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A new method for 3D individual tree extraction using multispectral airborne LiDAR point clouds

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ABSTRACT

Characterization of individual trees is essential for many applications in forest management and ecology. Previous studies relied on single tree detection from monochromatic wavelength airborne laser scanning (ALS) systems and they focused on the use of the geometric spatial information of the point clouds (i.e., X, Y, and Z coordinates). However, there is quite often a difficulty dealing with clumped trees when only the geometric spatial information is considered. The emergence of multispectral LiDAR sensors provides a new solution for individual tree structure acquisition. The aim of this paper is to investigate the performance of multispectral ALS data for delineating individual trees which are challenging by using the monochromatic wavelength ALS system. The proposed workflow utilizes the mean shift segmentation method on different feature spaces for crown isolation. In addition, both spatial domain and multispectral domain are used to refine the under-segmentation crown segments. Ten plots (2 sets of different structural complexity) located in the dense coniferous forest area in Tobermory, Ontario, Canada are selected as experiment data. Results show that the developed method correctly detects 88% and 82% of the dominant trees with and without multispectral information, respectively. Compared with segmentation using geometric spatial information solely, the main improvements are achieved for clumped tree segment with the distinguished multispectral features. This study demonstrates that multispectral airborne laser scanning data is more capable for individual tree delineation than monochromatic wavelength laser scanning data in dealing with forests with clumped crowns in dense forests.

1. Introduction

Classification of the forest habitat at individual tree level is becoming essential for many applications in forest management and ecology (Lefsky et al., 2002; Yang et al., 2016a). Single tree information is also valuable for updating forest inventories and estimating growth and yield (Yu et al., 2017), or even to identify trees with high biodiversity value (Eysn et al., 2015). The traditional methods of field inventory work to obtain such detailed information suffer from high labor cost as well as accessibility constraint (Eysn et al., 2015; Wang et al., 2016). Accurate and efficient methods for assessing forest structure at individual tree level are therefore of great importance. Nevertheless, the traditional remote sensing technologies such as the interpretation of optical imagery (Hall et al., 1995, Moskal and Franklin, 2002) have difficulties in meeting the 3D forest structures extraction.

Monochromatic wavelength airborne laser scanning (ALS) system has shown high potential in forest applications as it directly captures 3D forest structures (Wang et al., 2016; Yu et al., 2017), providing good solution for retrieving various forest variables, such as tree height (Unger et al., 2014), tree species (Harikumar et al., 2017), crown size (Unger et al., 2014; Popescu et al., 2003), stem density (Richardson and Moskal, 2011), wood volume (Hyyppä et al., 2001; Giannico et al., 2016) and biomass (Ene et al., 2017; Vauhkonen et al., 2014). The detection and the segmentation of the single tree crown is a fundamental step to accurately estimate individual tree structural attributes (Paris et al., 2016). The geometric spatial information has been widely used for individual tree extraction. Extensive efforts were investigated to extract individual trees by locating tree tops through local maxima from either canopy height model (CHM) or scattered point clouds. And then the tree crown segmentation was commonly achieved by applying the region growing or watershed methods (Hyyppä et al., 2001; Mongus and Žalik, 2015; Li et al., 2012). Many efforts focused on the geometric characteristics analysis of point clouds for tree crown detection. Ferraz et al. (2012) considered the local maximum both in density and height in ALS point cloud as a crown apex and applied a special-designed mean shift algorithm to delineate individual trees. Strîmbu and Strîmbu

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(2015) presented a graph-theoretical approach to tree crown delineation, where the weights were computed based on five different cohesion criteria to quantify topological relationships of tree crown components.

However, the methods have difficulties in extracting the clumped tree crowns of similar heights and density distribution as the clumped trees do not meet the assumption of the geometric constraint characteristics. For example, the clumped tree crowns with similar heights and density distribution may be mistakenly detected as a single treetop. On the other hand, the non-treetop local maxima may be falsely detected as treetops (Yang et al., 2016a).

Many efforts focused on the combination of multispectral/optical imagery and ALS data to compensate the lack of 3D structure from imagery and multispectral information from ALS data (Yu et al., 2017). Naidoo et al. (2012) concluded that the use of ALS and hyperspectral data yielded the highest classification accuracy and prediction success for the eight savanna tree species, with an overall classification accuracy of 87.68%. Ørka et al. (2012) demonstrated that simultaneous acquisition of ALS and medium-format digital imagery provided an efficient data acquisition strategy for tree species identification in forest inventory reporting an overall classification accuracy of 87–89%. Packalén and Maltamo (2006) produced considerably more accurate estimates for the species-specific volumes (volumes of pine, spruce, and deciduous trees) at the plot level by combining ALS data with aerial photographs. Although the use of the fused datasets is effective, there are challenging factors that limit the process outcome such as geometric and radiometric registration between the two datasets. Furthermore, the fused datasets were mainly used for tree species classification and species-specific parameters estimation. Few of the studies focused on the detection of individual trees, particularly, on the detection of the clumped trees with similar heights and density distribution. The development of an efficient method to delineate crowns to cover complex forest architecture is still one of the current challenges.

With the launch of the newly developed multispectral LiDAR sensor and technology, point clouds are collected with more spectral information which can be integrated to the data processing and facilitate the interpretation of the data. The aim of this paper is to investigate the performance of multispectral ALS to retrieve forest crown structure where geometric information alone fails especially in areas of clumped trees with similar heights and density distribution.

The rest of this paper is organized as follows: Section 2 illustrates the data set, and Section 3 elaborates the proposed framework to investigate the potential of multispectral ALS data for characterization of forest crowns. Section 4 and 5 report the experimental results and discussion. Finally, Section 6 draws the conclusions of the work.

2. Study area and dataset

2.1. Study area

The study area is centered at 45.24°N, 81.68°W, which is located in the forest area in Tobermory, Ontario, Canada (Fig. 1). Tobermory is a small community located at the northern tip of the Bruce Peninsula in the municipality of Northern Bruce Peninsula. The mean elevation of Tobermory is approximately 186 m, and the terrain is relatively flat. The vegetation across the data collection area is mainly dense coniferous, and a few deciduous forests. The forest vegetation in the area is dominated by white cedar (*Thuja occidentalis* L.), balsam fir (*Abies balsamea* (L.) P. Mill.) and paper birch (*Betula papyrifera* Marsh.) (Obbard et al., 2010).

2.2. Multispectral LiDAR data

The multispectral sensor, Optech Titan is a newly developed multispectral airborne LiDAR sensor, a revolutionary sensor that includes three active channels of different wavelengths, namely 1550 nm (Intermediate Infrared), 1064 nm (Near Infrared, NIR) and 532 nm

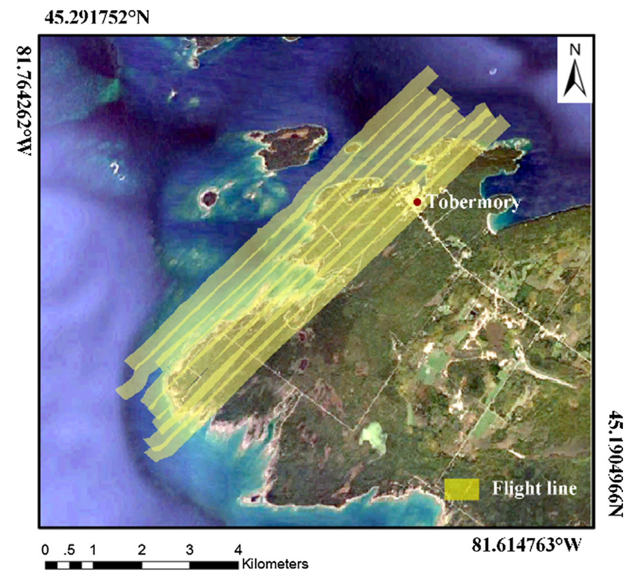

Fig. 1. The study area in Tobermory, and the multispectral airborne laser scanning coverage. The yellow stripes over the area are the flight lines for data collection.

(Visual Green) The data were acquired in April 2015 by Teledyne Optech. The flying altitude of the mission was about 457 m above the ground level at a speed of 259 km/h. The system operated at a pulse repetition frequency of 625 kHz and with a Scan angle (FOV) of 40°. It collected data with the three independent channels simultaneously, resulting in an average point density of approximately 58 pts/m^2. The flight lines contained a couple of shipwrecks, rocky coastline, shoals, and impressive water depths with dynamic intensities on the water bottom (Fig. 1).

The flight area extended approximately over 2000 ha, 10 forest plots were selected to investigate the potential of multispectral ALS data for characterization of forest crowns. Each test forest plot is a square with a fixed size of 30 m × 30 m. According to the complexity of forest structure, the 10 plots can be divided into two groups, 6 complex plots, and 4 simple ones. Complex plots are characterized by clustered spatial distribution, and larger variability in tree size, while simple plots have homogeneous attributes in terms of tree size and spatial arrangement.

Fig. 2 shows two examples, each for complex and simple plots. The tree numbers and tree heights in both complex and simple forest plots are listed in Table 1 by visual inspection from the ALS point clouds using the CloudCompare software (http://www.danielgm.net/cc/).

3. Methodology

In this paper, we present a three-step framework to isolate individual tree crowns from multispectral ALS point cloud and compare the results produced under different conditions (with and without multispectral information). We first apply the mean shift method in the spatial domain to segment individual crowns by exploiting the geometric pattern of crown points' distribution. Then the under-segmentation results are classified via the Support Vector Machine (SVM) classification and further refined by applying the mean shift in the joint feature space containing the spatial domain and the multispectral domain. The flow chart of the process is illustrated in Fig. 3. The individual tree crowns extraction and refinement focus on the dominant layer trees. Instead of extracting crowns from the simplified CHM, we delineate individual crowns from the point clouds directly by applying the mean shift segmentation method indifferent feature spaces.