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From pixel to vine parcel: A complete methodology for vineyard delineation and characterization using remote-sensing data

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ABSTRACT

The increasing availability of Very High Spatial Resolution images enables accurate digital maps production as an aid for management in the agricultural domain. In this study, we develop a comprehensive and automatic tool for vineyard detection, delineation and characterization using aerial images and without any parcel plan availability. In France, vineyard training methods in rows or grids generate periodic patterns which make frequency analysis a suitable approach. The proposed method computes a Fast Fourier Transform on an aerial image, providing the delineation of vineyards and the accurate evaluation of row orientation and interrow width. These characteristics are then used to extract individual vine rows, with the aim of detecting missing vine plants and characterizing cultural practices. Using the red channel of an aerial image, 90% of the parcels have been detected; 92% have been correctly classified according to their rate of missing vine plants and 81% according to their cultural practice (weed control method). The automatic process developed can be easily integrated into the final user's Geographical Information System and produces useful information for vineyard management.

1. Introduction

Since they provide precise and frequent large scale information, remote-sensing data can be used as an aid to decision-making. In winegrowing regions, accurate digital vineyards maps could be very useful to help the monitoring of quality compliance, especially for Controlled Origin Denomination areas, where strict criteria are imposed, such as a rate of missing vine plants below 25%. The management of pollution, erosion and flood risks are other fields that can take advantage of such maps as these risks depend on soil surface conditions, which are directly linked to the kind of culture and cropping practice (see for example, Lennartz et al., 1997 or Takken et al., 2001). Distributed hydrological models developed for cultivated catchments take into account the spatial heterogeneity of landscape through some characteristics of crop pattern and cultural practices. However, these characteristics are generally unknown and are thus simulated using geostatistical methods and some localized and costly field surveys. Consequently, information (even partial) on soil surface condition between rows could be usefully introduced in such models. Users' demands usually concern (1) vineyards location and delineation and (2) identification of some characteristics that can be connected to cropping practices or crop quality, such as interrow width, row orientation, the presence of grass between rows or missing vine plants (Montesinos Aranda and Quintanilla., 2006).

Many vineyard related studies in remote sensing (such as Lamb et al., 2004 or Zarco-Tejada et al., 2005) use the infrared channel of low spatial resolution images to characterize vine vigour. On Very High Spatial Resolution (VHSR) images, the plantation and training patterns (often in rows or grids) become distinguishable, providing great discrimination and characterization potentialities. However, realizing this potential with automatic processes requires the development of new image processing methods, allowing the analysis of textured image. Two kinds of approaches have been used to that aim for vineyard characterization: texture and frequency analysis. The former has recently been used by Da Costa et al. (2007) to extract vineyards boundaries from 0.15 cm resolution images. However, a main drawback of the approach relies on the necessity to manually select a window inside each vine block before processing. In this study, the results were qualitatively validated through a non-exhaustive visual control, what does not allow the assessment of the method efficiency. Moreover, a comparative study of vineyards detection methods (Delenne et al., 2008a) has shown the inferiority of such kind of textural approach in comparison with frequency analysis. This later, which takes advantage of the crop patterns periodicity, has been successfully used by Wassenaar et al. (2002) who applied a Fourier Transform to characterize already delineated vine blocks on 25 cm resolution images, and to estimate interrow width and row orientation. It can

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be assumed that this information could be efficiently used to extract and characterize each vine row, in a simpler way than the complex and time-consuming classical methods of deformable models, such as used in Bobillet et al. (2003). The 'vinecrawler' algorithm presented in Hall et al. (2003) was successfully applied on Australian vineyards. However, for most of European wineyards, this method would not be suited to process widespread VHSR images, where vine rows and interrows rarely contain more than two or three pixels (see Section 2.1).

This paper addresses the issue of vineyard detection, delineation and characterization at both parcel and row levels from VHSR aerial images. A frequency analysis approach is used for a coarse parcel delineation and a new algorithm is proposed for row detection and adjustment. The originality of the developed method stands in the fact that it is entirely automatic and produces a geographic data base in a 'shapefile' format, which can be integrated into any GIS used by vineyard managers.

Section 2 presents the study area and the proposed approach. The first step of vineyard delineation is only briefly recalled since it is based on already published works (Delenne et al., 2008a; Rabatel et al., 2008). All the following steps (vine row extraction and adjustment, parcel update and characterization) are new contributions and are thus described in more detail. Section 3 concerns the assessment of the method efficiency. Considering that the main objective of this paper is to present the whole workflow process, only results obtained by processing the red channel of an aerial image with a 50 cm spatial resolution are presented. This choice (discussed in Section 2.1) was guided by the increasing availability of such images in Europe and by results obtained in previous studies (Wassenaar et al., 2002; Delenne, 2006).

2. Materials and methods

In the following, the term 'parcel' will refer to an individual vineyard block with homogeneous characteristics (row orientation, interrow width, agricultural practices, etc.). The process workflow can be divided in three main steps: (1) vineyard detection, (2) initial parcel delineation, and (3) vine row extraction and boundaries refinement. At each step, some characteristics are derived, either to be directly added in the user's geographical database or to be used in a further processing step.

2.1. Study area and data

To assess the global process, a study area of 200 ha has been chosen, which is a subset of the La Peyne watershed (110 km^2) located near Roujan, in the Languedoc-Roussillon region (southern France) and which has been an experimental site for hydrological studies since the beginning of the 1990s.

Despite a general decrease, vine cultivation is still predominant in the study area and concerns about 70% of the agricultural area used. In this Mediterranean coastal plain, the diversity of agricultural practices leads to a great heterogeneity among the vineyards to be detected on remote sensing data. However, according to training mode, two main patterns can be observed: grid or line. About a quarter of the vine parcels considered in this study is trained in 'goblet', involving no wire or other support system and leading to a grid pattern, often square, with approximately 1.5 m $\times$ 1.5 m spacing. The line pattern concerns most of the recent vineyards, which are trained using horizontal wires to which the fruiting shoots are tied. Spacing between vine plants in the same row is smaller than spacing between rows (often 1 m $\times$ 2.5 m spacing in the study area). More adapted to mechanization, nowadays widespread training mode is named 'trellis' or 'wire-training'. Weed control practices in the study area are based on three main methods: chemical weeding, mechanical weeding and grass cover. Cultural practices are characterized by either applying the same weed control practice on each interrow or alternating various practices. The main combination modalities are: 1/1 (no alternation of practices), 1/2 (e.g. interrows alternatively grass covered and chemically weeded), 1/3 or 1/4. These cultural practices aim to control hydric stress, to improve soil bearing capacity and to reduce erosion effects.

Data acquisition was made during the first week of July 2005, when foliar development was such that both vine and soil were visible on aerial photographs, providing enhanced pattern visibility. Digital cameras (SONY DSC-P150) were used aboard an Ultra Light Aircraft (at noon and about 500 m height) to acquire RGB (three channels in the visible part of the electromagnetic spectrum: red, green and blue) and infrared images, with a spatial resolution of 50 cm[1]. The choice of these characteristics was guided by the two following reasons: (1) they are similar to the ones of largely available data in Europe (e.g. the BD-Ortho of the French National Geographical Institute), and (2) several frequency-based methods were already efficiently applied on such kind of data (Wassenaar et al., 2002; Delenne, 2006). Preliminary tests done on the blue, green, red, near infrared channels and on the NDVI and green-NDVI indices (Delenne, 2006) have shown that best results are obtained with the red channel. This is mainly due to the higher contrast between vine rows (vegetation) and interrows, generally occuring in the red channel, especially when the interrows are covered by grass. The influence of resolution has also been studied and it was demonstrated that resolutions ranging from 30 cm to 50 cm were optimal according to the interrow widths encountered (Delenne, 2006). Thus, only results obtained using the 50 cm resolution red channel will be presented in this paper.

For result validation, ground-truth data were collected at the same time as image acquisition. About 170 vine and non-vine parcels of the study area have been digitized in a GIS database. This also contains information concerning land use and, for the 121 vine parcels, characteristics of training mode (row or grid pattern), interrow width, orientation, soil surface condition between rows and under vine plants (covered by grass, chemically or mechanically weeded), rate of missing plants. Reference row orientations and interrow widths were obtained by precise on-screen measurements: row orientation was measured with a 1° precision and interrow width was calculated by dividing the width of the whole parcel by the number of interrows. Since only qualitative information were collected concerning the rate of missing plants, a photo-interpretation was performed to complete the database and classify parcel into three classes: less than 15% of missing vine plants, (2) between 15% and 30%, and (3) more than 30%. In what follows, this data base will be referred to as the 'reference database'.

2.2. Vine parcel detection and boundaries extraction

The two first steps (i.e. vine parcel detection and delineation) presented in this part are based on previously published works (Delenne, 2006; Delenne et al., 2008a; Rabatel et al., 2008), and are thus briefly recalled in this subsection.

Fourier theory (named after Joseph Fourier) states that almost any signal, including images, can be expressed as a sum of sinusoidal waves oscillating at different frequencies. Thanks to the Fast Fourier Transform (FFT) algorithm (Cooley and Tukey, 1965), the discrete Fourier transform of an image I can be quickly computed. Its amplitude, or Fourier spectrum, can be represented in the frequency domain as an image $\hat{I}$, symmetric with respect to its center. Each position (u, v) in the Fourier spectrum corresponds to a par-

[1] More information about the acquisition procedure can be found in http://www.lavionjaune.fr/.