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Research paper

A new artefacts resistant method for automatic lineament extraction using Multi-Hillshade Hierarchic Clustering (MHHC)

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A B S T R A C T

This paper presents a new method of automatic lineament extraction which includes the removal of the 'artefacts effect' which is associated with the process of raster based analysis. The core of the proposed Multi-Hillshade Hierarchic Clustering (MHHC) method incorporates a set of variously illuminated and rotated hillshades in combination with hierarchic clustering of derived 'protolineaments'. The algorithm also includes classification into positive and negative lineaments. MHHC was tested in two different territories in Bohemian Forest and Central Western Carpathians. The original vector-based algorithm was developed for comparison of the individual lineaments proximity. Its use confirms the compatibility of manual and automatic extraction and their similar relationships to structural data in the study areas.

1. Introduction

Lineaments are generally considered to be linear features manifesting in the land surface and land cover reflecting discontinuities of geological structures (mainly faults). Although various phenomena can form lineaments (rock boundaries, sedimentary layers, wetness and vegetation changes – see e.g. Gupta, 2003), distinct linear landforms are most frequently used to extract geological structures (Smith and Clark, 2005; Smith and Wise, 2007; Evans, 2012). If lineaments detection is based exclusively on the morphometric properties of the land surface, then the lineaments can be termed 'morpholineaments' (Minár and Sládek, 2009). Although morpholineaments are automatically extracted either directly from a Digital Elevation Model (DEM) (Vaz, 2011; Mallast et al., 2011) or from different derived surfaces, e.g. second derivatives of DEM (Wladis, 1999), shaded relief (hillshade) is the most frequently used derived surface (Abdullah et al., 2010; Masoud and Koike, 2011a; Jordan and Schott, 2005).

Image pre-processing (edge enhancement, noise removal using thresholding) followed by edge linking methods (Hough Transform, Canny edge detector) are mostly used for automated lines extraction (Table 1). In some cases, the pre-processing is part of the extraction (closed-source software modules).

Morpholineaments can be considered not only as a surface expression of particular lithospheric faults, joints and lithological boundaries (e.g. Solomon and Ghebreab, 2006; Štěpančíková et al., 2008; Batayneh et al., 2012), but also as an expression of a morphotectonic field – a manifestation of lithospheric stress fields in the landforms (Urbánek, 2005; Minár and Sládek, 2009; Sládek, 2010). When producing a morphotectonic field model, even a small artificial misrepresentation of the morpholineaments direction (artefacts) can lead to problematic interpretations of results. Artefacts formation during a raster based analysis is pointed out and solved in this paper.

The main objective of this paper is to present a new Multi-Hillshade Hierarchic Clustering (MHHC) artefacts resistant method for automated lineaments extraction. The second goal is to evaluate the correlation between automatically and manually delineated lineaments, test the algorithm's ability to detect linear geological features (such as faults and linear parts of rock boundaries) and extract the main tectonically significant directions for their following evaluation in morphotectonic analysis.

Although subjective visual assessment is the most common approach for validation of extracted lineaments (Kageyama and Nishida, 2004; Jordan and Schott, 2005), more objective approaches have been published. For example, Abdullah et al. (2010) computed simple statistics of count and length of lineaments to

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compare different datasets. Vaz et al. (2012) implemented the confusion matrices approach and the distance between lineaments and reference point data was calculated to prove correlation with ground truth datasets as a comparison metric by Mallast et al. (2011). A new method for comparing different lineament datasets has been developed in this study.

2. Data

Two geologically and geomorphologically different study areas were selected (Fig. 1): A) surroundings of Prášilské jezero (lake) in the Bohemian Forest (BF) and B) the boundary area between Žiar (Mts.), Malá Fatra (Mts.) and Turčianska kotlina (basin) in the Central Western Carpathians (CWC).

The input DEMs were generated using 5 m equidistant contour lines from topographic maps – 1:10,000 for CWC and 1:25,000 for the BF area. The vector contour lines were processed using the Create Hydrologically Correct DTM tool (Jedlička et al., 2015).

Existing, manually delineated morpholineaments (from the same source DEMs) were used for comparison (Minár and Sládek, 2009; Mentlík, 2006). This selection allowed the algorithm to be tested in different geological and geomorphological settings and, moreover, it provided the variability of the creation of manually delineated morpholineaments. Faults and lithological boundaries adapted from 1:50,000 geological maps (Pelc and Šebesta, 1994; Káčer et al., 2005) were used for expressing relationships to the geological structure.

Table 1
Overview of several approaches and software products for automatic lineament extraction.

Reference	Approaches and software products
Pradhan et al. (2010)	Manual extraction method based on automatically pre-processed images with enhanced edges
Abdullah et al. (2010)	PCI Geomatica with module LINE
Mallast et al. (2011)	ERDAS Imagine modules and PCI Geomatica
Argialas and Mavrantza (2004)	Optimised Hough Transform method (Fitton and Cox, 1998)
Soto-Pinto et al. (2013)	Hough Transform and software LESSA (Zlatopolsky, 1992)
Vaz (2011)	Wavelet edge analysis and morphological multi-scale gradient
Kageyama and Nishida (2004)	Hierarchical lineament detection method using land cover information in mixed pixels (mixels)
Masoud and Koike (2011a)	Segment Tracing Algorithm (STA) of Koike et al. (1995)

3. MHHC method for automated lineament extraction

MHHC is composed of six steps (Fig. 2): 1) Creation of DEM (P1), 2) Derivation of hillshades from DEM (P2a) plus their rotation (P2b), 3) Line extraction based on edge detection (P3), 4) Noise reduction (P4), 5) Cluster line analysis (P5), 6) Classification of lineaments (P6). The user driven parameters are marked by P in Fig. 2 and also in the text.

The algorithm was written in Python using the functionality of ArcGIS tools via ArcPy library. Line extraction was handled by PCI Geomatica software. The EASI scripting language was used to control PCI Geomatica tools.

3.1. DEM creation

The algorithm works with three types of input data:

1. the vector elevation data (contour lines and elevation spots),
2. the vector LIDAR data (elevation spots),
3. the raster DEM.

The output raster DEM is generated (or resampled in the case of the input raster DEM) within the boundary of the study area and with a specified output cell size. The spatial resolution is chosen depending on the scale and purpose of the analysis (P1 in Fig. 2). The raster pre-processing is part of the line extraction step which uses the LINE module (see Section 3.3 for details).

3.2. Hillshades creation

Masoud and Koike (2011a), Mallast et al. (2011) and Abdullah et al. (2010) mentioned the dependency of results on the

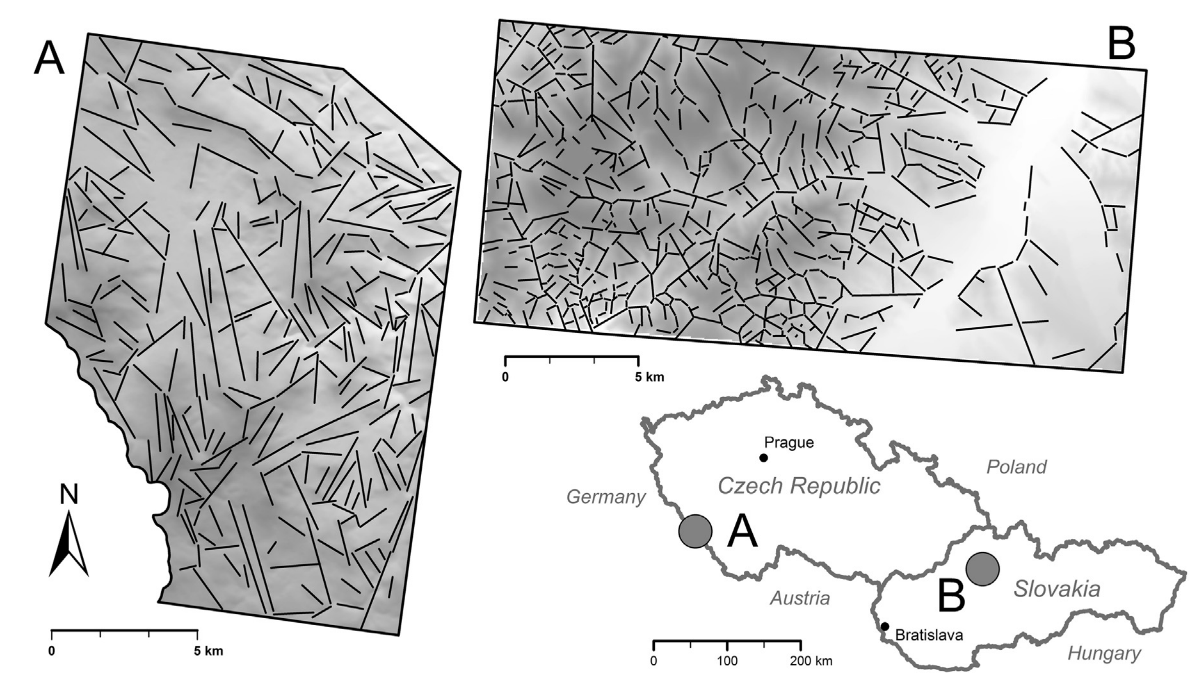

Fig. 1. Manually determined morpholineaments in both study areas. A) Bohemian Forest (surroundings of Prášilské jezero – lake). B) Central Western Carpathians.