A DIGITAL IMAGE PROCESSING APPROACH TO CREATING DTMs FROM DIGITIZED CONTOURS

Morakot Pilouk
Research Officer, Royal Forest Department
National Forest Land Management Division
Phaholyothin Road, Chatuchak, Bangkok, Thailand

Klaus Tempfli
Associate Professor, Department of Geoinformatics
International Institute for Aerospace Survey and Earth Sciences (ITC)
P.O.Box 6, 7500 AA Enschède, The Netherlands

ABSTRACT

DTMs derived from digitized contour lines often suffer from limited quality. The quality can be enhanced by automatically extracting skeleton lines from the contours prior to triangulation and subsequent interpolation. A hybrid set of raster and vector techniques is used for skeleton extraction and TIN generation, including distance transformation, Dirichlet tessellation, thinning, gap filling, line following, interpolation, and establishing topology. The program package has been developed for IBM-compatible PCs and is based on ILWIS.

KEY WORDS: DTM, contour lines, skeleton, triangulation, distance transform, tessellation, interpolation, cost-effectiveness

INTRODUCTION

"Recycling" graphic contour lines remains popular for spatial analysis in a digital environment. The availability of topographic maps in many countries, combined with the low decay rate of terrain relief data at medium and small scales, rapidly decreasing costs of scanners, PCs with digitizing tablets and 'GIS software', favour A/D-converted contours as data source for digital terrain relief models (DTM). Compared with a direct ground survey or photogrammetric techniques, data collection is cheap and does not require special expertise.

Defects of Contours

However, a digital surface description that is rooted in (graphic) contours suffers from limited quality. Non-photogram-metrists are often surprised that such a DTM is of lower fidelity than expected, especially when using it in erosion studies and the like, where slope and break of slope are important properties. One reason for the limited quality is the unfavourable sampling pattern inherent to digital contours. The high sampling density within lines and no information on terrain relief between these lines implies sub-optimal fidelity of digital surface representation. Another reason is the wealth of errors in contours depicted in maps. In addition to the errors of photogrammetric operations (aerial triangulation, orientation, measuring and plotting) and deformations of materials used, there are even more disturbing errors introduced by cartographic operations. Examples include displacement of contours when generalizing, "slope allowance" of contours in hilly and mountainous terrains, replacement of contour lines by symbols in areas with cuts and embankments, cliffs, etc. Added to these are the errors of the A/D conversion [12].

Figure 1 shows a typical example of a surface obtained from digitized contours and straightforward linear interpolation between the nearest contour points. Cut off hill tops, filled troughs, and terraces along ridge and drainage lines are disturbing artifacts for many DTM applications. These disturbing effects of common interpolation methods, when using bulk data such as digital contours, can be reduced/diminished by
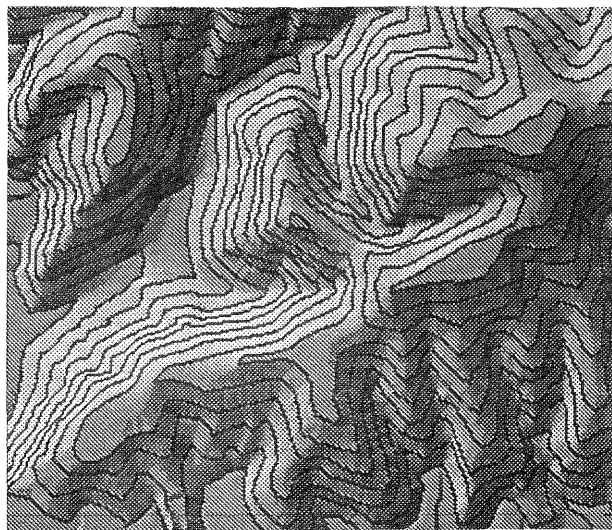

Fig. 1: Contours and derived DTM (enlarged portion of fig. A1)

supplying additional information about terrain relief at places of rapid slope change. In fact, several commercial DTM interpolation programs welcome breaklines and breakpoints, in addition to bulk data, in order to attain a better terrain relief reconstruction. Breaklines, structure lines and salient points can be conceived of as the skeleton of the terrain, sustaining regular surfaces.

Differential Modelling

Makarovic [9] proposed acquiring such skeleton information by photogrammetric selective sampling. The deficiencies of contours in difficult areas can be reduced and interpolation improved by combining contour data obtained from existing maps with skeleton data collected by photogrammetry. At the same time, supplementary samples at contour gaps can be incorporated. Tuladhar [13] reported improvement rates of DTM accuracy as great as 50%.

The disadvantages of this approach are that photographs, photogrammetric equipment and DTM expertise are needed, and that the required manual operations are time-consuming. Sacrificing quality but gaining in convenience and costs will be an

interesting alternative for several DTM applications. This can be achieved by automatically deriving skeleton lines from a given set of contours and subsequently using both data sets for constructing a triangulated irregular network (TIN) as the basis for interpolation.

Automated Derivation of Skeleton Lines

The underlying idea is to imitate manual interpolation on a contour map. In regular surface areas we interpolate directly between adjacent line segments. Where a group of contour lines spontaneously changes direction, i.e., at distinct ridge or drainage lines, we extract intuitively and approximately the relief skeleton before we interpolate. At peaks and pits we examine the neighbours of the inner contour to estimate the local extrema before we interpolate.

Obviously a contour pattern carries more information than just elevation at a set of points. Although the skeleton lines of contours--whether determined manually or automatically--are only an approximation of the relief skeleton, better DTMs will be produced than without this additional information. Triangulating the digitized contours and skeleton lines provides a natural structure for this kind of data, if it is assured that the skeleton lines do constitute triangle sides (see figure 2). Some of the very first DTM systems in the sixties were TIN-based (see, e.g., [15]). Now, being able to deal with topology is certainly one of the aspects which make TIN DTMs attractive again.
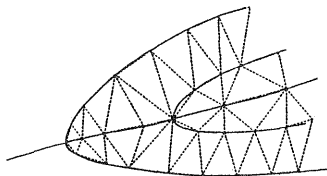
Fig. 2: Contours, skeleton and triangles

Cartographic generalization as applied to most existing topographic maps followed a comparable strategy: maintain the skeleton, modify the ĩills. It can be expected, therefore, that contours from topographic maps are of higher fidelity at structural locations. This is good to remember when trying to extract additional information from the contours in order to enhance DTM quality without recourse to further measurements.

Aumann et al [2] reported on two approaches under investigation for automatically deriving skeleton lines from contours: a vector and a raster approach. Both methods--one using aspect information, the other based on medial axis transformation--lead to a significant improvement of DTM fidelity. Li and Chen's [8] research initiative utilizes mathematical morphology for this purpose, relying on global shape operators rather than local ones.

For us, ILWIS [14] is the obvious developing platform. The present version runs on IBM-compatible PCs and offers a wealth of image processing and GIS tools. Its DTM component is raster based, converting digitized contours by Borgefors distance transformation and linear interpolation to grid data (see [6]). ILWIS includes digitizing software that supports manual digitizing of contour lines. For further processing, they are converted to a raster image.

An attractive alternative to creating such a contour raster image would be to scan the existing contour map, followed by automated pre-processing. This has been a subject of research activities for several years, and recent publications include [7], [16].

PROCESSING STEPS

Given contours in raster form, the series of processing steps shown in figure 3 produces a DTM of better fidelity than one produced by interpolating from the contours.
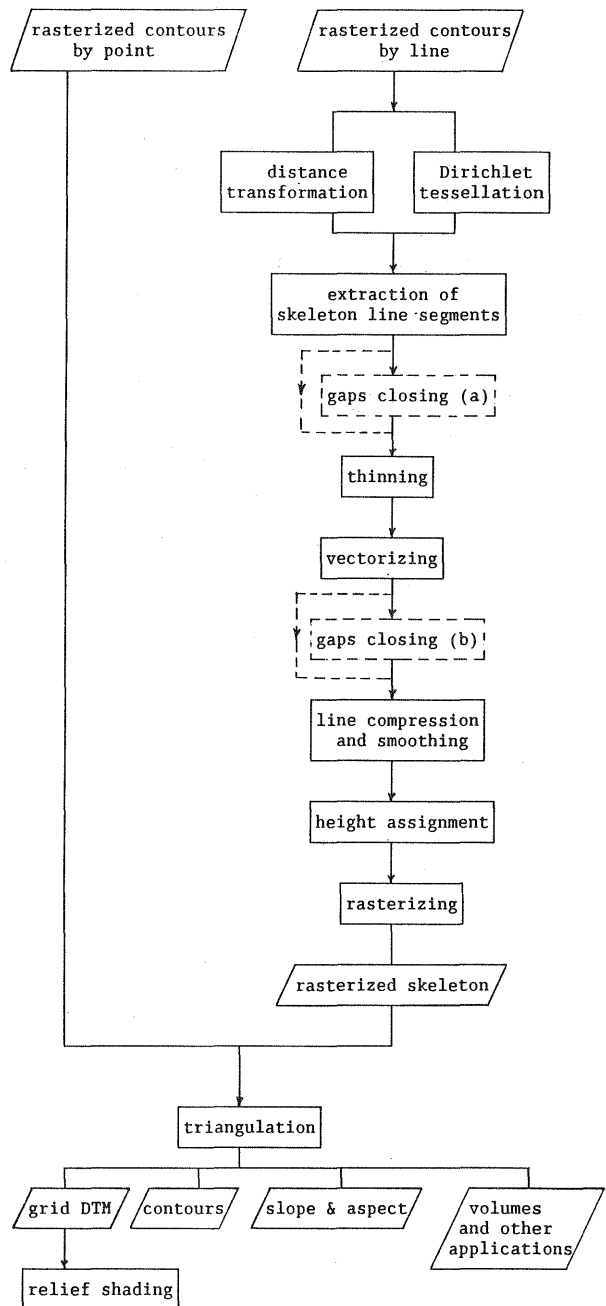
Fig. 3: Automated skeleton extraction and triangulation

In the following, the main features of the process are outlined; details about the algorithms and the developed experimental software are given in [10].

The starting point is a vector file of clean contours. To obtain the skeleton of the contour pattern, the vector-to-raster conversion is done such that an image of uninterrupted lines results. The lines are 1 pixel wide and carry the contour height.

Borgefors and Dirichlet

In the next step, two images are created simultaneously. The distance image shows shortest distances, i.e., for every pixel of the contour image, the distance to the nearest contour pixel. Based on Borgefors's analysis [4], we use Chamfer 3-4 for the distance transformation, giving priority to speed rather than to close approximation of Euclidian distance.

From the distance image, intermediate contours and segments of skeleton lines could readily be extracted, being the lines of local maxima. This is illustrated in figure 4, where relief shading was applied to the distance image of a simple shape, such as a closed contour line. The lines of interest appear as ridge lines. Figure 5.1 shows a set of contours together with the extracted lines of maxima which are also known as medial axes (see [3], [5]).
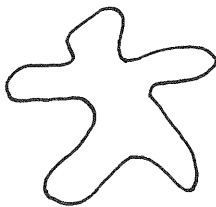

Fig. 4.1:
Contour lines

Fig. 4.2: Its relief
shaded distanace image

Since the intermediate contours are not of direct interest, a second image, the tessellated image, is generated, which facilitates singling out the skeleton line segments. The Dirichlet tessellation produces an image showing the 'zone of influence' of every contour line (see figure 5.2). Each contour band inherits the pixel value of the contour line it covers, and its borders are the intermediate contours. Drawing from Borgefors's suggestion [4], the tessellation is computed in parallel with the distance transform.

Given the two images, those medial axes are extracted that are surrounded by unique pixel values. This yields the desired skeleton segments (see figure 5.3).
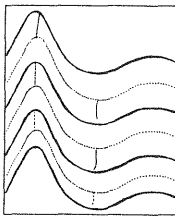

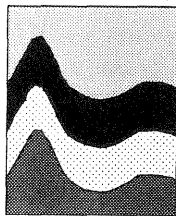Fig. 5.1:
Contour lines
and their
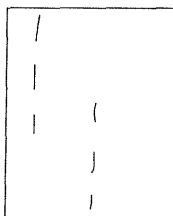medial axes

Fig. 5.2:
Tessellated
image of
the contours

Fig. 5.3:
Skeleton image

Closing of Gaps

Connecting segments to approximate ridge lines and drainage lines does not pose many problems for a human interpreter when he overlays the skeleton image on the contours. Automated gap closing, however, is rather difficult. The gaps are of unpredictable length, the skeleton lines may rapidly change direction, and there are trace segments which should not be connected. One possibility (indicated as (a) in figure 3) is to apply the distance transformation/Dirichlet tessellation to the intermediate contour image. Merging the first and second skeleton images and then applying dilation and subsequent thinning produces a fair result as long as the skeleton lines do not have sharp bends (see figure A2).

Another option is to first vectorize the line segments and then apply distance and direction criteria for gap closing (indicated as (b) in figure 3), similar to the method reported in [16]. And there are still more possibilities to be explored (see [10]).

3D Skeleton

After vectorizing the lines, which includes a conformal transformation to the coordinate system of the original contours, data reduction and line smoothing are applied. The resulting skeleton lines are intersected with the contour lines to furnish them with heights. Points are interpolated with sufficient density for later triangulation. Peaks and pits residing on skeleton lines of inner contours are extrapolated.

TIN

Triangulation is also achieved by a simultaneous distance transformation and Dirichlet tessellation. Its input is a merged raster image of contours and skeleton lines. This time the 'digitized points' are rasterized, the pixel value being set to the point number. The result of the Dirichlet tessellation is a Thiessen polygon image, which can be utilized for Delaunay triangulation (see figure 6).
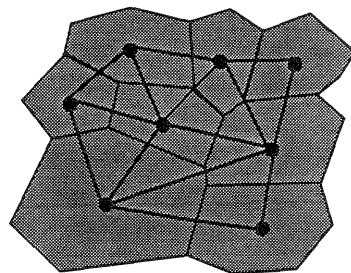

Fig. 6: Thiessen polygons and corresponding triangles

The triangles are composed by scanning the tessellated image once with a 2x2 mask. The triangles will not intersect (cross) when distinguishing between the upper and lower parts of the mask (see figure 7).

Although efficient, the algorithm does not necessarily compose those two triangles from four points that are nearly equilateral. Figure 8 illustrates that flat (horizontal) triangles are avoided by adding the extracted skeleton lines to the digitized contours.
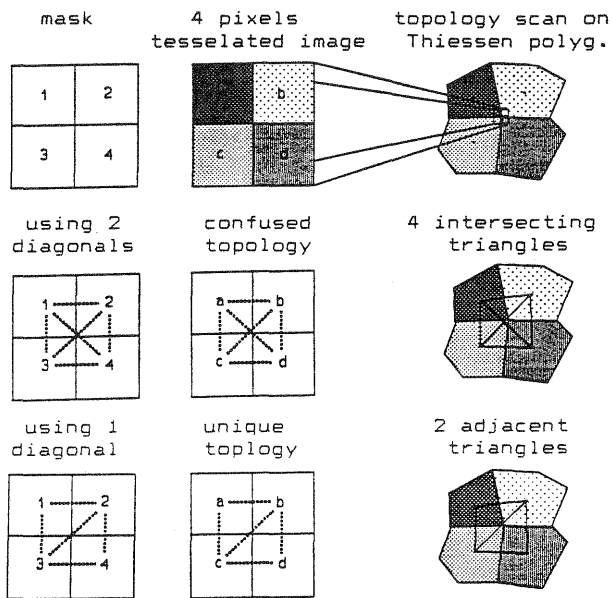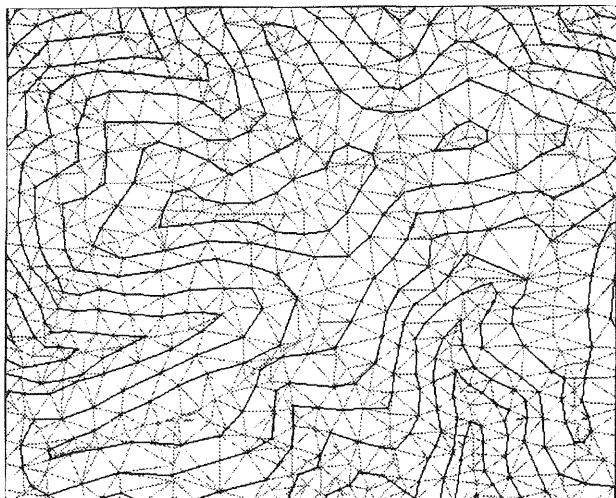
Fig. 7: Mask and result of topology scan

Fig. 8: TIN generated from contours and skeleton lines

Fig. 9: DTM from contours and skeleton

The topology of the network is documented by two tables. The first relates every triangle to its nodes by identification number; the second relates every triangle to its neighbours.

The TIN provides a better data structure than the original contours for deriving various DTM products, and without loss of information. Based on TIN, Alias [1] developed a set of programs for computing a grid DTM (in ILWIS format), generating contour lines and slope models. The improvement of the grid DTM, compared with figure 1, is illustrated in figure 9. Linear interpolation is a good choice for rough terrain with many breaklines. Other interpolation methods are adequate, if smooth surface representation is required (see [11]).

CASE STUDY

How does the automatically derived skeleton compare with a photogrammetrically sampled one? We selected mountainous terrain in southern France (near Bonnieux) as a test site. Contours of an area 3 by 3 km were digitized from a 1:50,000 topographic map with a contour interval of 20m. After interactive editing, the contours were rasterized with a 6.5m pixel size. Figure A1 shows the contours overlaid on the relief-shaded DTM which was produced directly from the contours. Figure A2 shows the automatically-derived skeleton lines, overlaid again on the same relief shades as in figure A1. The skeleton lines were produced as illustrated in figure 3.

Photogrammetric selective sampling was done on the Planicomp C120 1:60,000 photographs. Digitizing the ridge and drainage lines, peaks, pits and passes took some 4 hours. Figure 10 shows the portion of the overlaid skeletons that corresponds to figure 9 (a two-colour version of the entire area is given in [10]). The grid DTM generated through triangulation from contours and skeleton (see figure A3) has lost its plateaus!

Fig. 10: Superimposition of skeletons from manual and automatic extraction (the 'fringes' belong to the automatic one)

As shown in figure 10 (although it is difficult to discern which lines belong to which skeleton), the overall agreement of the two sets of lines is good. In addition to the differences caused by insufficient registration (the usual problem with control points), there are obvious differences in what is extracted by the two methods. The

automatic extraction identifies more short breaklines which the operator is likely to omit, either considering them as not relevant or overlooking them because of the complexity of natural surfaces.

Before being able to thoroughly evaluate the approach--including accuracy analysis--a few problems have to be solved still. They pertain to pre-processing of digitized contours, determining the most effective algorithm for gap closing, optimizing the 2D-raster to 3D-vector conversion, and enhancing TIN generation.

CONTEXT

The presented approach has the potential to improve the fidelity of DTMs derived from contour lines. As such, it is of interest for spatial analysis tasks that require terrain relief information but have access only to contours. The data source can be either topographic maps or digital contours which are offered as (standard) products, e.g., by national mapping agencies. This situation is frequently encountered in the project sphere of the engineering geosciences. Moreover, its application is not restricted to terrain relief. The approach can be used for digital surface modelling of any phenomenon that is expressed in isolines.

Of course, digital terrain modelling is not only a 'desk-top affair'. Several civilian and military mapping organizations have started programmes for producing and maintaining DTMs at a national level. Digitized maps are a prime data source for such elevation databases. The most cost-effective response to demands for higher quality is improved processing techniques. The approach presented here, however, contributes only to an upgrading perspective, not to keeping an elevation database up to date. Upgrading and updating existing DTMs, including reflections on economic issues in a multi-user environment, were presented in [12].

REFERENCES

[1] Alias, A. R., 1992. Triangular network in digital terrain relief modelling. M.Sc. Thesis, ITC, Enschede, The Netherlands.

[2] Aumann, G., Ebner, H., Tang, L., 1990. Automatic derivation of skeleton lines from digitized contours. Int. Arch. of Photogr. & Rem. Sensing, Vol 28-4, Tsukuba: 330-337.

[3] Blum, H., 1967. A transformation for extracting new descriptors of shape. Proc. Symposium "Models for perception of speech and visual form", MIT Press, Cambridge, Mass.: 362-380.

[4] Borgefors, G., 1986. Distance transformations in digital images. Computer Vision, Graphics, and Image Processing, Vol 34: 344-371.

[5] Ebner, H., Tang, L., 1989. High fidelity digital terrain models from digitized contours. 14th ICA Congress, Budapest.

[6] Gorte, B., Koolhoven, W., 1990. Interpolation between isolines based on the Borgefors Distance Transform. ITC Journal, 1990-3.

[7] Li, D., Chen, X.-Y., 1990. Automatic raster-vector converting from CCD-scanned topographic contour map. Int. Arch. of Photogr. & Rem. Sensing, Vol 28-3/2, Wuhan: 405-418.

[8] Li, D., Chen, X.-Y., 1990. Automatically generating triangulated irregular digital terrain model networks by mathematical morphology. Int. Arch. of Photogr. and Rem. Sensing, Vol 28-3/2, Wuhan: 419-430.

[9] Makarovic, B., Tuladhar, A.M., 1988. DTM from contour lines upgraded by photogrammetric selective sampling. Int. Arch. of Photogr. & Rem. Sensing, Vol 27 (B8/IV), Kyoto: 94-103.

[10] Pilouk, M., 1991. Fidelity improvement of DTM from contours. M.Sc. Thesis, ITC, Enschede, The Netherlands.

[11] Tempfli, K., 1982. Notes on interpolation and filtering. 3rd edition, ITC, Enschede, The Netherlands.

[12] Tempfli, K., 1991. DTM and differential modelling. Proc. ISPRS and OEEPE Joint Workshop "Updating digital data by photogrammetric methods", Oxford; OEEPE Publication No 27.

[13] Tuladhar, A.M., 1986. Upgrading DTMs from contour lines by photogrammetric selective sampling. M.Sc. Thesis, ITC, Enschede, The Netherlands.

[14] Valenzuela, C.R., 1988. ILWIS overview. ITC Journal, 1988-1.

[15] Viita, E., 1967. La mise au point en Finlande de la methode par surfaces. Soc. Franc. Photogr., Vol 27.

[16] Viseshsin, S., Murai, S., 1990. Automated height information extraction from existing topographic map. Int. Arch. of Photogr. & Rem. Sensing, Vol 28-4, Tsukuba: 338-346.
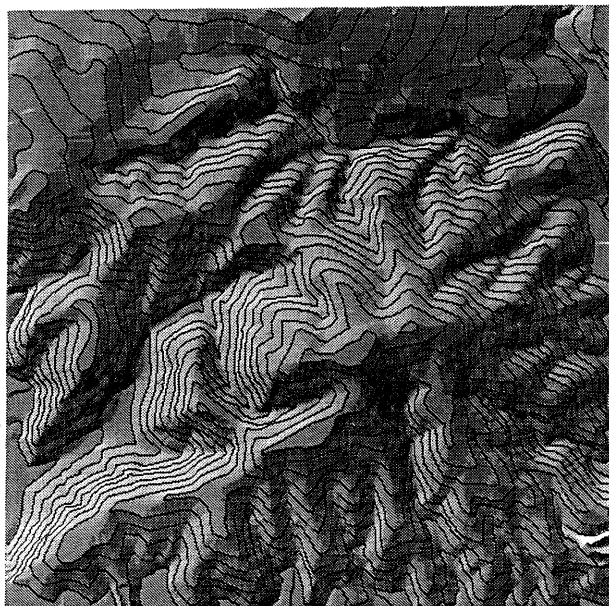
APPENDIX

Fig. A1: Contours and derived DTM

Fig. A2: Extracted skeleton lines and contours

Fig. A3: DTM from contours and skeleton