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Estimation of the Foliage Growth in Precision Viticulture from 3D Radar Proximal Sensing

Dominique Henry, Hervé Aubert
LAAS-CNRS
Toulouse, France
dhenry@laas.fr, haubert@laas.fr

Thierry Véronèse
Ovalie-Innovation
Auch, France
thierry.veronese@ovalie-innovation.com

Abstract—The estimation of the foliage growth of vineplants based on 3D radar proximal sensing is proposed in this paper. Measurements are performed with a ground-based 24GHz FM-CW radar and for different field polarizations. The statistical estimator derived from the 3D radar images is defined and correlated with the foliage growth of vineplants. This work and results may find applications in precision viticulture for estimating the leaf-to-fruit ratio.

Index Terms—precision agriculture, precision viticulture, proximal sensing, radar imaging

I. INTRODUCTION

In viticulture, measuring the foliage surface of a vineplant is as important as for predicting the yield or estimating the maturity of grapes. For winemakers, the so-called *leaf-to-fruit ratio* may delay the maturity of the grapes [1], affect the lignification [2] or the yeast assimilable nitrogen [3]. Measuring the leaf area of the vineplant is generally performed manually (e.g. by counting the number of leaves per shoot), or indirectly by measuring the Leaf Area Index (LAI) from optical or hyperspectral sensors. Optical or hyperspectral sensors provide a LAI estimation of the scanned scene from 2D images.

We investigate in this paper the estimation of the foliage growth in a vineyard from a 3D radar imaging polarimetric technique. The sensing system is a 24GHz ground-based FM-CW (*Frequency-Modulated Continuous-Wave*) radar that performs a 3D beamsweeping of each individual vineplant in a precision viticulture context. Such proximal sensing system has been recently used to estimate the grape yield [4]. Simultaneous estimations of the yield and the leaf area of the vineplant with a single measurement system could be helpful for the winemakers to retrieve the leaf-to-fruit ratio. Different configurations of polarization are investigated for five vineplants of the same grape variety at three periods of the year.

II. MATERIAL AND METHOD

The remote sensing device is a FM-CW radar with the carrier frequency $f_c=23.8\text{GHz}$ and the bandwidth $B=2\text{GHz}$. The transmitted power is 20dBm. The T_x antenna is a narrow beamwidth horn with a lens of aperture angle of 6° and a gain of 28dBi. The T_x antenna is linearly polarized. Letters V and H denote respectively vertical and horizontal polarizations of antennas. Two channels $R_{x,1}$ and $R_{x,2}$ receive the electromagnetic signal backscattered from the scene. The $R_{x,1}$ and



Fig. 1. Ground-based FM-CW radar performing a beamsweeping in front of a vineplant. The photograph has been taken in May 2017 and, as observed, the foliage of the vineplants starts to grow.

$R_{x,2}$ antennas are linearly-polarized rectangular horns with a gain of 20dBi. The receiving antennas are cross-polarized, such as $R_{x,1}$ and $R_{x,2}$ antennas are respectively in V and H polarizations. We define the *polarization configuration* p as the combination of polarizations between the T_x antenna and the $R_{x,1}$ or $R_{x,2}$ antennas. If the T_x antenna is V -polarized, then $p = VV$ or VH designate polarization configurations for respectively $R_{x,1}$ and $R_{x,2}$ channels. If the T_x antenna is H -polarized, $p = HV$ or HH designate polarization configurations for respectively $R_{x,1}$ and $R_{x,2}$ channels. The radar system is mounted on a pan-tilt platform that performs the beamsweeping in the azimuth and elevation planes.

To measure the foliage density of a given vineplant, the ground-based radar system is located between two vinerows in front of the vineplant of interest, as shown in Fig. 1. The distance between the vineplant and the radar is 1.5m. The beamsweeping is then performed in the azimuth plane between $\varphi_{min}=-20^\circ$ and $\varphi_{max}=20^\circ$ and in the elevation plane between $\theta_{min}=0^\circ$ and $\theta_{max}=25^\circ$. The resulting radar image is a 3D dataset in azimuth/elevation/range coordinates (φ, θ, R) . Radar images are composed of voxels with volume defined by $(d_\varphi=1^\circ, d_\theta=1^\circ, d_R=7.5\text{cm})$. The radar echo level representing the electromagnetic backscattering of the beamswept scene is associated to each voxel of coordinates (φ, θ, R) .

Five vineplants of variety *Grenache* (denoted respectively g_1, g_2, g_3, g_4 and g_5) are studied at three dates in May, June and September 2017. In May, there is almost no foliage on the grapevines. In June, the foliage grows and vineplants flower. In September, measurements are performed after the harvest, that is, when there is no electromagnetic backscattering of the

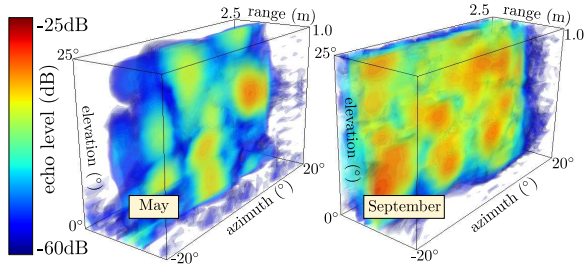


Fig. 2. 3D Radar images of the vineplant g_2 in polarization configuration $p = VV$ obtained in May 2017 (left) and September 2017 (right). Isosurfaces of echo level are displayed using a color scale from blue (-60dB) to red (-25dB).

grapes. During this period, the foliage grows substantially. 3D radar images in configuration $p = VV$ of the same vineplant are displayed in Fig. 2 in May (left) and September (right). Colors indicate isosurfaces of different echo levels from -60dB (blue color) to -25dB (red color). Between May and September, we observe that the number of isosurfaces raises as the echo level increases. As the foliage grows as well during this period, the correlation between the number of isosurfaces and foilage growth can be then conjectured. This correlation is acutally observed for the other four vineplants. From these first observations, we define the cumulative function F_p for a given polarization configuration p by :

$$F_p(v) = N_{p,v} \quad (1)$$

where $N_{p,v}$ represents the number of voxels in the radar image for which the echo level is higher than a predefined threshold denoted by v . As an example, the cumulative function F_p derived from radar images of the vineplant g_2 is displayed on Fig. 3 for $p = VV, VH$ and for different periods of the foliage growth (May, June and September). The threshold v varies from -90dB to -20dB with a resolution of 0.5dB and the distance R ranging from $R_{min} = 1.0m$ and $R_{max} = 2.5m$. For low thresholds (lower than -90dB), the number of voxels tends toward 22386, which is the total number of voxels in the radar image. Moreover, for high thresholds (higher than -20dB), the number of voxels tends toward zero, as there is always a threshold v larger than the highest echo level in the radar image. Between these threshold boundaries, F_p depends on the polarization configuration p . The most substantial variation of F_p is observed between May and June, that is, when the foliage grows rapidly. In order to quantify this variation, we define the following statistical estimator :

$$e_{I,p} = \sum_{k=1}^n N_{p,v_k} \cdot v_k \quad (2)$$

where v_k denotes the k^{th} threshold (in linear scale), and v_1 and v_n designate respectively the minimal and maximal thresholds of v . From Eqs. (1) and (2), $e_{I,p}$ is derived from the numerical integration of F_p displayed in Fig. 4 for five vineplants and for all polarization configurations. We observe the increase of $e_{I,p}$ (units in $voxel \times amplitude \ of \ echo \ level$) as the foliage grows for the five vineplants from May to September, excepting for

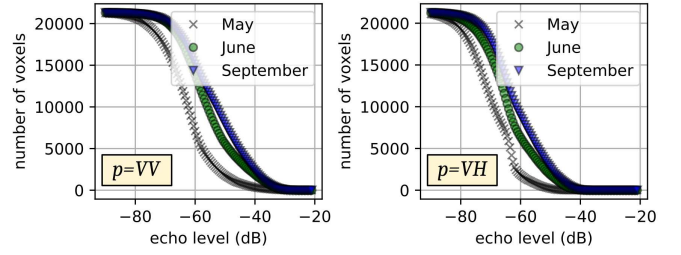


Fig. 3. Cumulative function F_p of the vineplant g_2 for two polarization configurations in May (black crosses), June (green circles) and September 2017 after the harvest (blue down triangles).

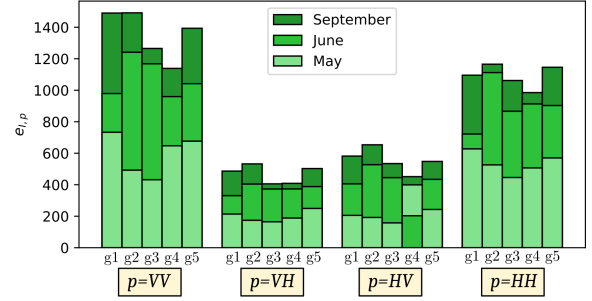


Fig. 4. Value of the statistical estimator $e_{I,p}$ for five grapevines and four polarization configurations in May, June and September 2017 after the harvest. $e_{I,p}$ clearly increases as the foliage grows.

the vineplant g_4 when $p = HV$. This exception may be explained by the inclined position of a metallic wire tensioner which was present in May and might generate cross-polarized electromagnetic backscattering. The increase of $e_{I,p}$ depends on the vineplant and/or the polarization configuration.

III. CONCLUSION

We defined in this paper a statistical estimator which is correlated to the foliage growth for different polarization configurations. The reported results must be correlated in the future with ground-truth measurements of the leaf area index and completed with the remote estimation of the grape yield. Such analysis may help the winemakers to estimate the leaf-to-fruit-ratio from radar imager.

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