From scanned topographic maps to digital elevation models

*by Patrice Arrighi * and Pierre Soille***

** 20 rue Marceau, F-92130 Issy-les-Moulinaux, Patrice.Arrighi@iname.com*
*** Image Analysis and Control Group, Silsoe Research Institute*
Wrest Park, Silsoe, Bedfordshire MK45 4HS, U.K., Pierre.Soille@bbsrc.ac.uk

ABSTRACT

In this paper, we present a general methodology for the generation of digital elevation models (DEMs) starting from scanned topographic maps. We concentrate on the extraction and filtering of the contour lines from the input maps. This is a difficult problem due to the presence of complex textured backgrounds and information layers overlaid on the elevation lines (e.g., grid lines, toponymy, etc.). Results are presented on a wide variety of samples extracted from a 1:50000 plate scanned at 300 DPI.

KEYWORDS digital elevation models, interpolation, image analysis, mathematical morphology

Introduction

Digital elevation maps or models (DEMs) are arrays of numbers representing the spatial distribution of terrain elevations. They can be seen as gray scale images whereby the value of a pixel represents an elevation rather than a luminance intensity (the brighter the gray tone level of a pixel, the higher the elevation of the terrain point corresponding to this pixel). Useful applications of DEMs can be found in civil/rural engineering, geographic information systems (GIS), geology, geomorphology, water resources management, photogrammetry, satellite imaging, etc. A comprehensive review of hydrological, geomorphological, and biological applications of DEMs is proposed in (Moore et al., 1992).

A low cost solution for generating a DEM consists in interpolating the elevation values between the elevation contour lines extracted from digitized topographic maps. The purpose of this paper is to present a methodology for producing a DEM starting from a scanned map. The paper is organised as follows. A brief overview of papers dealing with the processing of scanned maps is presented in Sec. 2. The proposed methodology is detailed in the three following parts: the contour line extraction and filtering (Sec. 3), the connection of disconnected contour lines (Sec. 4), and the geodesic interpolation (Sec. 5). Before concluding, Sec. 6 presents a series of results and discusses remaining problems.

Previous Work

Research on automated map recognition has been going on for many years resulting in a huge amount of publications. Early reports about the vectorization of line drawings already introduced the main necessary steps of any automatic procedure: (i) digitization of the original paper document using a scanner, (ii) thresholding, (iii) thinning of the resulting black patterns using some skeletonization procedure (some pre- and post-filtering may be necessary), and (iv) raster-to-vector conversion of the resulting thinned lines.

These steps can be found in (Leberl and Olson, 1982) for the automatic vectorization of clean contour and drainage/ridge sheets, in (Greenlee, 1987) for an early attempt to extract elevation contour lines on topographic maps, (Amin and Kasturi, 1987) for the recognition of lines and symbols, and (Musavi et al., 1988; Ogier et al., 1995) for the processing of land record maps. Kaneko (1992) proposes the use of directional distance propagations for extracting line structures in line drawings. A more general framework aiming at interpreting line drawings, i.e., separating text strings and different types of lines is described in (Kasturi et al., 1990). The extraction of road and drainage networks from the corresponding sheets is investigated in (Mariani et al., 1997).

In more complex maps, the use of the colour information is essential for recognizing its features. Colour scanners being increasingly cheaper, more recent papers deal with maps directly scanned in colours. For example, Ansoult et al. (1990) use the mean and variance of the hue channel for discriminating soil types on a digitized soil map. Ebi et al. (1994) transform the input RGB colour space into another colour space taking the chromaticity into account. Classification/clustering techniques are then applied to the bivariate histograms constructed from the resulting two chromaticity channels.

Our approach is new in the sense that we process raw colour topographic maps having no direct access to the individual sheets (i.e., information layers). In addition, our procedure is based on recent advances in morphological image processing and it includes some new ideas for extracting extreme points of a set. Finally, it addresses all steps necessary for generating a DEM from a paper topographic map (Fig. 1).

Reprinted from the Proceedings of Geovision'99, International Symposium on Imaging Applications in Geology, University of Liege, Belgium, D. Jongmans, E. Pirard, and P. Trefois Eds., Page 1.
http://web.ukonline.co.uk/soille/arrighi-soille99.pdf or http://ams.egeo.sai.jrc.it/soille/arrighi-soille99.pdf

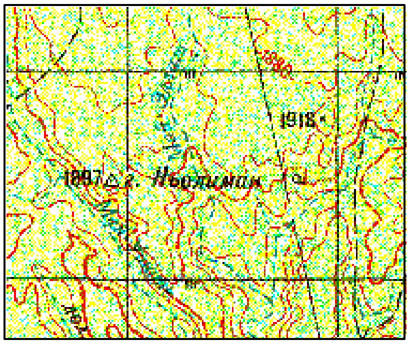

Fig. 1: Subset of a digitized topographic map

Contour Line Extraction and Filtering

The first step of our procedure consists in extracting a mask of all contour line. This is achieved by extracting all image pixels which have a red hue. However, the resulting lines are disturbed by many noisy pixels (see Fig. 2). Several morphological filters allow us to produce a clean mask of the elevation contour lines: (i) removal of all isolated pixels using a hit-or-miss transform, (ii) filling of all one pixel thick gaps using non-homotopic hit-or-miss operations with a family of composite structuring elements, and (iii) removal of all holes within the lines. By applying these filters to the image shown in Fig. 2, we get the image shown in Fig. 3.

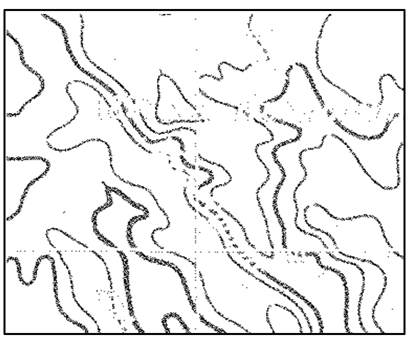

Fig. 2: Raw extraction of elevation contour lines

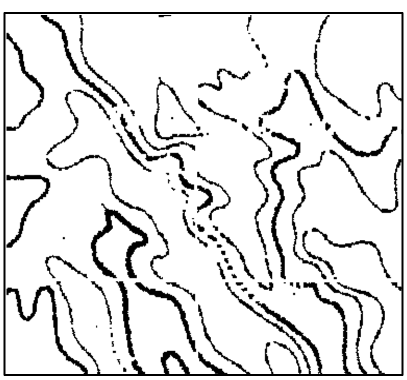

Fig. 3: After morphological filtering

Contour Line Reconnection

The most difficult task is to reconnect the elevation lines that are disconnected by other information layers such as the coordinate grid and the toponymy. Classical techniques first skeletonize the lines and then try to find relevant extremities of the skeleton for recovering the missing parts of the lines. There are problems with this approach because the skeletonization is very sensitive to noise and usually creates small branches at the extremities of the lines. These can be easily removed by pruning. However, by doing so, the resulting lines are shorter then the original ones and therefore some relevant information is lost. We propose to extract the extremities of the lines before skeletonizing them. This is achieved by generalizing the hit-or-miss transform used for extracting the extremities of one-pixel thick lines. In case the lines are not long enough to detect two extremities, these are defined as the extrema of the propagation function (Lantuéjoul and Maisonneuve, 1984). Once the extremities of the thick lines have been extracted, we thin them using a skeletonization with anchor points as proposed in (Vincent, 1991). A combination of a distance and direction criteria is then used for connecting the disconnected lines: Euclidean distances between extremities and differences between their direction are weighted and combined to compute a new distance. Once all of possible distances are computed, the extremities which produced the lower distance are connected and removed from the list of free extremities. This procedure is repeated until no more extremities are left.
In Fig. 4, the skeleton by anchor points is shown in gray and the connections that have been performed in black.

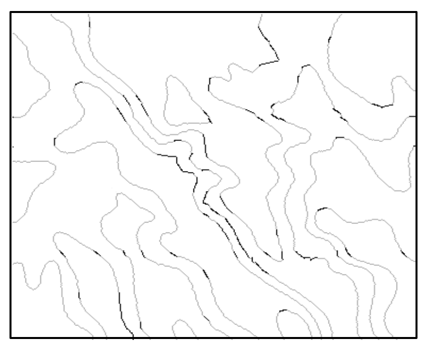

Fig. 4: Skeleton by anchor points and connection of the disconnected contour lines

Contour Line Valuation and Interpolation

Since we have not yet developed an OCR module for reading the elevation values present in the map, user-interaction is needed for inserting the elevation of the contour lines which do surround contour lines with a lower elevation. Hence, by assuming that the elevation difference between two successive contour lines is constant, we can

Reprinted from the Proceedings of Geovision'99, International Symposium on Imaging Applications in Geology, University of Liege, Belgium, D. Jongmans, E. Pirard, and P. Trefois Eds., Page 2.
http://web.ukonline.co.uk/soille/arrighi-soille99.pdf or http://ams.egeo.sai.jrc.it/soille/arrighi-soille99.pdf

automatically calculate the elevation of all remaining contour lines. Once this has been achieved, we use the geodesic interpolation technique developed in (Soille, 1991) to generate the final DEM. A grey scale representation of the output DEM generated from the topographic subset shown in Fig. 1 is shown in Fig. 5.

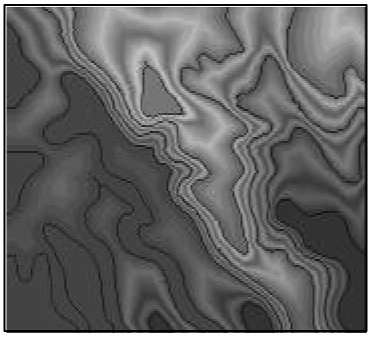

Fig. 5: Geodesic Interpolation of the levation values between the extracted contour lines

Results and Discussion

Our procedure has been tested on a full 1:50000 plate. The major source of errors is due to the fact that some connections are not successfull (failure rate of about 5%). Indeed, it may occur that two aligned lines separated by a small distance do not lead to a correct connection due to the presence of two other disconnected lines in their neighbourhood. Fortunately, once an incorrect connection has been performed, the other two lines cannot be futher connected because they would cross the first connection. Therefore, these errors are automatically detected and the user is asked for manually performing these connections.

Concluding Remarks and Perspectives

A procedure for automatically resolving the connections leading to inconsistencies still needs to be developed. By adding an OCR module, the elevation of the contour lines will be automatically inserted and will also help solving the connection failures. We are currently investigating a simple OCR technique based on the analysis of concavity regions as presented in (Soille, 1998a).

We also found that the automatic unwrapping of wrapped phase-maps (Soille, 1998b) is closely related to the problem of extracting and connecting elevation contour lines. The automatic extraction of growth rings (Som et al., 1993) is another related application. First results show that all three research areas will benefit from each other.

Finally, this paper illustrates that mathematical morphology is well suited to the processing of elevation data. This is not surprising because in morphology, any image is viewed as a topographic surface, the grey level of a pixel standing for its elevation. This explains why many morphological operators such as the watershed transformation are based on geomorphological concepts. Other applications of mathematical morphology to the processing of digital elevation models can be found in (Soille and Ansoult, 1990) for the automatic delineation of catchment basins and (Soille and Gratin, 1994) for the automatic extraction of drainage networks.

REFERENCES

AMIN, T. and KASTURI, R. 1987. Map data processing: Recognition of lines and symbols. Optical Engineering, 26(4):354-358.

ARRIGHI, P. 1998. Reconstruction 3-D de cartes numérisées. Master's thesis, LIRM, Université Montpellier II.

M. ANSOULT, P. SOILLE, and J. LOODTS. Mathematical morphology: a tool for automated GIS data acquisition from scanned thematic maps. Photogrammetric Engineering and Remote Sensing, 56(9):1263-1271, September.

EBI, N., LAUTERBACH, B., and ANHEIER, W. 1994. An image-analysis system for automatic data-acquisition from colored scanned maps. Machine Vision and Applications, 7(3):148-164.

GREENLEE, D. 1987. Raster and vector processing for scanned linework. Photogrammetric Engineering and Remote Sensing, 53(10):1383-1387, October.

KANEKO,T. 1992. Line structure extraction from line-drawing images. Pattern Recognition, 25(9):963-973.

KASTURI, R., BOW, S., EL-MASRI, W., SHAH, J., GATTIKER, J., and MOKATE, U. 1990. A system for interpretation of line drawings. IEEE Transactions on Pattern Analysis and Machine Intelligence, 12(10):978-992.

LANTUEJOUL, Ch. and MAISONNEUVE, F. 1984. Geodesic methods in image analysis. Pattern Recognition, 17(2):177-187.

LEBERL, F. and OLSON D. 1982. Raster scanning for operational digitizing of gaphical data. Photogrammetric Engineering and Remote Sensing, 48(4):615-627, April.

MOORE, I., GRAYSON, R., and LADSON, A. 1991. Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. Hydrological Processes, 5:3-30.

MARIANI, R., LECOURT, F., PIERROT DESEILLIGNY, M., LABICHE, J., and LECOUTURIER, Y. 1997.

Interprétation de cartes géographiques : algorithmes de reconstruction de réseaux hydrographiques et routiers. Traitement du Signal, 14(3):317-334.

MUSAVI, M., SHIRVAIKAR, M., RAMANATHAN, E., and NEKOVEI, A. 1988. A vision based method to automate map processing. Pattern Recognition, 21(4):319-326.

OGIER, J.-M., MULLOT,R., LABICHE, J., and LECOUTURIER, Y. 1995. Interprétation de documents par cycles perceptifs de construction d'objets cohérents. Application aux données cadastales. Traitement du Signal, 12(6):627- 637.

SOILLE, P. and ANSOULT, M. 1990. Automated basin delineation from digital elevation models using mathematical morphology. Signal Processing, 20:171-182, June.

SOILLE, P. and GRATIN, C. 1994. An efficient algorithm for drainage networks extraction on DEMs. Journal of Visual Communication and Image Representation, 5(2):181-189, June.

SOILLE, P. 1991. Spatial distributions from contour lines: an efficient methodology based on distance transformations. Journal of Visual Communication and Image Representation, 2(2):138-150, June.

SOILLE, P. 1998a. Grey scale convex hulls: definition, implementation, and application. In H. Heijmans and J. Roerdink, editors, Mathematical Morphology and its Applications to Image and Signal Processing, volume 12 of Computational Imaging and Vision, pages 83-90. Kluwer Academic Publishers, Dordrecht.

SOILLE, P. 1998b. Morphological unwrapping of interferometric phase-maps. In H. Heijmans and J. Roerdink, editors, Mathematical Morphology and its Applications to Image and Signal Processing, volume 12 of Computational Imaging and Vision, pages 383-390. Kluwer Academic Publishers, Dordrecht.

SOM, S., DAVIS, J., WELLS, P., and SVALBE, I. 1993. Morphology methods for processing tomographic images of wood. In K. Fung and A. Ginige, editors, Proc. DICTA'93: Digital Image Computing: Techniques and Applications, pages 564-571.

VINCENT, L. 1991. Efficient computation of various types of skeletons. In M. Loew, editor, Medical Imaging V: Image Processing, volume SPIE-1445, pages 297-311.

