POST-DOCTORATE PROPOSAL

Title : Mapping orchard leaf biochemistry from UAV imagery: a hybrid-based approach from 3D radiative transfer modeling and hyperspectral/LiDAR datasets

Reference: **PDOC-DOTA-2025-09**
(to be recalled in all correspondence)

Start of contract: 01/01/2026

Application deadline: 01/12/2026

Duration: 12 months

Keywords:

modelisation / inversion, radiative transfer, simulations, UAV imagery, hyperspectral, LiDAR, sensitivity analysis, , vegetation, orchards

Profile and skills required:

Formation: Engineering schools of optics or physics and/or Master's degree in physics or applied mathematics, PhD in remote sensing.

Desired Skills: signal / image processing, remote sensing, machine learning, ecology/environment, scientific programming (python), radiative transfer models.

Presentation of the post-doctoral project, context and objective:

Climate change and worldwide population increase lead to different key challenges for orchard management, such as the provision of a substantial food supply with a viable economy, the choice of resilient species varieties and the optimized use of inputs for sustainable practices (e.g. irrigation, phytosanitary and fertilization products). To that aim, UAV-borne acquisitions are increasingly used for precise monitoring at the individual tree scale, like the mapping of stress-related geometrical traits under different irrigation regimes [1], the prediction of macronutrients for fertilization decision-making [2] and the determination of health status from the estimation of biophysical/biochemical traits [3]. While RGB and multispectral cameras are widely used onboard UAVs, the potential of hyperspectral and the gain of combining with LiDAR information still require more investigations [4]. Moreover, when increasing the spatial resolution such as being at the centimetric scale raises new issues due to the impact of different sources of directional effects on the remotely sensed spectral signatures. First, we can note the anisotropy of the surface optical properties due to volume/surface scattering inducing specific light reflection directions [5], whose impact could be smoothed or neglected at higher spatial resolutions. Second, following the illumination and observation conditions, the 3D geometry of tree canopies induces the presence of self-/cast shadows, foliage gaps, and within-canopy multiple scattering driven by a variety of light-matter interactions (absorption, reflection and transmittance, between photosynthetic and non-photosynthetic materials) [6]. Therefore, deriving accurate estimations of vegetation traits from their optical properties needs appropriate methods to correct or take into account these directional effects.

For leaf trait estimation, a first category of methods relies on data-driven strategies or MLRA (Machine Learning Regression Algorithm) by building statistical regressions between UAV spectra and laboratory / in situ measured data (pigment contents, water and dry mater contents, spectral signatures, etc.). Such methods implicitly account for directional effects in the training database but with very large imprecisions, and they require a large amount of training samples, which is highly cost and time consuming [7]. A second category of methods is based on model-driven strategies. It includes the hybrid-based inversion methods with the use of radiative transfer models to simulate spectral response at leaf or canopy scale. They rely on the training of MLRA on simulated datasets or LUT (Look-Up-Table) relating directional spectral signatures with combinations of vegetation traits. For orchard trees remotely observed at very high spatial resolutions, these methods require as input a 3D representation of the scene that can be derived from abstract 3D models inspired by geometrical optics or LiDAR point clouds. The calibrated selected MLRA is further applied on remote sensing images to predict these traits that are finally validated with in situ measurements. Such methods have the advantage to provide a fine interpretation of light-matter interactions, and so, to account precisely for every source of directional effects.

To date for 3D vegetated landscapes, these hybrid-based inversion methods have been largely used for airborne/satellite remote sensing data from metric to decametric resolutions [8,9,10,11]. However, few studies have investigated them at centimetric spatial resolutions from UAV acquisitions [12,13]. And if so, they usually do not cover the full 0.4-2.5µm spectral range and only work with vegetation indices ([12]:490–800nm, [13]: 6 visible-near infrared bands), which limits the number of estimated traits (e.g. leaf pigments). In addition, they work at canopy level ([12]: individual tree crowns; [13]: mean of crown sunlit pixels), which hampers the ability to take full advantage of the centimeter-level spatial resolution to reach the leaf scale and analyze inter-canopy variability.

Thus, the objective of this post-doctorate proposal is to map the intra-individual variability of leaf biochemical traits within an orchard tree canopy from high spatial resolution UAV imagery, based on the development of a hybrid-based methodological framework by using DART radiative transfer model and LiDAR-based reconstructed 3D scenes. This work is part of the CANOP project [14] aiming to assess the health and nutritional status of peach and apricot trees in contrasted input managements and genotypes. Two campaigns occurred in 2024, the first in June and the second in September, involving hyperspectral UAV acquisitions at 1-3 cm, UAV-borne LiDAR acquisitions, and terrestrial LiDAR scans performed over some selected trees. In parallel, SPAD and DUALEX leafclip measurements were done on a collection of leaves per tree to have access to the distribution of leaf chlorophylls contents. Also, leaf water and dry matter content were measured on the same leaves.

The work will be divided in four steps:

1. Build 3D models of trees from LiDAR data to generate contrasted orchard scenes,
2. Perform a sensitivity analysis to have a better understanding of the contribution of light-matter interactions at pixel scale from UAV observations and to assess the most important sources of directional effects: this will be done by using the previously generated 3D scenes, building a design of experiments by accounting for instance for a variety of leaf biochemical traits and time of the day, then simulating UAV images with DART by constructing LUTs, and analyzing the top-of-canopy reflectance and radiative balance as outputs of DART simulations,
3. Validate the adequacy of simulated leaf spectra over tree crowns in a forward modeling approach: comparison between the previously generated LUTs and the real UAV imagery acquisitions,
4. Calibrate and validate a MLRA in an inverse modeling approach: comparison and selection of MLRA, performance assessment between simulated and measured data, production of maps of leaf biochemical traits and comparison with field measurements.

The candidate will make use of existing tools (leaf/wood separation and surface-based representation from LiDAR, simulations and inversion with DART), which will need to be adapted or improved, and will gain expertise in radiative transfer modeling. He/She will be integrated into the project and will participate in meetings and discussions with partners. Funding is provided for publications fees and the participation to an international conference.

If you are interested in this post-doctorate position, please send both a CV and a motivation letter to karine.adeline@onera.fr and sophie.fabre@onera.fr.

References:

[1] Caruso G. et al. (2019) High-resolution imagery acquired from an unmanned platform to estimate biophysical and geometrical parameters of olive trees under different irrigation regimes. PLoS ONE 14(1): e0210804.

[2] Kang Y.S. et al. (2024) Predicting Apple Tree Macronutrients Using Unmanned Aerial Vehicle-Based Hyperspectral Imagery to Manage Apple Orchard Nutrients. Drones 2024, 8, 369.

[3] Wu Y. et al. (2023) Multi-parameter Health Assessment of Jujube Trees Based on Unmanned Aerial Vehicle Hyperspectral Remote Sensing. Agriculture 2023, 13, 1679.

[4] Zhang C. et al. (2021) Orchard management with small unmanned aerial vehicles: a survey of sensing and analysis approaches. Precision Agric 22, 2007–2052 (2021).

[5] Bousquet L. et al. (2005). Leaf BRDF measurements and model for specular and diffuse components differentiation. Remote Sensing of Environment, 98, 201-211 or PhD thesis of Laurent Alain Bousquet, Paris, 2007 (http://www.theses.fr/2007PA077024).

[6] Adeline K. et al. (2021) Impact of Tree Crown Transmittance on Surface Reflectance Retrieval in the Shade for High Spatial Resolution Imaging Spectroscopy: A Simulation Analysis Based on Tree Modeling Scenarios. Remote Sens. 2021, 13, 931.

[7] Li Y. et al. (2023) Semi-supervised cooperative regression model for small sample estimation of citrus leaf nitrogen content with UAV images. International Journal of Remote Sensing, 44(23), 7237–7262.

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[9] Ali A. et al. (2020) Machine Learning Methods' Performance in Radiative Transfer Model Inversion to Retrieve Plant Traits fromSentinel-2 Data of a Mixed Mountain Forest. International Journal of Digital Earth 14 (1): 106–120.

[10] Ferreira M. P. et al. (2018) Retrieving structural and chemical properties of individual tree crowns in a highly diverse tropical forest with 3D radiative transfer modeling and imaging spectroscopy. Remote Sensing of Environment, 211, 276-291.

[11] Miraglio T. et al. (2022). Assessing vegetation traits estimates accuracies from the future SBG and biodiversity hyperspectral missions over two Mediterranean Forests. International Journal of Remote Sensing, 43(10), 3537-3562.

[12] Cimoli E. et al. (2024) Mapping functional diversity of canopy physiological traits using UAS imaging spectroscopy. Remote Sensing of Environment, Vol. 302, 2024, 113958.

[13] Cheng J. et al. (2022) Estimating canopy-scale chlorophyll content in apple orchards using a 3D radiative transfer model and UAV multispectral imagery. Computers and Electronics in Agriculture, Vol. 202, 2022, 107401.

[14] ANR JCJC CANOP project "Remotely sensed leaf biochemistry intra-individual variability in orchard tree CANOPies for agroecology" (2023-2026)(ANR-22-CE04-0002)(https://remotetree.sedoo.fr/canop/).

External collaborations:

Partner laboratories of the CANOP project (INRAE – EMMAH/TETIS/GAFL/PSH and UT3/CESBIO)

Host laboratory at ONERA:

Department: Optics and Associated Techniques

Location (ONERA center): 2 avenue Edouard Belin, Toulouse, France

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