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A dual growing method for the automatic extraction of individual trees from mobile laser scanning data

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ABSTRACT

Street trees interlaced with other objects in cluttered point clouds of urban scenes inhibit the automatic extraction of individual trees. This paper proposes a method for the automatic extraction of individual trees from mobile laser scanning data, according to the general constitution of trees. Two components of each individual tree – a trunk and a crown can be extracted by the dual growing method. This method consists of coarse classification, through which most of artifacts are removed; the automatic selection of appropriate seeds for individual trees, by which the common manual initial setting is avoided; a dual growing process that separates one tree from others by circumscribing a trunk in an adaptive growing radius and segmenting a crown in constrained growing regions; and a refining process that draws a singular trunk from the interlaced other objects. The method is verified by two datasets with over 98% completeness and over 96% correctness. The low mean absolute percentage errors in capturing the morphological parameters of individual trees indicate that this method can output individual trees with high precision.

1. Introduction

The detection and extraction of vegetation in the community of urban remote sensing is one of the hottest topics of current research (Alexander, 2009; Kankare et al., 2013; Lee et al., 2010; Yu et al., 2011). The significance of extracting individual street trees and further capturing trees' attributes, including their spatial positions and morphological parameters (e.g., tree height, trunk diameter, crown diameter, crown area, etc.), has been demonstrated. Such attributes of individual trees have been widely used in diverse applications, such as monitoring the growth and health of trees (Jutras et al., 2009), the navigation and positioning of vehicles and pedestrians (Maeyama et al., 1994), constituting parts of street and urban inventory (Jaakkola et al., 2010), and providing a data basis for 3D tree modeling (Raumonen et al., 2013), noise modeling (Fang and Ling, 2003), city green quantity estimation (Wang et al., 2008) and path planning (Simons and Johnson, 2008).

The advent of the mobile LiDAR system (MLS) provides an effective data collector that can flexibly and efficiently capture dense point clouds in wide ranges of urban road environments (Haala et al., 2008). Many studies that were based on MLS data have been conducted, such as object classification (Pu et al., 2011; Serna and Marcotegui, 2014; Yang et al., 2015) and object identification and extraction (Cabo et al., 2014; Jochem et al., 2011; Lehtomaki et al., 2010; Nalani, 2014; Rodríguez-Cuenca et al., 2015; Zhu et al., 2011), which shows the great potential of MLS data for extracting street trees.

Recently, some scholars have devoted themselves to the extraction of individual trees from MLS data and presented the ability to extract individual trees with high precision in a certain context. However, current methods suffer from low identification accuracy and low extraction precision in complex environments where dense objects are interlaced and mixed in a local area, even in cluttered situations of occlusion and overlapping between neighboring objects.

This paper aims to automatically extract individual trees from MLS data and provide an accurate data basis for capturing trees' morphological parameters.

This paper is organized as follows. Related works on LiDAR data and the extraction of individual trees are introduced in Section 2. The method for the extraction of individual trees is presented in Section 3, including coarse classification, seed selection, dual growing and gradual refinement. Two experimental datasets are

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conducted in Section 4 to validate the method. Finally, conclusions are drawn and future work is presented in Section 5.

2. Related works

2.1. Identification of trees from LiDAR data

More than ten years ago, some scholars began to focus on the detection and identification of trees from high-resolution remote sensing data. Gougeon (1998) classified the species of isolated individual trees by analyzing the spectral data of the canopy. Afterwards, some new methods were proposed to detect and depict the canopy and detect individual trees (Culvenor, 2002; Hirschmugl et al., 2007; Pouliot et al., 2005). However, this detection has been limited to the depiction and measurement of the canopy surface and its 2D outline.

The emergence of the light detection and ranging (LiDAR) system provided a rapid and cost-effective 3D data collection tool that enabled more precise detection and extraction of trees. According to different carrying platforms, the LiDAR system can be divided into airborne LiDAR system (ALS), terrain LiDAR system (TLS) and mobile LiDAR system (MLS, in full, vehicle-borne LiDAR system, VLS).

Recently, the extraction of vegetation from LiDAR data has attracted great attention. Initially, ALS data have been used to investigate forests (Morsdorf et al., 2004), estimate the wood volume and calculate the biomass (Popescu et al., 2003). Afterwards, many scholars used ALS data to identify and extract trees (Koch et al., 2006; Vega et al., 2014), estimate the geometric parameters of trees (Kwak et al., 2007; Van Leeuwen and Nieuwenhuis, 2010) and build tree models (Kato et al., 2009; Wang et al., 2008). Among them, methods for the extraction of trees show the ability to obtain accurate information regarding tree height and canopy size, which can be classified as point-based (Vega et al., 2014; Yu et al., 2011) and Canopy Height Model-based (Edson and Wing, 2011; Lee et al., 2010). Because of the restriction of the collecting mode, ALS data mainly reflect the top surface of the object. Thus, the lower structures of trees are always underexposed on account of the crown's sheltering effect. Thus, measuring the trunk diameter at breast height (DBH) from few laser points on the trunk is difficult (Bucksch et al., 2014). Under certain conditions, some multiple return measurements can produce point clouds with up to 120 points per square meter, which shows the feasibility of estimating the DBH (Dalponte et al., 2011).

Compared to ALS data, TLS data have higher sampling density and precision. However, collecting a wide range of TLS data for the extraction of individual trees is inefficient because of the poor mobility of TLS. Therefore, researches based on TLS data have paid little attention to the identification and extraction of individual trees. Instead, most of scholars mainly focused on the identification and extraction of tree structures (Bucksch and Lindenbergh, 2008; Bremer et al., 2013), the accurate measurement of tree morphological parameters (Kankare et al., 2013; Maas et al., 2008; Srinivasan et al., 2014), the fine modeling of trees (Delagrange et al., 2014; Raumonen et al., 2013), etc.

MLS is a flexible, fast and efficient device to collect 3D point clouds of objects with high precision in an urban road environment. The MLS data of trees includes both many crown points and abundant trunk points. This feature shows the great potential to extract individual trees from a complex street environment by using MLS data.

2.2. Extraction of individual trees from MLS data

Many studies have addressed extraction of trees from urban MLS data. According to the classification approach regarding segmentation algorithms (Vo et al., 2015), the current methods for the extraction of individual trees can also be roughly classified into cluster feature-based methods (Rutzinger et al., 2011; Yao and Fan, 2013; Zhong et al., 2013), model fitting-based methods (Monnier et al., 2012) and region growing-based methods (Wu et al., 2013).

Cluster feature-based methods are widely used in the extraction of individual trees from MLS data. Rutzinger et al. (2011) used the 3D Hough Transform and surface growing to remove large planes (ground and façades), segmented the remaining points to point clusters, and then used the standard deviation of the elevation to measure the surface roughness. An individual tree was extracted from clusters according to the surface roughness and point density ratio (between the point number below a certain height (0.5 m) and the total number of the cluster). Yao and Fan (2013) removed man-made objects by analyzing the spatial accumulation map of the point cloud and used the spectral clustering algorithm to segment the remaining points (including natural objects and a few vertical interference objects) into single objects. Finally, individual trees were extracted by shape analysis. Zhong et al. (2013) extracted individual trees according to the characteristic of vertical hierarchy. They firstly projected the remaining points into the horizontal plane or grids after removing ground points, then marked the continuous non-empty grids. The grids with the same mark were merged to constitute a point cloud of a single object which was divided into five layers by height. Finally, the morphological parameters of the tree (such as the height, crown width and tree diameter) could be obtained by analyzing the points in these layers. Thus, individual trees were distinguished from other objects by their morphological characteristics. These methods can quickly and successfully separate individual trees, but separated trees still contain many non-tree points, which may lead to errors in parameter estimation.

Model fitting-based methods are mostly used in the extraction of objects with a specific shape, such as planes (Vosselman et al., 2004) and spheres (Rabbani and Van Den Heuvel, 2005). Lalonde et al. (2006) used a 3D descriptor to describe local geometric shapes and divide point clouds into 3 classes: scatter, which mainly expresses volumetric objects (grass, crowns, etc.); surface, which mainly expresses planar objects (ground, façades, etc.) and linear, which mainly expresses linear objects (pole-like objects). However, the description results were still rough. Based on this research, Monnier et al. (2012) improved these descriptions, combined with probabilistic relaxation (Rosenfeld et al., 1976), and defined a new cylindrical descriptor. Individual trees could be extracted by combining the cylindrical trunk, which does not belong to the façade and is surrounded by a canopy, with the nearest volumetric crown. These model fitting-based methods can extract individual trees in some specific situations but exhibit poor performance in various situations or complex geometries. When using feature-based methods or model fitting-based methods, a refinement process is needed for each extracted tree cluster.

The region growing-based method was adopted by many scholars for 3D point cloud segmentation (Biosca and Lerma, 2008; Vo et al., 2015), including segmenting building structures (Dimitrov and Golparvar-Fard, 2015) and individual trees (Lu et al., 2014). Wu et al. (2013) used the Voxel-based Marked Neighborhood Searching (namely, region growing) method to extract individual trees from MLS data and successfully obtained the morphological parameters of trees. They calculated the compactness index (CI) of the shape that was formed by continuous non-empty voxels at a specific height section (1.2–1.4 m) to determine the seed voxels of trees. This method extracted individual trees with high precision and demonstrated excellent performance in a relatively simple environment with similar trees. However, the seed selection and growing criteria presented some problems. On the one hand, the seeds in the manual setting of the initial searching height impose