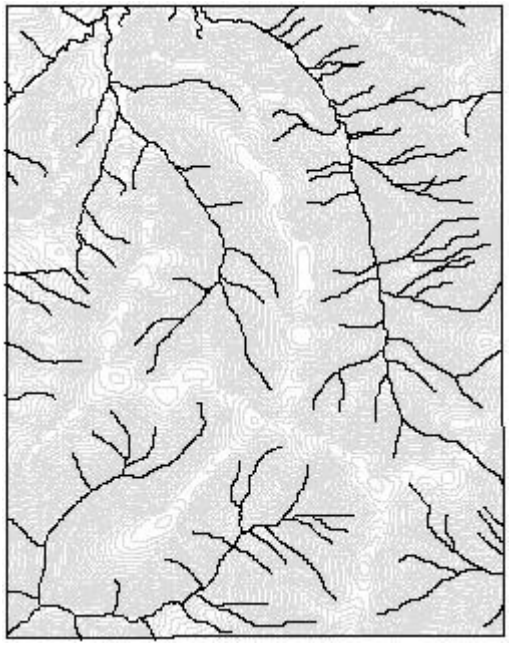

Figure 8. Extracted and smoothed ridge and valley lines

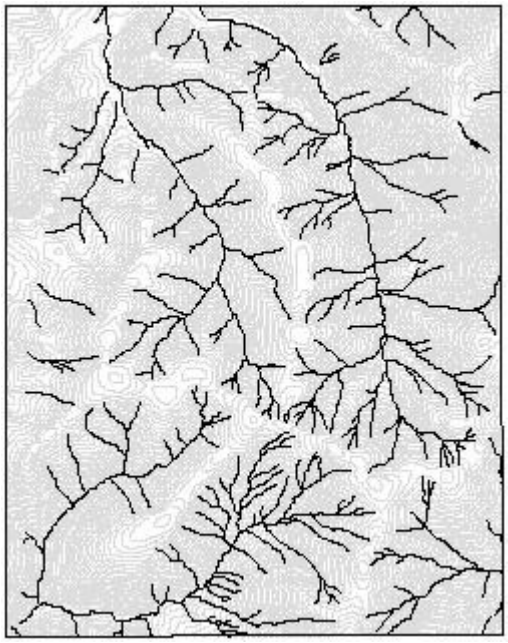

Figure 9. Digitized valley lines

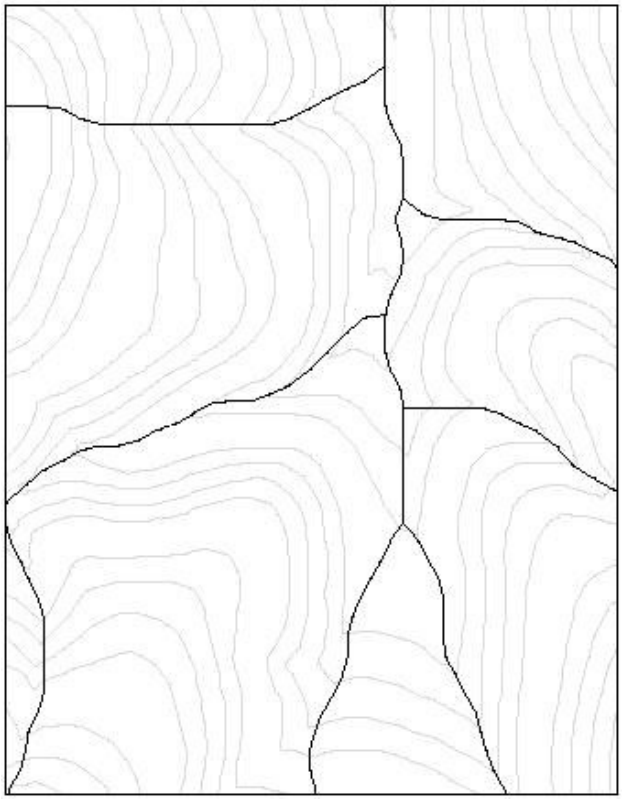

Figure 10. Some extracted valley lines at scale 1: 5000

5. CONCLUSION

Extracted valley lines obtained with the program give us general information about the characteristic of terrain. The results can be used in hydrological applications and generalization studies. If threshold value and grid distance of DEM points are expanded, the valley lines can be used in middle and small scale maps. On the other hand, it seems that 'RidgeValleyAxisPicker' program is not appropriate to large scale topographical maps to extract skeleton line properly in spite of the quite rapidly process time. In conclusion, the algorithm needs to be developed by adding some geomorphological and cartographic principals to the program in order to obtain more accurate results at large scale maps.

REFERENCES

Aumann, G., Ebner, H., Tang, L., 1991. Automatic derivation of skeleton lines from digitized contours. ISPRS J. Photogrammetry and Remote Sensing, 46, pp. 259-268.

Chang, Y.C., Hsu, S.K., Song, G.S., 1998. Automatic extraction of ridge and valley axes using the profile recognition and polygon breaking algorithm. Computers & Geosciences, 24(1), pp. 83-93.

Mark, D.M., 1984. Automated detection of drainage networks from digital elevation models. Cartographica, 21, pp. 168-178.

Meisels, A., Raizman, S., Karnieli, A., 1995. Skeletonizing a DEM into a drainage network. Computers & Geosciences, 21(1), pp. 187-196.

Seemuller, W.W., 1989. The extraction of ordered vector drainage networks from elevation data. Computer Vision, Graphics and Image Processing, 47, pp. 45-58.

Tang, L., 1992. Automatic extraction of specific geomorphological elements from contours. Geo-Informations-Systeme, 5(3), pp. 20-27.

Wood, J., 1996. The geomorphological characterisation of digital elevation models. Dessertation, Department of Geography, University of Leicester, Leicester, UK.

Weibel, R., 1992. Models and experiments for adaptive computer-assisted terrain generalization. Cartography and Geographic Information Systems, 19(3), pp. 133-153.

Yoeli, P., 1984. Computer-assisted determination of the valley and ridge lines of digital terrain models. International Yearbook of Cartography. 24, pp. 197-206.

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