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Virtual laser scanning (VLS) in forestry – Investigating appropriate 3D forest representations for LiDAR simulations with HELIOS++

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Virtual laser scanning (VLS) is a valuable method to complement expensive laser scanning data acquisition in the field. VLS refers to the simulation of LiDAR to create 3D point clouds from models of scenes, platforms and sensors mimicking real world acquisitions. In forestry, this can be used to generate training and testing data with complete ground truth for algorithms performing essential tasks such as tree detection or tree species classification. Furthermore, VLS allows for the in-depth investigation of the influence of different acquisition parameters on the point clouds and thus also the behaviour of algorithms, which is important when relating point cloud metrics to forest inventory variables. Finally, VLS can be used for acquisition planning and optimisation, as different configurations can be tested regarding their ability to create data of the required quality with minimal effort. For these purposes, we developed the open source Heidelberg LiDAR Operations Simulator HELIOS++ (written in C++) which is available on GitHub (https://github.com/3dgeo-heidelberg/helios), as a precompiled command line tool, and as Python package (pyhelios). HELIOS++ provides a high-fidelity framework for full 3D laser scanning simulations with multiple platforms and a flexible system to represent the scene. HELIOS++ models the beam divergence and supports the recording of the full waveform.

One important premise for the usefulness of VLS data is the use of an adequate 3D scene in the simulation. In this context, we conducted a study investigating point clouds simulated based on opaque voxel-based forest models computed from terrestrial laser scanning data using different voxel sizes. Coupling the LiDAR simulation with a database containing point clouds of single trees from terrestrial, UAV-borne and airborne acquisitions, allowed us to compare metrics derived from real and simulated data. Furthermore, by including the tree neighbourhood in the scene, we were able to consider occlusion effects between the trees.

We found that the voxel size is an important parameter, where values of e.g. 0.25 m lead to unrealistic occlusion effects of the mid- and understory, as only few gaps remain in the forest models through which the laser beam can pass. This results in fewer multiple returns, the vertical point distribution is shifted upwards, and tree metrics such as crown projection area and crown

base height are estimated poorly. Smaller voxel sizes are therefore preferable, though the appropriate voxel size depends on the resolution of the input point cloud. With very small voxels, the voxel model may become too transparent. To achieve realistic simulations without the need for a high number of voxels we suggest variable downscaling of voxel cubes based on appropriate local metrics such as the plant area density. This approach decreases the computational requirements for the simulation, as fewer primitives are present in the scene. In our study, the use of such scaled voxels derived for a grid size of 0.25 m achieves equally and partly more reliable estimates of point cloud and tree metrics than regular voxels at fixed side lengths of 0.05 and 0.02 m.