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Extraction of Surface Properties from a High Accuracy DEM Using Multiscale Remote Sensing Techniques

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Abstract

Research into understanding relationships between landscape pattern and process has been influenced by the introduction of fractal geometry and the advent of fractal analysis. With the increasing availability of high-resolution digital elevation data from increasingly larger areas of the Earth's surface, together with advances in geocomputation and the field of geomorphometry, the concept of fractals has became even more interesting for local level environmental applications. The work described in this paper aims at investigating the applicability of multifractal based techniques for the representation of high-resolution digital elevation models. A multifractal algorithm, initially developed for image processing, is employed for the construction of a multiresolution representation and for the reconstruction of approximate elevation models with arbitrary accuracy. It is showed to fully describe digital elevation models, while simplifying them. By addressing the issues of structure and scale, the multifractal formalism provides, unlike classical geomorphometrical tools, scale-invariant attributes for characterizing topography and landscapes. It is showed that the multifractal approach is a useful tool to analyze the topography represented by the digital elevation model.

1. Introduction

As a representation of the Earth's surface, a *Digital Elevation Model* (DEM) provides the basis for many geographic applications like Geographic Information Systems, topographic analysis, hydrological or geomorphological modeling or landscape visualization (Ackermann 1994). Indeed, extensively used topographic attributes, such as slope, aspect or curvature, can be straightforward computed over the grid structure of a DEM (Ackermann 1994, Chrysoulakis *et al.* 2003). However, the general ability of the DEM to represent the topography depends on both the roughness of the true surface and the resolution. Namely, since terrain contains variations on many scales, and different uses of terrain models require different accuracy, the scale imposed by the DEM resolution affects the topographic parameters (Quattrochi & Goodchild 1997). Relying on the observation that relief conserves the same statistical characteristics over a wide range of scales, some DEM characterization techniques have been developed that perform a *multiscale* analysis of the elevation data (Zhu *et al.* 2002, Bjørke & Nilsen 2003). One of the approaches that appears particularly fruitful in this context is *fractal* analysis (Burrough 1981, Goodchild & Mark 1987), based upon the concept of statistical *self-similarity* (Schertzer & Lovejoy 1991). *Topography* is not self-similar (Mark & Aronson, 1984), however it is well recognized that self-similarity makes fractals useful to describe and simulate topographic surfaces (Huang & Turcotte 1990, Xu *et al*., 1993, Polidori *et al.* 1991).

In particular, (multi)fractal (and, more generally, multiscale) methods are getting more and more importance for a scale-sensitive modeling of *high-resolution* (HR) elevation data. Indeed, with the increase of the resolution, *e.g.* required for local studies, DEM is a more detailed representation of the real

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surface (Chrysoulakis *et al.* 2004), and, as a consequence, familiar geometry of regular shapes does not capture well the irregular and less structured shapes displayed. HR DEM capture finer details of the land surface (although they do not necessarily provide a more accurate representation of topography). In this paper, we investigate the use of a *multifractal* model for the representation of HR DEM. More precisely, we refer to an existing technique, initially designed for image resolution reduction (Turiel & Parga 2000, Grazzini *et al.* 2004), in order to extract multifractal features. Indeed, HR DEM are usually dense with a lot of redundancy, which can be encoded efficiently by compression techniques: adjacent values are highly correlated, *i.e.* the terrain does not make unexpected shifts over small areas (*e.g.*, in flat areas, the elevation does not change, however the same elevation value is stored many times). This property makes compression algorithms attractive for DEM (Zhu *et al.* 2002, Bjørke & Nilsen 2003), as they try to lower storage requirements by removing redundancy in the data. Precisely, the algorithm we propose enables: (i) the construction of a multiresolution representation, which provides reasonable measures through different scales of observation, (ii) the reconstruction of an approximate terrain with arbitrary accuracy, which is especially suitable to capture the characteristics of terrain features. The multifractal representation of the DEM can be further exploited in order to derive information about the topographical property.

The paper is organized as follows: in the next section, we briefly discuss the scale issue for DEM analysis and we remind the multifractal model adopted herein; the results of the application of this model over a DEM produced, for the area of Heraklion (Greece), with HR multispectral ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery are then presented and discussed in section 3; finally, we propose in section 4 the natural extent that should be given to this preliminary work.

2. Theory and methods

2.1 The scale issue and the fractal approach

Topography results from many different processes operating over a range of spatial (but also temporal) scales. Thus, *scale* questions must be addressed to fully understand how these processes are reflected in the geographic pattern and form of the landscape (Quattrochi & Goodchild, 1997). Scale refers to the spatial dimensions at which entities, patterns and processes can be observed and measured. The resolution of a study area as represented by a DEM imposes this measurement scale. For this reason, an appropriate geometrical description of DEM should explicitly incorporates and model scale dependencies.

Specifically, search for scale-invariant topographic representations has considerable importance, *e.g.* in hydrological and geomorphological research. Traditional topographic parameters, such as slope, aspect, curvature, have not been shown to be scale invariant. One such scale-invariant parameter may be the fractal dimension used to characterize both self-similar and self-affine features[2]. Fractal analysis has been found to provide an appropriate mathematical tool for the analysis of complex natural topography (Burrough 1981, Mark and Aronson 1984) showing that it can capture essential characteristics of rough surfaces that conventional morphometric statistics may not (Xu *et al.* 1993, Huang & Turcotte 1990).

However, despite the growth of fractal analysis within Earth sciences, there remain some concerns over the extent to which natural surfaces are truly fractal if they do not display fractal behaviour across a wide range of scales (Polidori *et al.* 1991, Gallant *et al.* 1994). One property of fractal objects is that they reveal more detail as the computation proceeds and their shape appears unchanged when examined by varying magnification (Goodchild & Mark 1987). It follows that topographic surfaces are not well represented by

[2] Self-similarity refers to features where each small portion of an object is exactly like a larger part when magnified; self-affinity refers to features where, after magnification, the resemblance is not exact, but only statistical (Schertzer & Lovejoy 1991). According to fractal models, true self-similar surfaces would exhibit constant fractal dimensions at all scales.

conventional monofractal applications, as they exhibit multiscaling which can not be described by a single fractal dimension (Schertzer & Lovejoy 1991). They are better characterized using the more conceptually assumption of multifractal behaviour (Schertzer & Lovejoy 1991, Quattrochi & Goodchild 1997).

2.2 The multifractal representation

The multifractal formalism is known to perform well for both the analysis of real world terrain data, as well as the generation of synthetic terrain surfaces. It is generally recognized that the Earth exhibits multifractal characteristics (Schertzer & Lovejoy 1991). We make use of the multifractal model introduced in (Turiel & Parga 2000) to hierarchically represent the DEM. In practice, the algorithm described in (Grazzini *et al.* 2004) is applied on the DEM seen as the 2D planar projection of the topographic surface. Indeed, surface elevation, sampled at regular intervals, is treated as a height attribute, enabling the conversion to a greyscale image: extraction of structures from the DEM is then analogous to a pattern recognition problem. In the context of signal/image processing, the multifractal model mainly assumes that local singularities exist within images and that they are arranged in a complicated mesh of different scale-invariant (fractal) structures, each of them containing useful information about the variability of the signal at a given scale. It enables to define, through wavelet analysis (Turiel & Parga 2000), a local feature quantifying the strength of the transition the signal undergoes around each pixel in the image which is scale-invariant: the *singularity exponent*. This feature describes the scaling law behaviour in the image and enables to relate information across scales. For a full discussion on the model and a detailed description of the algorithm, the reader is refered to (Turiel & Parga 2000, Grazzini *et al.* 2004).

Note that, given the debates over what is fractal or not, we recognize that a surface does not need to be (multi)fractal for performing a multifractal analysis. What matters most is the reliability of the method used to determine the fractal parameters, and the way in which it is subsequently interpreted (Turiel *et al.* 2005). The approach does not depend on the assumption that topography is fractal and leads us to the general aim of the paper, which is to use fractal analysis to explore the scaling characteristics of the DEM.

3. Data and processing

3.1 The studied site and the DEM

The current study was carried out for the area of NW Heraklion Prefecture (Greece). In the framework of the REALDEMS (REmote sensing Application for Land cover and DEM Service) project, HR multispectral ASTER imagery (on board NASA's Terra spacecraft) was processed to produce accurate topographic surface with planimetric accuracy of 15.0m (Chrysoulakis et al., 2004): see Figure A, top left. These data have been selected because of the great importance of water resources for Greek islands.

3.2 Preliminary results

In Figure A, we point out the main capabilities offered by the multifractal approach formulated in the previous section. The results of the multifractal analysis performed on a DEM excerpt (top, middle) are presented: the computation of the singularity exponents provide a hierarchical representation of the image (bottom, left) which is further exploited to reconstruct an image similar to the original one (bottom, middle). It is noticeable that the multifractal reconstruction enables to retain the relevant edges without significant artifacts, no matter at which scale they happen. It results in very nicely smoothed homogeneous areas while the main information contained in the edges of the structures are preserved. Indeed, the image is partially reconstructed from the extraction of its most important features (Grazzini e*t al.* 2004). Thus, the structures are not geometrically damaged, what might be fatal for further computation. Consequently, when computed on the reconstruction instead of the original image, topographic parameters are mainly preserved; *e.g.* much of the drainage network remains intact, contributing area and contours computed from the original DEM and from the surface reconstructed are very similar (right).

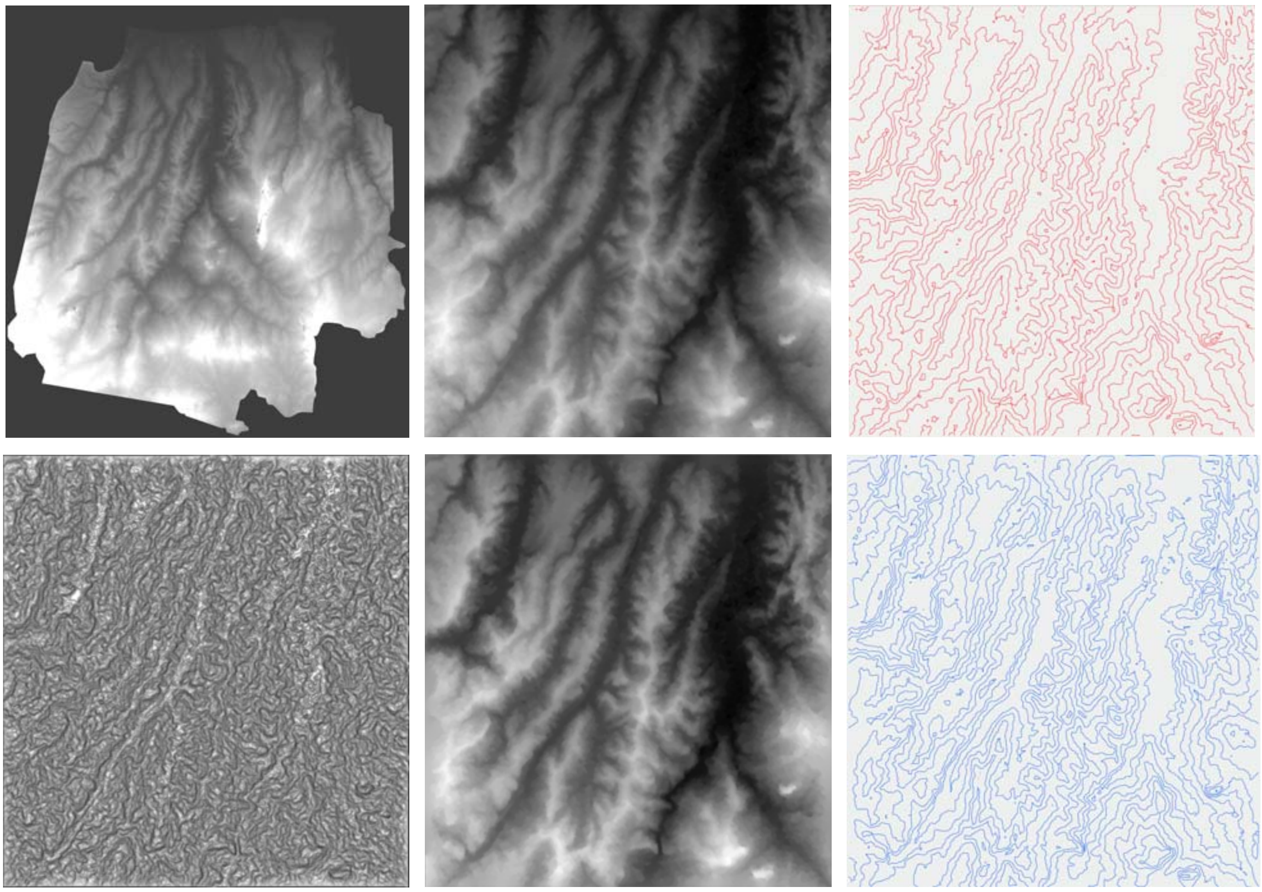

Fig. A: From left to right, top: original DEM produced with ASTER images covering Heraklion Prefecture, subregion of the DEM and representation of the drainage contours computed over this excerpt (red); bottom: local multifractal features computed over the previous subregion (the brighter a pixel, the greater the singularity at that point), corresponding multifractal reconstruction (*PSNR*=23.97dB) and contours extracted from it (blue). By visual inspection, the contours of the drainage network are close.

4. Conclusion

In this paper, an approach to represent topographic surfaces available in HR DEM is proposed. This is very important for local level environmental applications where HR determination and visualization of topography of the Earth's surface is required. A model based on the multifractal formalism for image processing and related with data compression concepts is adopted. It is showed to provide interesting solutions for the representation of the large amount of data available in HR DEM and for the extraction of significative features. It appears to offer new possibilities for interpolation within DEM. The main idea is to perform a simplification of DEM representation by reducing the resolution while preserving specific multifractal features. The efficiency of the methodology mainly lies on the ability of multiscale techniques to reproduce known experimental, statistical and geometrical properties of the structures under study. In particular, it was expected that the multifractal approach captures the basic nature of the Earth's topography, in a way unlike other geomorphological attributes, and provides a means for describing landscapes.

However, while the physical significance of landscape fractal characteristics still needs to be explained, some questions regarding the characteristics of topographic surfaces that induce the observed scale dependence of topographic attributes still remain. In particular, current research is geared towards developing methods to automatically produce and analyze superimposed geological structures.

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