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Automatic mapping of tectonic lineaments (faults) using methods and techniques of Photointerpretation / Digital Remote Sensing and Expert Systems

Research Team

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Introduction

Geologic lineament mapping is considered as a very important issue for problem solving in engineering, especially, in site selection for construction (dams, bridges, roads, etc), seismic and landslide risk assessment [1], mineral exploration [2], hot spring detection, hydrogeological research, etc. [3].

Lineament photointerpretation is a quite subjective process, requires expertise, training, scientific skills and is time consuming and expensive. Therefore, the need arises for automation of photointerpretation in order to reduce subjectivity and to help the analysts. This can be achieved using computer-assisted techniques, e.g. image processing and analysis techniques, pattern recognition and expert systems.

State of the art

From the thorough examination of the literature it was inferred that, computer-assisted methods for the detection of structural (tectonic) lineaments (namely faults and joints), were exclusively based on edge enhancement or spatial filtering techniques (directional and / or gradient filters) ([4], [5], [6], [7]), as well as morphological filters [8]). These methods produced edge maps requiring further processing (thresholding and thinning) for the linear segments to appear with one-pixel thickness. Optimal edge detectors (e.g. the Canny algorithm [9]) have already been successfully applied on natural scenes with quite satisfactory results (binary images with one-pixel thickness, efficient length and pixel connectivity), and this makes their application in geologic lineament mapping more tempting and worth investigating. Furthermore, length is stated as a crucial statistical parameter for lineament interpretation and classification and optimal edge detection techniques can produce segments with sufficient length and coherence.

Furthermore, edge extraction is not adequate for performing identification of geologic linear features, because they do not take the inherent geologic information into account. For this purpose, expert systems [10] and other knowledge-based systems [4] were implemented. The main drawback of these systems was their inefficiency to visualize the identified lineaments in a unified graphical environment.

Motivation and Objectives

The last decade, many approaches have been made worldwide to the direction of automated extraction of geologic (especially, tectonic) photolineaments. These efforts particularly focused on the implementation and use of feature extraction techniques, without taking into account the geologic nature of the features. The latter led to the extraction of “spurious” (non-interest) features, since these extraction techniques were solely based on the physical properties of the image (such as the brightness value of the feature) and not on the contextual properties of the surrounding terrain.

All the above conduced towards the design and implementation of a methodological framework for the identification and mapping of the topographic and geologic (mostly tectonic) photolineaments using topographic and geologic maps, satellite imagery and a Digital Elevation Model of the research areas.

The basic aim of this framework was the attempt for a more objective formalization of the mapping process. The final deliverable of our research project was a knowledge-based system for the identification of the topographic and geologic photolineaments which accomplished the following goals:

- The derivation of an edge map using the appropriately selected linear feature extraction algorithms and
- The assignment of those edges into topographic, geologic and other lineaments using spatial / contextual, spectral and semantic identification criteria and the construction of the final lineament map.

Methodology and Results

The applied methodology was divided into four (4) implementation phases:

A. Geodata acquisition and preprocessing

B. Main processing of the selected data

C. Investigation and implementation of selected edge detection and edge linking algorithms

D. Design of a knowledge-based lineament identification system.

A. Geodata acquisition and preprocessing

This stage was further divided into the following sub-phases:

- *Site selection:* Two different geotectonic fields were selected, namely the sedimentary terrain of Alevrada, Central Greece and the old volcanic terrain of Vatoussa, Lesvos.

- *Geo-data selection:* For this project (a) LANDSAT-TM and ETM+ multispectral images, (b) DEM and (c) ancillary data (topographic and geologic maps with a scale of 1:50,000), were acquired.
- *Data preprocessing:* The LANDSAT images and the DEM of the same areas were geometrically corregistered with the scanned topographic map of the same area (with a scale of 1:50.000) and geodetically transformed into the Transverse Mercator Projection and the Hellenic Geodetic Datum (HGRS87). Band 5 of the LANDSAT 5-TM image was selected for the implementation of the edge detection algorithms, because of its usefulness in lithological and structural mapping [11]. This band was initially contrast-stretched using a linear transform so as to achieve a visually better image for input into the edge detection algorithms.

B. Main processing of the selected data

The aim of this stage was the construction of appropriate thematic maps for their direct / indirect introduction to the knowledge-based lineament identification system. The thematic maps were derived using digital remote sensing methods and techniques applied on the satellite imagery and the DEM. Each of the derived thematic data represented a parameter for the identification of the lineament type (e.g. NDVI map stands for the existing vegetation of the terrain which is indicative of a well-drained system and the lithological terrain type).

Indicative used remote sensing methods and techniques were the following: (a) RGB color and pseudocolor composites, (b) Vegetation indices *MSAVI* and *NDVI*, (c) Spectral indices, (d) PCA analysis, (e) ISODATA and Maximum Likelihood Classification (MLC), (f) Shaded relief maps, (g) Gradient and aspect maps, (h) Horizontal curvature and cross-sectional convexity maps, etc.

Indicative results of these thematic maps are illustrated in Figure 1.

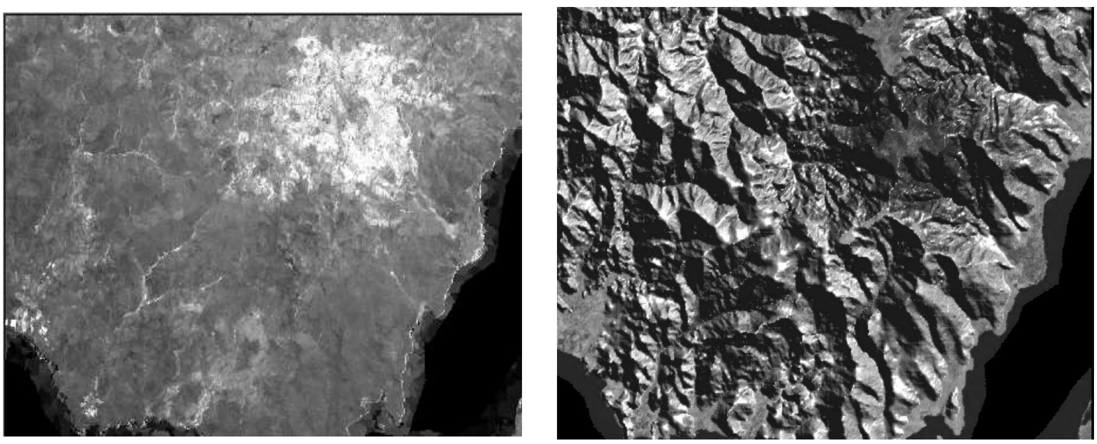

Figure 1. (From left to right): (1) The NDVI map of Vatoussa. (2) Shaded Relief Map of the DEM of the same area.

C. Investigation and implementation of selected edge detection and edge linking algorithms

The aim of this stage was the derivation of the final edge map to be identified in the knowledge-based lineament identification system.

The algorithms used at this stage stemmed from the domain of edge detection ((1)-(7)) and edge linking (*HOUGH* Transform) ((8)-(9)), and were the following: (1) The Canny algorithm [9], (2) The Rothwell algorithm [12], (3) The Bezdek algorithm [13], (4) The *LOG-LIN* algorithm [14], (5) The *EDISON* algorithm [15], (6) The Black algorithm [16], (7) The *SUSAN* algorithm [17], (8) The Fitton-Cox algorithm [18] and (9) The *KUIM* algorithm [19].

Indicative results of the application of the selected algorithms are illustrated in Figure 2.

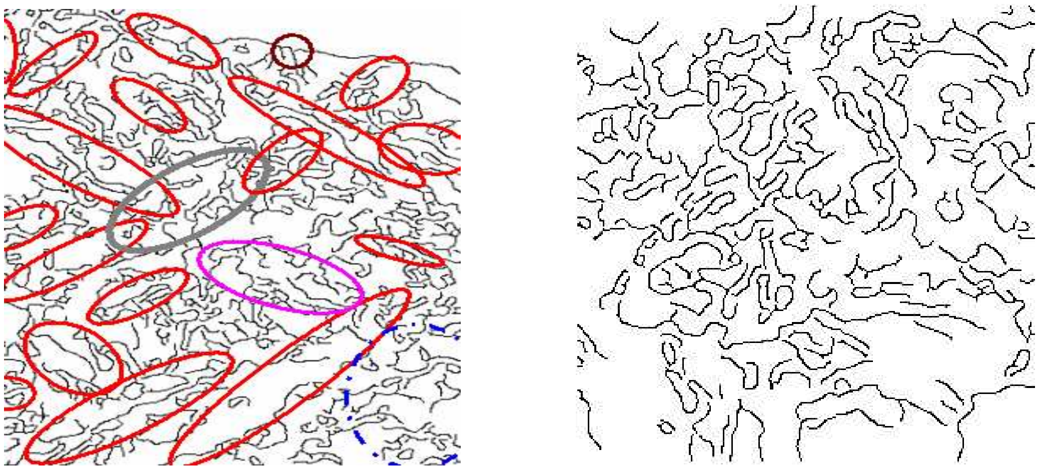

Figure 2. (From left to right): (1) The Canny algorithm applied on band 5 of the LANDSAT image of Alevrada. (2) The same algorithm applied on the image of Vatoussa

The evaluation of the applied edge detectors was performed using qualitative (visual assessment) and quantitative criteria (evaluation metrics by Kitchen - Rosenfeld [20] and Abdou - Pratt [21])

D. Design of a knowledge-based lineament identification system

The aim of this stage was the design of a knowledge-based system that could identify and discriminate the geologic and topographic lineaments from the non-interest linear segments. This system was designed following certain procedural stages that included: (1) the *conceptualization* of the lineament identification problem, (2) Knowledge *formalization* based on the intrinsic characteristics of the study areas and the acquired geo-data for the formation of the Lineament Knowledge Base (LKB), (3) *Multi-scale segmentation* of the input data in the object-oriented image analysis environment of **eCognition** and (4) *Knowledge representation* of the LKB using fuzzy rules.

Indicative results of the knowledge base implementation stage are presented in Figure 3.

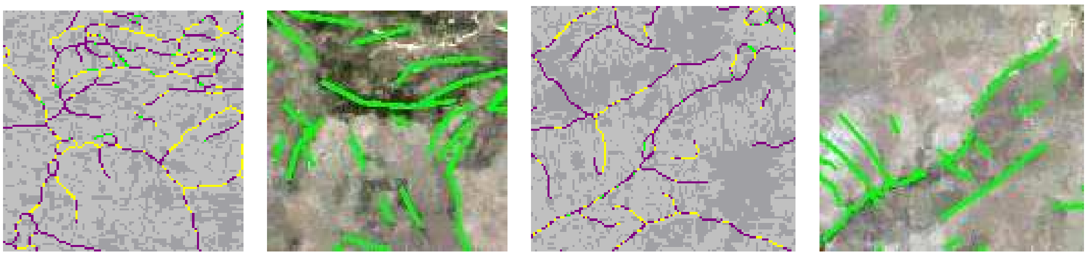

Figure 3. Results of the lineament identification system of Vatoussa. With yellow color topographic ridge segments are depicted, with mauve color fault segments are indicated. With green color fault segments are indicated on the ground-truth map of the same area subset.

Conclusions

We conclude that the proposed methodology for the design of a knowledge-based lineament identification system provides quite satisfactory results (as inferred from Figure 3) for geological purposes. Due to its multi-scale feature detection and representation ability, this methodology might potentially be adopted for the identification of several features of geological (e.g. landforms), or even anthropogenic origin (e.g. road segments, etc).

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