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A non-supervised approach using Gabor filters for vine-plot detection in aerial images

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ABSTRACT

Vine-plot mapping and monitoring are crucial issues in land management, particularly for areas where vineyards are dominant, like in some French regions. In this context, the availability of an automatic tool for vineyard detection and characterization would be very useful. Due to the periodic patterns induced by this culture, frequency analysis appears to be a very suited tool for vineyard detection in aerial images. A recursive process using Fast Fourier Transform algorithm was developed to meet this need. This results in vine-plot segmentation, with boundaries in polygonal form and characterization with accurate estimation of interrow width and row orientation. To foster large-scale applications, tests and validation have been carried out on standard very high spatial resolution remote-sensing data. About 80% of vine plots have been well or under-segmented and 11.4% not detected at all. More than 84% of vineyard surface have been detected.

1. Introduction

Remote-sensed data are a precious tool for land management, because they can give instantaneous information at a large scale (land occupation, water availability, etc.). Up to recently their limited resolution (mainly 10–30 m/pixel) has made that their analysis has mainly relied on spectral discrimination, each pixel being individually classified into predefined classes (water, vegetation, urban zones, etc.) according to its digital counts, *i.e.* intensity values, in various spectral channels.[1] For a few years now, new remote-sensing satellites, such as Ikonos (1999) or Quickbird (2001) have provided meter or submeter resolutions.[2] Concurrently, aerial images are increasingly available under digital format (scanning after film acquisition or acquisition from digital cameras). The entire coverage of European land with digital orthophotos is presently under way. This increasing availability of very high spatial resolution (VHSR) images offers a lot of new potential applications: the shape or the spatial structure of observed objects is becoming more distinguishable, providing greater discrimination and characterization potential, notably in the agricultural domain. For instance, various types of vegetation can be distinguished according to their spatial patterns (cereal crops, forests, orchards, etc.).

However, because they deal with spatial structures or shape, these new applications also require new image processing approaches, even if multispectral aspects remain important as a preliminary tool (*e.g.* to enhance the contrast

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[1] *E.g.* the channels and resolutions of the SPOT4 satellite, launched in 1998 are Panchromatic (10 m/pixel), Green, Red, Near and Medium Infra Red (20 m/pixel).

[2] Ikonos: 1 m panchromatic, 4 m multispectral; Quickbird: 0.61 m panchromatic, 2.44 m multispectral.

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of the patterns to be analyzed). In the present paper, we address the issue of vineyard detection and characterization from VHSR aerial images, for inventory and management purposes.[3] In this type of perennial crop, a very important feature is the spatial periodicity of the crop pattern, due to the training system (often in rows), which is clearly visible in VHSR aerial images. In such images, a vineyard can roughly be assimilated to a local planar wave of a given spatial frequency and orientation. In the Fourier space, it generates characteristics alined peaks corresponding to the frequency and its harmonics. Therefore, approaches based on spatial frequency analysis, and notably on the Fourier spectrum, are particularly suited. In Wassenaar et al. (2002), the detection of main amplitude peaks (fundamental frequencies) has been considered, as well as its robustness under various land conditions. The ability of such an approach to characterize vine plots (orientation, interrow width, training system) is clearly shown. In Chanussot et al. (2005), a Radon transform (similar to a Hough transform in this case) is applied to the Fourier spectrum of a few centimeters resolution image, in order to recover the parallel spectrum lines formed by the peaks and get a very accurate evaluation of row orientation. In these examples however, a preliminary delineation of the vine plots is required. In Ranchin et al. (1998, 2001), the authors attempted to apply such a Fourier spectrum approach for vine-plot detection, but they finally preferred a method based on the wavelet transform: image regions that present gray-level variations at a given spatial scale are highlighted by selecting a range of wavelet coefficients. However, this isotropic filtering scheme considered alone is not selective enough and must be, once again, combined with external information to separate vine plots from other agricultural plots. In Warner and Steinmaus (2005), periodical vineyard patterns are detected by computing and analyzing the gray-level autocorrelation function along some predefined directions in the image. This approach can be compared in many points to a frequency analysis.[4] However, only a few frequency orientations are considered (cardinal directions and diagonals). These few examples illustrate a basic issue of vine-plot detection (or other periodical patterns) in VHSR images, using Fourier analysis. On one side, periodical patterns have very specific and clearly defined properties in the Fourier domain, that should allow very effective filtering processes. On the other side, the range of possible orientations and interrow widths makes impossible, for computational reasons, a successive application of the corresponding selective filters on the image. Another alternative, that we have previously tested, is to apply one global filter covering all possible cases, *i.e.* an isotropic band-pass filter designed as a centered ring in the Fourier spectrum. In this case however, we do not benefit from the strongly anisotropic properties of the pattern, and thus get a lower selectivity, comparable to other approaches such as wavelet transform, edge detection, textural feature computation, etc.

In the present paper, we propose an original scheme that overcomes this paradox. A selective filter is applied to each plot, centered on its main spatial frequency component, in order to recover the plot shape. The main point is that this targeted frequency is issued from a previous Fourier spectrum analysis of the corresponding image area, using a recursive algorithm. A comparable approach is used in Muron and Jacquet (2001) on aerial images of olive trees: starting from a previous analysis of the Fourier spectrum image, the authors show that the selection of some amplitude peaks allows to recover the corresponding plot edges. However, these peaks are manually selected, the goal being to study their usability for tree counting, rather than for plot delineation. In our case, the objectives are to design an operational algorithm which applies this basic principle of selective filtering over large images for segmentation purposes. Therefore, the main challenge consists in designing an effective sequential process for image scanning, frequency peak selection and management of detected objects, rather than in the filtering process itself. The resulting recursive scheme presented here has been applied to large VHRS aerial images, and has proved its efficiency for vine-plot unsupervised detection and delineation. The following part presents the theoretical aspects and the recursive implementation of the proposed approach. Then, results obtained on an image presenting a large set of vineyard types and conditions are presented and discussed.

2. Gabor filter implementation

2.1. *Gray-level input images*

The present study is based on image processing techniques that exclusively deal with vineyard spatial structure in aerial images and do not consider their radiometric properties. These techniques use gray-level images with the only requirement of a sufficient contrast between vine rows and interrows for the discontinue structure to be visible. Moreover, as presented further, a normalization step has been designed in order to make the results independent of the initial contrast level. Therefore, the proposed method can be applied with various types of image sources. Depending on the spectral bands available in a given application context, the gray-level image can be, for instance, a NDVI computation (normalized difference vegetation index, combining red and near-infrared bands), the luminance computed from a RGB image, or a particular band of an image. The comparison of these various possibilities will not be addressed here.

2.2. *Gabor filtering*

Let us consider a typical gray-level image of vineyards and the corresponding Fourier spectrum obtained by the Fast Fourier Transform (FFT) algorithm (Fig. 1).

Several observations can be made on the Fourier spectrum representation (Fig. 1(b)):

(i) edge-effects: the horizontal and vertical lines intersecting at the spectrum center represent the frequency compo-

[3] See http://www.bacchus-project.com for more detailed applications (for example, the interrow width is linked to the seed density, and thus, to the plot productivity).

[4] The autocorrelation function can be obtained as the inverse Fourier transform of the power spectrum.