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Automated individual tree crown delineation from LIDAR data using morphological techniques

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Abstract. In current tree crown delineation from LiDAR data, treetops and 3D geometric shapes of tree crowns are frequently extracted from LiDAR-derived Crown Height Model (CHM) and used as references to localize and delineate crowns. However, it is difficult to detect deciduous treetops and delineate deciduous tree crowns. The 3D shape of a crown, which can be derived from CHM, may be taken as a half ellipsoid, and any horizontal slice of the ellipsoid contains the treetop and indicates not only the location but also the spatial extent of the crown. Based on such slices, a novel multi-scale method for individual tree crown delineation from CHM was proposed in this study. This method consists mainly of two steps: (1) morphologically open the CHM over the scale range of target tree crowns; and (2) take local maxima within each resulting opened CHM as the horizontal slices of target crowns at the corresponding scale level and integrate all the slices within the scale range together to represent the spatial distribution of target crowns. In an experiment on CHMs over two natural closed canopy forests in Ontario, Canada, the proposed method accurately delineated the majority of the tree crowns from closed canopy forests.

1. Introduction

High-density and small-footprint LiDAR (Light Detection And Ranging) data provide detailed height information of targets, from which a canopy height model (CHM) with a small grid size can be derived and then segmented to delineate individual tree crowns [1-7]. Various crown delineation methods have been developed for CHM and facilitate the forest survey [8-10]. In a typical crown delineation procedure, the CHM is smoothed to eliminate spurious local maxima caused by branches and then treetops are detected using local maximum filtering with a fixed or variable-size window [11], [12]. However, current tree crown delineation methods seldom work well on deciduous trees with significantly complex shapes with tree-like branches. In current tree crown delineation, treetops as apexes are frequently localized at first and then used as reference points for crown delineation [13]. It is normally assumed that a treetop can be represented by an apex close to the geometric center of the crown. Due to the complex structure of deciduous crowns, especially the fact that deciduous branches resemble trees, it is relatively difficult to detect deciduous treetops and delineate deciduous crowns.

For a tree crown, its treetop as an individual point indicates its position, whereas its horizontal extent defined by its edges indicates not only its position but also its spatial extent. A three-dimensional (3D) geometric shape of a crown, derived from the CHM generated from LiDAR data, can be taken as a half ellipsoid [14]. A horizontal slice of the crown can be drawn at any height and each slice shows as a horizontal slice, contains the treetop, and indicates the horizontal extent of the crown. From top to bottom of the crown, multiple slices can be obtained and jointly describe the 3D geometric shape of the crown. It is manifest that the bottom slice has a maximum size and best indicates the extent of the crown. Once morphologically obtained from the CHM, the bottom slices of different-size crowns can be used as references in tree crown delineation. Based on such Crown Slices from CHM, a novel multi-scale method for tree crown delineation from CHM was proposed in this study and called CSC for brevity. This method consists mainly of two steps: (1) morphologically open the CHM within the scale range of target crowns, extract multiple layers of object slices from opened CHMs, and integrate all layers of slices together; and (2) segment the CHM using the watershed approach with the integrated slices as references.

2. Methodology

The CSC method for delineating tree crowns from CHM consists of several steps as follows:

1) Take the width range of target tree crowns as the scale range of the crowns and decide a crown scale series in pixels with 2-pixel increments;
2) Remove non-crown areas, such as bare land and grass, from the CHM by setting relevant pixels at zero;
3) Extract object slices from the CHM within the scale scales of crowns;
4) Integrate the object slices previously extracted; and
5) Segment the CHM using the watershed approach with the merged slices as markers to produce a segmentation map.

In the step 2 of this flowchart, non-crown areas, such as bare land and grass, can be obtained by applying a height threshold to the CHM. In the step 3 of the flowchart, object slices are extracted from the CHM within the scale range of target crowns as follows:

a) Given any scale of r pixels within the series, smooth the CHM using a Gaussian filter to suppress branches, morphologically open the filtered CHM with a disk structure element (SE), and take the regional maxima within the opened CHM as slices. The diameter of the SE is equal to r pixels, and the Gaussian filter has a window size of r pixels by r pixels and a sigma (standard deviation, σ) value of $0.3r$ pixels. When the Gaussian filter is applied to the CHM, branches smaller than the filter will be effectively suppressed expectedly and larger tree crowns will be retained.
b) Repeat step (a) for each scale in the scale series to obtain all the layers of object slices within the scale range of crowns.

In this process, each layer of object slices stands for the spatial distribution of objects, such as branches, crowns, at the corresponding scale,. All of the layers are different in terms of slice count, size, and position. The multiple slices of a crown normally concentrically superimpose on each other, whereas a large slice may superimpose on slices of neighbouring objects, such as branches, clumped crowns, neighbouring crowns and grass. The multiple layers need be integrated together in order to yield a layer of slices which is free of branches and tree clusters.

In the step 4 of CSC flowchart, a series of layers of object slices $\{L_1, L_2 \ldots L_n\}$ is integrated as follows:

a) Take the first two layers, L_1 and L_2, as a fine layer and a coarse layer, respectively, and integrate them together;
b) Take the integrated layer L_2 as a fine layer and combine with next coarse layer, i.e., L_3; and
c) Repeat step 2 until all the layers are integrated together.

In the step (a) above, the fine layer L_1 and the coarse layer L_2 are integrated together as follows:

a) Refine the coarse layer by removing slices with circularity less than a threshold to eliminate tree clusters. The threshold was set at 0.9 in this study, with reference to an observation that circularity of tree crowns typically lies above 0.85 [14];
b) Combine the fine layer and the refined coarse layer using logic 'OR' operation; and
c) Refine the combined layer by removing slices with circularity less than the previous threshold to eliminate slices of tree clusters.

In this process, the circularity (c) of a segment can be calculated as follows [14]: $c = A/(\pi r^2)$, where A is the area of the segment and r is the largest distance between the centroid and border of the segment. As the circularity measure approaches 1, the segment approximates a circle. In this integration processing, taking into account the shape factor is to eliminate tree clusters and the resulting combined layer of object slices consists mostly of crown slices.

In the step 5 of CSC flowchart, the CHM is inverted and then segmented using the marker-controlled watershed segmentation approach [15]. This approach is initially used to segment digital elevation models (DEMs) of terrains into catchment basins. The approach simulates the immersion from markers to determine the flooded basins. Based on the similarity between geographic reliefs and tree crown surfaces, the segmentation approach is widely used to segment imagery for tree crown delineation, with treetops as markers, which are necessarily firstly carefully localized. In the CSC method, after original CHM is inverted, the marker-controlled watershed segmentation is applied with the integrated slices as markers.

3. Experiments

A study area (46°33′44″ - 46°34′03″N, 83°25′12″ - 83°25′19″W), near Sault Ste. Marie, Ontario, Canada, within the Great Lakes-St. Lawrence forest region, was selected to test the CSC method proposed in this study on different forests. In this flat area, the forest consists of various-sized trees, bushes, grasses, and forbs, and the stands involved range from 30 to 80 years old and have closed, multi-layered canopy structures. Two plots were selected in this area to test the CSC method on different closed canopy forests. Plot 1 with size of 77 m by 77 m is a mixedwood forest and plot 2 of 77 m by 77 m consists mainly of deciduous trees, including maples and birches. In plot 1, aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.) are the most common deciduous species, accounting for about 20% and 10% of the trees present, respectively. Jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* Mill. BSP) are the most common coniferous species at 50% and 10%, respectively.

The LiDAR data covering the study area were acquired in August 2009 using a Riegl Q-560 scanner. The flying height of 200 m above terrain and two overlapping flight lines resulted in a high sampling density of around 45 points/m^2. Since the minimum sampling spacing for the LiDAR data was around 0.15 m, the DSM and DEM of each study area were derived with a grid size of 0.15 m by 0.15 m using methods described in [2], [6], [12]. The CHM was derived as the difference between the

DSM and DEM, which was then smoothed with a 3 × 3 Gaussian low-pass filter to effectively eliminate noise, as in [2], [17].

The CHMs over plots 1 and 2 (figures 1(a) and 1(b), respectively) were processed using the CSC method proposed in this study. In the processing, a crown width range of 11-23 pixels was estimated for the study area and a series of crown scales {11, 13 … 23} in pixels with 2-pixel increments was employed. After morphologically opening the CHM over the two plots using a disk SE with diameter equal to the series of scales, multiple layers of object slices with different sizes and concentrically overlaid were generated (figure 2). It is manifest that those layers of object slices within a crown scale range need to be integrated together, in order to yield a layer of slices representing the spatial extents of target crowns. The final CSC-generated crown maps of the two plots are shown in figure 3. It can be seen from the figure that although the forest canopies are close, most of the target segments coincide with individual tree crowns. The maps were evaluated with reference to manual segmentation results using the criteria described in [18] and their statistics are listed in table 1. As shown in this table, roughly 84.9% of the mixedwood tree crowns within plot 1 and 65.9% of the deciduous tree crowns within plot 2 were correctly delineated by the CSC method, supporting the idea that the CSC method can generate a map of various-sized tree crowns comparable to manual interpretation. In addition, the CSC method performed differently on different forests. The high accuracy of the CSC-generated crown map over the plot 1 can attribute to the predominant coniferous tree crowns, whereas the lower accuracy of the CSC-generated crown map of the plot 2 is due to the complex structure of the deciduous tree crowns and the predominant deciduous tree clusters.

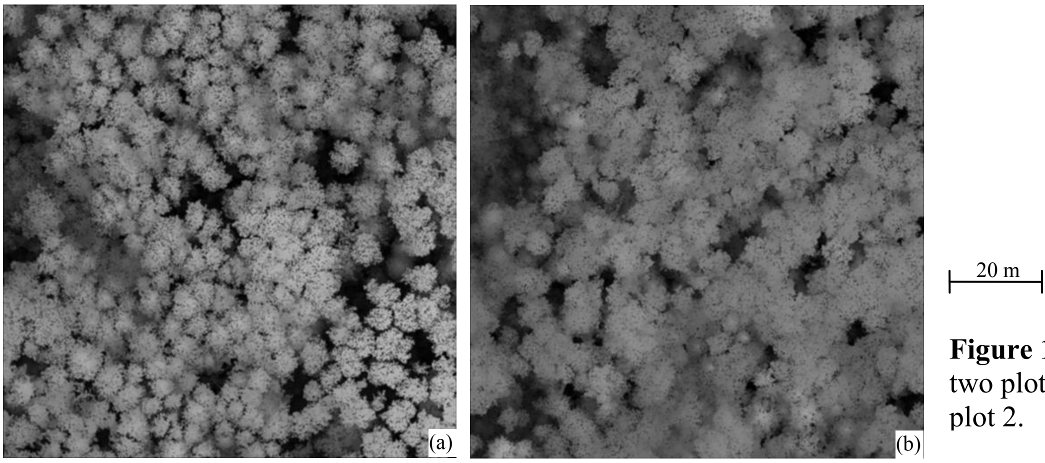

Figure 1. The CHMs of the two plots. (a) plot 1; (b) plot 2.

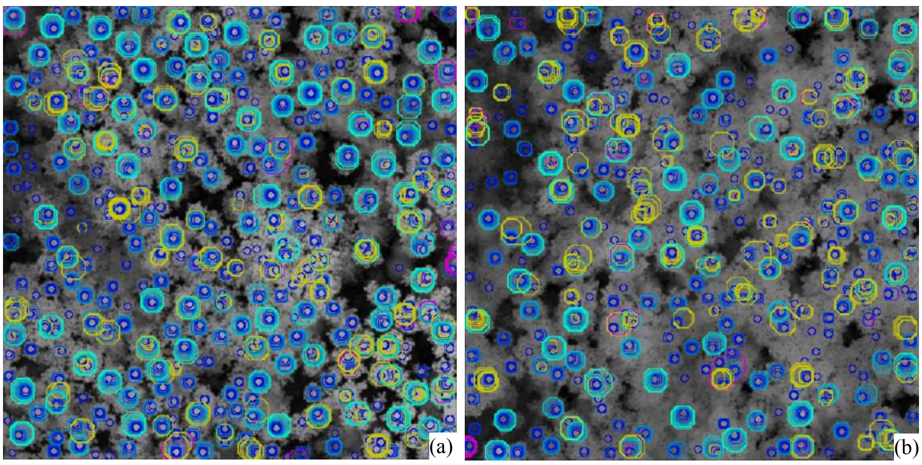

Figure 2. The horizontal slices of crowns at a wide range of scales. (a) plot 1; (b) plot 2.

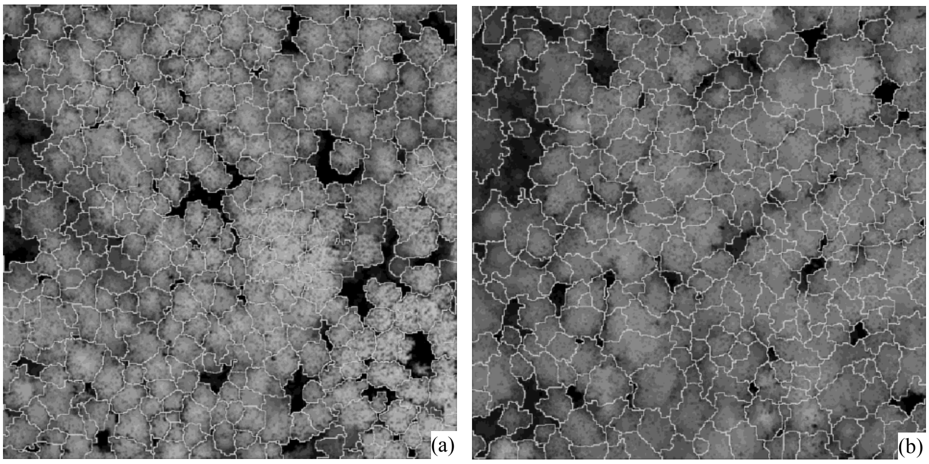

Figure 3. The crown maps of the two plots. (a) Pot 1; (b) plot 2.

Table 1. The accuracy statistics of the CSC-generated tree crown maps from LiDAR-derived CHMs on multi-layered, uneven-aged forests in the Great Lakes-St. Lawrence forest region, Ontario.

Plot	Total	Matched	Nearly matched	Omitted	Merged	Split	Segments covering no references	Accuracy (%)	Omission error (%)	Commission error (%)
1	252	202	12	12	17	9	8	84.9	11.5	6.8
2	170	97	15	16	8	34	10	65.9	24.7	25.9

4. Discussion

The branches, tree crowns, and tree clusters in a forest scene have multiple scales and overlapping scale levels. Such a multi-scale structure makes it difficult to accurately segment deciduous forests and mixed forests. In the crown delineation method for CHM proposed in this paper, each tree crown is represented by a morphologically derived slice, the multi-scale tree crowns are represented by multi-layered slices, and the multi-layered slices are merged into one layer and taken as markers in the watershed segmentation of the CHM. Each resulting slice contains the corresponding treetops and indicates the extent of the crown. The integration of object slices remove branches and select all the relevant treetops for the following watershed segmentation of the CHM. It is assumed in the integration step that tree crowns are circular, and therefore circularity is used to remove the slices of branches and tree clusters.

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References

[1] Brandtberg T, Warner T A, Landenberger R E and McGraw J B 2003 Detection and analysis of individual leaf-off tree crowns in small footprint, high sampling density lidar data from eastern deciduous forest in North America *Remote Sensing of Environment* **85** 290–303

[2] Hyyppä J, Kelle O, Lehikoinen M and Inkinen M 2001 A segmentation-based method to retrieve stem volume estimates from 3-D tree height models produced by laser scanners *IEEE Transactions on Geoscience and Remote Sensing* **39** 969–975

[3] Hyyppä J, Hyyppä H, Leckie D, Gougeon F, Yu X and Maltamo M 2008 Review of methods of small-footprint airborne laser scanning for extracting forest inventory data in boreal forests *International Journal of Remote Sensing* **29** 1339–1366

[4] Leckie D G, Gougeon F A, Walsworth N and Paradine D 2003 Stand delineation and composition estimation using semi-automated individual tree crown analysis *Remote Sensing of Environment* **85** 355–369

[5] Nelson R F 2003 Measuring individual tree crown diameter with lidar and assessing its influence on estimating forest volume and biomass *Canadian Journal of Remote Sensing* **29** 564–577

[6] Pitkanen J, Maltamo M, Hyyppa J and Yu X 2004 Adaptive methods for individual tree detection on airborne laser based height model *International Conference NATSCAN 'Laser-Scanners for Forest and Landscape Assessment – Instruments, Processing methods and Applications (Freiburg, Germany, 3-6 October 2004)* (*International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol *XXXVI, 8/W2)* pp 187–191

[7] Sohlberg S, Næsset E and Bollandsas O 2006 Single tree segmentation using airborne laser scanner data in a structurally heterogeneous spruce forest *Photogrammetric Engineering & Remote Sensing* **72** 1369–1378

[8] Koch B, Heyder U and Weinacker H 2006 Detection of individual tree crowns in airborne Lidar data *Photogrammetric Engineering & Remote Sensing* 72 357–363

[9] Popescu S C, Wynne R H and Nelson R F 2003 Measuring individual tree crown diameter with lidar and assessing its influence on estimating forest volume and biomass *Canadian Journal of Remote Sensing* **29** 564–577

[10] Schardt M, Ziegler M, Wimmer A, Wack R and Hyyppae J 2002 Assessment of forest parameters by means of laser scanning *International Archives of Photogrammetry and Remote Sensing* **XXXIV part 3A** 302–309

[11] Persson Å, Holmgren J and Söderman U 2002 Detecting and measuring individual trees using an airborne laser scanner *Photogrammetric Engineering & Remote Sensing* **68** 925–932

[12] Popescu S C, Wynne R H and Nelson R F 2002 Estimating plot-level heights with lidar: local filtering with a canopy height based variable window size *Computers and Electronics in Agriculture* **37** 71–95

[13] Pouliot D A, King D J and Pitt D G 2005 Development and evaluation of an automated tree detection-delineation algorithm for monitoring regenerating coniferous forests *Canadian Journal of Forest Research* **35** 2332-2345

[14] Wolf B -M and Heipke C 2007 Automatic extraction and delineation of single trees from remote sensing data *Machine Vision and Applications* **18** 317–330

[15] Meyer F and Beucher S 1990 Morphological segmentation *Journal of Visual Communication and Image Representation* **1** 21–46

[16] Hyyppä J and Inkinen M 1999 Detecting and estimating attributes for single trees using laser scanner *The Photogrammetric Journal of Finland* **16** 27–42

[17] Morsdorf F, Meier E, Kötz B, Itten K I, Dobbertin M and Allgöwer B 2004 LIDAR-based geometric reconstruction of boreal type forest stands at single tree level for forest and wildland fire management *Remote Sensing of Environment* **92** 353–362

[18] Jing L Hu B, Li J and Noland T 2012 Automated delineation of individual tree crowns from LiDAR data by multi-scale analysis and segmentation *Photogrammetric Engineering and Remote Sensing* **78(12)** 1275-1284