Computers and Electronics in Agriculture 103 (2014) 48–54

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Brachiaria species identification using imaging techniques based on fractal descriptors

João Batista Florindo [a], Núbia Rosa da Silva [a,b], Liliane Maria Romualdo [c], Fernanda de Fátima da Silva [c], Pedro Henrique de Cerqueira Luz [c], Valdo Rodrigues Herling [c], Odemir Martinez Bruno [a,b,*]

[a] *Scientific Computing Group, São Carlos Institute of Physics, University of São Paulo (USP), cx 369, 13560-970 São Carlos, São Paulo, Brazil*[1]
[b] *Institute of Mathematics and Computer Science, University of São Paulo (USP), Avenida Trabalhador são-carlense, 400, 13566-590 São Carlos, São Paulo, Brazil*
[c] *Department of Animal Science, College of Animal Science and Food Engineering, University of São Paulo, Avenida Duque de Caxias Norte 225, Caixa Postal 23, 13635-900 Pirassununga, São Paulo, Brazil*

ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form 2 January 2014
Accepted 9 February 2014

Keywords:
Fractal descriptors
Texture analysis
Brachiaria species identification

ABSTRACT

The use of a rapid and accurate method in diagnosis and classification of species and/or cultivars of forage has practical relevance, scientific and trade in various areas of study, since it has broad representation in grazing from tropical regions. Nowadays it occupies about 90% of the grazing area along Brazil and, besides the grazing areas to feed ruminants, *Brachiaria* also corresponds to about 80% of seeds being traded in all the world, bringing a large amount of money to Brazil. To identify species and/or cultivars of this genus is of fundamental importance in the fields that produce seeds, to ensure varietal purity and the effectiveness of improvement programs. Thus, leaf samples of fodder plant species *Brachiaria* were previously identified, collected and scanned to be treated by means of artificial vision to make the database and be used in subsequent classifications. Forage crops used were: *Brachiaria decumbens* cv. IPEAN; *Brachiaria ruziziensis* Germain & Evrard; *Brachiaria brizantha* (Hochst. ex. A. Rich.) Stapf; *Brachiaria arrecta* (Hack.) Stent. and *Brachiaria* spp. The images were analyzed by the fractal descriptors method, where a set of measures are obtained from the values of the fractal dimension at different scales. Therefore such values are used as inputs for a state-of-the-art classifier, the Support Vector Machine, which finally discriminates the images according to the respective species. The proposed method outperforms other state-of-the-art image analysis methods and makes possible the correct prediction of species in more than 93% of the samples. Such remarkable result is consequence of the better suitability of representing complex structures like those arising in the plant leaves by measures of complexity from fractal geometry. Finally, this high correctness rate suggests that the fractal method is an important tool to help the botanist.

1. Introduction

The knowledge and understanding of functional properties of plants make possible to develop advances in several areas like medicine to cure diseases, produce and improve species to feed people and animals (Camargo and Smith, 2009). Involving this last topic, the analysis of consumption by animals is very important because the animal production can be improved from grazed pastures. Specifically, ruminants have their amount of feeding directly linked with the processes of particle-size reduction during the feeding. Due to the physical strength of grasses, ruminant animals consume larger quantities of forages with lower resistance to breakdown (Herrero et al., 2001). Since the grass is extremely important for animal food, it becomes the object of study here being one of the main forms of ruminant feeding is through grazing *Brachiaria*.

The genus *Brachiaria* consists of herbaceous, perennial or annual, erect or decumbent. Belonging to the grass family, it presents approximately one hundred species, and therefore their correct classification is of great importance for the genetic improvement of forage species and purity of the species in the field of seed production (Parsons, 1972; Wenzl et al., 2000; Arroyave et al., 2013). Grouping plants into genus is a way of facilitating the understanding of the diversity of the grasses, according to the particularities of each species (Parsons, 1972).

* Corresponding author at: Scientific Computing Group, São Carlos Institute of Physics, University of São Paulo (USP), cx 369, 13560-970 São Carlos, São Paulo, Brazil. Tel.: +55 16 3373 8728; fax: +55 16 3372 2218.
E-mail address: bruno@ifsc.usp.br (O.M. Bruno).
[1] www.scg.ifsc.usp.br.

http://dx.doi.org/10.1016/j.compag.2014.02.005
0168-1699/

The study of techniques to classify species and/or cultivars of the genus *Brachiaria* has practical, scientific and commercial relevance, since it has broad representation in grazing from tropical regions. Originating in Africa, it has been easily adapted to the climatic conditions in Brazil and nowadays it occupies about 90% of the grazing area along the entire country. In economic terms, besides the grazing areas to feed ruminants, *Brachiaria* also corresponds to about 80% of seeds being traded in all the world, bringing a large amount of money to Brazil. To identify species and/or cultivars of this genus is of fundamental importance for practical issues of Biology, Agronomy and Animal Science, as well as in the fields that produce seeds, to ensure varietal purity and the effectiveness of improvement programs.

The classification of grasses is mainly based on the characters of the spikelet structure and its arrangement. The main taxonomic feature of the genus *Brachiaria*, despite not being present in many species, is the reversed or adaxial position of the spikelet and of ligule. This spikelet is relatively large, oval or oblong and it is arranged regularly in a row along one side of the rachis. However, the taxonomy of this genus is not satisfactory, both in terms of species composition and in their inter-relationship with other genus. Problems related to incorrect classifications often occur among *Brachiaria* species commonly used in pastures, as well as among accessions of germplasm collections.

In this context, this work proposes a computational imaging technique to address this taxonomical problem. The literature on applications of image analysis has shown a number of works classifying plant species based on the image of structures like the leaves. For example, in Mokhtarian and Abbasi (2004) a shape analysis method (considering only information from the contour) based on Curvature Scale Space is applied to the identification of species of *Chrysanthemum* achieving a success rate close to 100%. Another shape-based approach is proposed in Neto et al. (2006) to classify some species of weed. They use a variant of Fourier transform and obtain about 90% of success. In Wang et al. (2008), the focus is on the pre-processing of leaf images with complicated background. Again, a shape analysis is carried out and a general database of plants is classified with success rate close to 90%. Finally, in Backes et al. (2009), the authors propose to use information from the tonalities of all the pixels in the image inside the leaf, instead of using only information from the contour. They propose a method based on fractal geometry and achieve a great success rate on a complicated database of plants from the Brazilian flora.

Since there is a great variability among natural species of *Brachiaria*, to identify really discriminant characters becomes a difficult task so that seeking for techniques that improve the identification will contribute to studies within this theme, as well as provide a reasonable system of classification, since there is no such system for the genus *Brachiaria*. Based on this and taking into account the great results of fractal-based approaches on leaf images, as demonstrated in works like (Backes et al., 2009), the objective of this study was to take the volumetric Bouligand–Minkowski and Probability fractal descriptors associated with the Canonical Transform to classify samples from five species of *Brachiaria* cultivars. This methodology provides a set of coefficients for each image that will characterize it. The tests were performed in a large database with almost ten thousand of samples including the superior and inferior face of leaves obtaining 92.84% of correctness rate in the classification (of all leaves).

The text in this paper is organized as follows. In Sections 2, 2.2 and 3 the theory of the methods is explained. In Section 4 the description of the method Bouligand–Minkowski with probability dimension applied to texture characterization. Section 5 shows the experiments in a database of *Brachiaria* leaves and in Section 6 the results are analyzed. The paper is concluded in Section 7.

2. Fractal geometry

Fractal geometry (Mandelbrot, 1968) is the area of Mathematics which deals with fractal objects. These are geometrical structures characterized by two main properties: the infinite self-similarity and infinite complexity. In other words, these elements are recursively composed by similar structures. In addition, they exhibit a high level of detail on arbitrarily small scales.

In the same way as in the Euclidean geometry, fractal objects are described by numerical measures. The most widespread of such measures is the fractal dimension. Given a geometrical set X (set of points in the N-dimensional space), the fractal dimension of $D(X)$ is expressed in the following equation:

$$D(X) = N - \lim_{\epsilon \to 0} \frac{\log(\mathfrak{M}(\epsilon))}{\log(\epsilon)},$$

where $\mathfrak{M}$ is a fractality measure and ϵ is the scale parameter. The literature presents various definitions for the fractality measure (Tricot, 1995; Russ, 1994). The following sections describe two of such approaches.

2.1. Bouligand–Minkowski

One of the best-known methods for estimating the fractal dimension of an object is the Bouligand–Minkowski approach (Tricot, 1995). In this solution, the grayscale image $I : [1 : M] \times [1 : N]$ is mapped onto a surface S, using the following relation:

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

Then, each point having co-ordinates (x, y, z) is dilated by a sphere with variable radius r. Therefore, the dilation volume $V(r)$ may be computed by the following expression:

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

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

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

in which $(P_x, P_y, P_z) \in S$. In practice, the Euclidean Distance Transform (Fabbri et al., 2008) is used to determine the value of $V(r)$.

Finally, the fractal dimension D_{BM} itself is given by:

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

The limit in the above expression is calculated by plotting the values of $V(r)$ against r, in log–log scale, and the limit is the slope of a straight line fitting the log–log curve. Fig. 1 exemplify the process.

2.2. Probability dimension

Also referred to as Voss dimension, this method obtains the fractal dimension from the statistical distribution of pixel intensities within the image (Voss, 1986).

Like in the Bouligand–Minkowski method, the image analyzed is converted into a three-dimensional surface S. Hence, the surface is surrounded by a grid of cubes with side δ. By varying the value of δ, the information function N_P is provided through:

$$N_P(\delta) = \sum_{m=1}^{N} \frac{1}{m} p_m(\delta),$$

where N is the maximum possible number of points within a single cube and p_m is the probability of m points in S belonging to the same cube.