HOW MUCH COMMERCIAL TIMBER IN YOUR PLOT, HOW MUCH CARBON SEQUESTRATED IN THE TREES, HOW MUCH LIGHT AVAILABLE FOR UNDERCROPS? TERRESTRIAL LIDAR IS THE RIGHT TECHNOLOGY FOR ADDRESSING THESE QUESTIONS

Dauzat J[1*], Madelaine-Antin C[1], Heurtebize J[1], Lavalley C[1] and Vincent G[1]

* Correspondence author: dauzat@cirad.fr

Affiliation: (1) AMAP/BIOS, CIRAD, Montpellier, France

Introduction

Accurate and detailed information is highly needed for evaluating and optimizing the agroforestry systems that are inherently multifarious in terms of tree species, planting density and types of undercrops. Yet, up to recently, there were quite few methods for characterizing the 3D structure of such complex agro-systems. For instance the prime timber of a tree is routinely estimated from manual measurements of its trunk diameter and height. But, besides inaccuracies in these measurements, especially in case of crooked or knotty trees, the estimation of branches and twigs biomass remains fairly coarse, despite they can be commercialized as secondary timber products. The flaws of classical methods are even more blatant when dealing with the assessment of the sequestrated carbon in the standing biomass.

On the other hand the methods that are classically used for quantifying the light available for undercrops provide local information that can hardly be extended at plot scale. Direct measurements require light sensors that are moved across the plot or set at fixed positions. One difficulty then arises from the fact that measurements are sensitive to the sun position and to the radiative conditions (e.g. sunny or cloudy), making it difficult to extend results to different conditions. Alternatively indirect methods using the Plant Canopy Analyser (PCA) or hemispherical photographs (HP) can provide information which is not dependent on the radiative conditions. But a very dense sampling is needed for mapping the light over a plot.

Fortunately the recent advances in terrestrial lidar (Light Detection and Ranging) scanners (TLS) together with the development of algorithms dedicated to the analysis of collected data are now reshuffling the givens of the above questions. Several teams are developing algorithms for rebuilding virtual trees from TLS data (e.g. Boudon et al., 2014; Côté et al., 2013) and assessing their woody biomass. On the other hand, the lidar technology allows getting valuable information about the density of foliage in a three-dimensional space. Subsequently this information can be used to map the light available under the trees for any radiative condition. The goal of this paper is to illustrate how lidar scanning can be used to address the above-mentioned issues.

Material and methods

Experimental plot:

Lidar acquisitions were performed in an experimental agroforesty trial set at Vézénobres in France (44°03' N; 04°08' E). The trial was planted with hybrid walnuts trees (Juglans regia x J. nigra) in 1995 at low density (10m x 10m). On February 2015, three pruning treatments were applied to the trees for studying their impact on vegetable cultivation: severe pruning in a pollard style, medium pruning for getting more light over garden beds or minimal regular pruning of lowest branches.

Lidar scanning:

Lidar[1] scanners emit light pulses at very high frequency in known directions and measure the distance of surfaces returning an echo when hit by a pulse. Given this information, the 3D coordinates of each point generating an echo are recorded. Our acquisitions were performed with a Riegl VZ400, able to collect up to 300 000 points/sec with an accuracy of 5mm at distances of several hundred meters.

Fifty-six scans were first collected in September 2015 in order to get a full description of the canopy that was then used for calculating the light transmitted to the undercrops. A co-registration process was then applied to merge the point clouds obtained from the different scanning positions. To this aim, small “targets” (e.g. reflective balls or disks) were disseminated in the field in such way that they were visible from the different positions. Thus, by recording the

---

position of these targets, the scanner software can calculate the transformation matrices needed to merge the point clouds (**Figure 1**).

Figure 1: Merging point clouds. In that example darker points were obtained by scanning the tree from the left side and lighter ones were obtained from an opposite point of view. The two point clouds were merged automatically owing to reference targets located around the tree.

Other scans were performed between January and March 2016 on 12 trees (4 trees per pruning treatment) without leaves in order to get relevant information for rebuilding virtual trees and estimating their woody volume. The sampling strategy was adapted in order to have three spaced out points of view or more around each of the 12 selected trees.

Rebuilding virtual trees:

There are currently few available software programs dedicated to rebuilding trees from TLS acquisitions (Hackenberg et al, 2015; Raumonen et al, 2013). “SimpleTree” is free software available on the net (http://www.simpletree.uni-freiburg.de/). Illustrations given in result section were obtained with this software.

Spatial distribution of foliage and calculation of light transmission under trees

The AMAPvox software (Vincent et al, 2015) was specifically developed for calculating the density of foliage (Leaf Area Density; m^2m^{-3}) within a plot but, in contrast to methods used for HP or PCA analyses, the calculations are performed in three-dimensional space and provide the density of LAD/PAD in cubic cells (“voxels”). Then, given the local density of foliage throughout the plot, the transmission of incident light can be simulated for different sun positions and radiative conditions. Additionally, the software allows to simulate virtual hemispherical photographs (**Figure 2**) or virtual transmittance measurements of LAI2000/2200 PCA.

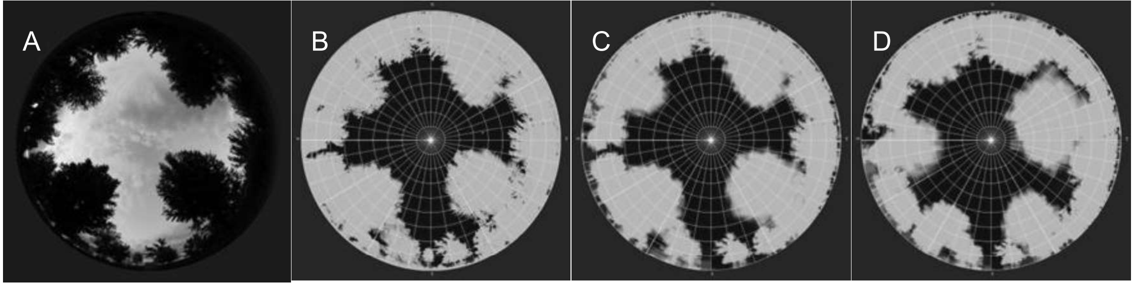

Figure 2: Lidar versus hemispherical photographs. A) Hemispherical photograph obtained using a fish-eye lens. B) Hemispherical scan obtained with the Riegl VZ400 TLS. C) Hemispherical photograph simulated from the voxelised leaf area density. D) Hemispherical photograph simulated from the voxelised LAD at a non-sampled position 5m apart from the previous position.

Results

Biomass and carbon:

Figure 3A shows the point cloud resulting from 4 crossed scans collected during winter. From this point cloud an individual tree was isolated (**Figure 3B**). The zoom on a part of its crown illustrates the quality of details that can be captured by TLS, each twig being clearly visible. Once the tree of interest was isolated, the point cloud was segmented into a set of cylinders fitted to trunk and branches segments. Finally, **Figure 3D** shows the virtual tree reconstructed with SimpleTree software. Given that his virtual tree is composed of cylinders, the volume of trunk and branches can be directly evaluated. **Figure 4** shows the distribution of wood volume according to the diameter of the cylinders.

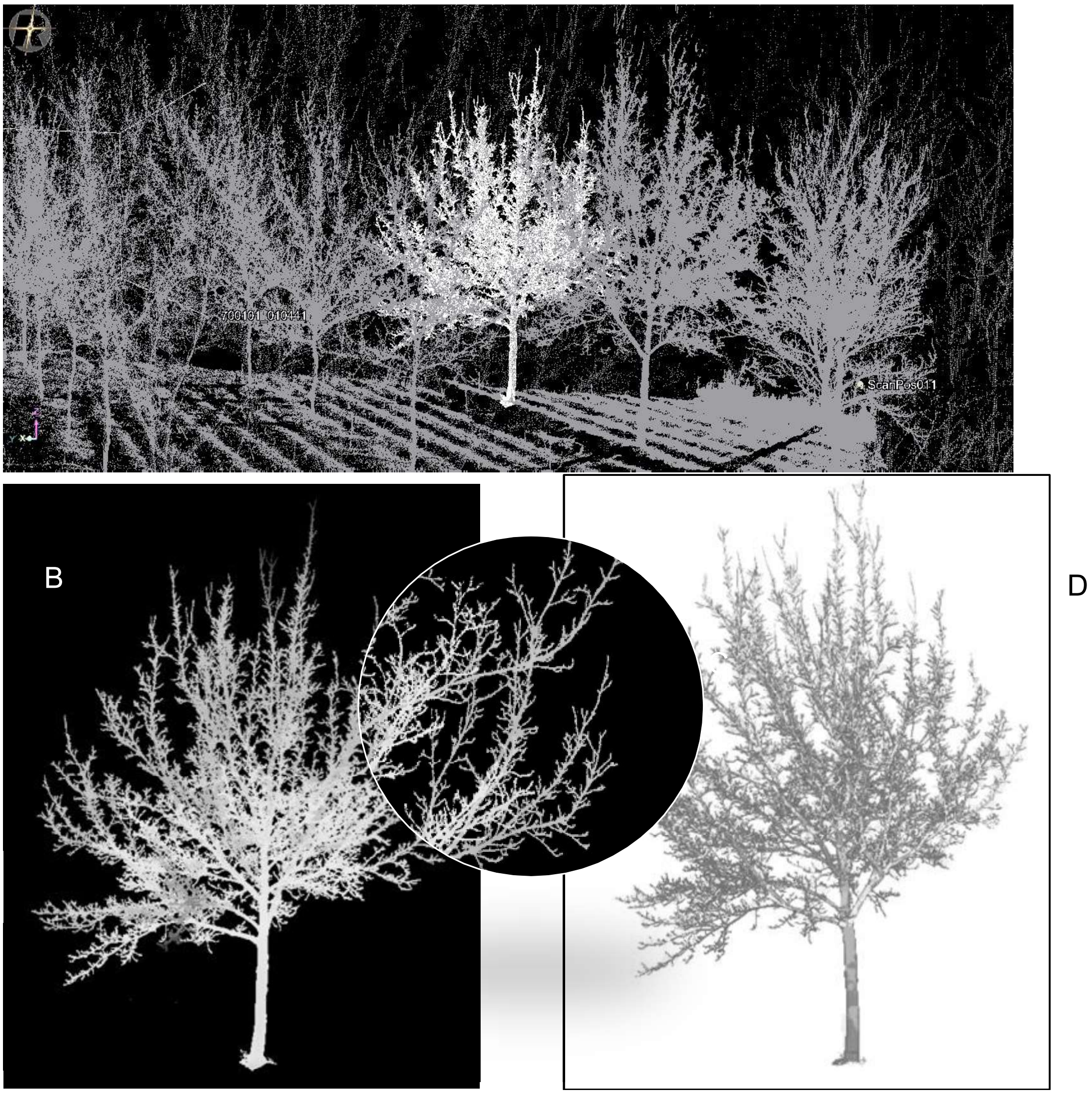

Figure 3: Processing TLS data. A) View of the point cloud obtained by combining three TLS viewpoints; B) View of the point cloud after selecting one tree; C) Zoom on a part of the crown; D) Virtual tree reconstructed from treatment of the point cloud with SimpleTree software. This virtual tree is composed of cylinders which diameter has been fitted to the points.

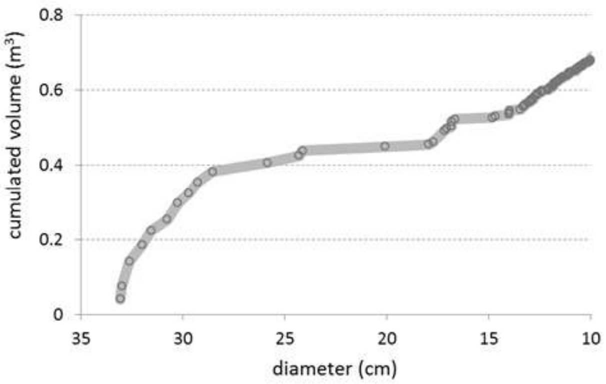

Figure 4: Example of wood volume extraction performed by SimpleTree Software. It can be seen that the trunk volume represents about 0.45 m^3.

<u>Foliage density and light available for undercrops:</u>

Figure 5A shows the result of the voxelisation procedure performed with voxel edges of 50cm. A leaf area density is associated to each voxel. Given this information, the voxels porosity to light can be calculated and maps of light transmitted at ground level can be readily generated (**Figure 5B**).

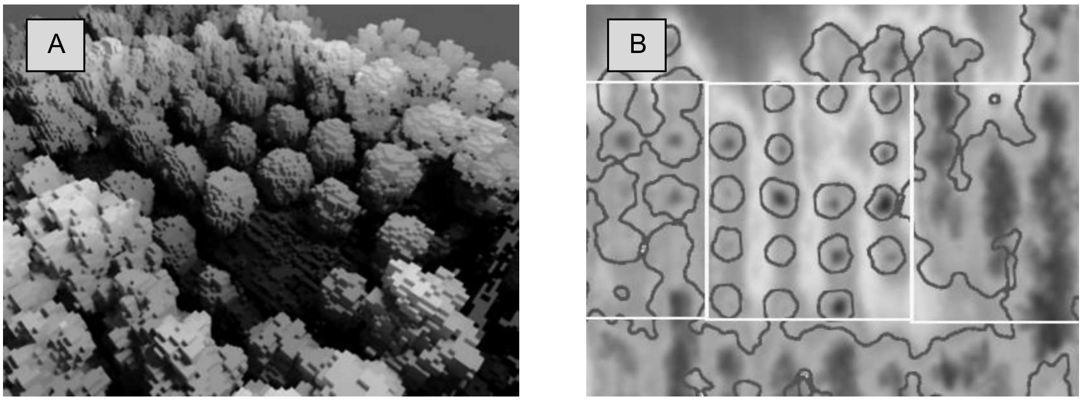

Figure 5: View of the plot voxelised with AMAPvox (A) and average light transmission rate at ground level (B). The most irradiated spots (light grey) appear clearly in the pollard treatment (centre) whereas the most shaded spots (dark grey) are located in the minimum pruning treatment (right).

Discussion

Compared to forest plantation about which foresters gained knowledge over years, agroforestry systems rarely benefit from passed experience in temperate countries, all the more due to the wide diversity of designs and tree species. Characterizing these systems in terms of wood biomass on the one hand and of shading cast on undercrops on the other hand is therefore very useful for evaluating and rationalizing the systems and their management. Fortunately, agroforestry systems are particularly well suited for performing lidar scanning because trees spacing limit the occlusions (i.e. parts of the trees that are not viewed from any scanner position).

TLS devices are still expensive (about 40-100 k€) but prices are decreasing while their performances are increasing. Furthermore it is important to have a good grasp of the amount of information that can be collected in a short time. For instance a few days may be sufficient for collecting data covering large areas (one or several hectares, depending on the sampling pattern chosen).

Algorithms for rebuilding trees from point clouds are not fully operational in all cases. They don’t perform well on small branches and twigs. However allometric relationships can be used for relating biomass of the smallest branches to the diameter of the branch bearing them (Ploton et al, 2016). Furthermore algorithms are becoming increasingly efficient and it is expected that software progress will allow processing routinely complex point clouds in the near future.

Rationalizing agroforestry practices starts from a better characterization of existing systems, in particular in terms of light transmission. In this respect, the information obtained from lidar scanning is unparalleled since it allows to map the light available for undercrops at different times of the day, for different radiative conditions and latitude. It is possible to go even further in so far as various virtual experiments can be performed. For instance, one can assess the gain of light if some trees are removed or simply pruned. As a general conclusion, lidar scanning could be a very useful tool for managing agroforestry systems!

References:
Boudon F, Preuksakarn C, Ferraro P, Diener J, Nacry P, Nikinmaa E, Godin C (2014). Quantitative assessment of automatic reconstructions of branching systems obtained from laser scanning. Ann Bot. 114:853–862.
Côté J-F, Fournier RA, Luther JE (2013) Validation of L-Architect model for balsam fir and black spruce trees with structural measurements. Canadian Journal of Remote Sensing. 39: S41–S59.
Hackenberg J, Spiecker H, Calders K, Disney M, Raumonen P (2015). SimpleTree —An Efficient Open Source Tool to Build Tree Models from TLS Clouds. Forests, 6, 4245-429.
Ploton P, Barbier N, Momo Takoudjou S, Boyemba Bosela F, Chuyong GB, Dauby G, Droissart V, Fayolle A, Goodman RC, Henry M, Kamdem NG, Katembo Mukirania J, Kenfack D, Libalah M, Ngomanda A, Rossi V, Sonke B, Texier N, Zebase D, Couteron P, Berger U, Pélissier R. 2016. Closing a gap in tropical forest biomass estimation: accounting for crown mass variation in pantropical allometries. Biogeosciences. 13: 1571-1585.
Raumonen P, Kaasalainen M, Åkerblom M, Kaasalainen S, Kaartinen H, Vastaranta M, Holopainen M, Disney M, and Lewis P (2013). Fast automatic precision tree models from terrestrial laser scanner data. Remote Sensing, 5: 491-520.
Vincent, G., C. Antin, et al. (2015). Mapping plant area index of tropical forest by Lidar: calibrating ALS with TLS. Silvilaser 2015, La Grande Motte, France.

PROJET SOUTENU PAR FONDATION DE FRANCE

This work was supported by Fondation de France.