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Optimal 3D reconstruction of plants canopy from terrestrial laser scanner data by fusion of the 3D point information and the intensity value

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Highlights: We develop an algorithm to digitize *in situ* canopy and to tag automatically each of its leaves. This algorithm fuses the distance information and the intensity values of a terrestrial LiDAR scanner.

Keywords: Terrestrial LiDAR, leaves geometry, LiDAR intensity, shape-from-shading, Kalman filter

INTRODUCTION

Terrestrial LiDAR scanner (TLS) provides a novel tool for generating in a high measurement rate an accurate and comprehensive 3D geometrical description of the canopy. This device sends a laser beam and gives a precise estimation of the distance to the object surface with which it interacts. Combined with a zenithal and an azimuth rotation, it creates a virtual scene of its surrounding in the form of a TLS point cloud. It became a common metrology tool in several domains and draw itself plant scientists' attention. Despite the good accuracy of the measurement (estimation errors less than a few millimeters for most TLS in the measured range), only general indicators such as LAI, vertical plant profile and vegetative volume have been extracted (e.g. Rossel et al., 2009). These indicators are frequently used in physical models for canopy/environment interaction, such as light interception models (Sinoquet et al. 2005). However, these models rely on constraining hypothesis such as homogeneous distribution of leaves, infinitely small leaf elements, etc. In many applications, these assumptions simply do not hold and the condition of use of these models is therefore invalid. As an alternative, TLS can be used to reconstruct realistic foliage geometry that can be subsequently used in realistic physic-based models.

Several techniques based on surface fitting have been developed to digitized isolated leaves (Loch et al. 2005, Quan et al. 2006, Chambelland et al. 2008). They rely on user intervention and remain tedious for entire canopy reconstruction. In addition, they do not deal with *outliers points* present on leaves edges (Hebert & Krotkov 1992) and they suppose a high *signal-to-noise* ratio (i.e. variability due to the size of the object vs. variability of the noise), which is not always possible for field measurements.

The goal of this study is to digitize an entire canopy from laser TLS data so that the noise impact on the leaves reconstruction and segmentation is minimized. For this, we exploit the intensity information provided by the TLS. This information depends on the local inclination of the measured surface and thus provides complementary information to the distance measured by the scanner. Thanks to this information we could design a method for segmenting and reconstructing leaves geometry accurately from canopy scans. Leaf segmentation combines the intensity and distance information to detect outliers point, while leaf 3D reconstruction is made from intensity information using a propagation approach based on Shape-From-Shading (Durou et al. 2004). This reconstruction is progressively fused with the distance information using a Kalman filter to optimally merge both information from both sources (intensity and distance).

METHODS

In general, the intensity of pixels in an image is correlated to incidence angle of the light beam with the surface of the object at that point. Based on this information it is thus possible to design methods to reconstruct the local geometry of the scanned objects, i.e. the leaves. However, we have to face two main issues: i) the distance has an effect on the intensity amplitude and must be corrected; ii) The algorithm to reconstruct surfaces from the intensity must be able to integrate distance information.

To solve i), Balduzzi et al. (2011) have proven that the distance effect on intensity could be corrected and that a relationship between the incidence angle α and the intensity I can be built for a given leaf material. To solve point ii), an algorithm of *shape-from-shading* (Durou et al. 2004) is developed. This algorithm proceeds by spatial *propagation* of an initial surface solution patch. Decisions to segment the reconstructed surface (here leaves) are taken during the reconstruction propagation.

To set it up, we proved several mathematical properties, in particular that: 1) the propagation can be done along the greatest slope direction on an iso-intensity region; 2) those directions can be computed from any 3D curves belonging on the surface when the incidence angle information is provided; and 3) the surfaces generated by those greatest slope line are specific surfaces called the *sand-pile surfaces.*

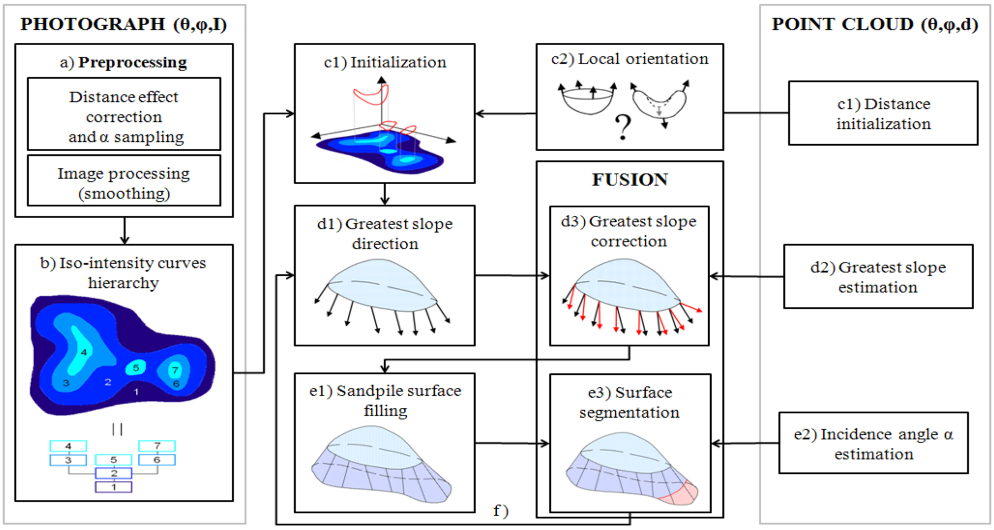

Fig 1. Algorithm flowchart for the surface reconstruction.

Thanks to those previous properties, the following pipeline has been set up (figure 1):

a) After the correction of the distance effect and the initialization of the I to α relationship, the intensity picture is smoothed out to make iso-intensity contours apparent.

b) Those contours are hierarchized to drive the propagation: the iso-intensity contours of highest value (maxima) will be the seeds of the propagation carried out along the iso-intensity contour hierarchy.

c) 1: The distance values of the seeds are initialized thanks to the point cloud. It is the initial boundary of the reconstructed surface.
   2: At the same time, the analysis of these boundary geometries (e.g. sink or saddle case) makes it possible to disambiguate the positive (up) or negative (down) local orientation of the surface.

d) 1: The greatest slope directions are computed along the boundary of the reconstructed surface to start or to continue the propagation.
   2: Simultaneously, we estimate the greatest slopes direction thanks to the point cloud.
   3: The comparison of the two greatest slope calculations gives estimation on the confidence we can have on both. A Kalman filter is used to fuse them depending on this confidence.

e) 1: Sand-pile surfaces fill the space in between two isophotes, i.e. the surface portion that corresponds to iso-intensity region; and between two consecutive greatest slopes.
   2: The incidence angle α is estimated on the corresponding point cloud portion.
   3: As for d.2), we obtain an indication on the confidence we can have on both calculation. This indicator is used to make decision on the segmentation.

f) Finally, the propagation continues on the new reconstructed surface boundary (step d1) until the surface is entirely segmented.

Our algorithm is able to reconstruct and to segment step by step a surface from its intensity picture and its 3D point cloud. The uncertainties on distance and intensity are minimized using a Kalman filter.

PRELIMINARY RESULTS

To test the algorithm, we have generated several virtual surfaces. The greatest slope retrieving and the propagation are robust even if we can note that the accuracy of the reconstruction is a function of the intensity and may be significant as the incidence angle approaches 90°. Figure 2 iii) shows the reconstruction of a virtual ellipsoid when both of its picture and point cloud are given (fig 2. i and ii).

In this talk, we will present leaves reconstruction and segmentation in the case of real scans (figure 3).

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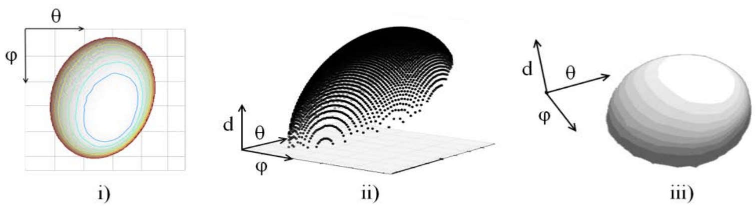

Fig 2. Reconstruction of a virtual ellipsoid. i) Its intensity picture and the iso-intensity curves (colored); ii) the initial 3D point cloud; iii) the reconstruction.

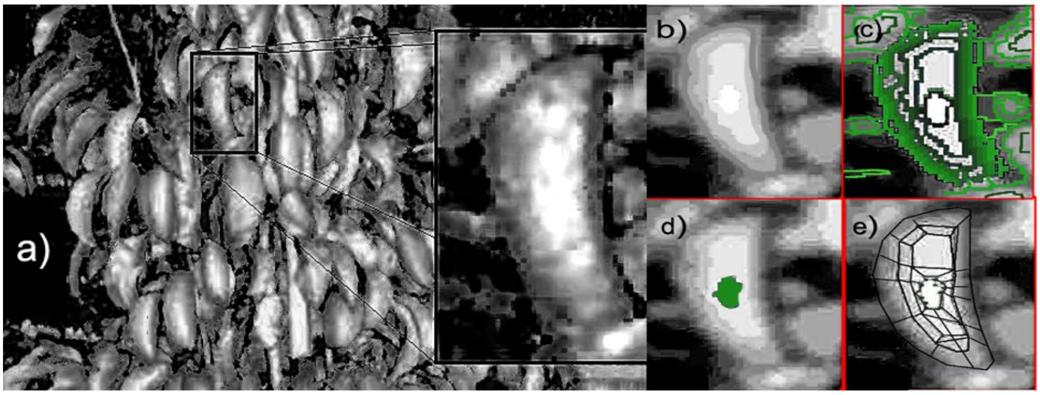

Fig 3. Illustration of the reconstruction algorithm. a) We focus on a single leaf of a pear tree canopy; b) the intensity picture is smoothed to make the iso-intensity region appearing; c) the iso-intensity contour are extracted and hierarchized; d) the iso-intensity region of maximal value is taken as the propagation seed; f) the greatest slope are propagated and the leaf is segmented.

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