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Simulation of small footprint full waveform LiDAR signals from seedling stand vegetation using Monte Carlo ray tracing and statistical models of 3D vegetation structure

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Accuracy of small footprint airborne light detection and ranging (LiDAR) in predicting stand mean characteristics such as stem volume was first demonstrated 10–15 years ago, and LiDAR is currently being applied in practical scale forest inventory in many countries. Despite the accuracy, method development is still needed for solving certain problems, e.g. tree species recognition and detecting the need for stand treatments. Simulation tools can be useful in studying effects of different sensor and target properties on the obtained signal. Monte Carlo ray tracing (MCRT) is computationally intensive, but generally considered as one of the most accurate methods for radiative transfer modeling in vegetation canopies as it aims at modeling the real photon paths (Widlowski et al. 2008). For input, a representation of geometric-optical properties of the scene is needed. Recent studies demonstrate use of MCRT with explicit, leaf/needle level 3D models in remote sensing studies, including LiDAR (Hancock et al. 2012; North et al. 2010).

The overall aim of this study was to develop a LiDAR simulator based on MCRT. More detailed aims were 1) to evaluate the simulator performance by comparing simulated signals against real data, and 2) to use the simulator for finding best suitable sensor characteristics for classification of common species in Finnish seedling stands. Statistical models of the 3D structure of three common species, silver birch (*Betula pendula*), raspberry (*Rubus idaeus*) and fireweed (*Epilobium angustifolium*), were used. The model of silver birch was obtained from Lintunen et al. 2011. For the other species, measurements on the shoot structure were made in the field, and the amount of shoots per square meter was linked to leaf area index (LAI). The validation dataset consists of field samples in Hyytiälä, Southern Finland (61°50′N, 24°20′E), and two separate LiDAR acquisitions.

The validation results show that species-specific characteristics of the LiDAR waveforms can be accurately reproduced with MCRT and the vegetation models used. Also, the mean signal levels (peak amplitude) were reasonably close to real data (max. 19% difference). If absolute accuracy is required, more detailed measurements on vegetation parameters (e.g. leaf area, leaf angle distribution, reflectance properties) as well as reflectance characteristics of the calibration targets are needed. In addition, validation of the scattering model against laboratory measurements is recommended. To design a best suitable sensor for seedling stand inventory, three sensor parameters (footprint size, pulse width, sampling frequency) were altered one at a time, and the classification accuracy of simulated LiDAR waveforms between the three selected species was evaluated. It was shown that classification accuracy increases with larger footprint size, but saturates at app. 0.35 m footprint. Effects of pulse width and sampling frequency were negligible. The computation times with our non-optimized algorithms and a normal desktop computer were 10–40 s per LiDAR pulse. We conclude that ray tracing simulator is a useful tool for developing new interpretation techniques, and testing hypotheses considering the interpretation of LiDAR data.

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