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Canopy network reconstruction from point cloud data

Quantitative description of tree canopy architecture is important for creating and validating mathematical growth models of botanical trees (1-2), estimating the interactions with the environment (3) and to describe phenotypic traits of the tree canopy (4). In addition to traditional field measurements, emerging technologies like terrestrial laser scanning enable us to capture a 3-dimensional view of the canopy organization within minutes. However, there are many challenges to decipher the resulting point cloud data and to describe the underlying canopy structure. Network models have been proposed based on theoretical grounds, as suitable approximations to the hierarchical structure of tree branches in the canopy. Here we show that it is possible to: (i) reconstruct canopy networks from point cloud data; (ii) characterize the statistical properties of these canopy networks. Despite the fact that global network models are sensitive to small sampling errors in the capturing process of the canopy organization, we show that they are powerful to discriminate trees of the same species under significantly different growing conditions.

In this case study experiment we compare 6 apple trees (*Malus x domestica* Borkh. cv. 'Honeycrisp'). Three of these six trees are grown in a so-called Trellis system, while the other 3 trees are free standing. All six trees are measured with two methodologies. 1.) A manual field measurement of the six trees capturing branches up to 1mm in diameter and 2.) A terrestrial laser scanner sampling branches between 5-10mm in diameter.

A terrestrial laser scanner represents the sampled tree as a point cloud in 3D by measuring the round trip time of the laser beam between the scanner and the tree surface. A recently developed algorithm to derive a skeleton description from laser scanned trees, (5), allows us to represent the canopy architecture as a loop-free graph, which can be analyzed in terms of the topology formed by branch tips and branching points whose neighborhood relation is given by the surface. In simplified network models, the number and type of side branches (a topological metric) and the internode length (a topological metric) over the order numbers given by the branching hierarchy are considered as sufficient to describe a branching network. Both parameters can be derived directly from the field measurement and the skeleton graph derived from the point cloud. Practically we obtain the network description by assigning the Horton-Strahler order to the skeleton graph. A Horton-Strahler order assigns the order number 1 to the youngest branches and maximal order number to the trunk with respect to the branching hierarchy. In contrast to the commonly used Horton-Strahler ratios we compute the so-called Tokunaga ratios whose development is summarized in (6). Tokunaga ratios have the benefit to exploit the complete skeleton-graph. Here, "complete" means that side branches of order difference greater than 1 with respect to the branch where they originate from are not omitted in the describing side-branch-statistics. We discriminate both growing conditions, i.e. Trellis vs. free-standing, by analyzing the side-branch-statistics and the internode length.

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