Large-Scale Natural Forest Inventory with Mobile LiDAR Point Clouds

Jinyuan Shao[1], Yi-Chun Lin[2], Cameron Wingren[1], Sang-Yeop Shin[2], William Fei[2], Joshua Carpenter[2], Ayman Habib[2], and Songlin Fei[1]

[1]Department of Forestry and Natural Resources, Purdue University; [2]Lyles School of Civil Engineering, Purdue University

PURDUE UNIVERSITY | Forestry and Natural Resources | Lyles School of Civil Engineering

Abstract

Large-scale assessment of forest environment is essential for ensuring the resilience of this fragile ecosystem. To achieve a detailed large-scale inventory of natural forest, the usage of Light Detection and Ranging (LiDAR) is essential. However, localizing and measuring a single tree from a complex natural forest with billions of points are still challenging. By taking advantage of Mobile LiDAR Systems (MLS) and deep learning, we developed a novel and fully automated framework for forest inventory at a large scale. Experimental results showed that we were able to localize and measure all stems at the individual tree level in 20 hectares of a natural forest in less than 20 min using MLS.

INTRODUCTION

- The need for large-scale, accurate forest inventory data has never been more critical as forest ecosystems continue to face pressures from climate change, deforestation, and other human activities.
- Light Detection and Range (LiDAR) has been proven as an effective technology for forest inventory by offering complete 3D information with non-destructive scanning.
- Compared to static Terrestrial Laser Scanning, mobile LiDAR mapping systems using Unmanned Aerial Vehicle (UAV) and Backpack units are more flexible and scalable.
- However, localizing and measuring one single tree from a large-scale natural forest mobile LiDAR data with billions of points is still challenging due to the following reasons: (1) processing of massive points, (2) complex environments and (3) cross LiDAR platforms.
- In this research, we present a fully automated and scalable framework to conduct large-scale complex natural forest inventory using Backpack and UAV LiDAR.

STUDY SITES

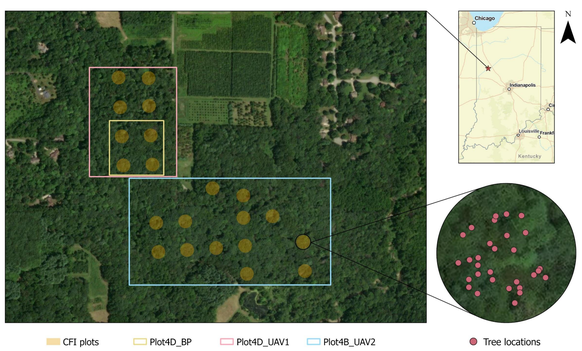

Figure 1. The map of study sites. Two study sites, Plot 4D (pink box) and Plot 4B (blue box), are located in Martel Forest in Indiana. Plot4D_UAV1 (pink box) and Plot4B_UAV2 (blue box) were scanned by two different UAV LiDAR systems. Plot4D_BP (yellow box), one part of Plot 4D was scanned by a Backpack LiDAR system. The bottom-right figure shows a close view of one of the CFI plots, each point represents an individual stem location. Plot4D_UAV1 and Plot4B_UAV2 contain 8 and 13 CFI plots, respectively. Plot4D_BP contains 4 CFI plots that are shared with Plot4D_UAV1.

FRAMEWORK

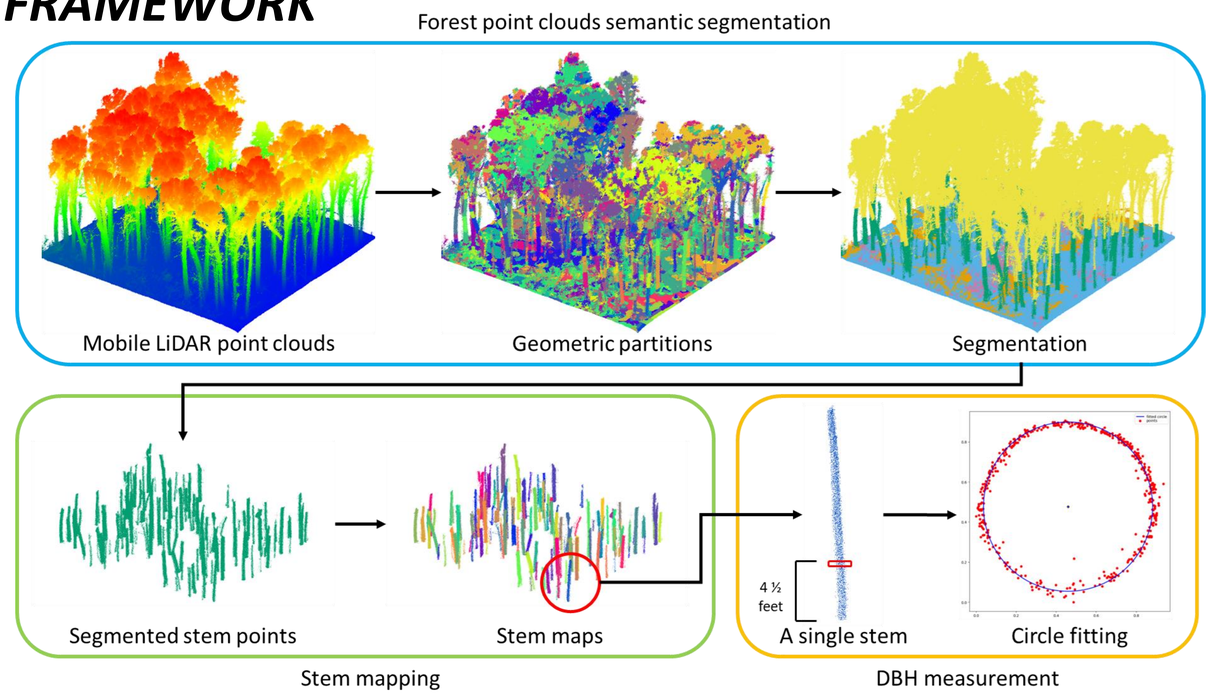

Figure 2. The proposed framework for large-scale natural forest inventory with mobile LiDAR point clouds. Semantic segmentation is first performed in natural forest LiDAR point clouds (blue box) with superpoint graph (SPG). Then the segmented stem points are further clustered into individual stems (green box). For each clustered stem, a cross-section at 4 feet from the ground is cropped and the circle fitting algorithm is performed to evaluate the DBH (yellow box).

INVENTORY FOR 20 HECTARES OF NATURAL FOREST

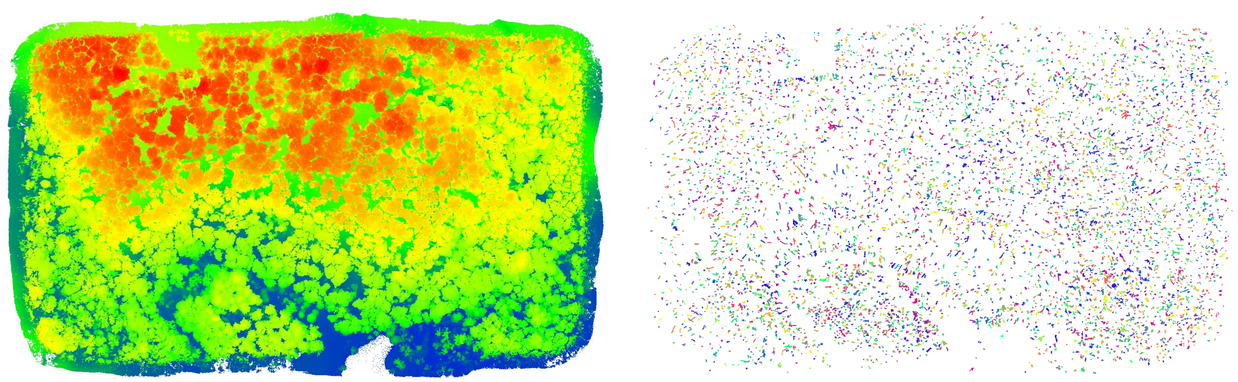

Figure 3. Illustration of super large-scale forest inventory from Plot4B_UAV2 (Bird's eye view). The left figure is Plot4B natural forest point cloud colored by height, and the right figure is stem mapping results colored by individual tree trunks. The whole Plot4B point cloud contains 436 million of points with areas of 20 hectares. UAV data collection took 40 min and data processing took 20 min.

RESULTS

Table 1. Segmentation performance in Plot4D_UAV1

Plot4D_UAV1	Precision	Recall	F1-Score	IoU
Ground	0.982	0.995	0.988	0.976
Debris	0.698	0.321	0.440	0.282
Trunks	0.875	0.887	0.881	0.787
Crowns	0.991	0.994	0.992	0.984
Shrubs	0.476	0.119	0.190	0.105
Overall Accuracy			98%	

Table 2. Segmentation performance in Plot4D_BP

Plot4D_UAV2	Precision	Recall	F1-Score	IoU
Ground	0.976	1.000	0.988	0.976
Debris	0.217	0.166	0.188	0.104
Trunks	0.906	0.996	0.949	0.903
Crowns	0.998	0.995	0.996	0.992
Shrubs	0.976	0.256	0.406	0.254
Overall Accuracy			97%	

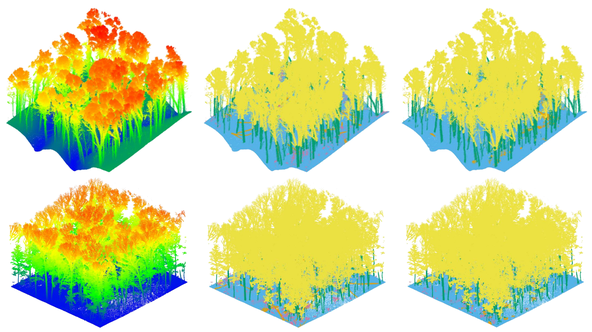

Figure 4. Semantic segmentation results for natural forests. From left to right: input point cloud colored with height, reference and prediction colored by classes. Top figures are from Plot4D_UAV1 and bottom figures are form Plot4D_BP.

Table 3. Stem mapping accuracies.

	TP	FP	FN	GT	Precision	Recall
Plot4D_BP	107	0	4	111	1.00	0.96
Plot4D_UAV1	198	5	9	207	0.98	0.96
Plot4B_UAV2	187	3	7	194	0.98	0.96

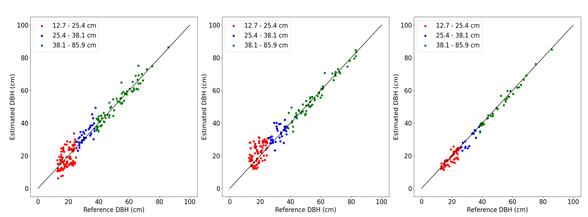

Figure 5. Relationship between measured DBH and reference from left to right: Plot4D_BP, Plot4D_UAV1 and Plot4D_UAV2

CONCLUSION

The proposed framework can segment complex forest components using different LiDAR data sources and have good performance for stem mapping and DBH estimation. Our research provides a practical, reproducible, and scalable solution for large-scale natural forest inventory, which can be used for scalable estimation of wood volume and biomass.

Landrieu, L., Simonovsky, M., 2018. Large-scale point cloud semantic segmentation with superpoint graphs, in: Proceedings of the IEEE conference on computer vision and pattern recognition, pp.4558–4567.
Carpenter, J., Rentauskas, D., Makkar, N., Jung, J., Fei, S., 2023. Improving deciduous forest inventory plot center measurement using unoccupied aerial systems imagery. Journal of Forestry 121, 262–271.
Lin, Y.C., Shao, J., Shin, S.Y., Saka, Z., Joseph, M., Manish, R., Fei, S., Habib, A., 2022. Comparative analysis of multi-platform, multi-resolution, multi-temporal lidar data for forest inventory. Remote Sensing 14, 649.
Qi, C.R., Su, H., Mo, K., Guibas, L.J., 2017a. Pointnet: Deep learning on point sets for 3d classification and segmentation, in: Proceedings of the IEEE conference on computer vision and pattern recognition, pp. 652–660.