THESIS PROPOSAL

Title : Mapping of orchard health and nutritional status from multimodal drone acquisitions in support of agro-ecological practices

Reference : **PHY-DOTA-2023-24**

Start : October 2023	**Application deadline :** June 2023

Keywords

UAV imagery, hyperspectral, polarization, 3D LiDAR, vegetation biochemical traits, orchards, agro-ecology

Profile of candidate and desired skills

Formation : Engineering schools optics or physics, Master's degree in physics or applied mathematics

Desired Skills : signal / image processing, remote sensing, machine learning, ecology/environment, scientific programming

Presentation of the topic, the context and objective

Due to the increasing world population, a critical issue today is food supply, combining substantial production, sustainable practices and a viable economy. The current challenge is to cope with multiple pressures coming from both biotic (e.g., diseases, pests) and abiotic (e.g., droughts) factors. Agro-ecology provides solutions that aim to design production systems based on the functionalities offered by ecosystems while minimizing environmental pressures and preserving natural resources [Ministry of Agriculture and Food]. However, its implementation requires a good understanding of the agroecosystem functioning, e.g., in order to optimize cropping practices (pesticides, irrigation, pruning, etc.). The use of remote sensing data at different spatial scales, from the individual (tree) to the whole plot, is a non-destructive and high temporal alternative to assess the state and functioning of an agroecosystem. In orchards, the inter-crown variability in health and nutritional status is commonly assessed by visual scores and measurements of water potential and nitrogen content (averaged at the tree scale). In order to obtain a better characterization of orchard condition, we propose to shift to the assessment of their intra-crown variability [1]. Indeed, the latter takes into account the structural heterogeneity of the tree crown and allows a better discrimination of the spatial extension of symptoms that are characteristic of the presence of diseases and pests. Moreover, it guides towards a spatialized and adapted treatment for a given tree.

For this purpose, drone acquisitions allow to reach the centimeter scale and to map finely the tree canopy by targeting each leaf. The leaf reflectance measured for each pixel in the 0.4 - 2.5 µm optical range is dominated by spectral absorptions specific to biochemical traits that are leaf pigments (e.g. chlorophylls, carotenoids and anthocyanins), as well as water and dry matter contents. These biochemical traits are related to the physiological activity of the leaf (e.g. photosynthesis, transpiration, growth) [2]. Therefore, their estimation and spatio-temporal evolution is closely correlated to the health and nutritional status of the leaf [3]. Thanks to their high spectral richness and fine spectral resolution, hyperspectral data are the most suitable to jointly estimate all biochemical traits [4]. The methodology to estimate these traits from leaf optical properties can be either empirical (using machine learning from reflectances or spectral indices), physical (inversion on simulated data by radiative transfer modeling codes - RTM), or hybrid (machine learning on simulated data) [4]. The methodology to characterize health/nutritional vegetation status from biochemical traits is generally empirical [1,3]. Nevertheless, the major problem when working at very high spatial resolution is that there are two types of directional effects (spectral and geometric) that need to be taken into account:

(1) the directional (or anisotropic) behavior of the leaf reflectance: the total reflectance is the sum of a specular and a diffuse component [5]. The former is dependent only on surface properties and does not provide information on biochemical traits, unlike the latter. We will therefore try to get rid of the contribution of the specular component. Since the specular component generates linear polarization on the unpolarized incident sunlight, we will try to work with polarimetric data in order to either subtract the specular component from the total measured reflectance [6], or to calculate spectral indices based on the degree of linear polarization [7].

(2) the angular orientation of the leaf which will more or less exacerbate the effect of (1) for given angular illumination conditions (with always vertical viewing conditions). It will be important to determine it to know if we are close to the specular configuration. For this, we will rely on 3D LiDAR data.

Thus, it will be necessary to adapt traditional methods to correct for these directional effects and obtain better estimates of leaf biochemical traits.

The objective of this PhD is to map the health and nutritional status of leaves within a tree to capture their intra-crown variability by coupling photometric (non-polarimetric) hyperspectral, polarimetric and 3D LiDAR drone acquisitions. The output mapping products can be used for targeted applications to improve agro-ecological practices: optimization of input management (fertilization, pesticides, irrigation) [8] and selection of resilient varieties [9]. This PhD is funded by the French National Research Agency and is part of the ANR JCJC CANOP project "Remotely sensed leaf biochemistry intra-individual variability in orchard tree CANOPies for agro-ecology" (2023-2026). The two study sites are located in Avignon and include a peach and an apricot orchard. Preliminary work will have been done using laboratory measurements to characterize the directional effects 1) and 2) at the leaf scale under controlled conditions. It will be necessary to evaluate how to apply and adapt them for outdoor acquisitions on the tree canopy.

The working plan will be split into 3 steps:

First, biochemical traits will be estimated from hyperspectral photometric data acquired by drone at centimeter scale. The processing of pure leaf pixels can be done based on classification from vegetation spectral indices to discriminate leaves, woody elements (trunk and branches) and fruit/flower, from 3D LiDAR data. Then, the estimation of leaf biochemical traits on these pixels will rely on (i) the application of empirical regressions, (ii) the inversion of the leaf-scale RTM code, PROSPECT [10], and (iii) the combination of both. Regressions and inversion codes will already be available via previous work that will be performed in the laboratory as part of the project. Finally, the estimated values of the biochemical traits will be validated with field measurements. This first work will serve as a basis since it does not correct for directional effects.

Second, we will evaluate the contribution of 3D LiDAR data to take into account the orientation of the leaves (see (2)). The acquired point clouds will be converted into angular information using a methodology that will have been previously tested in the laboratory [11]. Then, an empirical approach will be tested to estimate the biochemical traits by taking as input both the previous hyperspectral data and these angular data. It will be compared to the inversion of the RTM code PROCOSINE [12] which is an extension of PROSPECT with the addition of two parameters (the leaf zenith angle and an arbitrarily determined specular coefficient). In general, these two codes, PROSPECT and PROCOSINE, will be tested for their limitations when moving from the leaf scale under laboratory conditions to the canopy scale under outdoor conditions. The results will be compared with those of the first step.

At last, we will evaluate the contribution of polarimetric data to take into account the anisotropy of optical properties (see (1) and (2)). A bi-directional photometric and polarized reflectance model of the leaf [13] and empirical regressions developed in the laboratory linking optical properties to leaf traits (based on [6,7]) will be tested on the multimodal data set. The performance of the three approaches in estimating biochemical traits will be assessed and combined. The detailed mapping of these traits within the crown of a tree will be converted into health/nutritional status with already established relationships. The link with the targeted agro-ecological applications could be carried out with the collaboration of expert laboratories in this field.

The PhD student will participate in two field campaigns in 2024 that will include different types of measurements, i.e., multimodal drone acquisitions, 3D LiDAR ground measurements, and spectral field measurements to characterize the environment. Several leaf samples as well as complementary spectral and health/nutritional condition measurements will also be planned.

If you are interested in this PhD, please send both a CV and a motivation letter.

<u>Bibliographic references:</u>

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Collaborations

Partner laboratories of ANR JCJC CANOP (TETIS – J.-B. Féret, CESBIO – J.-P. Gastellu-Etchegorry, N. Lauret, PSH – G. Vercambre, GAFL – M. Roth)

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