Efficacy of Deep Learning for Below-Canopy Reconstruction of Satellite and Aerial Sensing Point Clouds through Fractal Tree Symmetry

Authors : Dhanuj M. Gandikota

Abstract : Sensor-derived three-dimensional (3D) point clouds of trees are invaluable in remote sensing analysis for the accurate measurement of key structural metrics, bio-inventory values, spatial planning/visualization, and ecological modeling. Machine learning (ML) holds the potential in addressing the restrictive tradeoffs in cost, spatial coverage, resolution, and information gain that exist in current point cloud sensing methods. Terrestrial laser scanning (TLS) remains the highest fidelity source of both canopy and below-canopy structural features, but usage is limited in both coverage and cost, requiring manual deployment to map out large, forested areas. While aerial laser scanning (ALS) remains a reliable avenue of LIDAR active remote sensing, ALS is also cost-restrictive in deployment methods. Space-borne photogrammetry from high-resolution satellite constellations is an avenue of passive remote sensing with promising viability in research for the accurate construction of vegetation 3-D point clouds. It provides both the lowest comparative cost and the largest spatial coverage across remote sensing methods. However, both space-borne photogrammetry and ALS demonstrate technical limitations in the capture of valuable below-canopy point cloud data. Looking to minimize these tradeoffs, we explored a class of powerful ML algorithms called Deep Learning (DL) that show promise in recent research on 3-D point cloud reconstruction and interpolation. Our research details the efficacy of applying these DL techniques to reconstruct accurate below-canopy point clouds from space-borne and aerial remote sensing through learned patterns of tree species fractal symmetry properties and the supplementation of locally sourced bio-inventory metrics. From our dataset, consisting of tree point clouds obtained from TLS, we deconstructed the point clouds of each tree into those that would be obtained through ALS and satellite photogrammetry of varying resolutions. We fed this ALS/satellite point cloud dataset, along with the simulated local bio-inventory metrics, into the DL point cloud reconstruction architectures to generate the full 3-D tree point clouds (the truth values are denoted by the full TLS tree point clouds containing the below-canopy information). Point cloud reconstruction accuracy was validated both through the measurement of error from the original TLS point clouds as well as the error of extraction of key structural metrics, such as crown base height, diameter above root crown, and leaf/wood volume. The results of this research additionally demonstrate the supplemental performance gain of using minimum locally sourced bio-inventory metric information as an input in ML systems to reach specified accuracy thresholds of tree point cloud reconstruction. This research provides insight into methods for the rapid, cost-effective, and accurate construction of below-canopy tree 3-D point clouds, as well as the supported potential of ML and DL to learn complex, unmodeled patterns of fractal tree growth symmetry.

Keywords : deep learning, machine learning, satellite, photogrammetry, aerial laser scanning, terrestrial laser scanning, point cloud, fractal symmetry
Conference Title : ICRSEC 2023 : International Conference on Remote Sensing in Ecology and Conservation
Conference Location : New York, United States
Conference Dates : January 30-31, 2023