Comparative Evaluation of Machine Learning-Based Models for Individual Tree Segmentation from Forest Point Clouds

Introduction:

Precise identification and delineation of individual trees or even small forests within forest settings is the backbone of many ecological and forestry related practices such as forest inventory, biomass estimation, carbon stock versus forest inventory, and structural biodiversity determination. After the success of laser scanning techniques in terrestrial and mobile applications (TLS and MLS), forest researchers and practitioners now access great high-resolution

and dense 3D point clouds. Nevertheless, it is necessary to use good segmentation methods to convert these unstructured data into useful and workable information.

Deep learning, a type of machine learning (ML), has become a very effective way to automate segmenting complex 3D point clouds. This thesis will discuss and review state-of-the-art models based on ML that utilize semantic and instance segmentation of forest trees on point clouds acquired through MLS & TLS. The last objective is to determine tree-level parameters that include the height, diameter at breast height (DBH), trunk volume, and stand-level estimation of biomass and carbon.

Objectives

The objectives of this thesis are

- To review and compare machine learning-based segmentation methods for 3D forest point clouds
- To implement two suitable models for semantic and instance segmentation.
- To evaluate and extract tree-level and stand-level forest metrics (height, DBH, volume, biomass, carbon content)

Reviewed Segmentation Methods:

The models that were researched includes Point2Tree, TreeLearn, 3DFin, ForAInet, PointNet++, KPConv, PointCNN, and RandLA-Net.

Point2Tree: Point2Tree is a deep learning-based framework, which is customized to mobile laser scanning data. It combines the semantic segmentation model of PointNet++ and a graph instance segmentation method (TLS2Trees). Point2Tree is modularized, and it has hyperparameter optimization based on the Bayesian method. It allows splitting up of the forest components such as stems, vegetation, ground, and CWD and offers the option to extract the forest measures such as DBH and the height of the trees.

TreeLearn: Another deep learning strategy that was the original technique applied to the Terrestrial Laser Scanning (TLS) data is called TreeLearn. It does semantic filtering followed by instance segmentation with learned embeddings or center-offset regression. TreeLearn has high instance segmentation performance (F1-score up to 0.85) and especially performs well in structured forest plots. Though this was considered to be developed on TLS, it is possible to use this architecture slightly relying on MLS data.

3DFin: 3DFin is a registry-based software to perform automated forest inventory based on TLS and MLS point clouds. It is geometrically filtered and statistically identified to recognize tree stumps and acquire DBH, height, and spatial location. It does not support instance segmentation and does not give per-pixel detailed semantic classes.

ForAInet: The ForAInet model is a 3D convolutional neural network (CNN) that has been designed to do instance and semantic segmentation of airborne LiDAR (ALS) data. It takes voxelized data as input and can give detailed forest structure output. Even though it is quite strong, it is not as friendly to stay-on-the-ground data, as it must be greatly adapted to utilize it with MLS.

Other reviewed architectures include general-purpose deep learning models that include PointNet++, KPConv, RandLA-Net, and PointCNN. The models have performed very well. Urban and unstructured scenes, however, tend to need large, annotated datasets and retraining to become effective at forests.

Justification for Model Selection

According to the review in this selection, the Point2Tree and TreeLearn models have been chosen as the most appropriate models applicable to this thesis. The Point2Tree is customized to MLS data, so it suits the dataset under analysis. The modular design, the semantic classes of the forest, and the possibility to combine those things with instance segmentation and metric assessment tools predetermine the formation of the inquiry of detailed analysis of forests.

TreeLearn is selected as an addition type that provides the alternative approach of deep learning to the instance segmentation. It works especially well to separate individual trees in structured plots and can be modified to work in an MLS-based point cloud. Its code availability can possibly be poor, but since it can be compared in terms of its methodological structure and the accuracy of segmentation proven, it can be used as a benchmark to make a comparative reference.

Other models that included 3DFin and ForAInet could not be implemented based on issues with segmentation depth, compatibility of input data, or the inability of the model to deploy deep learning features. The more promising general-purpose models were not chosen on account of the time required to train and tune to the forest, as well as integrate.

Conclusion:

This thesis suggests implementing and measuring two of the latest machine learning algorithms (Point2Tree, TreeLearn) on the segmentation of individual trees of point clouds in forests. These models were chosen due to the demonstrated precision and the suitability of the model to work with MLS & TLS data and facilitate semantic and instance segmentation. Their joint use will enable sturdy extraction of the forest mensuration values and may facilitate the development of more scalable, automatic forest inventory processes. The results of the present study will add to the objective of operationalizing ML-based segmentation in ecological monitoring, forest planning, and environmental research.