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POST-DOCTORATE PROPOSAL

Title : Characterization of the leaf spectro-polarizing effects upscaled to tree canopy for chlorophyll estimation from proximal imaging acquisitions

Reference : **PHY-DOTA-2023-04**
(to be recalled in all correspondence)

Start of contract: June 2023	**Application deadline:** until fulfilled

Duration: 12 months

Keywords:

Polarized imaging, centimetric scale, optical properties, leaf chlorophylls content, tree vegetation, experiments

Profile and skills required:

Formation : PhD in optics or physics or applied mathematics

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

Candidates should have less than 3 years after their PhD degree

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

The use of proximal imaging acquisitions from ground-based [1] or UAV-based [2] platforms at centimetric scales is a promising non destructive way to monitor vegetation status with high accuracy. It has been proven for many applications in precision agriculture, phenotyping or single plant-oriented management. Actually in the Vis-NIR range (0.4 – 1 µm), leaf optical properties, namely reflectance and transmittance, are mainly dominated by strong spectral absorptions induced by leaf pigments, and essentially chlorophylls [3]. These latter play a major role in the plant photosynthesis activity, and thus, are keys elements for a better understanding of the plant physiological status (i.e. health, nutrition, growth) and primary production.

However when upscaling the leaf to a whole tree canopy, the remotely-sensed reflected light is actually more a combination of different contributions due to combined 3D geometric and radiative effects. In fact, the leaves in a tree are spatially distributed within the crown and have each one their specific angular orientation, which infers multiple shadowing, scatterings, transmission and absorptions with photosynthetic (neighbouring leaves) and non-photosynthetic wood materials (i.e. trunk and branches). In addition at centimetric scales, the directional effects of the material optical properties can no longer be neglected while they are mostly smoothed or with a lower intensity at lower spatial resolutions (metric/decametric scales)[4,5,6]. More precisely at the leaf scale, the total reflectance can be decomposed into its diffuse (i.e. isotropic) and specular contribution. The first effectively enters the leaf and interacts with chlorophylls molecules in the chloroplasts before being scattered out of the leaf while the second is directly reflected from the surface according to the Snell-Descarte law [7]. Since specular contribution is mainly function of leaf surface properties (e.g. refractive index and rugosity), it can vary strongly among tree species having different leaf anatomy (ex: presence of wax and hairs)[8]. As such, for given illumination and viewing directions, it is challenging to study a leaf in a tree in natural conditions compared to a leaf in controlled environments like in laboratory conditions.

The issue is that an inaccurate estimation of leaf optical properties will necessarily lead to biases in leaf chlorophylls content estimation from empirical regressions. Some studies focused on the design of spectral indices less influenced by the canopy structure [1, 2]. Others removed the specular reflectance contribution in spectral indices based on the fact that the specular contribution is wavelength-independent in the Vis-NIR range [8]. Other studies rely on the linearly polarized state of the reflected light generated in the specular direction. They either subtract it from the total measured reflectance [9] or compute the DOLP (Degree Of Linear Polarization)[10]. The second has the advantage of not requiring calibration while the first need normalization with a reference target. Most recent state of the art literature have carried out studies for single leaves, potted plants and hedges in indoor and outdoor conditions with polarized measurements [11], and very few with polarized imaging [12] even though it provides a better spatial variability and thus statistical analysis. However, to our best knowledge, scaling these results from leaf to a tree canopy has not been studied yet, as well as the assessment of the multi-angular impact of solar conditions throughout a complete day.

The objective of this post-doctorate is to characterize the spectro-polarizing characteristics of leaf optical properties from proximal Vis-NIR multispectral polarized imagery to estimate leaf chlorophylls content in a tree canopy. The goal is to provide first orders of magnitude of these spectro-polarizing effects in function of the image spatial resolution, the daily temporal variation and the sensor spectral characteristics. The study will focus on at least two tree species having different or extrema polarimetric optical behavior, with varying illumination conditions, for fixed leaf geometries inside the tree and vertical acquisitions. The methodology will rely on the use of spectral indices to estimate leaf chlorophylls contents, either taken from the literature or designed specifically in the frame of this study.

The working plan will be the following:

- Set up and perform an experiment to acquire outdoor images with the polarized camera over a tree canopy with multiple acquisitions over a full day along with chlorophyll-meter measurements on some leaves (and other relevant measurements such as spectroscopic ones),
- Post-process the collected data including geometric/radiometric corrections, derivation of the Stokes vector (describing the polarization state of acquired light) and DOLP per pixel and per spectral band images for each acquisition, computation of relevant spectral indices,
- Same as before by studying different spatial resolutions (from a single leaf to several leaves) by image spatial aggregation,
- Carry out statistical analysis to assess the spectral variance of Stokes parameters and DOLP values observed within a single image (for leaves with different orientations), its temporal evolution (for different solar illumination angles) and spatial variation (different spatial resolutions),
- Perform sensitivity analysis by studying the performance of regressions built between the derived spectral indices and the previously chlorophylls measurements used as proxies,
- Summary of the results, scientific paper writing and conference presentation.

This post-doctorate 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). This work will contribute to set up the appropriate experiment and methodology to be applied further to orchard sites.

If you are interested in this post-doctorate position, please send both a CV and a motivation letter to the persons of contact.

References :

[1] Jay, S., et al. "Estimating leaf chlorophyll content in sugar beet canopies using millimeter-to centimeter-scale reflectance imagery." Remote Sensing of Environment 198 (2017): 173-186.

[2] Jay, S., et al. "Exploiting the centimeter resolution of UAV multispectral imagery to improve remote-sensing estimates of canopy structure and biochemistry in sugar beet crops." Remote Sensing of Environment 231 (2019): 110898.

[3] Ustin, S. L., Gitelson, A. A., Jacquemoud, S., Schaepman, M., Asner, G. P., Gamon, J. A., & Zarco-Tejada, P. (2009). Retrieval of foliar information about plant pigment systems from high resolution spectroscopy. *Remote Sensing of Environment*, *113*, S67-S77.

[4] Peltoniemi, J. I., Gritsevich, M., & Puttonen, E. (2015). Reflectance and polarization characteristics of various vegetation types. In Light scattering reviews 9 (pp. 257-294). Springer, Berlin, Heidelberg.

[5] Breon, F. M., Tanre, D., Lecomte, P., & Herman, M. (1995). Polarized reflectance of bare soils and vegetation: measurements and models. IEEE Transactions on Geoscience and Remote Sensing, 33(2), 487-499.

[6] Maignan, F., Bréon, F. M., Fédèle, E., & Bouvier, M. (2009). Polarized reflectances of natural surfaces: Spaceborne measurements and analytical modeling. Remote Sensing of Environment, 113(12), 2642-2650.

[7] Bousquet, L., Lacherade, S., Jacquemoud, S., & Moya, I. (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).

[8] Sims, D.A., & Gamon, J.A. (2002). Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. Remote Sensing of Environment, 81, 337-354.

[9] Li, Y., Sun, Z., Lu, S., & Omasa, K. (2020). Improvement of leaf chlorophyll content estimation using spectral indices from nonpolarized reflectance factor in the laboratory and field. IEEE Journal 870 of Selected Topics in Applied Earth Observations and Remote Sensing, 13, 3669-3682.

[10] Yao, C., Lu, S., & Sun, Z. (2020). Estimation of leaf chlorophyll content with polarization measurements: Degree of linear polarization. Journal of Quantitative Spectroscopy and Radiative Transfer, 242, 106787.

[11] Sun, Z., Wu, D., Lv, Y., & Zhao, Y. (2017). Polarized reflectance factors of vegetation covers from laboratory and field: A comparison with modeled results. Journal of Geophysical Research: Atmospheres, 122(2), 1042-1065.

[12] Maxwell, D. J., Partridge, J. C., Roberts, N. W., Boonham, N., & Foster, G. D. (2016). The effects of plant virus infection on polarization reflection from leaves. PLoS One, 11(4), e0152836.

External collaborations :

ANR CANOP laboratory consortium (ONERA, EMMAH, CESBIO, TETIS, GAFL, PSH)

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