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A bottom-up approach to segment individual deciduous trees using leaf-off lidar point cloud data

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ABSTRACT

Light Detection and Ranging (Lidar) can generate three-dimensional (3D) point cloud which can be used to characterize horizontal and vertical forest structure, so it has become a popular tool for forest research. Recently, various methods based on top-down scheme have been developed to segment individual tree from lidar data. Some of these methods, such as the one developed by Li et al. (2012), can obtain the accuracy up to 90% when applied in coniferous forests. However, the accuracy will decrease when they are applied in deciduous forest because the interlacing tree branches can increase the difficulty to determine the tree top. In order to solve challenges of the tree segmentation in deciduous forests, we develop a new bottom-up method based on the intensity and 3D structure of leaf-off lidar point cloud data in this study. We applied our algorithm to segment trees in a forest at the Shavers Creek Watershed in Pennsylvania. Three indices were used to assess the accuracy of our method: recall, precision and F-score. The results show that the algorithm can detect 84% of the tree (recall), 97% of the segmented trees are correct (precision) and the overall F-score is 90%. The result implies that our method has good potential for segmenting individual trees in deciduous broadleaf forest.

1. Introduction

Light Detection and Ranging (Lidar) is an optical remote-sensing technique that uses ultraviolet, visible, or near-infrared light to measure the distance to, or the properties of, targeted objects (Jensen, 2007). It is more advanced than other traditional remote-sensing techniques, as it can derive 3D images of distant objects from the pulses that are reflected off a target (Jensen, 2007). The 3D images enable researchers to study the stereostructures and topological relationships of targets, so lidar has been extensively applied in forest studies (Dubayah and Drake, 2000; Lim et al., 2003).

Individual tree segmentation from remote-sensing data has a variety of applications in forest research (Zhao et al., 2012). For example, tree structure information (such as tree height and crown size) can be directly acquired with high segmentation accuracy (Solberg et al., 2006; Li et al., 2012). Other attributes, such as biomass and carbon storage, can also be derived using empirical equations based on the tree structure once it has been segmented (Chen et al., 2006; Zhao et al., 2009). In addition, using tree segmentation, forest inventory, which is of great importance to forest management, can be built up and managed without time-consuming labor work (Hyyppä et al., 2005).

Numerous methods have been developed for segmenting individual trees from lidar data, as shown in Table 1. For example, Hyyppä et al. (2001) derived the canopy height model (CHM) from the highest laser pulse and used region growth to segment the tree. Persson et al. (2002) used a two-dimensional(2D) Gaussian filter to smooth digital canopy model and determined the tree location by searching for local maxima. Popescu et al. (2003) applied local maximum technique (LM) and a curve profile fitting algorithm to delineate tree crowns. Brandtberg et al. (2003) used automatic scale selection for deciduous tree detection. Koch et al. (2006) also used local maximum filter to detect the tree tops; then they combined a pouring algorithm, assumptions regarding the tree shapes, and final detection of the crown edges to delineate tree crowns. Chen et al. (2006) utilized marker-controlled watershed segmentation algorithm to isolate the trees; in the process, they used the lower limits of the prediction intervals of the regression curve between the crown size and tree height to determine the window size for searching local maxima. As shown in Table 1, most

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Table 1
Different individual tree segmentation methods from 2001 to 2012.

Algorithm	Reference	Location	Forest type	Leaf condition	Lidar system	Lidar point density (points/m^2)	Accuracy[a]
Region growing	Hyyppä et al. (2001)	Finland	Coniferous	– –	TopoSys-1	8–10	– –
Local maxima	Persson et al. (2002)	Sweden	Coniferous and deciduous	– –	TopEye	– –	71%
Scale-space theory	Brandtberg et al. (2003)	USA	Deciduous	Leaf-off	TopEye	12	– –
Valley-following approach	Leckie et al. (2003)	Canada	Coniferous	Leaf-on	Lightwave model 110	2	67.2%
Local maxima	Weinacker et al. (2004)	Germany	Coniferous and deciduous	– –	TopoSys	– –	68.7% (ave)
Maxima elimination	Pitkänen et al. (2004)	Finland	Coniferous and deciduous	– –	TopoSys-1	10	41.6%
Watershed	Mei and Durrieu (2004)	France	Coniferous and deciduous	– –	TopoSys	– –	66.5 (ave)
Watershed	Koch et al. (2006)	Germany	Deciduous	Leaf-on	TopoSys	5–10	72.73 (ave)
Watershed	Chen et al. (2006)	USA	Deciduous	Leaf-on	ALTM 2025	9.5	64.10%
Region growing	Solberg et al. (2006)	Norway	Coniferous	Leaf-on	ALTM 1233	5	66%
Morphological image-analysis method	Kwak et al. (2007)	Korea	Coniferous and deciduous	– –	ALTM 3070	1.8	74.1 (ave)
Multi-scale template matching	Korpela et al. (2007)	Finland	Coniferous and broadleaved	Leaf-on	ALTM 3100	6	96.2%
Region growing	Pang et al. (2008)	USA	Coniferous and deciduous	– –	ALTM	1.6–7	80%
Normalized cut[b]	Reitberger et al. (2008)	Germany	Coniferous and deciduous	Leaf-off	Riegl LMS-Q560 scanner	25	56%
Voxel space projection[b]	Wang et al. (2008)	Poland	Coniferous and deciduous	– –	TopoSys-II	7–8	72.12% (ave)
CHM + normalized cut[b]	Reitberger et al. (2009)	Germany	Coniferous and deciduous	Leaf-on and leaf-off	TopoSys-II and Riegl LMS-Q560	10–25	66%
DHP (density of high point)	Rahman and Gorte (2009)	Netherlands	Coniferous and deciduous	Leaf-on	FLI-MAP 400 system	70	>60%
Adaptive multiscale filter[b]	Lee et al. (2010)	USA	Managed pine forest	Leaf-on	UF-ALSM system	14.2	95%
Local maxima + adaptive filtering	Ene et al. (2012)	Norway	Coniferous and deciduous	Leaf-on	ALTM-3100	10.4	43.6%
Normalized cut[b]	Yao et al. (2012)	Germany	Coniferous and deciduous	Leaf-off and leaf-on	Riegl LMS-Q560 system	25	95%
Watershed	Yu et al. (2011)	Southern Finland	Coniferous and deciduous	Leaf-on	ALTM 3100	2.6	69%
Watershed	Jing et al. (2012)	Canada	Coniferous and deciduous	Leaf-on	Riegl Q-560 scanner	45	69% (ave)
Local maximum with Gaussian mask	Smits et al. (2012)	Latvia	Coniferous and deciduous	Leaf-on	ALS 50 II	9	87.50%
Region growing[b]	Li et al. (2012)	USA	Coniferous	Leaf-on	ALTM	>6	90%

[a] For methods that did not give an overall accuracy, average accuracy (ave) for different evaluations stated in the paper were calculated; '– –', not available.
[b] The method is based on point cloud segmentation.

methods are based on CHM, and only six out of 24 methods are based on point cloud segmentation. However, CHM based methods are not ideal because uncertainties will be introduced during the interpolation process, as well as only first return points have been used for CHM segmentation approach. Also, problems will occur if the canopy is tightly interlocked and homogenous (Koch et al., 2006). Some small trees in the intermediated and low height level cannot be detected since they are invisible in the CHM (Reitberger et al., 2009a).

New methods for detecting and segmenting trees directly from lidar point clouds have been developed recently. For instance, Reitberger et al. (2009b) used the RANSAC algorithm to reconstruct tree stems and a normalized cut method to isolate trees, but the detection rate of their method was less than 70%. Li et al. (2012) developed a method for isolating individual trees in mixed conifer forest based on the relative spacing between the trees. Although this method gives a good performance in coniferous forest, it does not work well when it is applied in deciduous forest. Also, please be aware that the verification methods and criteria for different references listed in Table 1 are not the same, so the accuracy of different algorithms is only for rough comparison. For example, Chen et al. (2006) and Rahman and Gorte (2009) used manually delineated reference data to evaluate the segmentation results, Jing et al. (2012) and Weinacker et al. (2004) used manual delineation to verify the results in large portion of their studying regions, while Reitberger et al. (2009b) and Wang et al. (2008) used field corrected references to verify their algorithm performances.

Current tree crown delineation methods, which are effective in coniferous forest, work less effectively in deciduous forest (Weinacker et al., 2004; Koch et al., 2006; Jing et al., 2012). For example, it is difficult for some methods to determine tree tops because the tree crowns have a wide range of sizes and their branches interlace with each other which may resemble trees in deciduous forest. This will cause false detection and split large trees into several small trees. One of the methods used to overcome this problem in deciduous forest is to find the tree trunk of each tree first. If we can detect the position of each tree trunk, falsely identified trees consisting of interlacing branches from large trees will not be created.

The intensity is a measure of the amount of energy reflected back to the sensor. It is a function of many variables, such as laser power, incidence angle, sensor–target distance, absorption by air,