Physica A 493 (2018) 189–202

Contents lists available at ScienceDirect

Physica A

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

Texture classification using non-Euclidean Minkowski dilation

Joao B. Florindo [a,b,*], Odemir M. Bruno [a]

[a] Scientific Computing Group[1], São Carlos Institute of Physics, University of São Paulo, Av. Trabalhador São Carlense, 400, 13560-970, São Carlos, SP, Brazil

[b] Institute of Mathematics, Statistics and Scientific Computing, University of Campinas, Rua Sérgio Buarque de Holanda, 651, Cidade Universitária "Zeferino Vaz" - Distr. Barão Geraldo, CEP, 13083-859, Campinas, SP, Brazil

HIGHLIGHTS

- New descriptors for the classification of texture images are proposed.
- Based on an alternative morphological dilation using L^p metric.
- The method is assessed in the classification of UIUC and Outex databases.
- Other state-of-the-art approaches are outperformed in texture classification.
- The obtained results suggest its use in a wide range of applications.

ARTICLE INFO

Article history:
Received 15 June 2017
Received in revised form 7 October 2017

Keywords:
Fractal geometry
Texture analysis
Pattern recognition
L^p metric

ABSTRACT

This study presents a new method to extract meaningful descriptors of gray-scale texture images using Minkowski morphological dilation based on the L^p metric. The proposed approach is motivated by the success previously achieved by Bouligand–Minkowski fractal descriptors on texture classification. In essence, such descriptors are directly derived from the morphological dilation of a three-dimensional representation of the gray-level pixels using the classical Euclidean metric. In this way, we generalize the dilation for different values of p in the L^p metric (Euclidean is a particular case when $p = 2$) and obtain the descriptors from the cumulated distribution of the distance transform computed over the texture image. The proposed method is compared to other state-of-the-art approaches (such as local binary patterns and textons for example) in the classification of two benchmark data sets (UIUC and Outex). The proposed descriptors outperformed all the other approaches in terms of rate of images correctly classified. The interesting results suggest the potential of these descriptors in this type of task, with a wide range of possible applications to real-world problems.

* Corresponding author at: Institute of Mathematics, Statistics and Scientific Computing, University of Campinas, Rua Sérgio Buarque de Holanda, 651, Cidade Universitária "Zeferino Vaz" - Distr. Barão Geraldo, CEP, 13083-859, Campinas, SP, Brazil.

E-mail addresses: jbflorindo@ime.unicamp.br (J.B. Florindo), bruno@ifsc.usp.br (O.M. Bruno).

1 http://scg.ifsc.usp.br.

https://doi.org/10.1016/j.physa.2017.10.012

1. Introduction

The analysis of images with the aim of extracting meaningful information from the digital representation of an object of interest has become more and more important in the last decades. A number of applications can be found in various fields of the science, such as Medicine [1], Engineering [2], Physics [3], and many others.

Among the problems most commonly arising in image analysis we have the classification, that is, the identification of categories of objects in a database based on their digital representation. When dealing with two-dimensional images, the most usual digital representation are binary images showing shapes, contours and silhouettes, and intensity images, either represented by gray-scale or color pixels. In the second case the amount of information enclosed in the image is usually much larger than on binary shapes, what makes the research of more advanced methods for their analysis a fruitful area of study in the literature.

Here we focus on the problem of classification of gray-level images, even because in many situations the analysis of color images can also be adequately addressed by a gray-level approach after a simple conversion from color to gray-scale images. A large number of methods for the analysis and, in particular, for the classification of gray-level images have been proposed during the last years. Most of them rely on an attribute named *(visual) texture* [4]. In this context, textures are particular patterns, either spatial or statistical, naturally arising in images captured on the real world by distinct devices such as cameras [5], microscopes [6], scanners [7], etc. The high complexity of pixel arrangements in those images leads to a need for advanced mathematical tools capable of expressing all the richness present in such patterns by a reduced set of image descriptors.

Among the techniques that have been successfully applied to real-world problems, especially in the classification of biological images, we can mention the Bouligand–Minkowski fractal descriptors. The point of Bouligand–Minkowski approach that we intend to highlight here is that, on top of all the theory concerning fractal geometry, that method is based on the morphological Minkowski dilation within a three-dimensional space. This observation naturally suggests more in-depth investigation on how this type of operation might be useful in providing meaningful descriptors for texture images.

In this context, this work proposes to employ alternative strategies to carry out such morphological operation based on distance metrics other than the well-known Euclidean distance. In this way we enlarge the possibilities of approaches to obtain relevant descriptors of gray-scale texture images, posteriorly used to classify these images into categories of interest. First, the gray-scale texture is mapped onto a three-dimensional cloud of points where the first two coordinates are the image coordinates and the third one is the gray-level of the pixel at that point. In the sequel, more than simply computing the Euclidean distances as usual in the literature, we propose to compute L^p distances, a generalized metric of what the Euclidean metric is a particular case ($p = 2$). Following the idea behind the Bouligand–Minkowski descriptors, the cumulative distribution of the transform is used to provide the image descriptors.

The obtained descriptors are used to classify two classical texture benchmarks, that is, Outex [5] and UIUC (version employed in [8]) databases and the performance is compared to other state-of-the-art approaches in the literature, namely, Fourier [9], Gray-Level Co-occurrence Matrix (GLCM) [10], multifractals [11], LBP [12], and textons [13,14]. The comparison in Table 4 confirmed the potential of the proposal by showing that the descriptors outperformed all the other ones in terms of rate of images correctly classified.

2. Bibliographical review

Classically, methods for the classification of texture images have been categorized into four groups [4]: structural, statistical, model-based and transform-based.

Structural methods work on well-defined primitives and mathematical morphology [15] is a classical example of this approach. Despite the importance of a rich symbolic description provided by this method, it has shown to be more efficient in image synthesis than in image analysis [4].

On the other hand, transform-based methods derive in general from the representation of the digital image in the frequency domain. Such representation is indeed quite meaningful for texture analysis as the periodicity of certain structures so common in visual textures can be described more faithfully in frequency space. Examples are Fourier [9] and wavelets [16] descriptors. In this category, Fourier is the most simple and computationally efficient method, but the absence of spatial localization is a drawback in many situations. Wavelets partially address this point, but still suffers from translation invariance.

Statistical methods focus on how the pixels are related, without accounting for any especial structure or hierarchy of objects in the image. Examples are Haralick cooccurrence matrices [10], and more recently Local Binary Patterns (LBP) [12], textons/bag-of-features [13,14], Scale-Invariant Feature Transform (SIFT) [17], and others. Whereas Haralick method has historical importance, the later ones have presented outstanding results in texture classification, especially material images. Despite the demonstrated potential of these methods, unlike the transform-based approaches, they do not have solid mathematical background, which limits the possibilities of using established tools from advanced mathematics and physics to enhance the performance of the method in a particular application and also makes difficult to understand the real meaning of these descriptors in applied contexts.

Model-based methods attempt to combine the efficiency of methods that quantify inter-pixel and inter-region relations with a mathematical or physical model, whose theory is already well-established in its original context. Examples are