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Local fractal dimension and binary patterns in texture recognition[☆]

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ABSTRACT

The present work proposes a new texture image descriptor, combining the local binary patterns extracted from the grey-level image (classic approach) with those extracted from the local fractal dimension at each point of the image. In this way, these descriptors express two important measurements from the image, i.e., the variation among pixel intensities in each local neighbourhood and the local complexity (pixel arrangement) at each point. Such combination provides a rich and robust descriptor even for the most complex textures. The effectiveness of the proposed solution is evaluated in the classification of two well-known benchmark databases: UIUC and USPTex, showing that the combined features outperform all the other compared approaches in terms of correctness rates in the classification of grey-scale texture images.

1. Introduction

Fractal-based techniques [4,15] and Local Binary Patterns (LBP) [18] have been applied to a large number of problems in different areas, particularly, those problems that can be addressed by the analysis of texture images [7,8].

Since the initial works, the literature has presented a number of improvements for both techniques. Regarding LBP, several adaptations have been described both to enhance the image analysis as well as to best fit some particular applications. For instance, in [19], an enhanced rotation-invariant descriptor is proposed. In [10], the authors propose the completed LBP (CLBP) by separately considering the magnitudes and signs of the differences among neighbour pixels. Still, in [20] an extension to a ternary system to represent local patterns is proposed. Besides, adaptations of the method can be easily found for face recognition [1], dynamic textures [24], iris recognition [14], video surveillance [2], etc.

On the other hand, fractal-based analysis has also evolved in several ways since Mandelbrot [15]. The fractal dimension was extended to more complete descriptors in methods like multifractals [23], where the fractal dimension is computed over sets of pixels in the image satisfying certain regularity criteria. In multiscale fractal dimension [17], some geometrical features are extracted from the self-similarity curve of an object to compose the descriptors. In fractal descriptors [4], the entire self-similarity curve is used. In local fractal dimension approaches [13], a fractal measure is estimated over each pixel by taking into account the respective neighbourhood.

Although both fractal-based and LBP techniques present interesting results, the combination of them is still not explored in texture analysis. A particular motivation to verify such combination is the local approach efficiently utilized by LBP, but that could be leveraged by considering measures more advanced than the simple pixel intensity. In fact, the grey-level of a pixel is a simplistic measure of the image and cannot faithfully express important properties of the image, such as light changing, roughness, etc. On the other hand, fractal measures provide a realistic framework for describing natural structures and can richly represent these properties.

In this context, this work proposes to combine the LBP features computed over the grey-level values with those computed over the local fractal dimension of the image. The effectiveness of the proposed features is assessed on classifying two well-known texture data sets used as benchmark, that is, UIUC [12] and USPTex [3]. The success rate of our method is compared to other texture descriptors in the literature and our approach outperforms all of them.

2. Local binary patterns

Local binary patterns, introduced in [18], is one of the most successful approaches to texture analysis, providing great results in many applications. The method constructs a histogram of patterns of threshold in the neighbourhood of each pixel in the image. To obtain the code of a pixel, the intensity of this pixel is compared to the pixels in its 8-neighbourhood in clockwise direction. If the neighbourhood pixel intensity is greater than the central pixel, we assign the value 1, otherwise, we assign 0. This code of 0s and 1s

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(binary) is converted into a decimal value. Finally, the LBP features are given by the histogram of the binary codes. Although there are enhanced versions of LBP, here we adopt its original definition using 8-neighbourhood, as we are interested only on the local patterns.

3. Fractal theory

Fractals are geometrical structures characterized by two key properties: infinite self-similarity and infinite complexity. The first property implies that a fractal is composed of repeated copies of itself at reduced scales, while the second one means that the object has different structural details at any scale. The geometry of such unconventional objects, named fractal geometry, is an interesting alternative to the classic Euclidean geometry. As well as in the Euclidean reference we can measure the objects in different ways, like using area, perimeter, etc., in fractal geometry the most used measure is the fractal dimension.

There are several methods proposed to estimate the fractal dimension, all of them follow a simple general rule. Let X be a fractal object represented by a set of points in the N-dimensional space. The fractal dimension D is given by

$$D = \lim_{r \to 0} \frac{\log(\mathfrak{M}(r))}{\log(r)}, \tag{1}$$

where $\mathfrak{M}$ is a measure of self-similarity which depends on the particular method and r is a scale parameter.

3.1. Local fractal dimension

Even though the fractal dimension is a rich and powerful metric for natural objects, it is a global feature and not efficient to represent local properties expressed in the level of pixels and small neighbourhoods. There are different approaches to estimate a local metric of complexity and self-similarity [6,15]. Here, we use the density method, as described in [23] (Fig. 1). This method assigns the value of a density function to each pixel. Let $x \in \Re^2$ be the pixel being processed and let $B(x, r)$ a closed ball with centre at x and radius r. The density function $D(x)$ at the point x is given by

$$D(x) = \lim_{r \to 0} \frac{\log(\mu(B(x, r)))}{\log(r)}, \tag{2}$$

where μ is a finite and regular Borel measure defined for $r > 0$ as $\mu(x, r) = kr^D(x)$, for some real constant k. The work in [23] proposes three ways of defining the measure μ of the texture image I in practice. Here, we employ the most simple and direct solution, which defines it as

$$\mu(B(x, r)) = \int\int_{B(x,r)} G_r * I dx, \tag{3}$$

where $*$ expresses for the convolution operator, which in discrete domain for an image I and an $m \times n$ kernel K is defined at each point with coordinates (i, j) (image space) by

$$C(i, j) = \sum_{i'=1}^{m} \sum_{j'=1}^{n} I(i + i' - 1, j + j' - 1) K(i', j') \tag{4}$$

and G_r is the radial Gaussian kernel with the variance σ multiplied by the factor r:

$$G_r = \frac{1}{r\sigma\sqrt{2\pi}} e^{\frac{-||x||^2}{2\sigma^2 r^2}}, \tag{5}$$

where σ is a parameter empirically set. In discrete images, the value of μ in Eq. (3) simply corresponds to the average pixel intensity inside the disc $B(x, r)$. This function measures how the intensities scale with the distance, following a power-law relation, and gives us a useful measure of the uniformity around each point

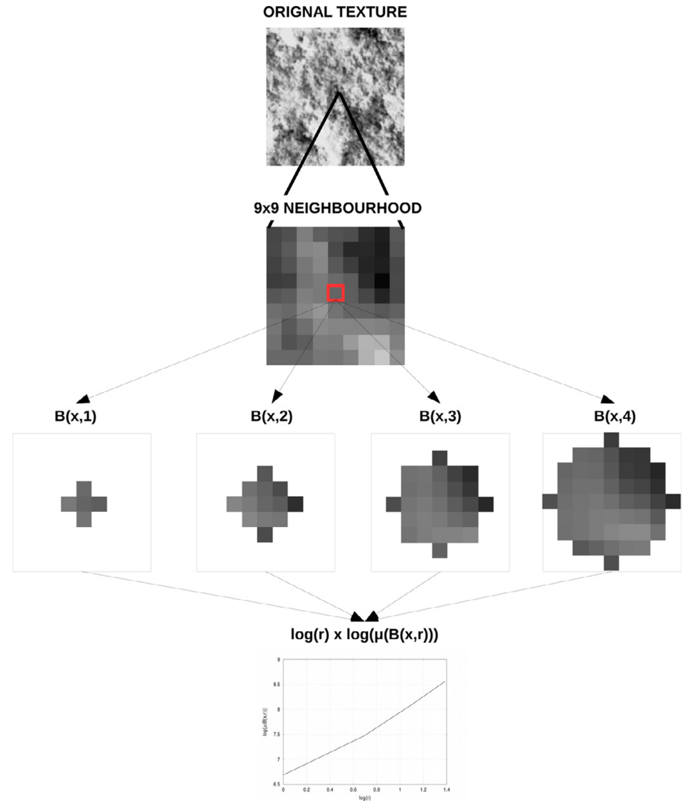

Fig. 1. Local fractal dimension measuring the irregularity of an object. From top to bottom, the original texture, the neighbourhood of a pixel where the dimension should be estimated, the smoothed ball with $r = 1, \ldots, 4$ and the plot of $\log(r) \times \log(\mu(B(x, r)))$.

of the image. The local dimension computed over the entire image is illustrated in Fig. 2(a). As can be seen, the dimension is larger at the edge points, caused by the discontinuity in the pixel intensities.

4. Proposed method

The effectiveness of LBP method is well known and discussed in the literature. Nevertheless, while the pixel intensities provide an essential and direct view of the texture, there are other perspectives of the same texture described in the literature and that could be better explored in the LBP method.

One of such alternative views from the image is given by the fractal dimension and more particularly the local fractal dimension in each pixel of the texture. The fractal dimension measures how the most regular and irregular patterns are distributed over the texture, giving a mapping of the complexity at each point. This information is capable of predicting, for instance, whether a pixel pertains to a homogeneous region or a heterogeneous neighbourhood. For example, the local dimension inside an area of the image containing an edge separating two regions with distinct aspects would be larger, given the higher variation in the pixel intensity present in that part of the image, resulting in the faster growing of the log–log curve. This is a meaningful local feature that cannot be expressed by using the pixel grey-level. Furthermore, these two views also bring a description of the interrelationships among neighbour pixels both concerning the relative intensities and the level of self-similarities among those pixels. These are independent measurements that convey important information.

The proposed features are obtained by concatenating the LBP and local fractal descriptors, followed by the application of the