DECTION AND HEALTH ANALYSIS OF INDIVIDUAL TREE IN URBAN ENVIRONMENT WITH MULTI-SENSOR PLATFORM

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ABSTRACT

With the technology enhanced, 3D mobile light detection and ranging (LiDAR) can produce more accurate 3D information for the objects. Meanwhile, hyperspectral remote sensing has more number of wavelengths and provides a higher resolution spectrum of objects. This paper proposes a multi-sensor platform to provide these two data for health detection at the individual tree level in urban environments. We firstly locate and segment the suspected tree objects by ground removal and Euclidean distance clustering. Then we take use of spectrum to remove non-tree objects, e.g., buildings, light poles. After that, we use LiDAR data to compute the geometric parameters of each tree and hyperspectral data to analyze its health situation.

Index Terms— individual tree detection, health monitoring, LiDAR, point cloud, hyperspectral, spectrum

1. INTRODUCTION

In recent years, using 3D mobile LiDAR (light detection and ranging) point clouds to detect and extract objects has become an active research. However, the LiDAR data only presents the geometrical information of the scanning object for object detection. Hyperspectral remote sensing has numbers of wavelengths and provides very high-resolution spectrum of objects. The hyperspectral data thus is a useful feature for object detection. Particularly, tree objects with different growth status present different spectrum curves, which can be utilized as a clue to predict the health of trees.

There are several methods, which are mainly voxel-based, for extracting individual tree from Terrestrial LiDAR data. In [1], Wu *et al.* presented a Voxel-based Marked Neighborhood Searching (VMNS) method for identifying street trees and measuring their morphological parameters from VLS (vehicle laser scanning) data. Vonderach *et al.* [2] also developed an extended approach based on voxel structure, for a fast and non-destructive extraction of branch volume, DBH (diameter at breast height) and height of single trees from TLS (terrestrial laser scanning) point clouds. In [3], a voxel-based normalized cut segmentation method was introduced to separate the adjacent or overlapped objects. The authors also proposed a model-driven method to extract 3D trees based on a pairwise 3D shape descriptor. Different from them, Huang *et al.* [4] adopted PCA (principal component analysis) to get the geometrical feature for tree detection.

The hyperspectral data is also used to extract individual tree with LiDAR data. In [5], Zhang et al. derived NDVI (Normalized Difference Vegetation Index) image from hyperspectral data to identify non-tree objects. The spectral reflectance of plants is related to many physiological characteristics, e.g., nitrogen content, chlorophyll content or water content. In [9], a series of content indices based on hyperspectral data have been pointed for estimation of these content. For different plants, the calculation accuracy of these indices are variable.

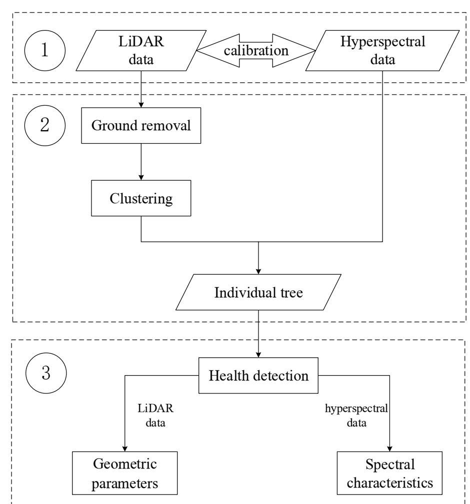


Fig. 1. Workflow of individual trees' health detection.

Comparing to the airborne LiDAR, terrestrial LiDAR can get more details in complex environments. With both hyperspectral data and LiDAR data, it can provide more complete features of trees. Therefore, using those data, it's potential to extract individual tree from urban environments as well as to evaluate the health status of the trees. The workflow of our method is shown as Fig. 1.

2. METHODOLOGY

As shown in Fig. 1, we divide the whole process into three parts: calibration, individual tree extraction, and health detection. Before data processing, we need to register LiDAR camera and hyperspectral camera. After that, we segment the objects located by ground removal and Euclidean distance clustering. Then we take use of spectrum to remove non-tree objects, e.g., buildings, light poles. After getting individual trees, we use LiDAR data to get the geometric parameters of each tree, i.e., tree height, DBH (diameter at breast height), crown diameter and inclination of the tree. Finally, the hyperspectral data is also used to detect the health situation of trees.

2.1. Registration

The registration of LiDAR camera and hyperspectral camera is to locate the same objects in two sensors. This part is not the main focus of this paper. We adopt the method pointed in [7] by Dun, to get the registration between LiDAR data and hyperspectral data. This method is performed on image and depended on control points (CP) and feature-mutual information.

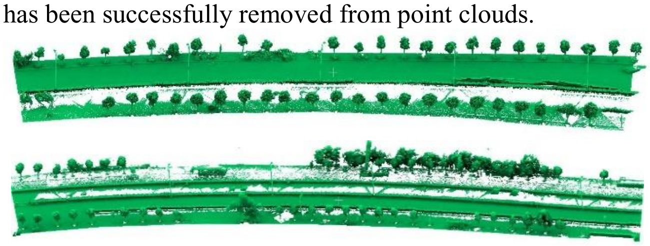
Firstly, coarse registration parameters are obtained by GPS and CP registration. Then the Powell algorithmic is performed to get precise registration, with the parameters obtained before as initial parameters, and feature-mutual information for measure similarities. The registration between LiDAR image and hyperspectral image is thus completed.

2.2. Individual tree extraction

In this part, we aim to extract individual tree from point cloud data and to obtain each tree's location, preparing for the health detection of each tree. This part consists of three steps: data preprocessing, point cloud clustering and filtering.

2.2.1. Data preprocessing

The point cloud data we obtained contains a large part of data outside the street, we thus cut them based on the roadside. Fig. 2 (a) shows the data after cutting. Then, to reduce calculation, we adopt the ground removal algorithm in [6], which is called region growing judging criterion, to remove ground surface from LiDAR data. As shown in Fig. 2(b), the ground surface has been successfully removed from point clouds.



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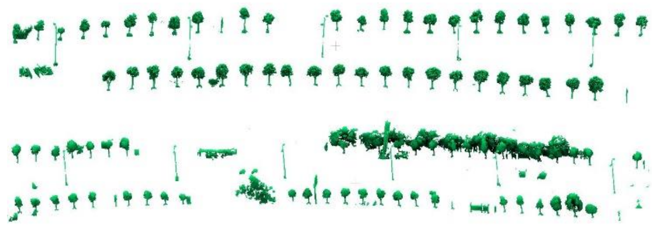


(b)

Fig. 2. Ground removal: (a) data after cutting outside parts, (b) off-ground points

2.2.2. Point cloud clustering

After ground removal, we adopt the Euclidean distance clustering to cluster isolated points into individual objects. However, these objects still have a few points not belonging to trees after clustering. Because the urban street trees have the similar height in road scene, we set a standard height range to remove the object whose top points is lower than 3meters and higher than 10 meters. We also delete the object whose DBH is higher than 0.5 meters. The result is shown in the Fig. 3, points with different colors indicate different objects.

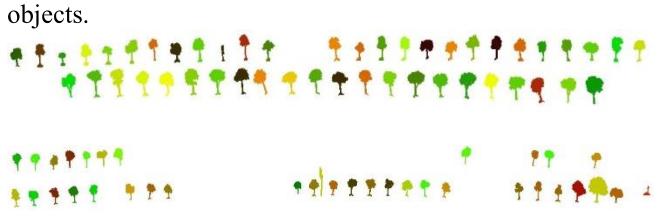


Fig. 3. Point cloud clustering

2.2.3. Filtering

The clusters we got above may contain some non-tree objects, e.g., light poles and signboard shown in Fig. 3.Therefore, the NDVI (Normalized Difference Vegetation Index) derived from hyperspectral data is used for this purpose.

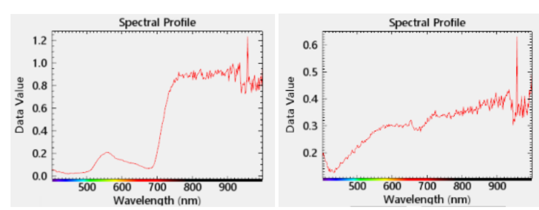


Fig. 4. Spectrum of tree leaf (left) and rock (right)

The spectrum of the tree is different from other things, attributed to the unique ability of absorbing light. Fig. 4 shows the spectrum of one point on the tree leaf and on rocks, respectively. As we can see, for healthy vegetation, the difference of the spectral data between NIR and R is large. That's because the light in R is strongly absorbed by green plants and NIR is highly reflective and highly transmissive. It presents the salient feature on vegetation object. In this regard, we select the hyperspectral data bands at 800 nanometers (nm) and 670nm to filter the non-vegetation objects.

$$\text{NDVI} = \frac{R_{800} - R_{680}}{R_{800} + R_{680}} \quad (1)$$

Fig. 5 shows the final result of individual tree extraction.

Fig. 5. Individual trees

2.3. Health analysis

In this part, LiDAR data is used to compute the geometric parameters of individual trees: height, DBH, crown diameter and inclination of the tree. We believe that these parameters can present the health status of a tree. And then the hyperspectral data is provided to further evaluate physiological characteristic for trees' growth state. Finally, the health of trees can be analyzed through these parameters and characteristics.

2.3.1. Geometric parameters of trees

(1) Height

The maximum altitude of the points within an individual tree is represented by Z_{max} , while the minimum altitude represented by Z_{min} . Then the formula for height (H) calculation can be simplified as:

$$H = Z_{max} - Z_{min} \quad (2)$$

(2) Crown diameter

We adopted the approach based on a step-wise vertical slicing of the point cloud and circle fitting to compute the diameters of trees [8]. Firstly, points are cut as slices of 5 cm vertical thickness, from bottom to the top. Then circle fitting based on least squares is applied. The formula is as follows,

$$x^2 + y^2 + ax + by + c = 0 \quad (3)$$

$$A = \frac{a}{-2} \quad (4)$$

$$B = \frac{b}{-2} \quad (5)$$

$$R = \frac{\sqrt{a^2 + b^2 - 4c}}{2} \quad (6)$$

$$Q(a, b, c) = \sum[(X_i^2 + Y_i^2 + aX_i + bY_i + c)]^2 \quad (7)$$

where a, b, c are required parameters, and x, y represent coordinates of points on the plane. A and B is the center point of the circle, and R is the radius. The Q indicates the loss function. As seen, the parameters has the best performance would minimize Q. And the biggest diameter will be set as the crown diameter of one tree.

(3) DBH

To compute the DBH of each tree, we choose the points range from 1.2m to 1.4m above the ground. Similarly, circle fitting is applied to compute the diameters of the slices between 1.2m and 1.4m, and the average is the diameter at the breast height.

(4) Inclination

As shown in Fig. 6, the inclination of the tree can be obtained through two points: A and O. The point A is the middle point at the height of 1.4m above the ground. And point O is the middle point at the bottom of the tree object. Based on point A, we can get projection point A' and then compute the angle θ, which is the inclination of the tree.

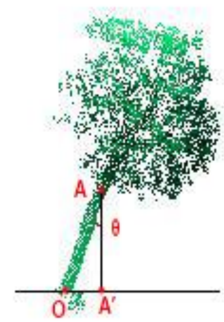


Fig. 6. The inclination of the tree

2.3.2. Physiological parameters

The spectrum of plants can reflect the physiological state of many plants. Many vegetation index models have been proposed to enhance certain characteristics or details of vegetation, which is calculated from the combination of reflectivity of two or more bands, e.g. NDVI, EVI, VOG, NDNI. Through these indices, most physiological parameters can be simply measured, e.g., nitrogen content, chlorophyll content, water content and some complex characters like utilization efficiency of incident light. The personnel in this field will also use the truly measured data and the calculated vegetation index to make a regression to establish a large area calculation model, which is not the focus of this paper. The proposed multi-sensor platform provides both LiDAR and multispectral data for potential health analysis at the individual tree level. The in-depth analysis about that can be performed in further study.

3 RESULTS AND DISCUSSIONS

The MLS point clouds for experiments were acquired by RIEGL VMX450 mobile laser scanning system, and hyperspectral data was obtained by Headwall's Nano-Hyperspec, which is designed for the VNIR (400-1000nm) spectral range. All the data was acquired in September, 2016, located in Huandao Road, Xiamen. The dominant species of tree in distribution is camphor tree, an evergreen tree. 175 trees were extracted from point clouds in this area by our automatic extraction method. The accuracy of tree extraction is 0.97 and the recall is 0.90.

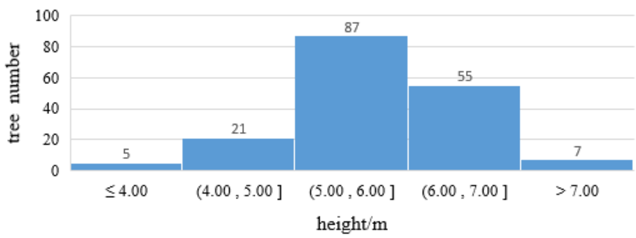
3.1. Geometric parameters of trees

3.1.1. Results

At the health detection stage, we compute the geometric parameters of individual trees. The results are showed as Table I.

The average height of 175 trees is 5.91 meters tall, 65% lower than average. Among them, there are 5 trees lower than 4 meters, which is so short that should be checked the status. The average DBH and crown diameter is 0.22 m and 2.53m. Besides, the inclination in 33 trees are higher than 15 degree, and 18 of them are even higher than 30 degree. These trees should be righted.

Table I. Geometric parameters of trees



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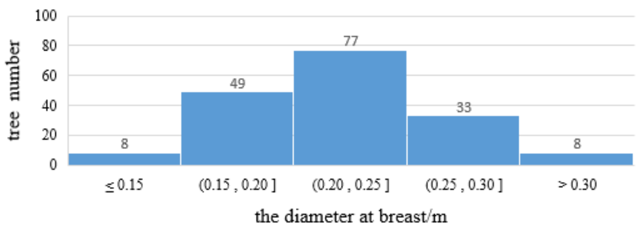

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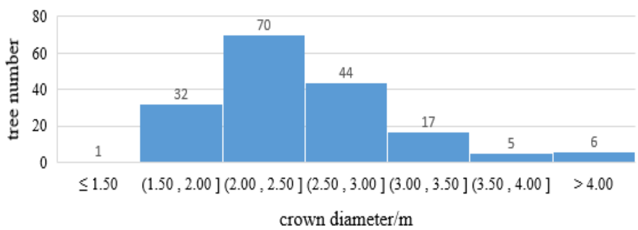

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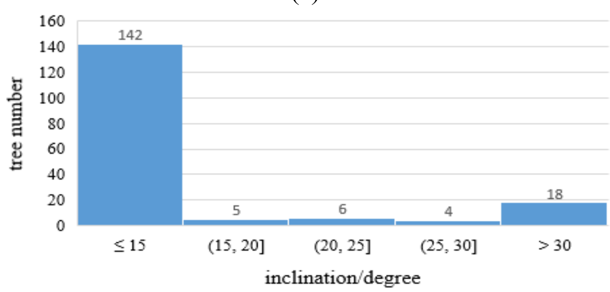

(d)

3.1.2. Accuracy

Because real measurement data is lack to detect the accuracy of the method used for computing parameters, we adopted an OnyxTree (a 3ds max plug-ins) software to generate simulated trees. OnyxTree can help to get the approximate true values of one tree, including trunk width, the height and other details. After statistic analysis, those geometric parameter error calculated by our method, e.g., the height, DBH and crown diameter reaches 0.87%, 0.56%, 2.08%, respectively.

3.2. Conclusion

In this paper, we detail a method combining terrestrial LiDAR data and hyperspectral data to extract individual tree from urban environments as well as to evaluate the health status of the trees. Attributed to the given three-dimensional structure of point cloud, we can get precise geometric parameters of trees, which is used to evaluate growth status of trees. Simultaneously, hyperspectral data is provided further estimating physiological characteristics of trees, like nitrogen content, chlorophyll content or water content. The in-depth analysis about that will be performed in further study.

ACKNOWLEDGMENT

This work was support by Project supported by the National Natural Science Foundation (Grant No.61771413).

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