In-field hyperspectral imagery for high-throughput phenotyping

Combining opto-physical modelling of plant structures and chemometrics tools for robust calibration of in-field hyperspectral images; application to plant phenotyping (PhD 2014-2017)

ABSTRACT

Short range hyperspectral imagery is a promising tool for phenotyping and vegetation survey. When associated with partial least square regression (PLS-R), it allows high spatial resolution mapping of the plant chemical content at the canopy scale.
However, several optical phenomena have to be taken into account when applying this approach to vegetation scenes in natural conditions. For instance, additive and multiplicative factors due respectively to specular reflection and leaf inclination can be overcome by spectral preprocessing. But the most challenging phenomenon is multiple scattering. It appears when a leaf is partly lightened by the reflected or transmitted light from surrounding leaves, resulting in strong non linear effects in its apparent reflectance spectrum. Though this effect can be taken into account in some remote sensing models at the canopy scale, no study has been proposed until now concerning its impact on spectral prediction of vegetation chemical content by short range imagery.

The objective of this project, associated with a PhD work, was to analyze these effects in the context of hyperspectral imagery for vegetation phenotyping purpose, and to propose spectral processing methods to overcome them.

The methodological development has been based on simulation tools included in the open source platform OpenAlea (http://openalea.gforge.inria.fr/dokuwiki/doku.php). A typical wheat canopy scene has been modelled using Adel-Wheat and combined with the light propagation model Caribu. The proposed tool simulates the apparent reflectance of every visible leaf in the canopy for a given actual reflectance and transmittance, allowing to synthetize realistic hyperspectral images.
This simulation approach has allowed us, in a first step, to analyze the distribution of deviations due to multiple scattering in the spectral space, and then to infer a correction method in the frame of PLS regression. This method relies on the building of two subspaces EW and EB respectively generated by the analytic formulation of multiple scattering and by the variable of interest. It allows us to define a projection operation on EB subspace along EW direction (oblique projection), in order to remove multiple scattering effects while preserving useful information. This projection operation is then applied on every spectra during learning phase and using phase of the PLS model.

The method has first been developed and tuned using simulated data, in the frame of leaf nitrogen content (LNC) prediction of wheat leaves. For this purpose, reflectance spectra (450-1100 nm) of 57 wheat leaves have been collected using a ASD filed spectrometer (FieldSpec®, Analytical Spectral Devices, Inc., Boulder, Colorado, USA), while their LNC was measured through reference chemical analyses. Regression models with and without oblique projection have then been built from the ASD spectra and applied to simulated data. The model with oblique projection provided excellent results (R^2 = 0.931; RMSEP = 0.29% DM), compared to the classical one (R^2 = 0.915; RMSEP = 0.42% DM).

The same method has then been applied in real conditions on wheat pot plants and field plants. For this purpose, some leaves have been collected and laid on a black paper background to be imaged, in order to build PLS models that have then been applied on in-situ plants. These experimentations have confirmed that the classical PLS-R induces a strong overestimation of LNC on leaves surrounded by other leaves, and that oblique projection corrects this overestimation (same prediction on surrounded then isolated leaf).

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PERSPECTIVES

The perturbation subspace EW being built analytically, the method only requires learning samples collected in laboratory. This makes a considerable progress for in-field phenotyping, which in a first time will be applied in plant phenotyping studies led by the AGAP team at the DIASCOPE experimental unit.