Urban Forestry & Urban Greening 35 (2018) 66–71

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Terrestrial photogrammetric stem mensuration for street trees

John W. Roberts[a,*], Andrew K. Koeser[a], Amr H. Abd-Elrahman[b], Gail Hansen[c], Shawn M. Landry[d], Benjamin E. Wilkinson[e]

[a] *Department of Environmental Horticulture, CLCE, IFAS, University of Florida—Gulf Coast Research and Education Center, 14625 County Road 672, Wimauma, FL, 33598, United States*

[b] *School of Forest Resources and Conservation - Geomatics, IFAS, University of Florida—Gulf Coast Research and Education Center, 1200 North Park Road, Plant City, FL, 33563, United States*

[c] *Department of Environmental Horticulture, CLCE, IFAS, University of Florida, PO Box 110670, Gainesville, FL, 32611-0670, United States*

[d] *School of Geosciences, University of South Florida, 4202 East Fowler Avenue, Tampa, FL, 33620, United States*

[e] *School of Forest Resources and Conservation, IFAS, University of Florida, PO Box 110565, Gainesville, FL, 32611-0565, United States*

A R T I C L E I N F O

Keywords:
Photogrammetry
Point cloud
Remote sensing, individual tree level
Right-of-way
SfM
Street tree inventory
Urban

A B S T R A C T

Much of forest science is dependent on accurate stem measurements, and relatively new photogrammetric techniques may be suitable for modeling stems from the terrestrial perspective. From imagery taken along a windbreak and urban roadways we tested the viability of photogrammetric modeling for producing accurate diameter at breast height measurements. Treatments for different point cloud models differed based on intervals between control points (i.e., every 5 m, 10 m, 25 m, and an absence of target control points) and site conditions (i.e., urban mixed species vs. a windbreak of *Pinus taeda*) over 100 m sections in the Tampa Bay, FL area. Stem diameter measurements from both the windbreak (n = 53) and the urban sites (n = 93) showed high conformity between field-derived and point cloud model measurements (linear regression showed R^2 values > 0.9 and RMSE values ranging from 7.04 − 12.35%) with the number of control point targets having little influence on modeled DBH accuracy. Modeled stems of larger trees had greater associated error relative to DBH tape measurements, which can be attributed, in part, to problems with estimating diameter from non-circular stems of certain urban species (i.e., *Quercus virginiana*). Future work will focus on georeferencing these datasets and extracting data on other aspects of stem biometry (e.g., lean angle of stem, stem volume, etc.).

1. Introduction

Stem diameter is one of the most basic measurements for forest management. Many biometrics (e.g., biomass, basal area, crown cover, stocking levels, etc.) can be estimated from stem diameter data and scaled to a given area of interest (i.e., generally at the stand or landscape level) (Avery and Burkhart, 2002). Manual field measurements with a diameter at breast height (DBH) tape from ~1.4 m aboveground has long been the conventional method for measurement of stem diameter. In urban areas, DBH is useful for modeling economic benefits (Nowak et al., 2002), air pollution (Freer-Smith et al., 2004; Janhäll, 2015), and local climate (Ren et al., 2013). Many cities are able to devote only marginal resources towards updating existing street tree registers (Maco and McPherson, 2003; Roman et al., 2013), or neglect this process altogether (Vogt et al., 2015). Consequently, alternate sources of urban forest measurements, like those from terrestrial sensing, could enhance long-term monitoring efforts with reduced durations between intervals of data collection and providing a source of street tree inventory for municipalities that forego detailed tree documentation (Roy et al., 2012).

Terrestrial photogrammetric techniques can produce similar products to laser scanned point clouds, but require little more than a digital handheld camera. Biometric measurements for stationary lifeforms like trees have been investigated (Abd-Elrahman et al., 2010; Morgenroth and Gomez, 2014). Koeser et al. (2016) showed structure from motion (SfM) photogrammetry could be used for volumetric measurements of tree root systems with a root mean square error (RMSE) of 40.37 cm^3 (12.3%) − a process that has historically been performed with water displacement. Miller et al. (2015) showed stem diameter from SfM point clouds could be measured with a RMSE of 2.14 mm (11.93%) and a bias of -0.16 mm (-0.88%) for potted nursery trees. Open forest plots have also been mapped with close-range SfM photogrammetry, as Liang et al. (2014) showed DBH could be estimated to a RMSE of 2.39 cm (6.6%) – a similar result to TLS. Surový et al. (2016) showed stems

* Corresponding author.
E-mail address: jwr.09@ufl.edu (J.W. Roberts).

https://doi.org/10.1016/j.ufug.2018.07.016
Received 20 December 2017; Received in revised form 4 July 2018; Accepted 19 July 2018
Available online 20 July 2018

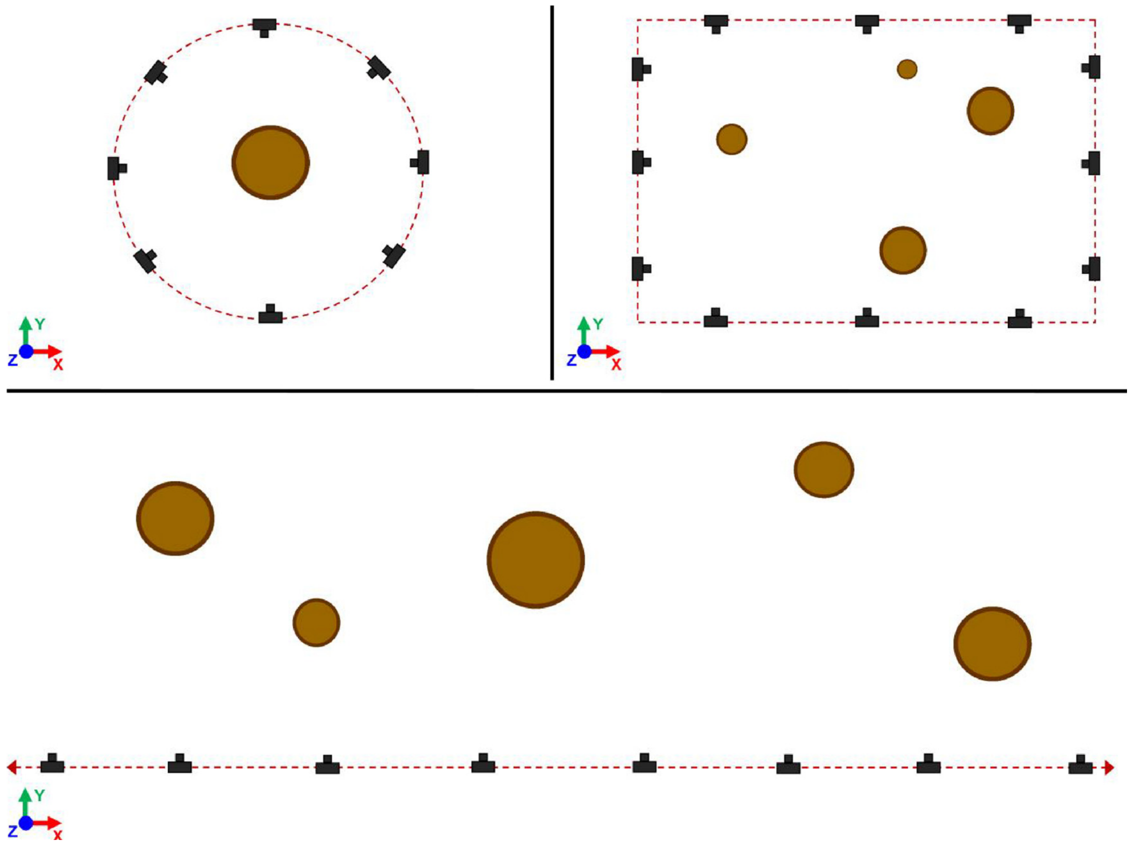

Fig. 1. A diagram of camera positioning used to create point clouds of individual trees (top left) and forest plots (top right) for past studies, relative to the proposed positioning of this study (below).

modeled within a close-range photogrammetry program from another study on a forest plot had a RMSE of 0.59 cm, but with a relatively high standard deviation of 0.72 cm.

Despite the many demonstrations of SfM photogrammetry for field stem measurements, the technology still has certain limitations. Creating SfM models is still work-intensive relative to manual field measurements (Gatziolis et al., 2015). However, mapping larger areas can potentially compensate for the required data processing time and measuring stems from photogrammetric models, while also providing documentation of the modeled environment. Tree measurements of street trees on public right of way (ROW) properties present certain challenges and opportunities for close-range photogrammetry. Past studies on measuring tree diameter from SfM point clouds benefitted from favorable geometry, generally, where a closed loop of camera positions facing inward can better estimate the camera positions needed to create an accurate model (Hartley and Zisserman, 2003). The closed-loop camera geometry allows for all sides of the tree to be modeled and more easily measured, but may be impractical for collecting imagery since each tree requires an individual data capture event that is more time intensive than a single-pass of multiple of trees (Fig. 1). Additionally, large loops not focused on individual trees, like those used to create SfM models by Liang et al. (2014), can lead to high error with increased distance from camera position. Therefore, a more viable photogrammetric system for covering large areas must balance camera geometry, image capture efficiency, and a relatively close camera proximity to the subject trees to create an accurate model.

Control points on are often used to help determine camera position and orientation in creating orthorectified models (Wolf et al., 2014). Many programs that perform close-range photogrammetry already detect common features between photos and then select common points (i.e., pixels) to create a point cloud model, but the presence of coded targets (i.e., that can be identified through pattern recognition by photogrammetric software) can significantly aid this process and create models with greater accuracy (Shortis and Seager, 2014).

In order to decrease potential error, the collection of many overlapping photos can potentially compensate for poor camera positioning geometry along a relatively straight line (Fig. 1). However, control point targets can greatly increase the spatial accuracy of photogrammetric models (Wolf et al., 2014), and are regularly used to create close-range photogrammetry models over relatively large terrestrial areas since compositionally similar images can be difficult to process (Sapirstein, 2016). Therefore, the objectives of this study are to test the viability of creating SfM point clouds for measuring trees along stretches of terrestrial environments, and to assess the influence of different densities of control point targets on the accuracy of SfM stem diameter measurements.

2. Methods

2.1. Study site and field methods

Data were collected along 100 m transects to test different conditions. A windbreak composed of loblolly pine (i.e., *Pinus taeda* L.) at the University of Florida Gulf Coast Research and Education Center in Wimauma, FL (~27°45′40″ N and ~82°13′40″ W) provided ‘ideal’ conditions with highly-circular stems and relatively uniform light conditions. The windbreak could be compared to some conventional forestry stands where trees are planted in rows in a single planting event. In contrast, nine urban sites were randomly selected along designated hurricane priority routes within Tampa, FL (27.9710°N, 82.4650°W), to represent the heterogeneity expected for species composition, stem characteristics, and photo capture conditions that exist along street right-of-ways.

A digital single-lens reflex (DSLR) camera (EOS Rebel T3, Canon