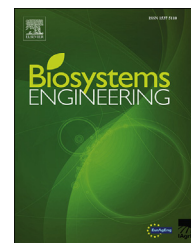


Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Multi-tree woody structure reconstruction from mobile terrestrial laser scanner point clouds based on a dual neighbourhood connectivity graph algorithm



Valeriano Méndez ^{a,*}, Joan R. Rosell-Polo ^b, Miquel Pascual ^c,
Alexandre Escolà ^b

^a Department of Applied Mathematics, Polytechnic University of Madrid, Ciudad Universitaria, s/n, 28040, Madrid, Spain

^b Research Group on AgroICT & Precision Agriculture, Department of Agricultural and Forest Engineering, University of Lleida – Agrotecnio Center, Av. Rovira Roure, 191, 25198, Lleida, Spain

^c Department of Horticulture, Fruit growing, Botany and Gardening, University of Lleida, Rovira Roure, 191, 25198, Lleida, Spain

ARTICLE INFO

Article history:

Received 18 January 2016

Received in revised form

18 April 2016

Accepted 25 April 2016

Published online 24 May 2016

Keywords:

Multi-tree reconstruction

LiDAR

Mobile terrestrial laser scanner

Point cloud

Tree training

Ligneous structure

A process is presented for the vector reconstruction of fruit plantations based on the model developed by Verroust and Lazarus. To solve occlusion problems, the use of a dual graph of local and extended connectivity is proposed. The process allows vegetation variables such as the length and volume of the ligneous structure to be measured, enabling studies such as intensity of pruning operations. The process has been tested against simulated models and real trees with different training systems: open-vase system (peach trees) and central leader hedgerow system (pear trees). The cost of the algorithm will be given by the cost of the implementation of Dijkstra's algorithm, which in its standard version is of potential ($O(n^2)$). Algorithm accuracy was checked against point clouds of virtual trees. The reconstruction was also applied before and after a pruning operation of real trees to enable a study of the evolution of the vegetation indices. Results showed the algorithm to be suitable for multi-tree reconstruction of both central leader and open-vase training systems.

© 2016 IAGRE. Published by Elsevier Ltd. All rights reserved.

1. Introduction

The geometric reconstruction of a tree is fundamental for a detailed analysis of its structure. Using massive data support

with information about geometry, measurements can be made of direct (leaf area, canopy volume or wood volume) and indirect tree vegetation parameters (LAI, leaf density, canopy permeability or radiation interception), which provide information about the productive characteristics of trees related to

* Corresponding author. Department of Applied Mathematics, E.T.S. Ingenieros Agrónomos, Polytechnic University of Madrid, Ciudad Universitaria, s/n, 28040, Madrid, Spain. Tel.: +34 917 308 355.

E-mail address: valeriano.mendez@upm.es (V. Méndez).

<http://dx.doi.org/10.1016/j.biosystemseng.2016.04.013>

1537-5110/© 2016 IAGRE. Published by Elsevier Ltd. All rights reserved.

Nomenclature

b	Number of sets in a branch
c	Centroid of a group of points, coordinates (x_c y_c z_c)
d_e	Maximum extended distance over which neighbour points are selected
d_l	Maximum local distance over which neighbour points are selected
E	Cloud of enveloping points to each branch of a virtual tree. The point cloud is obtained from an enveloping mesh on the cylindrical surfaces so that there are no occlusions in the cloud
G_s	Geodesic graph of tree s
$GD_{s,i}$	Geodesic distance from point P_i to root r_s
HMT	Hidden Markov Tree
k	Maximum number of k -level sets in which the cloud points are grouped
KPI	Key performance indicator
LS	SimLidar-obtained cloud with simulation of lateral scan of a virtual tree
m	Total number of trees
M	Connectivity matrix
md_s	Maximum geodesic distance to root r_s
MTLS	Mobile terrestrial laser scanner
n	Total number of points in cloud
nb	Total number of branches in reconstructed model
NB_e	Extended neighbourhood graph obtained with d_e
NB_l	Local neighbourhood graph obtained with d_l
$\bar{n}_i^j(t)$	Surface area which encloses the 3D reconstructed branch object
PC	Point cloud
P_i	Individual point of cloud
p	Total number of points in a given set
q	Number of sections in which the total md_s geodesic distance is divided
θ_k	Polar angle which defines a spherical sector to select the closest point at a distance smaller than d_l or d_e
φ_p	Azimuth angle which defines a spherical sector to select the closest point at a distance shorter than d_l or d_e
r_s	Point of the base of the tree s which is taken as root of the geodesic graph
$\vec{r}(t)$	Piecewise polynomial curve which defines the axis of a branch
r	Radius
rd	Minimum radius
ru	Maximum radius
s_i	Set of points
t	Linear parameter in $\vec{r}(t)$ used for least squares fit of the radii distribution
TLS	Terrestrial laser scanner

their shape and structure. The direct use of rasterised information or image analysis, from photographs for example, can allow obtaining some of these parameters (Phattaralerphong & Sinoquet, 2004). The vector reconstruction of the geometry of the tree provides support for these objectives and lays the foundation for the implementation of virtual construction models, such as the use of the statistical framework of the hidden Markov tree (HMT) model introduced by Crouse, Nowak, and Baraniuk (1998) and used to undertake realistic constructions of apple trees by Durand, Guédon, Caraglio, and Costes (2005) and Costes et al. (2008).

In parallel, with the use of massive data provided by photogrammetry or airborne laser scanning (ALS) for tree detection and general parameter estimation, geometry at individual tree level has been studied using two main approaches. The first comprises the use of digital photographs (Shlyakhter, Rozenoer, Dorsey, & Teller, 2001; Mizoue & Masutani, 2003; Phattaralerphong & Sinoquet, 2004, 2005; Tan, Fang, Xiao, Zhao, & Quan, 2008). Image information is processed to determine the existence of vegetation and, based on sensor parameters (horizontal distance from camera to tree and tree height), a projection is made onto a voxel space through which the crown volume and leaf area are estimated (Phattaralerphong & Sinoquet, 2004). The use of a smaller voxel size to increase precision dramatically increases running time.

The second approach involves the use of a terrestrial LiDAR system or terrestrial laser scanners (TLS), which allows dense point clouds to be obtained from which a detailed description of the geometry can be extracted. Detection of the woody geometry from the TLS was considered by Simonse, Aschoff, Spiecker, and Thies (2003) using Hough transforms, while Gorte and Winterhalder (2004) and Gorte and Pfeifer (2004) generated the topology of the skeleton from a voxel space. The use of a TIN (triangulated irregular network) to obtain vector information about the ligneous structure of a tree is limited as a result of the presence of a large number of small branches (Fig. 1). Pfeifer, Gorte, and Winterhalder (2004) and Méndez, Rosell-Polo, Sanz, Escolà, and Catalán (2014) obtained a model of the scaffold branches and stems from a cylinder fit. Other mixed methods, which combine scanner data with high resolution image-obtained texture information, have been proposed by Reulke and Haala (2005). ICP (Iterative Closest Point) algorithms have also been employed, used to minimise the difference between two point clouds. The algorithm iteratively revises the rotations and translations required to minimise the distance between the points of a cloud with respect to another cloud taken as reference. The ICP algorithms have been used to register point clouds, i.e. fit the orientations obtained in different scans (Besl & McKay, 1992; Henning & Radtke, 2006). Pfeifer et al. (2004) used cylinders in a kind of a following-the-line approach to do the reconstruction. Hackenberg, Spiecker, Calders, Disney, and Raunonen (2015) used a similar approach but changing the cylinders to spheres. In Raunonen et al. (2013), “the model is constructed by a local approach in which the point cloud is covered with small sets corresponding to connected surface patches in the tree surface”.

Assigning the point of a cloud obtained with the TLS to the different components of the plant is easy in the case of the

Download English Version:

<https://daneshyari.com/en/article/1710833>

Download Persian Version:

<https://daneshyari.com/article/1710833>

[Daneshyari.com](https://daneshyari.com)