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Fractal descriptors for discrimination of microscopy images of plant leaves

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Abstract. This study proposes the application of fractal descriptors method to the discrimination of microscopy images of plant leaves. Fractal descriptors have demonstrated to be a powerful discriminative method in image analysis, mainly for the discrimination of natural objects. In fact, these descriptors express the spatial arrangement of pixels inside the texture under different scales and such arrangements are directly related to physical properties inherent to the material depicted in the image. Here, we employ the Bouligand-Minkowski descriptors. These are obtained by the dilation of a surface mapping the gray-level texture. The classification of the microscopy images is performed by the well-known Support Vector Machine (SVM) method and we compare the success rate with other literature texture analysis methods. The proposed method achieved a correctness rate of 89%, while the second best solution, the Co-occurrence descriptors, yielded only 78%. This clear advantage of fractal descriptors demonstrates the potential of such approach in the analysis of the plant microscopy images.

1. Introduction

There is a strong need for the development of systems to predict plant species, given the difficulty in recognizing species as it requires in-depth knowledge about the species. Moreover, in most cases, it is necessary to obtain flowers, fruits or seeds for the species identification. However, these features are not available all the time for analysis [1]. Because of this weakness, it becomes necessary robust computing systems capable of recognizing species by analyzing only the plant leaves. Recent studies have shown that the leaves can also be an important element for classifying plant species, by obtaining features such as shape, texture and color for the characterization of each sample.

In [2], Casanova et al. extracted texture features of windows cropped from leaves obtained by a scanner. For this purpose they developed a system for feature extraction using Gabor wavelet filters. The feature vector used for representing each image was composed of the results obtained by computing the energy of each filtered image, varying the rotation and scale parameters of Gabor method. A variety of studies have investigated the potential of the complexity analysis of texture tissues and leaf anatomical characteristics by extracting the canonical fractal dimension and multiscale fractal dimension [3, 4, 5, 6, 7, 8]. Structures such as the cuticle, epidermis and full thickness of the leaves were analyzed through their color and texture characteristics [7, 9, 10]. On another studies, the vein is used for analysis of leaf species. In this case, the leaf image is segmented to extract the venation and some features of this venation are extracted for classification [11, 12, 9].

In this study we aim at exploring the use of information contained in the anatomical structure of cross-section median leaf veins obtained by microscopy for identification of species. The fractal dimension through the Bouligand-Minkowski volumetric method was extracted, generating texture descriptors for each histological image. Such descriptors represent the spatial arrangement of pixels within each texture on different scales, and such arrangements are directly related to the inherent properties of the material depicted in the image. The descriptors obtained by this method are generated from the expansion of a surface texture mapping of gray levels of each pixel in the texture. Subsequently, the classification of descriptors that represent the images is made by using the Support Vector Machine (SVM) classifier, with the best classification performance with about 89% accuracy, using 5-fold cross-validation whereas the second best approach compared, co-occurrence matrix, achieved a 78% accuracy.

This work is divided into 5 sections. The following section discusses the volumetric Bouligand-Minkowski fractal dimension for the extraction of texture features. Section 3 describes the experiments with 10 plant species ans the results of such experiments and the conclusions are stated on the Section 4.

2. Volumetric Bouligand-Minkowski Fractal Descriptors

Bouligand-Minkowski is one of the most used methods to estimate the fractal dimension of real-world objects. Here, we describe the approach to estimate the dimension of objects represented in a gray-level texture image.

Let $I : [1 : M] \times [1 : N] \rightarrow \Re$ be the digital image representing the texture. Firstly, this image is mapped onto a three-dimensional surface S, by means of the following definition:

$$S = \{(i, j, k)|(i, j) \in [1 : M] \times [1 : N], k = I(i, j)\}.$$

In the following, each surface point with co-ordinates (x, y, z) is dilated by a sphere with radius r. This radius is varied within a pre-defined range. For each value of r, the volume of the dilated structure $V(r)$ may be computed by:

$$V(r) = \sum \chi_{\mathfrak{D}(r)}[(i, j, k)],$$

where $(i, j, k) \in S$ is any point in the surface, χ is the characteristic function and $\mathfrak{D}(r)$ corresponds to the following set:

$$\mathfrak{D}(r) = \{(x, y, z)|[(x - P_x)^2 + (y - P_y)^2 + (z - P_z)^2]^{1/2} \leq r\},$$

where $(P_x, P_y, P_z) \in S$.

The fractal dimension D_{BM} is given by:

$$D_{BM} = 3 - \lim_{r \to 0} \frac{\log(V(r))}{\log(r)}.$$

Although the fractal dimension is a meaningful measure of an object, it is not sufficient to describe more complex patterns like those in the plant leaves analyzed here. Therefore, we employ a generalization of the fractal dimension, named fractal descriptors [4]. In this approach, instead of only using the global value of the dimension, a set of features are computed from the dimension taken at different scales. In practice, the set of descriptors u are obtained from Equation 2:

$$u : \log(r) \to \log(V(r)).$$

3. Experiments and Results

The volumetric Bouligand-Minkowski fractal dimension was applied to 127 vein images of 10 species of Brazillian flora: *Anacardium humile*, *Annona crassiflora*, *Aristolochia galeata*, *Arrabidaea brachypoda*, *Aspidosperma subincanum*, *Baccharis salzmannii*, *Banisteriopsis stellaris*, *Bauhinia pulchella*, *Bauhinia ungulata* and *Byrsonima laxiflora*. Medial segments of leaves (n=4, four individuals per species) were collected at Brazilian Cerrado (tropical savanna ecoregion), being processed by histological routine to obtain cross-sections, as shown at Figure 1. The images were obtained in a trinocular microscope Axio Lab A1, 10X lens coupled to a digital camera AxioCam ICc 1.

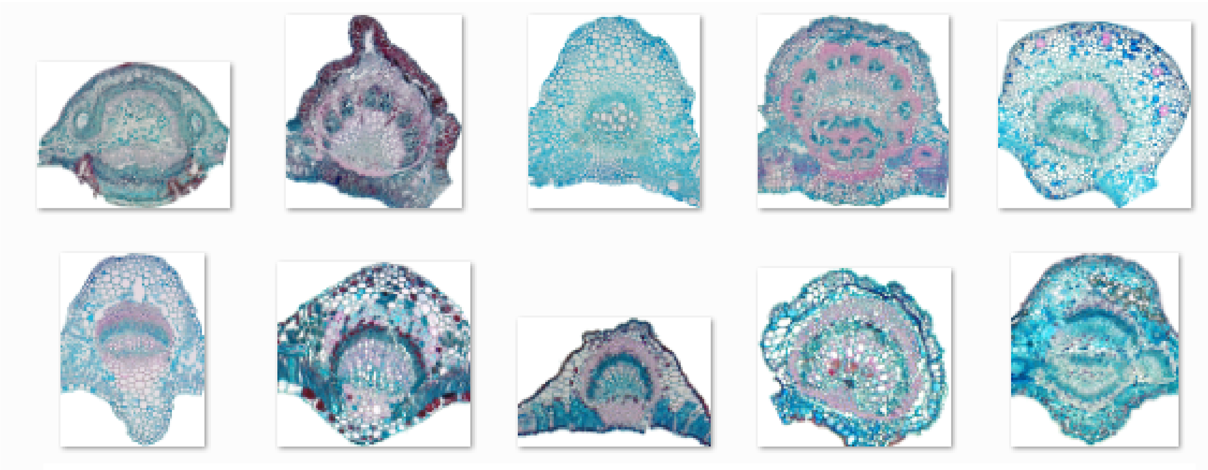

Figure 1. Cross-section of foliar veins of each specie. First line, from left to right: *Anacardium humile*, *Annona crassiflora*, *Aristolochia galeata*, *Arrabidaea brachypoda* and *Aspidosperma subincanum*. Second line, from left to right: *Baccharis salzmannii*, *Banisteriopsis stellaris*, *Bauhinia pulchella*, *Bauhinia ungulata* and *Byrsonima laxiflora*.

The leaves are classified by a Support Vector Machine (SVM) classifier, using a 5-fold cross-validation scheme. The fractal descriptors are compared to two other texture descriptors widely used in the literature: Gray-Level Co-occurrence Matrix (GLCM) and Gabor-wavelets descriptors. Table 1 shows the success rates in the classification of the species.

Table 1. Results: compare classification performance of ten different species.

Method	Success Rate (RMSE)
Gabor descriptors	77.1($\pm$ 0.2)
GLCM descriptors	77.9 ($\pm$ 0.2)
Fractal descriptors	89.0($\pm$ 0.1)

4. Conclusions

The fractal descriptors provided an accurate and reliable result in the discrimination of the plant species. Such performance complies with the capabilities of these descriptors described in the literature. The measures of fractal dimension at different scales gives a detailed picture of the complexity of micro and macro-patterns inside the object analyzed and this is tightly related to anatomical and physical properties of the plant leaf. The results also confirmed the potential of fractal descriptors as a powerful method for analyzing plants using only their leaves. This is a remarkable finding, as the leaves are almost always available and the computational technique is simple and inexpensive.

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