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Texture analysis by fractal descriptors over the wavelet domain using a best basis decomposition

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HIGHLIGHTS

- The proposed method extracts texture descriptors based on wavelets fractal dimension.
- It combines fractal geometry and in wavelets theory for the texture analysis.
- The method demonstrates excellent performance in different datasets.

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ABSTRACT

This work proposes the development and study of a novel set of fractal descriptors for texture analysis. These descriptors are obtained by exploring the fractal-like relation among the coefficients and magnitudes of a particular type of wavelet decomposition, to know, the best basis selection. The proposed method is tested in the classification of three sets of textures from the literature: Brodatz, Vistex and USPTex. The method is also applied to a challenging real-world problem, which is the identification of species of plants from the Brazilian flora. The results are compared with other classical and state-of-the-art texture descriptors and demonstrate the efficiency of the proposed technique in this task.

1. Introduction

In the last years, the literature has shown a large number of works applying fractal geometry to image analysis and computer vision. Such works have applied the fractal theory to the analysis of images in areas as diverse as botany [1], astronomy [2], biomedicine [3], face recognition [4], image segmentation [5], among many others.

Nevertheless, most of these works employ only the fractal dimension to describe the object of interest. Although in some situations this is enough to model the solution of a problem, in many cases a more in-depth approach is necessary. In fact, the fractal dimension is a single real value and cannot express all the richness of a more complex object. Besides, in case of real-world objects, this value depends on the scale of analysis and thus it is not a robust global measure. Some different approaches have been proposed to address these issues, such as the multifractals [6], local fractal dimension [7], multiscale fractal dimension [8] and fractal descriptors [9].

Here, we focus on the fractal descriptors approach, considering the promising results previously obtained both over benchmark textures as well as in different applications [10,9,11,12]. The general idea of such descriptors is to extract the features from the self-similarity (power-law) curve of the image. Usually, such features are computed through classical

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methods of fractal dimension computation. However, despite the large number of works combining wavelet and fractal analysis in the literature [13–15], as far as we know, no work has proposed to analyse the power-law curve in the wavelet domain.

In this way, we propose a novel method to obtain fractal descriptors based on the best-basis selection algorithm to compute the fractality of the wavelet space. The fractality function and, consequently, the fractal descriptors are obtained from the cost function and magnitude of this particular kind of wavelet transform. In this way, such descriptors represent the complexity expressed at different levels of details within the texture, combining the scale decomposition of the wavelets with the self-similarity/complexity analysis of fractals and allowing to obtain a rich representation of the analysed image.

The proposed fractal descriptors are compared to other classical and state-of-the-art texture descriptors in the classification of benchmark textures. Its performance is compared to the Gray-level Co-occurrence Matrices (GLCM) [16], Multifractals [6], Fourier [17], Gabor-wavelets [18] and Local Binary Patterns [19]. The efficiency of our proposal is tested in Brodatz [20], Vistex [21] and USPTex [22] textures, besides a real-world dataset of leaf images of plants from the Brazilian flora. The classification is carried out by Linear Discriminant Analysis (LDA) [23] and the results show the best performance of the proposed method in all tested datasets. This work is divided into nine sections. In the next section, we show a brief description of some related works. Section 3 describes fractal geometry and more specifically fractal dimension. In Section 4, we describe the wavelet transform using best basis decomposition and its inherent fractal-like behaviour. Section 5 shows the proposed method, while Section 6 describes the experiments performed with the aim of demonstrating the efficiency of the proposed technique. Section 7 shows and discusses the results for the benchmark databases. Section 8 applies the proposed descriptors to a real world problem (plant analysis) and Section 9 expresses the conclusions of the work.

2. Related works

In the literature, there are a reasonable number of works proposing to combine wavelet decomposition and fractal analysis to extract features from texture images. To achieve this objective, different strategies are proposed and some interesting results are obtained for particular applications. Most of such methods can be roughly divided into two groups: based on multifractals and based on the fractal dimension.

The multifractal analysis based on wavelet leaders [13] is one of the most popular approaches. Wavelet leaders are the maximum local response of a discrete wavelet transform at a particular scale and spatial neighbourhood. Such values are employed to estimate the local Hölder exponent and, following the classical multifractal scheme, the image features f_α are given by the fractal dimension of each set of points in the image whose Hölder exponents equal α. Other works [24,15,25] propose some enhancements to this method, most of them adding some type of invariance to the features.

The other category of methods is that relying on computing the fractal dimensions of sub-bands of the wavelet decomposition. An interesting solution of this type is described in Ref. [14], where the author obtains features from the fractal dimension of different sub-bands of a wavelet-packet transform. He also uses the dimension as a criterion to decompose or not a sub-band. In Ref. [26], the fractal features are computed over the sub-bands as well but using an over-complete wavelet transform. In Refs. [27,28], the Hurst exponent (related to the fractal dimension) is estimated from statistical momenta of a wavelet-packet transform.

There are still some works that fall outside any categorization but they are less related to our proposal. This is the case of works like [29], where fractal and wavelet descriptors are provided independently, or [30], where a bank of Gabor filters are employed, and despite being theoretically related to wavelets, in practice, there is no relation with the wavelet decomposition.

Nevertheless, the method proposed here does not suit in any of these categories as there is no computation and categorization of local Hölder exponents, like for multifractals, and the fractal dimension is not used either. Instead the entire power-law curve intrinsic to fractal analysis is used to provide the image features, ensuring, in this way, a direct and at the same time complete description of the texture.

3. Fractal geometry

3.1. Fractal dimension

The formal concept of fractal dimension is defined in Ref. [31] and coincides with the definition of the Hausdorff–Besicovitch dimension dim_H. Mathematically, the dimension dim_H of a geometric set X is calculated by the following expression:

$$dim_H(X) = \inf_d \{d \geq 0 | C_H^d(X) = 0\}, \tag{1}$$

where $C_H^d(X)$ is the d-dimensional Hausdorff measure of X, defined by:

$$C_H^d(X) = \inf_{r_i} \left\{ \sum_i r_i^d \middle| \text{there exists a cover of } X \text{ using balls of radii } r_i > 0 \right\}. \tag{2}$$