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Texture analysis using graphs generated by deterministic partially self-avoiding walks

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ABSTRACT

Texture is one of the most important visual attributes for image analysis. It has been widely used in image analysis and pattern recognition. A partially self-avoiding deterministic walk has recently been proposed as an approach for texture analysis with promising results. This approach uses walkers (called tourists) to exploit the gray scale image contexts in several levels. Here, we present an approach to generate graphs out of the trajectories produced by the tourist walks. The generated graphs embody important characteristics related to tourist transitivity in the image. Computed from these graphs, the statistical position (degree mean) and dispersion (entropy of two vertices with the same degree) measures are used as texture descriptors. A comparison with traditional texture analysis methods is performed to illustrate the high performance of this novel approach.

1. Introduction

Texture is a visual attribute widely used to describe patterns and characteristics of images. In fact, it is one of the most important visual attributes for image analysis and pattern recognition. Texture consists of the repetition of a gray-scale or color pattern on an image, or even the lack of repetition or pixel organization. On one hand, the definition of the texture concept can become vague and abstract, which leads to a lack of a formal definition in the literature [1]. On the other hand, its characteristics are straight connected with physical properties of an object surface [2–4], which make textures very attractive for a wide range of applications, such as medical images diagnose [5–7], remote sensing [8], geological images [9], microscope images [10,11], etc.

Texture analysis is supported by a wide variety of different descriptors proposed along the years. There are different approaches to deal with texture, some examples are properties obtained from spectral analysis (e.g., Fourier descriptors [12] and Gabor filters [13]), statistical analysis of the pixels (e.g., co-occurrence matrices [14], local binary pattern [15], feature-based interaction map [16]) and complexity of pixels distribution (e.g., fractal dimension [4,17–18]).

Recently, a partially self-avoiding deterministic walk (deterministic tourist walk, DTW) algorithm has emerged as a very promising approach for texture analysis [20–23]. It considers independent walkers leaving from each pixel to exploit an image characteristics. Each walker moves from one pixel to another according to a deterministic rule and a given memory. This results in partially self-avoiding trajectories, which can be separated into two parts: one, where the walker mainly explores new pixels and the other, where the walker is trapped in an attractor, a cycle of pixels from where the walker cannot escape. Image analysis using the tourist walks is usually performed through statistical analysis over the joint distribution of transient times and attractor periods [20–22]. As a result, the trajectory produced by each tourist is not taken into account during the image analysis step. The attractor and transient lengths are used to build histograms. Here, we present a new concept: instead of focusing on attractor and transient length histograms, we use the generated trajectories to build a graph. The generated graph is capable to characterize the image texture patterns.

This paper starts presenting a review about the deterministic partially self-avoiding walk in Section 2. In Section 3, we show how to build a graph from the trajectories engendered by the tourist, given a walking rule and memory. A signature capable to represent these graph properties and, as a consequence, characteristic from the original image is proposed in Section 4. Experiments using images extracted from the Brodatz album [24] are presented in Section 5. Section 6 presents the obtained results and a discussion. Finally, in Section 7, we conclude and propose future studies.

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2. Deterministic partially self-avoiding walk

The partially self-avoiding deterministic walk algorithm [25–29] can be understood as a tourist wishing to visit N cities distributed in a map of d dimension, where each city is visited at each time step according to the rule of walking to the nearest city which was not visited in the last μ steps. This rule produces a partially self-avoiding trajectory, which can be separated into two parts: a transient part of length t and an attractor final part, which ends in a cycle with period p, $p \geq \mu+1$, and from where the tourist cannot escape. From the distribution of transient times and cycle periods one has been able to characterize thesaurus [30] and perform cluster analysis [31]. Also, stochastic versions of this algorithm have been addressed [32–34]. These walks have been used in other contexts, such as the modeling of the searching behavior of social monkeys [35], foraging of primates [36], emerging of power-laws in deterministic walks [37] and exploration of heterogeneous media by deterministic agents [38].

Recently, from these deterministic partially self-avoiding walks algorithm has emerged as a very promising approach for texture analysis [20–22]. Consider a digital image containing N pixels with a gray-level scale ranging from 0 to 255 associated to each pixel. A traveler walks from one pixel to another belonging to its 8-neighborhood, according to the following rule: move to the nearest or furthest neighbor pixel (i.e., the one which differs in minimum or maximum gray-level, respectively, from current position) and that has not been visited in the last μ ($\mu \in [1,N]$) previous steps. This algorithm has been adapted to deal with color images [39].

Considering each image pixel as a starting point of the tourist walk, the joint distribution of transients t and attractors p, $S^{(N)}_{\mu,2}(t,p)$ is achieved (Fig. 1). Studies have been performed over this joint distribution to provide a feasible signature for image textures [20–22]. It is also important to note that, once the walking rule is defined (to move to minimum or maximum difference), the rule must be considered for all pixel and cannot be changed along the trajectory.

3. Building graph from walks

Instead of considering the transient time and cycle period joint distribution to achieve a texture signature, we propose a novel approach to use the deterministic partially self-avoiding walk. We focus now on the behavior of the trajectories produced by each tourist during its walk on the texture image. Each trajectory consists of a set of transitions between two pixels performed by the tourist, for a given memory μ and walking rule. The motion from one pixel to another can be interpreted as a connection between these two pixels in the image. As a result, the trajectories can be used to build a graph, which describes the tourist transitivity and, as a consequence, the attractive regions in the image (attractors). Therefore, we propose to use these walks on gray scale images to generate a graph, which holds information about the texture pattern.

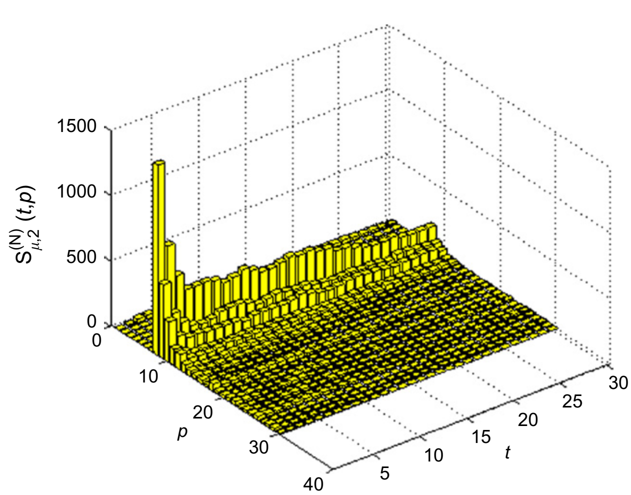

Fig. 1. Example of the transient time and cycle period joint distribution computed from the deterministic partially self-avoiding walk on a gray scale image.

Consider a graph $G_{\mu,rule}=(V,E)$, where μ is the memory and *rule* is the walking rule (minimum or maximum difference) used by the tourist to move over the image. Initially, each image pixel corresponds to a vertex in the graph (i.e., $N=V$) with no edges connecting them ($E=\{\}$). As the tourist moves from pixel i to pixel j on the image (Fig. 2), a non-directed edge $e_{i,j}$ is added to E. Note that this is performed only if $e_{i,j} \notin E$, so that, duplicated vertices are not added to the graph.

Taking each image pixel as a starting point for the tourist walk, a graph representing the deterministic self-avoiding trajectories found by the traveler is built (Fig. 2c). None of the vertices is disconnected from the graph. Once these trajectories depend on the gray-level distribution in an image region, vertices connections are altered according to different texture patterns. Thus, the graph comprehends important characteristics concerning the transitivity and attractive image regions. Studying its properties, a feasible signature for texture analysis is proposed as follows.

4. Proposed signature

The proposed approach performs texture characterization through properties of the graph generated from the deterministic partially self-avoiding walk. To accomplish this purpose, two graph measurements are considered: the graph *degree* and *joint degree*.

The *degree* of a vertex v_i, $d(v_i)$, represents the connectivity of that vertex in the graph. It is defined as the number of edges of the graph bound to v_i:

$$d(v_i)=|\{e \in E | v_i \in e\}| = |\{v_j \in V | \{v_i,v_j\} \in E\}| = |\partial v_i|, \tag{1}$$

where $\partial v_i = \{v_j \in S | (v_i,v_j) \in E\}$ represents the set of neighbor of v_i and $|\cdot|$ denotes the cardinality of a set [40].

Joint degree is a measure of correlation between the degrees of two vertices connected by an edge [41]. Here we consider the probability of having a vertex v_i connected to another vertex v_j. Since both

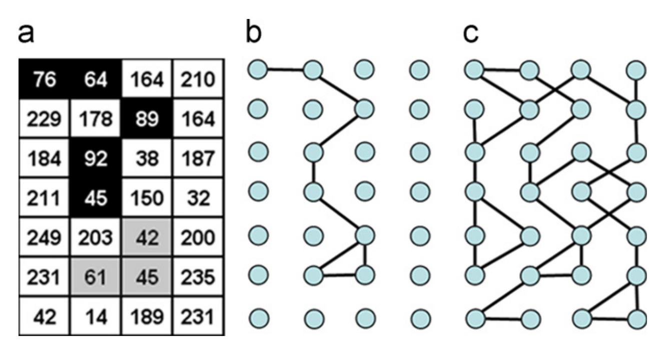

Fig. 2. (a) Example of a deterministic partially self-avoiding walk on a gray scale image using minimum contrast difference and the last visited pixel is not allowed ($\mu=1$) (transient time in black, attractor cycle in gray). A walker leaves from pixel "76" and goes to the one of minimum contrast in the neighborhood "64". From this pixel, the walker repeats the search and find pixel "76", but this pixel is not allowed since it is in the memory window, so that the walker goes to the second minimum contrast pixel "89". The process is repeated, and the walker passes by the pixels "92" and "45" before being trapped the cycle with pixels: "42", "45" and "61". (b) Each pixel in (a) corresponds to a vertex in (b). Edges are added into the graph by following the walk. (c) The full graph is obtained with the tourist leaving from all the pixels.