3D surface reconstruction of trees using a region-based active contour model

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Abstract—In this paper, a novel method is proposed for 3D surface reconstruction of trees using a region-based active contour model. Both individual tree crowns and clusters of trees are first segmented for further exploration. Multiple horizontal slices corresponding to different heights are obtained. The 3D structure is built using raw data from light detection and ranging (LiDAR) point clouds. The results indicate that this approach is effective for 3D surface reconstruction of trees including individual trees and clusters of trees.

Keywords—LiDAR, a region-based active contour model, 3D surface reconstruction, segmentation

I. INTRODUCTION

Forests are closely related with the development of life and human civilization. Through the use of light detection and ranging (LiDAR), forest attributes (such as tree height, canopy closure, and diameter at breast height) can be effectively estimated. These attributes are often employed to evaluate forest growth, competition, and photosynthesis [1], carbon sequestration, standing timber volume, and biomass of trees [2],[3],[4].

Canopy height models (CHMs) are often used to represent horizontal and vertical distribution of tree canopies. Once a digital elevation model (DEM) and a digital surface model (DSM) are interpolated from LiDAR point clouds, a CHM can be obtained by subtracting the DEM from the DSM [5]. However, CHMs are limited in their capacity to accurately retrieve individual tree and crown attributes[6] [7] [8]. The CHMs’ limitations are often due to applying inappropriate crown shapes, overlap with adjacent trees, or canopy gaps [9] [10]. Also, contained surface irregularities [5], tree top dislocation in the CHMs [11], and underestimation of tree height are commonly reported [12][13].

Parametric height models (PHM) describe the forest canopy as a series of cones fitted to the LiDAR point clouds. From it, tree crowns can be extracted through simple geometric operations [8]. However, for parametric height models, the negative height bias or positive height bias still exists in the results. When fitting cones to the LiDAR point clouds, there exists matching errors depending on the property and distribution of LiDAR point clouds.

In order to overcome the weaknesses and limitations of the above models, in this paper, we propose a new 3D surface reconstruction method for tree canopy using a region-based active contour model.

II. METHODOLOGY

A. Study area

The study area is located in the Soquel Demonstration State Forest in California, USA. The LiDAR data were collected on March 29, 2007 by the GeoEarthScope Northern California LiDAR project (Prentice et al. 2009), and downloaded from
the OpenTopography Facility at the San Diego Supercomputer Center. The LiDAR point density is approximately 9.6 points m$^{-2}$. Major tree types in the study area include Douglas fir, redwood, and oak.

B. Data processing

Preprocessing of LiDAR data is necessary before separating data points into height layers. A digital elevation model (DEM) was created from ground points using inverse distance weighted (IDW) interpolation. The height from ground for each LiDAR point was then obtained by subtracting the DEM-derived ground elevation beneath the point from the elevation of the point.

C. Segmentation using a region-based active contour model

The active contour model along with level set technology has been widely applied to many research fields including computer vision and medical image processing[14][15][16]. Chan and Vese [17] introduced a variational model based on the level set function $\phi_{t,x,y}$, for which the zero level set segments the image domain into several intensity homogenous regions by minimizing the following function. The level set function $\phi_{t,x,y}$ presents the zero-level curve at time $t$ or the evolution of the curve.

$$\begin{align*}
F(c_1, c_2, \phi) = & \mu \int_{\Omega} \delta(\phi(x,y)) | \nabla \phi(x,y) | \, dx \, dy \\
+ & v \int_{\Omega} H(\phi(x,y)) \, dx \, dy \\
+ & \lambda_1 \int_{\Omega} | u_0(x,y) - c_1 |^2 H(\phi(x,y)) \, dx \, dy \\
+ & \lambda_2 \int_{\Omega} | u_0(x,y) - c_2 |^2 (1 - H(\phi(x,y))) \, dx \, dy
\end{align*}$$

\hspace{1cm} \text{(1)}

where $u: \Omega \rightarrow R$ is an image defined on $\Omega$, $c_1$ and $c_2$ are constants, and $H(\cdot)$ is the Heaviside function and $\delta(\cdot)$ is Kronecker delta function. Of the four terms in equation (1), the first is the length of the contour; the second is the area within the contour; the third and fourth terms are proportional to the energy within and outside the contour, respectively.

This minimization problem is solved by taking the Euler-Lagrange equations and updating the level set function $\phi$ by gradient descent.

$$\frac{\partial \phi}{\partial t} = \delta(\phi) \mu \cdot \text{div} \left( \frac{\nabla \phi}{| \nabla \phi |} \right) - \lambda_1 (u_0 - c_1)^2 \\
+ \lambda_2 (u_0 - c_2)^2 \hspace{1cm} \text{.........(2)}$$

For a 3D reconstruction, each slice of an object must first be obtained. The slice is related with detection and location of the object in each 2D image. As an effective model, the level set technology provided by Chan and Vese [17] can detect the locations of boundaries very well, and is insensitive to placement of the initial curve in the image. We use this model to separate the individual trees or clusters of trees from their backgrounds and to obtain the contours of the individual trees or clusters of trees.

D. 3D reconstruction of individual trees or clusters of trees

For each height, we utilize the above active contour method to complete the segmentation. So, at different heights, the contours of individual trees or clusters of trees may be obtained.

After obtaining a series of tree slices (boundaries) from different heights, a 3D canopy of trees is reconstructed by putting all slices together following their height orders.

Using interpolation or MESH function in Matlab, 3D reconstruction with finer and smoother canopy surface is obtained for individual trees or clusters of trees.

III. EXPERIMENTAL RESULTS AND ANALYSIS
Fig. 1(a) shows a 2D image of trees from LiDAR data at heights (h ≥ 25 m). By employing the region-based active contour model to separate individual trees or clusters of trees from their backgrounds, the contours of individual trees or clusters of trees are obtained and shown in Fig. 1(b) and 1(c).

A 3D canopy surface is reconstructed by putting together a series of tree slices (boundaries) corresponding to different heights following their height orders. After using interpolation or the MESH function in Matlab, a finer and smoother canopy surface is achieved.

Fig. 2(a) shows a series of slices for an individual tree. Fig. 2(b) is a 3D canopy surface reconstruction with smoother surface for the tree.
In the Fig. 1, boundaries of trees in 2D image at heights \( h \geq 25 \text{ m} \) are segmented using a region-based active contour model. Using the same methods and process, boundaries of all trees in 2D image at different heights are also segmented and obtained. After putting all trees’ slices at different heights in the study area together, 3D canopy surface reconstruction with smoother surfaces of trees, including individual trees and clusters of trees, has been obtained and displayed as Fig. 4.

IV. CONCLUSIONS
In this paper, based on a region active contour model, we propose a new method for 3D canopy surface reconstruction of individual tree crowns and clusters of trees from LiDAR point clouds. The proposed method allows for delineations of 3D forest canopy naturally from the contours of raw LiDAR point clouds.

The proposed model is suitable not only for a series of ideal cone shapes, but also for other kinds of 3D shapes. More importantly, several contours corresponding to different heights are very useful to quantify the 3D shapes. More importantly, several contours corresponding to different heights are very useful to quantitatively describe attributes and categories of trees.

V. REFERENCES


