Airborne Remote Sensing of Vineyards for the Detection of Dead Vine Trees

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Abstract—Airborne remote sensing technology can be used to accurately monitor vineyards. In this paper we present a method to detect missing or dead trees. This is achieved by exploiting the periodic structure of a vineyard: equally spaced trees are planted in parallel rectilinear rows. This clearly appears on the spectrum which can be analyzed using the Radon transform. Simple morphological operators then enable the detection of unusual spaces within the plantation rows, corresponding to missing trees.

I. INTRODUCTION

Airborne imagery systems and remote sensing technology have become an effective tool for vineyard management [1]. For instance, color infrared aerial photographs (CIR) can be used for a precise evaluation of the vineyard canopy, as well as a more effective battle against phylloxera, thus leading to optimized harvests [2]. CIR images can also be used to map and characterize soil variability [3]. Finally, hyperspectral images also allow the application of precision viticulture practices [4].

Detecting and counting dead vine trees is a key issue in wine production. This is especially true for extremely high value ‘Grands Crus’ vineyard plantations where the production is very strictly ruled and monitored. This is also true for other reserve programs with tremendous economic potential. In this case, assessing the potential for re-planting is of great interest. In this paper, we propose to address this problem using airborne color imagery and image processing tools. In the following, we present a method to automatically achieve this task that would be fastidious with a visual inspection.

The proposed method takes advantage of the regularity of a vineyard: a vineyard is composed of several parallel rows, and each row is composed of equally spaced vine trees. Therefore, frequentional and morphological tools can be used.

The paper is organized as follows: after a preprocessing (section II), section III shows how the orientation of the vineyard rows can be automatically estimated using the Fourier spectrum of the pre-processed image and its Radon transform. Section IV describes the automatic estimation of the typical inter-tree distance within one row. Again, it is based on the Fourier spectrum. Finally, a method to detect the irregular intra-row vine gaps is presented in section V. These atypical gaps correspond to the locations of missing trees.

II. PRE-PROCESSING

The pre-processing step consists in firstly isolating one given field. This could be achieved manually or by mapping the land registry, stored in a GIS, on the acquired images after registration. One original airborne color image is presented on figure 1. From this image, using the classical RGB representation, one grey level picture $I(x, y)$ is obtained by substracting the Red component to the Green component.

$$I(x, y) = \text{Green}(x, y) - \text{Red}(x, y)$$  \hspace{1cm} (1)

Note that by jointly using visible and near-infrared ranges, the classical Normalised Difference Vegetation Index (NDVI) could also be used as an indicator of photosynthetically active vegetation, thus helping to separate vinetrees from the soil. The use of hyperspectral images could also lead to more accurate classification. However, the simple combination used in this study (Green minus Red) turned out to be discriminative enough for this purpose on all the pictures we tested. Figure 2 presents this grey level picture on which the method described in the following will be applied.

III. ESTIMATION OF THE ORIENTATION

Vineyard plantations are usually organized in regularly spaced rectilinear parallel rows. Consequently, the processed images are highly anistropic and feature a periodic oriented
Fig. 2. Grey level picture after combination of the color components.

texture. This is clearly visible on the spectrum (modulus of the 2D Fourier transform [5]) computed as:

\[ FT(u, v) = \left| \int \int I(x, y) \exp[2i\pi ux + 2i\pi vy] \, dx \, dy \right| \]  

(2)

On the spectrum, presented in figure 3, information concentrates on thin parallel lines. These lines are orthogonal to the orientation of the rows in the original image.

![Fourier spectrum (zoom)](image)

Fig. 3. Fourier spectrum (zoom).

Three peaks are clearly visible. They correspond to the three main lines appearing in the spectrum. These peaks have the same abscissa since they correspond to parallel lines. This abscissa of the column with the largest value within the whole \( R(\theta, \rho) \) corresponds to the angle of the orientation of the spectrum and thus gives the orientation \( \alpha \) of the vineyard as follows:

\[ \alpha = 90 - \arg \max_\theta \{ R(\theta, \rho) \} \]  

(4)

IV. ESTIMATION OF THE INTER-TREE SPACE

From the spectrum, we also automatically derive the inter-tree space \( d \). Starting from the origin of the Fourier spectrum, the first peak along the direction estimated thanks to the Radon transform is sought. The distance between the origin and this peak is inversely proportional to the periodicity of the features along one vine row, i.e. inversely proportional to the typical inter-tree space. After a calibration, the coefficient of proportionality is estimated leading to the knowledge of the inter-tree space, denoted \( d \) in the following.

V. DETECTION OF THE MISSING TREES

After the estimation of parameters \( \alpha \) and \( d \), the detection of missing trees can be achieved. Based on the use of classical morphological operators, it is composed of three steps defined in the next three subsections. For more information on mathematical morphology, please refer to the following books [6][7][8][9]
A. Connecting regularly spaced trees

A linear structuring element $SE_{1.5d,\alpha}$ is constructed. It is one pixel wide, $E(1.5d)$ pixels long and it has an orientation of angle $\alpha$. A morphological closing $\phi$ is then applied with this structuring element to the initial grey level picture:

$$I_1(x, y) = \phi_{SE_{1.5d,\alpha}}(I(x, y))$$

The effect of the morphological closing operator is the removal of all the features in the picture that are darker than their immediate surroundings and that are smaller that the structuring element (i.e. dark features in which the structuring element does not fit). The gap separating two vine trees appears darker than the trees themselves and the chosen structuring element is slightly longer than the typical gap. The closing operation therefore results in the connection of all regularly spaced neighbouring vine trees within each vine row (regular gaps are removed). However, if a tree is missing, the distance between two consecutive trees becomes longer than the structuring element and the closing operation thus does not connect them. The obtained picture is presented in figure 5.

$$I_2(x, y) = \phi_{SE_{3d,\alpha}}(I(x, y))$$

The obtained picture is presented in figure 6: all the gaps have been filled.

B. Connecting all the trees

Another directional morphological closing is performed on the initial grey level picture. A structuring element with the same orientation $\alpha$ is used, but with a larger length. This time, all the trees within one row should be connected, even if there were missing trees. Therefore, the length of the structuring element should be larger than any possible inter-tree gap within one row. In our experiments, we chose a length of $3d$. However, this parameter is not very sensitive, since much larger structuring elements could be used with the same result.

$$I_3(x, y) = I_2(x, y) - I_1(x, y)$$

In $I_1(x, y)$ only the typical regular gaps are filled, whereas in $I_2(x, y)$ all the gaps are filled. Consequently, the difference between these two pictures highlights atypical gaps corresponding to missing trees. Note that this subtraction can also be interpreted in terms of Top-Hat operator, another classical morphological tool. The result is presented in figure 7.

$$I_3(x, y) = I_2(x, y) - I_1(x, y)$$

To reduce the false alarm rate and thus provide a reliable detection, some spurious features are removed using a median filter of size $7 \times 7$. The size of the filtering window for this post-processing may vary depending on the size of the individual tree crowns. However, for one given state of development of the plantation, this size is easily set by the user.

A simple threshold is applied to take the final binary decision and enable the localization and counting of all the missing trees. The final binary image is presented in figure 9.
The four dead trees that one could count on the original color image have been successfully detected.

VI. CONCLUSION

In this paper we have presented a method aiming at detecting all the missing vine trees missing in a vineyard. In a first part, we see how the regularity of the plantation can be used to automatically estimate the direction of the wine rows and the typical inter-tree distance within the rows. This automatically achieved by analyzing the Fourier spectrum of the original image and the Radon transform of this spectrum. In a second part, classical morphological operators are used to detect unusually long spaces between two consecutive trees. These locations correspond to missing tree. However, this method fails in the case of irregularly spaced or too sparse plantations. Some improvements are also required to handle curved rows.

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