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Texture analysis using fractal descriptors estimated by the mutual interference of color channels

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A B S T R A C T

This work presents a method for color texture analysis based on fractal geometry. The method is based on its predecessor [4] and consists of mapping each color channel onto a surface and dilating such surface by spheres with a variable radius. The descriptors are obtained from the relation between the volumes of the dilated surfaces and the dilation radii. The dilation process creates a mutual interference among the color channels. The proposed descriptors measure the degree of such interference as well as the complexity of pixel intensity arrangements. This combination provides a robust and precise texture description. The efficiency of the method is assessed in a classification task of well-known texture data sets and the results demonstrate that it outperforms the best approaches described in the literature.

1. Introduction

The availability of inexpensive image capture devices, as well as the increase in processing power and memory of recent computers, promote the development and study of several approaches to image analysis. Such approaches use, in most cases, information about shapes, textures or colors of the image or some combination of these features. Notably, color is a powerful descriptor of objects analyzed in many research areas, as it is a psychophysical attribute with fundamental importance in human perception and is also relevant for any computer vision system [22]. Applications of color analysis range from Material Science [1,13] and Optics [5,36] to Computer Science [26,27] and Medicine [17,23]. Due its relevance, several works have been developed in recent years in color analysis, examples are [6,18,21,25,32,39,41,46].

Roughly speaking, color texture analysis can be divided into two categories [28]:

1. Methods that process color and texture information separately;
2. Methods that consider color and texture as a connected phenomenon.

The methods in the first category assume that spatial structure variations are independent of the color distribution and hence use different and independent computational methods to analyze the same image. The obtained features can be combined in a last stage to be used in the classifier. A simple example is the use of Gabor features [30] and histograms [35] to characterize the spatial structure and color distribution, respectively.

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In the second category, no separate color feature is used. These methods characterize the color distribution and spatial structure jointly, without auxiliary methods. Multichannel versions of gray-level texture descriptors are the most common methods here. A simple example is the use of Gabor features on R, G and B channels simply concatenated into a color texture descriptor [28].

The predecessor of the method proposed here [4] belongs to the second category, that is, is a multichannel version of the gray-scale fractal dimension applied to texture analysis [2]. The work of Backes et al. [4] also proposed an alternative feature vector (ψ_{RGB}) where all the three channels are analyzed simultaneously (i.e. in a single three-dimensional volume). Although the main idea of this alternative is quite good and interesting, it does not present better results than the multichannel version.

Here, we propose a modified methodology in order to explore the relationship between the color channels of the texture pattern instead of the characteristics of a single color channel. This is an idea more related to an alternative feature vector proposed in [4] and presents excellent results, even better than their multichannel version.

The method initially maps each color channel onto a three-dimensional surface, then dilates each point on this surface using a sphere with a variable radius. For each color and each radius, we obtain the volumes of the dilated structure. These values express the complexity of the intensity/color distribution, that is, they quantify the level of detail at each analyzed scale. The measures of volume are concatenated to compose the feature vector.

We also do not consider the R, G and B mapped surfaces as a unique merged 3D structure as in [4]. Moreover, the method proposed here characterizes the spatial structure and color distribution without separating the image into channels, as done with Gabor features on R, G, B spaces. The proposed approach considers the influence of color and pixel area on neighboring colors, thus, for example, the blue channel influences the information from the red and green channels.

As the radius increases, the spheres start to interfere with each others, and the volumes are directly affected by the color distribution. In this way, the proposed descriptors combine the efficiency of fractals in describing complex structures with the richness of color analysis. Thus these descriptors are capable of capturing and describing nuances that represent fundamental aspects like roughness, luminance patterns and color distribution, among many others. These attributes are an expressive source of information for the visual system and also constitute a powerful resource for an automatic computer vision system.

That characteristic takes us to a method that combines color and texture at a higher level and is universally applicable. Unlike most methods for color texture analysis (that are multi-channel versions or combine different methods), the characterization of the color texture is done in a single step, exploring this kind of information in a different way.

The novel descriptors are tested on two color texture data sets known in the literature, and the results demonstrated that the developed method constitute a highly efficient texture analysis technique, comparable with the best known color texture methods in the literature. Particularly, the proposal achieved the best result in Outex database, whose classification is a hard problem considering the number of samples as well as the inter-class similarities.

This work is divided into seven sections. The following describes fractal geometry concepts, particularly, fractal dimension. The third section shows the description of the fractal descriptors theory. Section 4 explains the proposed methodology. The following section describes the experiments, while Section 6 presents the results for the experiments and Section 7 reports our conclusions.

2. Previous related works

Fractal descriptors in general are based on the idea of estimating the fractal dimension of an object of interest at different scales. It was initially developed as a generalization of another method named Multi-scale Fractal Dimension (MFS) [31]. In MFS, such scale-specific dimension is estimated by the derivative of the fractality curve and the object features are provided by particular properties of the derivative curve (minimum, maximum, area under graph curve, etc.). A particularly successful solution of MFS was applied to shape classification in [8,37], based on the Bouligand–Minkowski fractal dimension. In that case, the objects being analyzed are outlines of plant leaves represented in binary images. Each foreground object (outline) is dilated by circles of radius r and the fractality curve corresponds to the curve of the total area $A(r)$ of the dilated structure against the radius r in a $\log - \log$ plot.

Fractal descriptors as they are currently used have been presented in [2] in an application to the automatic identification of plant species. In this case, the image being analyzed is a gray-level texture, i.e., instead of a binary object of interest clearly identified now the gray-levels of all pixels in the image are relevant in the analysis. The use of an intensity image also requires the mapping of such image onto a three-dimensional cloud with the aim of providing a more suitable representation for the morphological dilation in the Bouligand–Minkowski method (called volumetric in this case). Now the dilation is carried out by spheres with radius r and the total dilated volume $V(r)$ is computed. Finally it was also noticed that using the fractality curve $\log V(r) \times \log r$ was more efficient than the derivative for texture images.

Considering that in many applications the information conveyed by the color feature of the image is of great importance, a color-adapted version of fractal descriptors was developed in [3]. In that work the authors propose to map the three color channels into a unique 3D space and dilate the cloud without any distinction between the channels.

Here, we propose a step further to the combination of channels in [3], by taking into account the interaction among the different color components. Such objective is accomplished by obtaining individual signatures of each color channel keeping track of the region in the space influenced by the dilation of the other channels. Unlike [3] where the dilation of a unique