

Automated tree crown delineation from imagery based on morphological techniques

L Jing^{1*}, B Hu², J Li², T Noland³, and H Guo¹

¹ Center for Earth Observation and Digital Earth, Chinese Academy of Sciences, Beijing, China 100094

² Department of Earth and Space Science and Engineering, York University, Toronto, Ontario, Canada M3J 1P3

³ Ontario Ministry of Natural Resources, Ontario Forest Research Institute, 1235 Queen St. West, Sault Ste. Marie, Ontario, Canada P6A 2E5

*E-mail address: jinglinhai@hotmail.com

Abstract. In current tree crown delineation from imagery, treetops and three dimensional (3D) radiometric shapes of tree crowns are frequently extracted from a spectral band or a brightness component of the image and taken as references to localize and delineate tree crowns. However, color components of the image are rarely used together with the brightness component of the image to facilitate localizing and delineating crowns. The 3D radiometric shape of a crown can be derived from a brightness or color component and may be taken as a half-ellipsoid. From top to bottom of such a half-ellipsoid, multiple horizontal slices can be drawn, contain the treetop, and indicate both the location and the horizontal extent of the crown. Based on such a concept of horizontal slices of crowns, a novel multi-scale method for individual tree crown delineation from imagery was proposed in this study. In this method, the brightness and color components of the image are morphologically opened within the scale range of target crowns, horizontal slices of target crowns are extracted from the resulting opened images and integrated together to localize crowns, and one component is segmented using the watershed approach with reference to the integrated slices. In an experiment on high spatial resolution aerial imagery over natural closed canopy forests, the proposed method correctly delineated approximately 74% of mixedwood tree crowns and 59% of deciduous crowns in the natural forests.

1. Introduction

Various individual tree crown delineation methods have been developed for optical imagery [1-7]. In current tree crown delineation methods, treetops are frequently localized at first and then used as reference points for crown delineation [6]. It is normally assumed that a treetop can be represented by a radiometric-maximum point close to the geometric center of the crown. Due to the fact that deciduous branches resemble trees, it is relatively difficult to detect deciduous treetops and crown boundaries and then delineate deciduous crowns. Current tree crown delineation methods normally employ the digital-count differences between crowns and surroundings in an individual spectral band



or an individual component of the image, brightness and color differences between crowns and surroundings are rarely utilized together to localize crowns. Moreover, for a tree crown, its treetop as an individual point indicates only its position, whereas its horizontal slices specify not only its position but also its horizontal extent. A three-dimensional (3D) radiometric shape of the crown, derived from imagery, can be taken as a half-ellipsoid [8], and multiple horizontal slices of the crown can be drawn from top to bottom of the crown and jointly characterize the 3D shape of the crown. Once obtained from a brightness or color component of the image, such slices of crowns may be taken as references in the delineation of target crowns. Based on such a concept of Crown Slices from Imagery, a novel multi-scale method for individual tree crown delineation from imagery was proposed in this study and called CSI for brevity. This method consists mainly of two steps: (1) morphologically open a brightness component and a color component of the image within the scale range of target crowns, respectively, extract a layer of object slices from each resulting opened image, and integrate all the layers of object slices together; (2) segment one component using the watershed approach with the integrated slices as references.

Two natural closed canopy forests in a study area ($46^{\circ}33'44''$ - $46^{\circ}34'03''$ N, $83^{\circ}25'12''$ - $83^{\circ}25'19''$ W) in Ontario, Canada were selected to validate the CSI method proposed in this paper. The study area is near Sault Ste. Marie, Ontario, Canada, within the Great Lakes-St. Lawrence forest region and consist 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. In order to test the CSI method on different closed canopy forests, two plots were selected in this area. Plot 1 with size of 77 m by 60 m (figure 1(a)) is a mixedwood forest mainly composed of aspen (*Populus tremuloides* Michx., 20%), white birch (*Betula papyrifera* Marsh., 10%), Jack pine (*Pinus banksiana* Lamb., 50%), and black spruce (*Picea mariana* Mill. BSP, 10%). Plot 2 of 77 m by 77 m (figure 1(b)) consists of deciduous trees, including maples and birches. The aerial multispectral imagery over the study area was acquired at about 250 m aboveground in August 2009, using an Illunis XMV-4021C camera at three broad spectral bands: blue (with center wavelength of 450 nm), green (550 nm), and red (625 nm). The imagery was geo-referenced using on-board GPS (Global Positioning System) and inertial system and has a spatial resolution of 0.15 m.

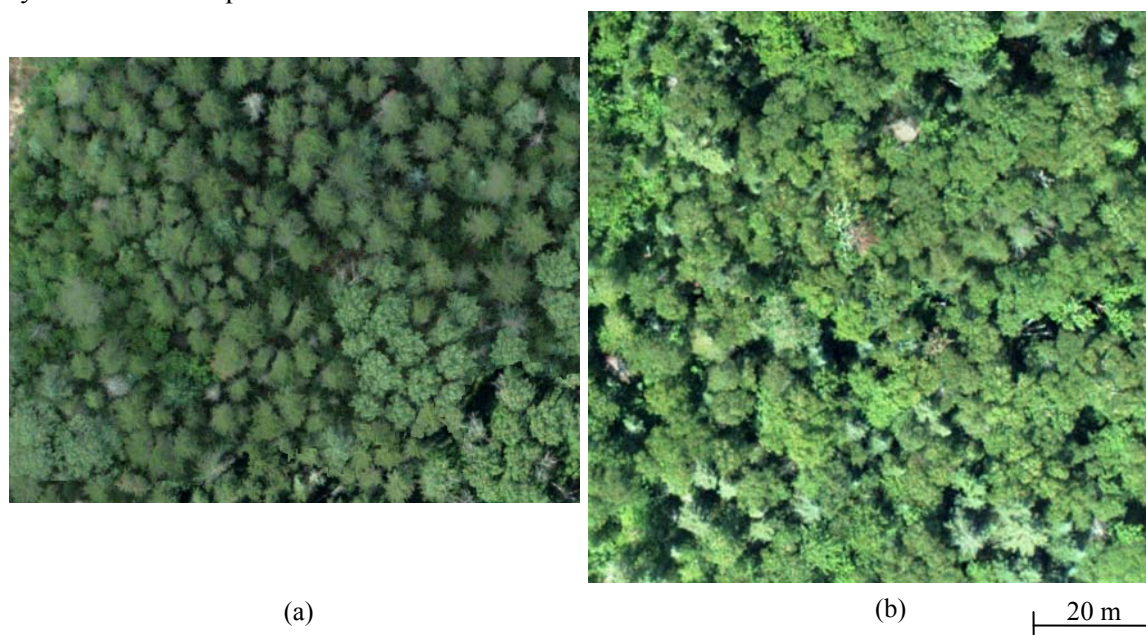


Figure 1. The aerial images of the two plots. (a) plot 1; (b) plot 2.

2. Methodology

Horizontal slices of crowns can be obtained using the morphological opening technique for grayscale imagery [9], which can separate objects within a grayscale image based on sizes and shapes. Given a spatial scale and a grayscale image of forest, a disk structuring element (SE) with diameter equal to the scale can be designed, and an opening operation with this SE on the image can sift the objects smaller than the SE and retain larger ones which can fully contain the SE. The resulting opened image consists of objects not smaller than the SE, including branches, crowns, and tree clusters. The top of each remaining object in the opened image, shown as a local regional maximum, is approximately circular and indicates not only the position but also the horizontal extent of the object. All of the object tops in the opened image constitute a layer of slices. Given a natural forest scene, multiple scales of relevant crowns can lead to multiple opened images followed by multiple layers of object slices. The latter form jointly represent the 3D radiometric shapes of the target crowns and can be integrated together to yield a complete layer of crown slices. Such a layer of crown slices well defines the horizontal extents of the crowns and thus can be taken as references instead of treetops in tree crown delineation.

In order to effectively delineate multi-scale tree crowns from imagery, the CSI method employs crown slices morphologically extracted not only from a brightness component of the multispectral image, but also from a color component of the image, as follows:

- 1) Take the width range of target crowns as the scale range of the crowns and then decide a scale series of the crowns with 2-pixel increments.
- 2) Transfer the image to obtain a brightness component and a color component of the image, such as the first and second principal components.
- 3) Remove non-vegetation areas, such as shadow, water, and bare land, from both components by setting relevant pixels at zero.
- 4) Morphologically extract object slices from both components within the scale series of target crowns.
- 5) Integrate all the layers of object slices extracted from each component.
- 6) Merge the two resulting integrated layers of object slices generated from the two components.
- 7) Segment one component using the watershed approach with the merged slices as markers to yield a segmentation map.
- 8) Remove non-crown areas, including bare land, roads, buildings, bushes, and grass, from the previous segmentation map to obtain a tree crown map.

In the step 3 of the procedure above, shadow and water areas with low brightness values are masked by applying a threshold to the brightness component, and bare land areas are effectively masked by applying a threshold to the color component, based on their significant color differences from vegetation. In the step 4 of the procedure, object slices are extracted from each component within the scale series of target crowns, as follows:

- a) Given the smallest scale of r pixels within the series, smooth the component using a Gaussian filter to suppress branches, morphologically open the component with a disk SE, and take the local maxima within the opened image 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) of $0.3r$ pixels. When the Gaussian filter is applied to the component, branches smaller than the filter will be effectively suppressed, whereas larger tree crowns will be retained. The sigma of $0.3r$ pixels was experimentally determined.
- b) Repeat step (a) for each other scale within the scale series to obtain all the layers of object slices within the scale range of target crowns.

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

In the step 5 of the CSI procedure, a series of layers of object slices obtained from one component, $\{L_1, L_2, \dots, L_n\}$, 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 as a fine layer and integrate it with the next coarser layer, i.e., L_3 .
- 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 the circularity of tree crowns normally lies above 0.85[8].
- b) Combine the fine layer and the refined coarse layer using a logic 'OR' operation.
- c) Refine the combined layer by removing slices with circularity less than the previous threshold to eliminate slices of tree clusters.

In this procedure, the circularity (c) of a segment is calculated by [8]: $c = A/(\pi r^2)$, 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 the step 6 of the CSI procedure, two integrated layers of object slices, i.e., L_b from the brightness component of image and L_c from the colour component, are merged as follows:

- a) Calculate the circularity of each slice in the two layers.
- b) For each slice s_b in layer L_b , find all the slices s_c superimposed by it in layer L_c . If its circularity is higher than the mean circularity value of slices s_c , all slices s_c are eliminated; otherwise, slice s_b is removed.
- c) Combine the modified layers L_b and L_c using a logic 'OR' operation.

In this integration processing, the shape factor of circularity is taken into account in order to eliminate tree clusters. The resulting combined layer consists mostly of crown slices.

In the step 7 of the CSI procedure, one component of the image, brightness or color, is inverted and then segmented using the marker-controlled watershed segmentation approach [10]. This approach is widely used to segment imagery for tree crown delineation [11].

In the last step of the CSI procedure, non-crown areas, such as bare land, buildings, water, and grass, are removed from the segmentation map previously obtained to yield a tree crown map. With similar brightness and color values but significantly different textures, tree crowns and grass can be separated. After grass slices are determined, remove segments superimposing on grass slices, remove non-vegetation areas from each segment, remove small segments, and fill holes in segments to yield a tree crown map expected.

3. Experimental results

The images over plots 1 and 2 (figures 1(a) and 1(b)) were processed using the CSI method proposed in this study and the resulting tree crown maps are shown in figures 2b and 2b, respectively. In the processing, a crown width range of 11-23 pixels (1.65-3.45 m) was estimated in this study for the study area and a series of crown scales $\{11, 13, \dots, 23\}$ in pixels with 2-pixel increments was employed in the CSI delineation. The first and second principal components of each image were taken as the brightness and color components in the CSI method, respectively. As shown in these crown maps, most of the crown boundaries within the plots 1 and 2 coincide well with the between-crown valleys in the images.

In order to further evaluate the automatically delineated crown maps, the original images were manually segmented by an independent experienced researcher. The automatically delineated crown maps and the manually delineated maps were referred as target and reference, respectively. In each of the crown maps, the incomplete segments near map boundaries were removed so that only the remaining, complete segments were used in the following evaluation. Visual comparison shows that each target map and the corresponding reference map were consistent for the majority of the tree crowns, whereas some of the reference crowns were omitted, merged, and split in the target maps. All

the reference segments were classified into the following five categories regarding their spatial relationships with the target segments described in [12]. The accuracy statistics of all the CSI-generated crown maps are listed in table 1. As shown in this table, roughly 74% of the mixedwood tree crowns within plot 1 and 59% of the deciduous tree crowns within plot 2 were correctly delineated by the CSI method. These statistics support the idea that the CSI method can generate a map of various-sized tree crowns comparable to manual interpretation.

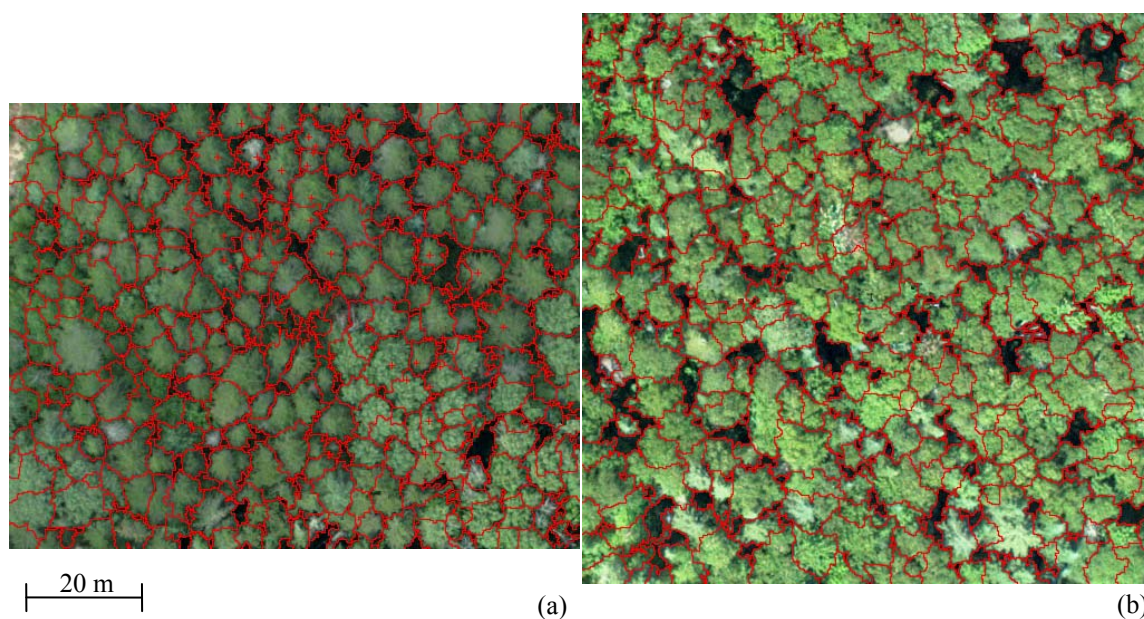


Figure 2. The crown maps of the two plots. (a) Plot 1; (b) plot 2.

Table 1. The accuracy statistics of the CSI-generated tree crown maps from imagery 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	219	132	30	17	26	14	26	74.0	19.6	18.3
2	168	79	20	10	18	41	15	58.9	16.7	33.3

The CSI method performed differently on different forests. The high accuracy of the CSI-generated crown map over the plot 1 can attribute to the predominant coniferous tree crowns with similar sizes and obvious between-crown valleys. The lower accuracy of the CSI-generated crown map of the plot 2 is due to the complex structure of the deciduous tree crowns and the predominant deciduous tree clusters. As demonstrated from the aerial image over plot 2 (figure 1(b)), the densely growing deciduous tree crowns within the plot are tightly overlapping and irregular, and the between-crown valleys are blurred. These crowns have no obvious treetops and are only visually distinguishable based on shape and spatial distribution of their pixels.

4. Discussion

In the CSI method proposed in this study, both the brightness and color components of the image are morphologically opened within the scale range of target tree crowns, slices of objects in the image are extracted from the resulting opened images. As a regional maximum rather than an individual point, each slice contains the corresponding treetop and indicates the horizontal extent of the tree crown.

Objects within a forest, such as tree crowns, bushes, grass, have multiple scales. The multi-scale structure of forest, together with the complex structures of deciduous crowns, makes it difficult to localize and delineate tree crowns from deciduous and mixedwood forests. In this study, multiple scales within the scale range of target crowns lead to multiple layers of horizontal slices of the multi-scale crowns, and the latter are combined into a complete crown slice well representing the horizontal extents of the crowns. The integration procedure described in the CSI method proposed in this paper is mainly based on a shape factor of circularity to separate crowns from branches and tree clusters. The procedure will be improved by considering LiDAR (Lighting Detection And Ranging) data in the future.

5. Acknowledge

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