Algorithms for the extraction of lineaments from airborne laser scanning data

Markus Maukisch, Johann Stötter, Frederic Petrini-Monteferri & Martin Rutzinger

Abstract

Laser scanning is an operational method for collecting high resolution and accurate height and reflection information of the earth surface. As the laser beam partly penetrates tree and scrub vegetation, surface structures covered by vegetation can be mapped. To extract linear structures (lineaments) from laser scanning data different methods were developed and implemented using e.g. the Software GRASS GIS. Enhancements of these methods will allow multi-scale analysis. This means that changing scales will be considered for the lineament extraction thereby classifying extracted linear structures by their size.

Keywords: airborne laser scanning, GIS, lineaments, natural hazard management, spatial planning

1 Introduction

Natural lineament structures such as torrents, ridges, mountain crests, geologic faults, and fractures, are formed by different geomorphological and geological processes. The basis for lineament mapping is a digital terrain model (DTM) derived from airborne laser scanning (ALS) data. In this paper four approaches for analysing lineaments are presented. Using the GIS-Software GRASS (GRASS Developer Team 2007) a method for investigating surface curvature is consulted. A second approach applies visual analysis of hill shades by semi-automatically extracting lineaments and storing them as a vector dataset in a spatial database. Both algorithms use neighbourhood relationships between a certain number of pixel elements (moving window approach). The resulting pixel clusters are skeletonised using morphologic filtering and stored as vector objects. A third approach has a completely different focus and involves more user interaction. A tool integrated in the GIS-Software ArcMap updates shaded relief representations of a DTM while the user rotates the map. This eases the visual detection of lineaments. Finally, a fourth concept, which is still on an experimental level, performs an image segmentation of the DTM to extract homogeneous slope polygons with respect to slope aspect and gradient. In this case, the borders of the slope polygons represent the lineaments.

2 State of the art

A big number of different ridge- and value extraction algorithms can be found in literature. The choice of a suitable algorithm depends much on the origin of the DTM data and on the application purpose. Heitzinger & Karger (1998) introduce an algorithm to extract break lines from contour line based DTMs. The semi-automatic approach of Briese (2004) to detect 3D break lines requires "seed lines" requiring manual digitalisation. This approach is designed for the use of DTM with points input data such as laser scanning DTMs. Wladis (1999) presents an automatic lineament filter. This work is one example for an image processing filter that analyses the changes in frequency of elevation values in a given raster neighbourhood. A similar concept detects ridges by collecting local elevation maxima in a defined moving analysis window (Székely & Karátson 2004). The derived information on lineaments is then used to detect eroded and degregated volcanic structures. A recent study in Sweden (Nyborg et al. 2007) uses laser scanning data and lineament extraction algorithms to find fractures in geological deformation zones for the purpose of fixing a geological stable location for long-term nuclear waste deposition. An application in hydrology is the investigation of the relation between the lineaments and drainage patterns and groundwater occurrence (Edet et al. 1998).

3 Area of investigation

The data used in the following investigations contains the city of Innsbruck/Tyrol and its surroundings. Eighty flight strips covered an area of approximately 220 km^2 that was scanned with an Optech ALTM 3100 in November 2005.

4 Methods

4.1 Data acquisition (airborne laser scanning)

An Optech scanner recorded first, second, third, and last reflection. The 3D raw data points classified in ground and non-ground points were converted to a digital surface model (DSM) and a DTM with 1 m cell size respectively. These raster models gave input to the presented algorithms. The scanner deflects the laser beam at right angles to the flight direction. The return time of the laser pulse determines the distance from the plane to the earth's surface. Simultaneously, a Global Positioning System (GPS) and Inertial Navigation System (INS) measure the position and location of the plane. In combination with scan angle measuring, the 3D position of each laser reflection on the earth's surface can be measured (Wever & Lindenberger 1999).

4.2 Data preprocessing (interpolation, generating raster images)

All lineament extraction algorithms presented here require a preprocessed DTM. The data obtained during a laser flight is preprocessed in a number of steps, which comprise preparation, GPS evaluation, system calibration, data projection to the country-specific system, and laser points classification (Wever & Lindenberger 1999). The original point cloud is filtered to eliminate vegetation and building points and converted to raster data to generate a high accurate DTM. The algorithms for lineament extraction presented in the following are based on the use of such preprocessed raster data. These preprocessing steps are nevertheless not part of the algorithms presented here.

In some cases preprocessing and data collection can produce data errors. On the one hand this uncertainty in surface models is according to Wood (1996) still only partly separable from geomorphological patterns using mathematical filters. On the other hand it appears reasonable that this uncertainty of surface models can also be reduced by enhancing the resolution of the measurements and the density of measurement points as done by ALS.

5 Laser Information System (LIS)

The project presented here also includes the integration of the algorithms into an existing laser information system designed and developed by Höfle et al. (2006) and Höfle (2007) (cf. figure 1). The storage of ALS primary data used the spatial database management system PostgreSQL/PostGIS. This database server provides user access management and has multi-user capabilities. Raster datasets (e.g. DTMs) derived from the primary data and the here presented inputs for the terrain analysis algorithms are organised on the client side in GRASS GIS.

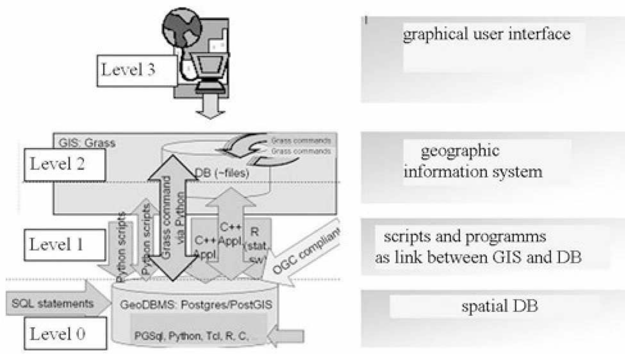

Figure 1: Laser data information system LIS (adapted from Höfle et al. 2006).

6 Implementation and results

In general three basic methods for lineament extraction are pursued:

- geometric analysis of topography (GRASS GIS) see chapter 6.1
- visual analysis on rotating shaded reliefs (GRASS GIS, ESRI-ArcMap) see chapter 6.2
- objects-based image analysis (OBIA) (eCognition) see chapter 6.3.

6.1 Upper and lower edge detection using GRASS-GIS

An example for the geometric analysis of topography a script detecting the upper and lower edge of ridges and walls is integrated into the Open-Source Software GRASS GIS following the principles of an object-based image analysis (OBIA) approach. This approach uses standard processing steps segmentation, feature calculation and classification. Thus the method deals with images derived from spatial data but not necessarily with maps. A curvature raster based on an ALS DTM is the input for the image analysis. This curvature raster is generated using a 15 x 15 m calculation window. The size of this calculation window must fit to the scale of the investigated landscape forms. Figure 2 shows an example for a curvature input raster image in an urban environment.

- **Segmentation:** By interactively applying curvature threshold values on this image, concave and convex zones representing lineaments are extracted. A morphological filter thins these areas to finally extract the line vectors.
- **Feature calculation:** As shown in Rutzinger et al. (2007) the step of deriving lineaments from these linear object primitives can not be done completely automatically. By interactively optimising the size of the analysis window and by adapting the segmentation threshold value lineaments can be extracted. Also

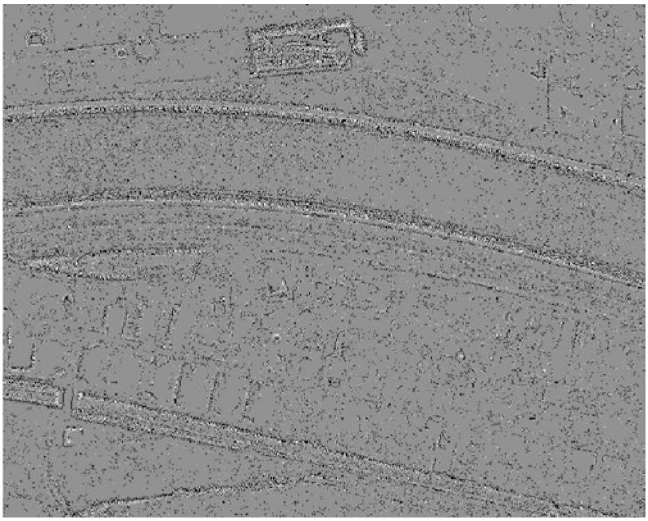

Figure 2: Curvature raster image with street and river dams.

with the calculation of the Voronoi diagram polygons for the line segments it is possible to calculate features based on this topological neighbourhood area. Figure 3 shows line objects for wall structures and valleys in an erosion torrent (cf. Geist et al., in press).

- **Classification**: Changing the size of the analysis window also leads to a classification of lineaments corresponding to their size. Furthermore it is useful to attach the mean inclination of the lines as an attribute to the line features. In this way for example mountain ridges can be distinguished from moraine structures.

6.2 Analysis on rotating shaded relief maps

6.2.1 Command „l.shade.rotation" for GRASS-GIS

This approach developed by Höfle et al. (2006) was first implemented in GRASS GIS and then modified and implemented as ESRI-ArcGIS extension. It superposes a user-defined number of shaded relief images (figure 3 and figure 4) representing the illumination of the DSM in different solar azimuth directions. The sum of these images reveals concave and convex surface structures by defining a minimal and maximal threshold. A morphologic filter can thin these to finally extract line vectors in the same manner as described in chapter 6.1.

6.2.2 Rotation tool for ESRI-ArcMap

User requirements lead to the development of a special laser data visualisation tool and its implementation as extension in the commonly used standard software ArcMap. A user-friendly mouse control rotates a shaded relief raster image on the screen in real time, while the illumination angle adapts automatically. This tool has a wide application field. It is valuable for geomorphologic or also archaeological investigations. A Beta version of this tool is already available. Concerning the present project the possibility of interactive mapping of break lines and lineaments on the

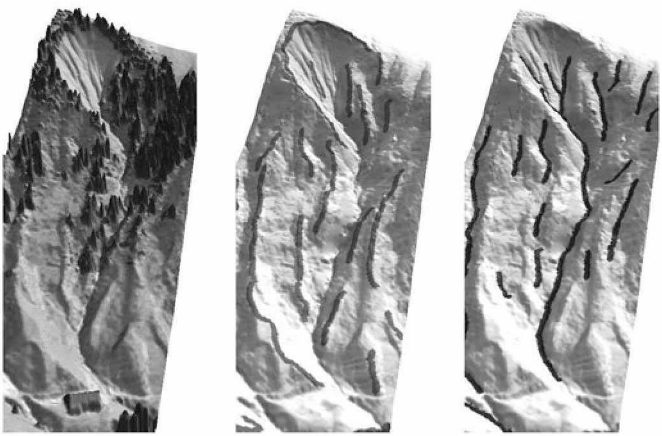

Figure 3: Infrared image overlaid on a shaded digital surface model (left). Digital terrain model with extracted upper (middle) and lower edges (right).

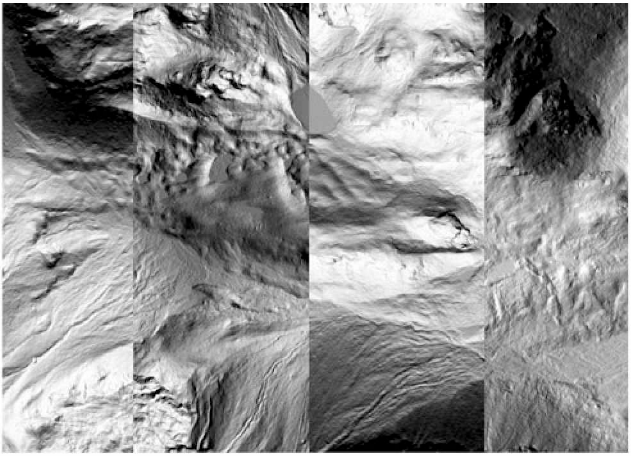

Figure 4: Shaded relief maps derived from the same terrain model, changing the parameter azimuth (from left to right: sun coming from north, east, south, west)

screen is the main focus. Figure 4 shows different surface structures using different illumination angles.

6.3 Object-based image analysis of slope gradient and aspect

The purpose of a classification of slope gradient and slope aspect is the mapping of homogeneous slope regions. The borders of these terrain facets represent in many cases slope discontinuities or lineaments. The slope gradient is weighted and superposed with slope aspect. Thereby a raster image of slope classes (figure 5) can be derived, which is again subjected to OBIA. A polygon feature class is derived from generalising this image by joining smaller slope zones with larger zones. The borders of the individual polygons represent slope discontinuities.

Similar concepts to derive terrain facets are described by Drăguţ & Blaschke (2006) and Rowbotham & Dudycha (1998). The isolated pixel information does not include topological relationships (Drăguţ 2006). Trying to combine pixels to polygons makes topological operations possible. Topological information about a lineaments neighbouring polygons can be used to classify the lineaments by the polygons' geometry. Landscape objects like lineaments occur across very different scales. Not only the length of the lineament itself but also the size and shape of neighbouring polygons provide important information on the lineaments' significance.

7 Outlook

The method for edge detection described in chapter 6.1 can derive 3D vector lines using an ALS DTM as input data, which match well with the upper and lower edges of surface discontinuities. During the running project, the degree of automatisation and the scalability of the lineament algorithms are optimised. Also the calculation of

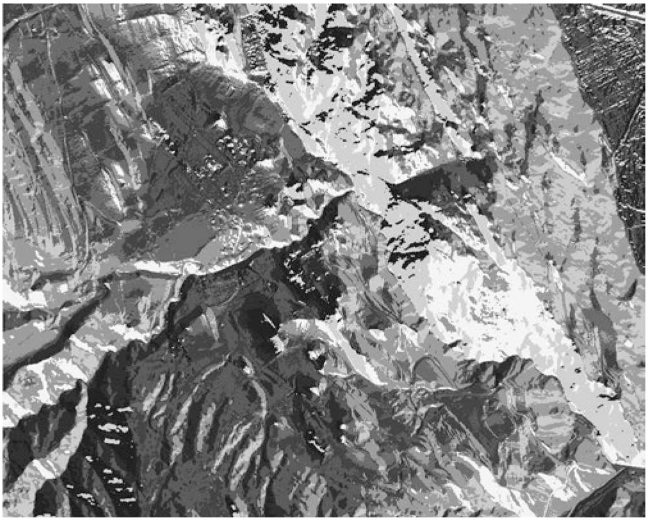

Figure 5: Slope facet classes raster image of a mountain gorge (center), agricultiral terraces (left side) and geologic fractures (right side).

further classification features for each line segment is planned. As scale is in itself a useful landscape diagnostic (Wood 1996), it should be used as a feature as well. During one processing run of the lineament extraction commands a analysis window with a fixed size is used. Repeating the process with different sizes of the analysis window will allow an analysis over different scales. Considering different sampling neighbourhoods a more detailed line classification can be achieved.

There will be a practical implementation of the described break line extraction algorithms as part of the Laser Information System LIS for the provincial government of South Tyrol. During 2008 the responsible departments for natural hazard assessment will dispose of a break line extraction tool based on the concepts described above.

References

Briese, C. 2004, "Three-dimensional Modelling of Break lines from Airborne Laser Scanner Data", *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 35(B/3),* 1097–1102

Drăguţ, L. & T. Blaschke 2006, "Automated classification of landform elements using object-based image analysis", *Geomorphology 81*, 330–344

Edet, A.E., C.S. Okereke, S.C. Teme & E.O. Esu 1998, "Application of remote-sensing data to groundwater exploration: A case study of the Cross River State, southeastern Nigeria", *Hydrogeology Journal 6(3),* 394–404

Geist, T., B. Höfle, M. Rutzinger, N. Pfeifer & J. Stötter 2007, "Laser scanning – a paradigm change in topographic data acquisition for natural hazard management", in: Veulliet, E., J. Stötter & H Weck-Hannemann (eds.), *Sustainable natural hazard management in alpine environments*, Berlin

GRASS Developer Team 2007, Geographic Resources Analysis Support System (GRASS), GNU General Public License. ITC-irst, Trento, Italy. on: http://grass.itc.it (28.09.2007)

Heitzinger, D. & H. Kager 1998, "High quality DTMs from contour lines by knowledge-based classification of problem regions", *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 4, 32(4), 230–237*

Höfle, B. 2007, *Detection and utilization of the information potential of airborne laser scanning point cloud and intensity data by developing a management and analysis system*, (Dissertation Thesis at the Department of Geography, University of Innsbruck), Innsbruck

Höfle, B., M. Rutzinger, T. Geist & J. Stötter 2006, "Using Airborne Laser Scanning Data in Urban Data Management – Set Up of a Flexible Information System with Open Source Components", *Proceedings UDMS 2006: Urban Data Management Symposium,* Aalborg

Nyborg, M., J. Berglund & C. A. Triumf 2007, "Detection of lineaments using airborne laser scanning technology: Laxemar-Simpevarp, Sweden", *Hydrogeology Journal* 15(1), 29–32

Rowbotham, D. N. & D. Dudycha 1998, "GIS modelling of slope stability in Phewa Tal watershed, Nepal", *Geomorphology 26,* 151–170

Rutzinger, M., M. Maukisch, F. Petrini-Monteferri & J. Stötter 2007, "Development of Algorithms for the Extraction of Linear Patterns (Lineaments) from Airborne Laser Scanning Data", *Proceedings of the Conference 'Geomorphology for the Future',* 161–168

Székely, B. & D. Karátson 2004, "DEM-based morphometry as a tool for reconstructing primary volcanic landforms: examples from the Börzsöny Mountains, Hungary", *Geomorphology 63*, 25–37

Wever, C. & J. Lindenberger 1999, "Laser Scanning – A Mapping Method Gains Ground. Experiences of 10 years laser scanning", *Photogrammetrische Woche 1999,* 125–132

Wladis, D. 1999, "Automatic lineament detection using digital elevation models with second derivative filters", *Photogrammetric Engineering & Remote Sensing 65(4),* 453–458.

Wood, J. D. 1996, *The geomorphological characterisation of digital elevation models*, (PhD Thesis, University of Leicester), on: http://www.soi.city.ac.uk/~jwo/phd (27.09.2007)