treeX: Unsupervised Tree Instance Segmentation in Dense Forest Point Clouds

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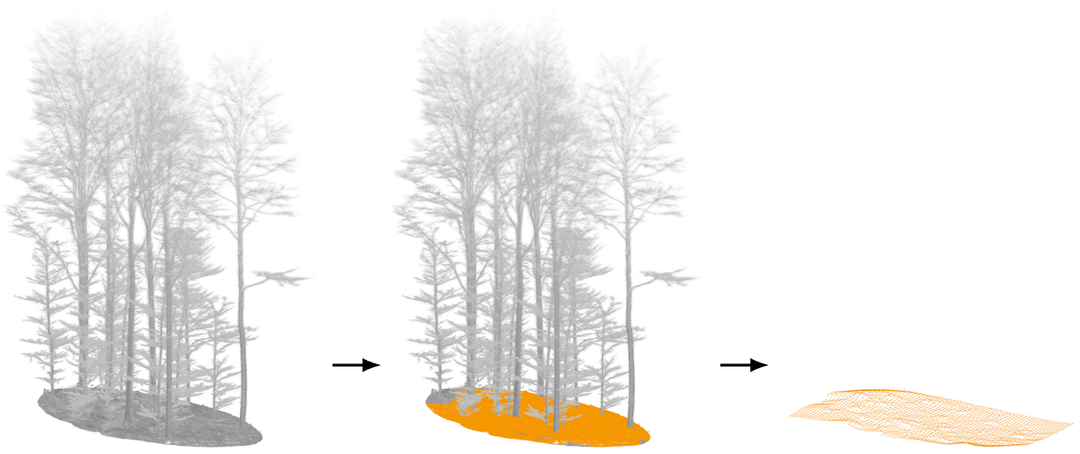
Context and Research Contributions

- Dense forest point clouds captured with terrestrial, personal, and UAV-borne laser scanning require efficient methods for tree instance segmentation
- We propose treeX, an unsupervised, resource-efficient algorithm, which combines clustering-based stem detection with region-growing-based crown delination
- Parameter presets for ground-based (TLS / PLS), and UAV-borne laser scanning (ULS) point clouds facilitate the application of treeX in varying forest scenarios

Algorithm Overview

(1) Construction of a Digital Terrain Model

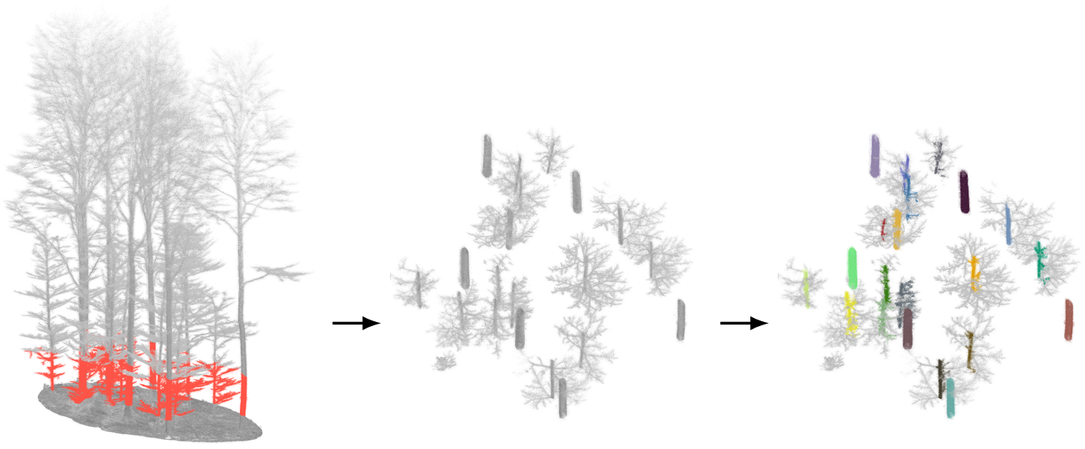


(a) Algorithm input: 3D point cloud with xyz-coordinates for each point and optional reflectance intensity values

(b) Terrain classification using the cloth simulation filtering algorithm

(c) Rasterized digital terrain model

(2) Detection of Tree Stems



(a) Extraction of all points within a predefined height range above the terrain

(b) Stem layer points

(c) Candidate stem clusters

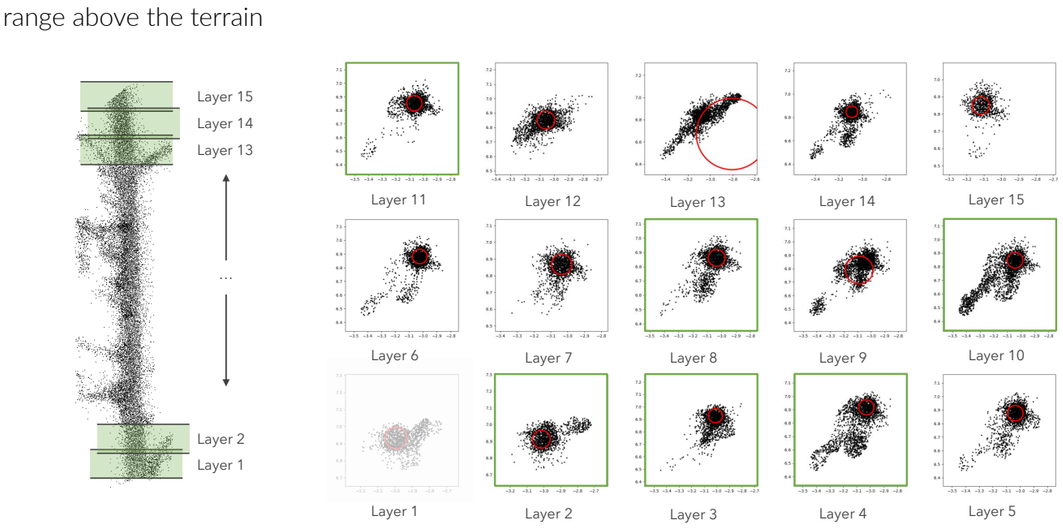
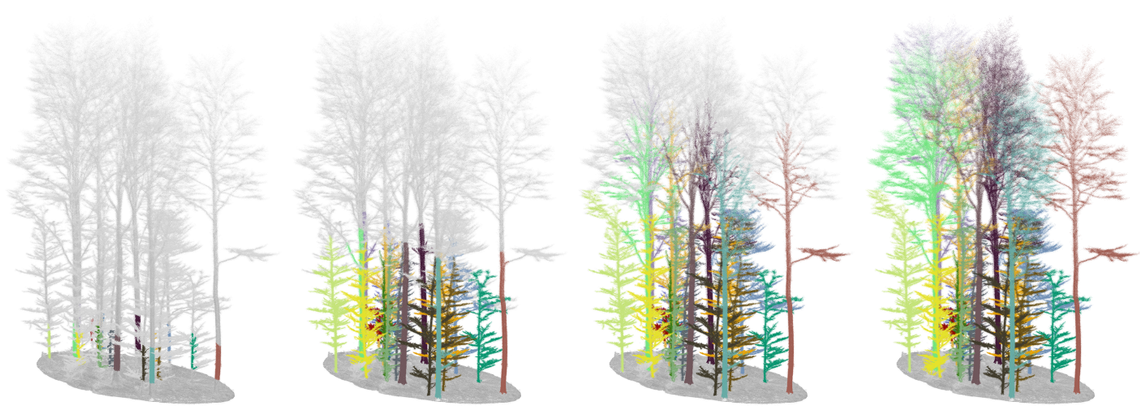


Figure 3. The candidate stem clusters are divided into 15 overlapping layers, and a circle is fitted to each layer. The subset of six layers with the lowest variance in circle diameters is selected (highlighted in green). If the variance of these layers falls below a predefined threshold, the cluster is retained as a valid stem detection, and the six layers are used to estimate the stem position and diameter.

(3) Delineation of Tree Crowns



(a) Initial seed points

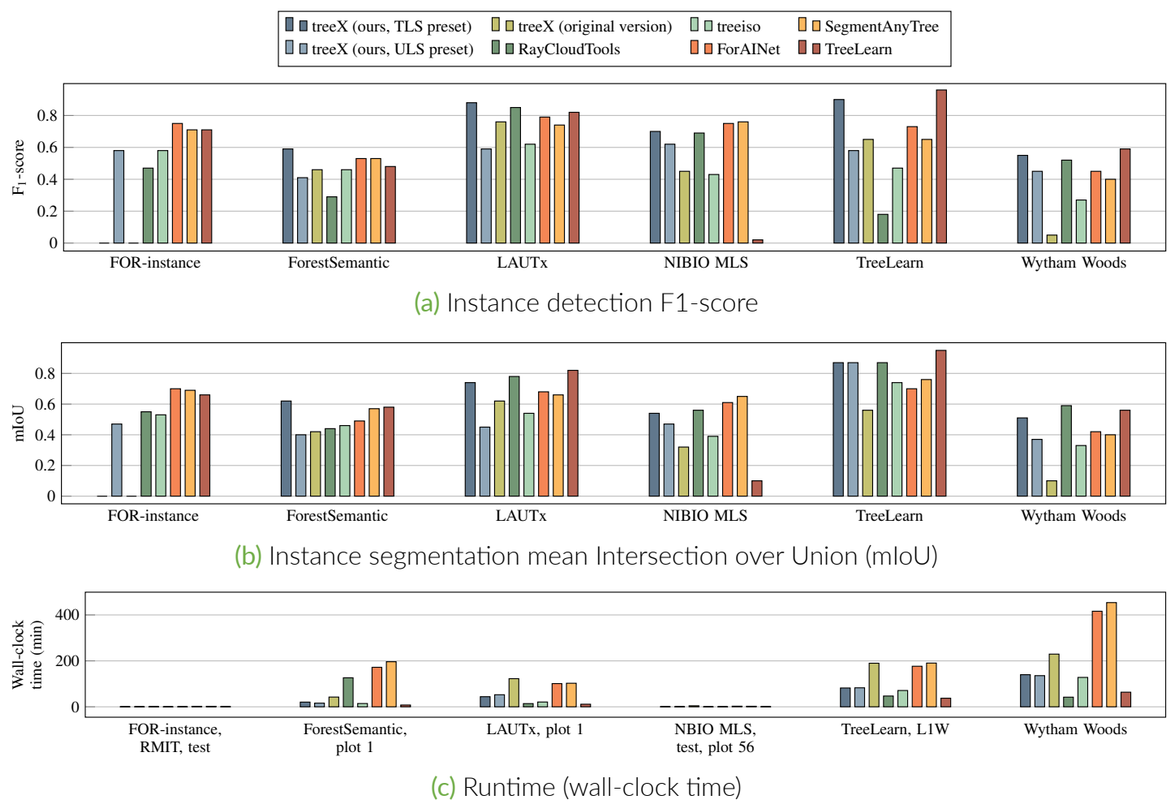
(b) Region growing results after 100 iterations

(c) Region growing results after 250 iterations

(d) Region growing results after 500 iterations

Figure 4. An iterative region growing procedure is used to delineate the tree crowns.

Evaluation Results



(a) Instance detection F1-score

(b) Instance segmentation mean Intersection over Union (mIoU)

(c) Runtime (wall-clock time)

Figure 5. The algorithm was evaluated on six publicly available datasets and compared with six open-source methods. Without relying on annotated training data, treeX achieved comparable or superior accuracy, especially on dense terrestrial point clouds. Its runtime is also comparatively low, despite not using a GPU.

Main Findings

- Our method is particularly effective when applied to dense TLS and PLS point clouds of stands with good stem visibility
- For ULS data, the sparser representation of below-canopy areas increases the likelihood of stem detection errors and thus limits the broader applicability of our method to ULS data
- We see two main areas of application for our method:
  - It can be used as a computationally efficient and interpretable alternative to deep learning approaches when the characteristics of the input data are well-known and align with the strengths of our method
  - It can serve as a tool for the automatic or semi-automatic generation of labeled training data, supporting the development of more generalizable deep learning methods
- We provide a well-tested and well-documented implementation of our method in the pointtree Python package

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