Developing the potential of light Lidar systems for the management of French private forests

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Context:

Forests provide multiple services that are important to preserve for future generations. In a context of climate change and biodiversity erosion, it is essential to implement forest management practices enabling forests to fulfill their role as carbon sinks and reservoirs of biodiversity, while continuing to play their production and recreation roles. In France approximately 75% of French forests are privately owned. These forests are often very fragmented and sometimes under logged. Given the costs associated with owning a forest estate, achieving sustainable management of private forests implies that their management ensures a minimum economic return. The Simple Management Plan (SMP) is a tool that defines medium and long-term management objectives, as well as forestry operation plans. To best conciliate environmental and production objectives in SMPs, foresters need reliable information on their properties. Information on the structure of forest stands, in addition to species composition, is particularly useful. Managers commonly rely on summary information at the stand level (e.g. dominant height, basal area) and on indicators of tree diameters or heights distributions to define the management objectives for a given stand and plan forestry operations or estimate timber volumes and productivity.

In this context, using Lidar is a valuable option to provide part of the information needed for forest management. Lidar (LIght Detection And Ranging) is a particularly interesting technology for measuring vegetation structure (Durrieu et al. 2015; Lim et al. 2003; Van Leeuwen and Nieuwenhuis 2010). These active remote sensing systems provide precise distance measurements based on elapsed time between the emission of a laser pulse and the measure of the backscattered signal. The spatial position on the Earth's surface of all the recorded returns is calculated from both the position and orientation of the Lidar system, which are measured using respectively a differential global positioning system (DGPS) and an accurate inertial unit. Data is typically delivered by service providers as a 3D point cloud. Each point corresponds to a target at the origin of an echo with a sufficiently high intensity, i.e. group of leaves, branch or trunk for vegetation (Chauve et al. 2009; Wagner et al. 2006). The use of Lidar has moved from research to operational applications in favorable contexts, which are generally characterized by open availability of data combined with a relative simplicity of forest stands, like in most Northern European countries (Naesset 2007; White et al. 2013; Wulder et al. 2008).

In France, several recent projects have proposed models for predicting forest parameters that are adapted to the national forest context (e.g. ANR FORESEE project (2010-2014) led by the FCBA) (Bouvier et al. 2015; Monnet et al. 2015; Véga et al. 2016). These results led the National Forestry Board (ONF) to acquire Lidar data over pilot sites to assess the feasibility of using these data to prepare management plans. However, the methods for reliably estimating structural forest types remain to be developed.

The use of Lidar in private forests faces additional constraints, in particular forest fragmentation resulting in an inadequate cost/flexibility ratio when data are acquired using airborne Lidar systems. Recently, Lidar on light aircrafts (drones and ULM) have been developing and offer the required flexibility, thus significantly reducing the cost of data per unit surface (Matese et al. 2015). Moreover, the combination with optical imagery can bring additional valuable information to describe forest stands, particularly their composition. The use of sensors embedded on drones appears as an interesting solution to explore for forest applications. However, developing the use of light Lidar systems for private forest management requires knocking down three barriers. On the one hand, data characteristics are different from those of airborne Lidar data. Point densities are higher and ranges of acquisition angles wider, which involve checking the effectiveness of existing processing methods and models and adapting them where appropriate. On the other hand, there is a need to further research to achieve a fine characterization of forest structure for an effective management of wood resources (e.g. estimation of height or diameter distributions) but also for assessing the ecological value of the stands (Wang et al. 2010). Finally, it is essential to work on our capacity to mobilize existing reference data sets, combining past field and Lidar data sets, in order to reduce the need for new field data to calibrate and validate predictive models of forest attributes.

Objectives:

The objective of this PhD work is to develop products that provide foresters with the information they need to achieve the sustainable management objectives targeted by the French private forest sector. To that aim, we will build on the potential offered by light Lidar systems, combined where necessary with optical imagers, to describe and map stands at a cost that is affordable for forest owners.

Three sub-objectives are identified:

1- To validate the capacity to transfer ALS methods to process data acquired by UAV or ULM
2- To develop specific methods to improve Lidar-derived products and to propose new products (forest parameters) by taking advantage of the higher point density and the greater variability of viewing angles that characterize data acquired by light systems.
3- To optimize costs by capitalizing and remobilizing existing information; field surveys on reference plots will be stored in databases along with the corresponding point cloud subsets and the conditions for remobilizing this information when a new site is analyzed will be studied.

Foreseen approaches by sub-objective:

1- To transfer methods developed to process ALS data to the case of drone or ULM Lidar data, the PhD student will rely on the literature and on the experience of Irstea and Info Geo Drones to select the best models developed to estimate a set of parameters of interest (e.g. dominant height, wood volume, aboveground biomass, basal area). The way the models behave according to acquisition conditions will be evaluated in order to determine their applicability domain. The models will also be adapted to better take into account the specificities of the new Lidar data.

2- The higher point densities and the wider scan angle ranges that characterize Lidar data acquired with light systems provide more information on trunks and crowns and open the way to the improvement of individual tree detection methods and to the assessment of stem densities and trunk diameter distributions (dbh). Today, the latter parameters are difficult to estimate from ALS data. The high point density also open the way to the development of methodologies combining tree and surface approaches (stand level) to make the most of each approach and improve the prediction of forest attributes. In addition, combining Lidar data with optical images could help refining stand characterization.

3- A significant part of the cost associated to Lidar data processing is linked to the acquisition of field reference data that are contemporaneous with Lidar acquisitions. These reference data are essential for the calibration / validation of the models. If existing data could be mobilized for this calibration/validation step it would help overcoming the issue of information cost. The capacity to mobilize existing data sets depends to a large extent on our capacity to normalize Lidar information and to make information derived from the signal (e.g., LAD profiles, usual Lidar metrics) comparable between several Lidar data sets. To progress in this direction, data will be acquired with different acquisition conditions (point density, flight height) on the same study sites. A set of Lidar-derived parameters that are relevant to build predictive models and that are robust to the changes in acquisition conditions will be proposed. Using such parameters should enable models to be calibrated partly based on archive data sets, thus limiting the need for reference datasets contemporaneous with the latest Lidar acquisition. For this third sub-objective, the contribution of deep learning and domain adaption approaches will also be explored. If successful, this particularly innovative part of the work could have a major impact on the operational use of Lidar data, whether acquired from light systems or from aircraft.

Selected Bibliography:

Bouvier, M., Durrieu, S., Fournier, R.A., & Renaud, J.-P. (2015). Generalizing predictive models of forest inventory attributes using an area-based approach with airborne Lidar data. *Remote Sensing of Environment, 156*, 322-334

Chauve, A., Vega, C., Durrieu, S., Bretar, F., Allouis, T., Deseilligny, M.P., & Puech, W. (2009). Advanced full-waveform Lidar data echo detection: Assessing quality of derived terrain and tree height models in an alpine coniferous forest. *International Journal of Remote Sensing, 30*, 5211-5228

Durrieu, S., Véga, C., Bouvier, M., Gosselin, F., Renaud, J.-P., & Saint-André, L. (2015). *Optical remote sensing of tree and stand heights*. Taylor & Francis Group

Lim, K., Treitz, P., Wulder, M., St-Onge, B., & Flood, M. (2003). Lidar remote sensing of forest structure. *Progress in Physical Geography, 27*, 88-106

Matese, A., Toscano, P., Di Gennaro, S.F., Genesio, L., Vaccari, F.P., Primicerio, J., Belli, C., Zaldei, A., Bianconi, R., & Gioli, B. (2015). Intercomparison of UAV, aircraft and satellite remote sensing platforms for precision viticulture. *Remote Sensing, 7*, 2971-2990

Monnet, J.-M., Chirouze, E., & Mermin, É. (2015). Estimation de paramètres forestiers par données Lidar aéroporté et imagerie satellitaire RapidEye: Étude de sensibilité. *Revue Française de Photogrammétrie et Télédétection*, 211-212

Naesset, E. (2007). Airborne laser scanning as a method in operational forest inventory: Status of accuracy assessments accomplished in Scandinavia. *Scandinavian Journal of Forest Research, 22*, 433-442

Van Leeuwen, M., & Nieuwenhuis, M. (2010). Retrieval of forest structural parameters using Lidar remote sensing. *European Journal of Forest Research, 129*, 749-770

Véga, C., Renaud, J.-P., Durrieu, S., & Bouvier, M. (2016). On the interest of penetration depth, canopy area and volume metrics to improve Lidar-based models of forest parameters. *Remote Sensing of Environment, 175*, 32-42

Wagner, W., Ullrich, A., Ducic, V., Melzer, T., & Studnicka, N. (2006). Gaussian decomposition and calibration of a novel small-footprint full-waveform digitising airborne laser scanner. *ISPRS Journal of Photogrammetry and Remote Sensing, 60*, 100-112

Wang, K., Franklin, S.E., Guo, X., & Cattet, M. (2010). Remote sensing of ecology, biodiversity and conservation: A review from the perspective of remote sensing specialists. *Sensors, 10*, 9647-9667

White, J.C., Wulder, M.A., Vastaranta, M., Coops, N.C., Pitt, D., & Woods, M. (2013). The utility of image-based point clouds for forest inventory: A comparison with airborne laser scanning. *Forests, 4*, 518-536

Wulder, M., White, J., Fournier, R., Luther, J., & Magnussen, S. (2008). Spatially Explicit Large Area Biomass Estimation: Three Approaches Using Forest Inventory and Remotely Sensed Imagery in a GIS. *Sensors, 8*, 529-560