Automatic Generation of Cartographic Features for Relief Presentation Based on LIDAR DEMs

Juha OKSANEN, Christian KOSKI, Pyry KETTUNEN, Tapani SARJAKOSKI, Finland

Key words: LIDAR, DEM, automated cartography, topographic mapping

SUMMARY

National mapping agencies (NMAs) around Europe are facing the challenge, where customers expect ever increasing level of detail and frequent updates of topographic maps. Web-map applications have brought us the world, where few fixed scale topographic maps are just a starting point for rendering real multiscale topographic maps with dozen of scale levels. All this NMAs are expected to do with decreasing amount of public funding. At the same time, disruptive technologies, such as airborne laser scanning and advanced geospatial data processing, have fundamentally changed our possibilities for doing automatic or semi-automatic topographic mapping.

The focus of our work is on LIDAR DEM -based generation of contours that are the dominant cartographic elements in topographic maps. We will demonstrate solutions for automatic extraction of index, intermediate and supplementary contours. In addition, we will identify remaining cartographic challenges, including logical conflicts between the contours and hydrographic features, and propose methods to overcome these issues.

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1. INTRODUCTION

National mapping agencies (NMAs) around Europe are facing the challenge, where customers expect ever-increasing level of detail and frequent updates of topographic maps. Web-map applications have brought us the world, where few fixed scale topographic maps are just a starting point for rendering real multiscale topographic maps with dozen of scale levels. All this NMAs are expected to do with decreasing amount of public funding. At the same time, disruptive technologies, such as airborne laser scanning and advanced geospatial data processing, have fundamentally changed our possibilities for doing automatic or semi-automatic topographic mapping.

In the National Land Survey of Finland (NLS), we aim at increasing the level of automation in topographic mapping. Among the first pilot projects in the construction of the forthcoming National Topographic Database (NTDB), we have started to investigate the methods for automatic cartographic relief presentation based on LIDAR DEMs. The motivation for the work comes from the prevailing factors of demand and supply. Firstly, Finland started to use the new elevation system N2000 already in 2007, but contours in the current Topographic database (TDB) by the NLS are still in the previously used N60 elevation system. Secondly, the complete country-wide coverage of the DEM based on airborne laser scanning will be achieved by 2019, which, on one hand, will reveal the inconsistencies in the TDB’s manual contours, but on the other hand enables the use of automatic contouring methods for the whole country.

Our paper will concisely summarise the developed methods for extraction of index, intermediate and supplementary contours. In addition, we will identify remaining cartographic challenges, including logical conflicts between the contours and hydrographic features, and propose methods to overcome the issues.

2. AUTOMATIC EXTRACTION OF CONTOURS

Cartographic representation of the Earth’s relief in topographic maps has evolved from use of qualitative mountain symbols to systematic use of hachuring, and finally during 18th century, to use of contour lines (Imhof 1982). While the 20th century can clearly be seen as the century of contour domination, digital revolution including wide-spread use of geographical information systems, as well as disruptive technologies, such as airborne laser scanning, challenges the traditional view of cartographic relief presentation. Despite the technological pressure, contours have still been unbeatable in topographic maps, where the elevation data is always visualised together with a number of other topographic features. In this setting, the graphical load of the relief presentation should be minimized, which can be achieved by contour representation.

Solutions for automatic generation of contours are numerous, but the well-known property of numerical isohypses, i.e. the “mathematical” contours extracted without cartographic quality considerations, is that contours may appear jagged, they may visually touch each other at the viewing scale, or even cross etc. Furthermore, since local fluctuations in contour location are proportional to cotangent of the underlying terrain’s slope, numerical isohypses on flat terrain are visually cluttered and noisy.

To overcome these issues, more sophisticated methods for automatic contouring have been presented (Lecordix et al., 2009; Jaara and Lecordix 2011; Rosenkranz et al., 2012; Tyler and Greenlee, 2012). The limited suitability of the developed methods for Finnish topography led us to our own development work, where the criteria for contours were set as follows:

- Contours need to form closed lines (i.e. the start and end point should match) and they should be longer than predefined thresholds (including supplementary contours)
- Contours represent real and relevant surface forms keeping in mind the representation scale
- Contour interval system (index-intermediate-supplementary) need to be logical and consistent, traditionally in Finland 20 m–5 m–2.5 m system has been used
- Contours need to be smooth, except in thalwegs
- Contours need to be visually coherent despite the local relief
- Contours should not cross or even touch each other at the representation scale
- Supplementary contours are used only, when the surface forms between index or intermediate contours are unintuitive

In addition to the criteria listed, we aimed at development of a method containing minimal number of comprehensive production steps and local feature-based operations.

2.1 Contour generation with adaptive filtering of DEM

The design of contour generation method developed in the project has been documented comprehensively in Kettunen et al. (*in press*). The following paragraph summarises the principles.

To overcome common problems of simple numerical isohypses, we ended up in a method where the level of filtering of the input DEM is proportional to the local relief of the terrain. In practise, we used topographic position index (TPI) as the indicator of the local relief (Weiss 2001), which controls the strength of DEM smoothing. The steps of the process are as follows:

1. Calculation and scaling of a TPI from the original NLS-DEM2, output C-TPI
2. Light (Standard deviation = 2, Filter radius = 2) and strong (6, 10 respectively) smoothing of the DEM with circular Gaussian filter, outputs S-DEM1 and S-DEM2
3. C-TPI-weighted combination of S-DEM1 and S-DEM2: C-TPI * S-DEM1 + (1 – C-TPI) * S-DEM2, output C-DEM
4. Extraction of contours with 2.5 m interval from C-DEM, output CONT
5. Generalisation of extracted contours by removal of short contours, output CONT_GEN

When comparing numerical isohypses with the result of our procedure (Figure 1), it is clear that most of the criteria related to deficiencies of numerical isohypses have been fulfilled. While in steep terrain the differences between the approaches are small (Figure 1, a and b), significant improvements caused by adaptive filtering are visible in flat terrain (Figure 1, c and d).

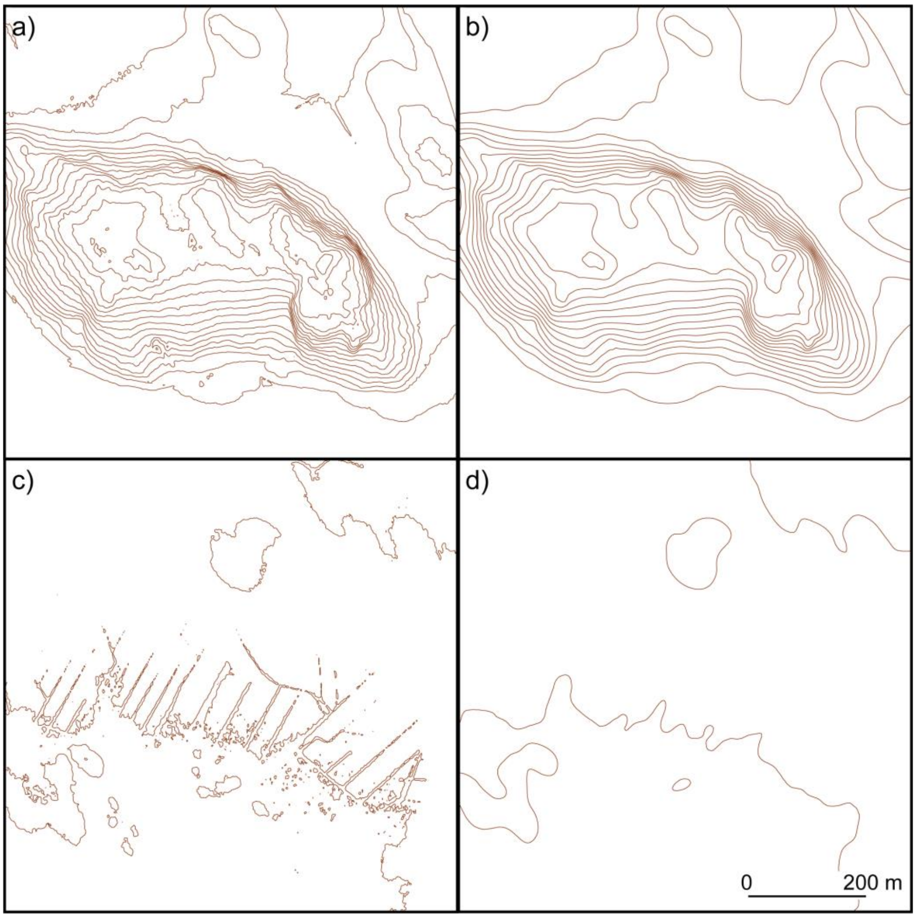

Figure 1. Numerical isohypses derived automatically from unsmoothed DEM (a and c) and contours derived by our method based on adaptive DEM smoothing (b and d).

2.2 Extraction of supplementary contours

While the basis in the extraction of supplementary contours is the same as in the extraction of contours in general, the methodological challenge is to appropriately remove supplementary contours in places where they are not needed. Our method (Figure 2) utilises the ideas of slope classification used for localised contour removal in steep terrain (Mackaness and Steven 2005):

1. Preparations
    a. Extracting the supplementary contour lines (SC-set) from CONT_GEN
    b. Extracting the shortest contours from the SC-set (length < 300 m)
    c. Interpolating a new DEM (intDEM) from the contour lines

2. Removing segments of supplementary contours in narrow gaps between intermediate contours
    a. Calculating slope from the interpolated DEM
    b. Polygonising steep areas (slope >= 10˚)
    c. Removing line segments in the SC-set that intersect with the polygonised areas
3. Removing inessential supplementary contour lines that do not serve for correctly perceiving the elevation
    a. Calculating the difference between values of the intDEM and the NLS-DEM2
    b. Identifying areas with a notable difference in elevation (> 1 m) between the two DEMs, and polygonising these areas (DA-polygons)
    c. Removing small DA-polygons (area < 400 m²)
    d. Removing contour lines in the SC-set that do not intersect with the DA-polygons
4. Removing inessential segments of the remaining supplementary contour lines that do not serve for correctly perceiving the elevation
    a. Creating a copy of the SC-set
    b. Removing contour segments in the copied set where the contours intersect with the DA-polygons
    c. Removing short contour fragments in the copied set (length < 200 m)
    d. Splitting the remaining fragments into equal-distance sections (length =< 70 m)
    e. Removing sections that touch the DA-polygons, or that are far apart from the intermediate contour lines (where any part of the section is further than 35 m away)
    f. Removing contour segments in the SC-set that overlap the remaining sections of the copied set
5. Refinement
    a. Merging the short contours that are extracted in phase 1 with the SC-set
    b. Removing the shortest supplementary contours from the set (length < 50 m)

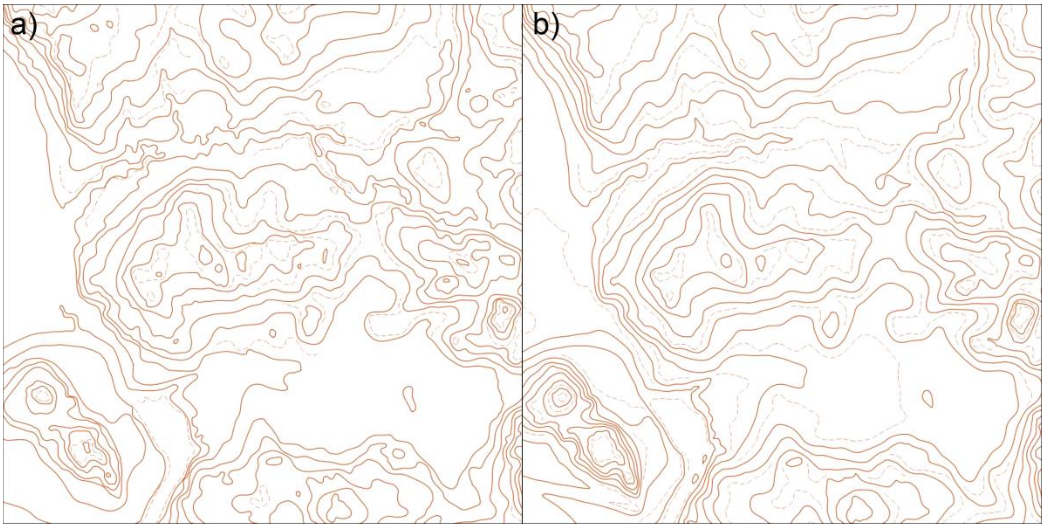

Figure 2. Index/intermediate contours (solid lines) and supplementary contours (dashed lines) from the current manually mapped TDB (a) and from our automatic contouring process (b).

3. REMAINING CHALLENGES

While the methods appear very promising, there are still issues that need to be resolved prior to release of production versions of the tools. Firstly, the method's sensitivity to small surface features could be improved. In some cases narrow depressions and small hummocks close to steep slopes get over-filtered. Also, areas of small hilltops appear to get too flat. Considering supplementary contours, in some places the method's insensitivity to small surface forms between regular contour intervals results in too generalized representation. Furthermore, consistency of contours with other topographic features, such as hydrographic lines and regions (Figure 3), needs to be handled. While inconsistencies of automatically generated contours with water bodies (Figure 3C) are possible to be corrected in a separate post-processing step, fixing positional errors in thalwegs sets the need for using LIDAR DEM also as a part of hydrographic mapping process.

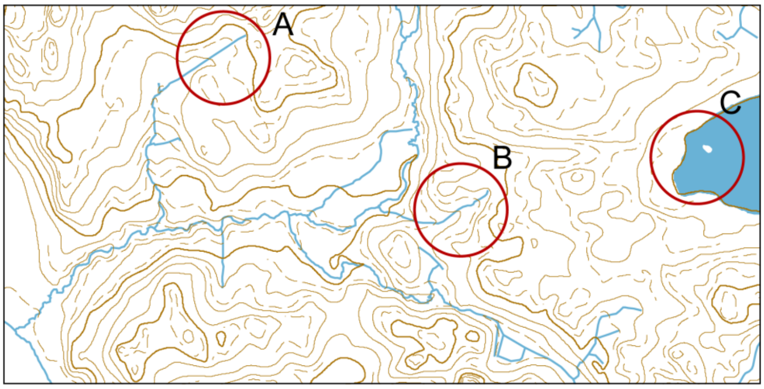

Figure 3. Examples of minor inconsistencies between the automatically extracted contours and manually mapped hydrographic features in the current TDB. A) and B) positional mismatch of thalwegs revealed by inconsistent contours and hydrographic lines, C) poor visualisation of a contour having the same elevation as the water body.

4. CONCLUSIONS

In the paper we demonstrated solutions for automatic extraction of index, intermediate and supplementary contours from NLS-DEM2. The developed method is simple and efficient, and the chosen approach has a potential for being used as a starting point for development of a production version of the tool. The deficiencies, including over-filtering in some topographic situations and potential inconsistencies between contours and other topographic features, still need to be refined.

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BIOGRAPHICAL NOTES

Dr. Juha Oksanen acts as a Research Manager in the Department of Geoinformatics and Cartography at the Finnish Geospatial Research Institute (FGI), which is part of the National Land Survey of Finland (NLS-FI), and leads the research group on analysis and visualization of geospatial data. He received his M.Sc. and Ph.D. degrees in geography from the University of Helsinki. His research interests include cartography, geovisualisation and analysis of imperfect geospatial data.

Dr. Pyry Kettunen acts as a Senior Research Scientist in the Department of Geoinformatics and Cartography, FGI, NLS-FI. He received his D.Sc. (Tech.) from Aalto University School of Engineering and M.Sc. (Tech.) from Helsinki University of Technology. Kettunen's research interests include cartographic visualisation, web maps and spatial cognition.

Mr. Christian Koski is a Research Scientist in the Department of Geoinformatics and Cartography, FGI, NLS-FI. He received his M.Sc. (Tech) degree in geoinformatics from Aalto University School of Engineering. His research interests include cartography and geovisualisation.

Prof. Tapani Sarjakoski is the Head of the Department of Geoinformatics and Cartography, FGI, NLS-FI. He received his M.Sc. (Tech.) and D.Sc. (Tech.) degrees in photogrammetry from the Helsinki University of Technology. Currently he also serves as an Adjunct Professor in geoinformatics at the University of Helsinki, and as an Adjunct Professor in photogrammetry at the Aalto University. His current research interests include high-performance geocomputing for massive datasets and integration of high-performance geocomputing solutions to Web-based user applications.

CONTACTS

Dr. Juha Oksanen
Finnish Geospatial Research Institute/
National Land Survey of Finland
Geodeetinrinne 2
02430 Masala
FINLAND
Tel. +358 40 831 4092
Fax +
Email: juha.oksanen@nls.fi
Web site: http://www.fgi.fi/