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Trunk volume prediction of individual *Populus euphratica* trees based on point clouds analysis

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ABSTRACT

The *Populus euphratica* is one of the most important plant species for maintaining desert riparian forests in the lower reaches of Tarim River. Estimation and analysing of trunk volume of trees are crucial to the evaluation of forests biomass and ecosystem services. Although many approaches to estimating trunk volumes have been proposed, they are usually not only labour intensive but also destructive and therefore not feasible for such protected species as *P. euphratica*. There are two main contributions in this paper: First, we propose a new framework to calculate the volume of tree trunks using point clouds with a deep camera in a Tango smartphone and a Google Play app. Second, a mathematical model is provided for predicting trunk volume based on the relationship between trunk volumes and morphological characteristics. The proposed framework can also deal with irregularly shaped tree trunks. The non-destructive method, which uses an easily accessible and low-cost device, can make a significant contribution to protecting desert riparian forests and is also applicable to other tree species.

1. Introduction

Assessing forests volumes (biomass) accurately is an essential factor for monitoring the flows of energy and nutrients in ecosystems and for managing and protecting forest resources because trees biomass also reflects the impact human activity and environmental changes (Urquiza-Haas et al., 2007) on forests growth.

In terms of their effects on forests, sampling methods used in forests biomass research are either destructive or on non-destructive (Montes et al., 2000; López-López et al., 2017). Destructive sampling methods usually involve cutting branches, the crown, trunks, or even entire trees (Saarinen et al., 2017). Various tree components can be measured directly from trees by sampling or subsampling (Parresol, 1999). Destructive sampling methods were used extensively in the early days of forests biomass research.

These methods are easy to implement and highly accurate. For instance, Shaiek et al., (2011) collected foliage, branches, and stems from 26 trees in Tunisia and constructed biomass equations for maritime pines; Mugasha et al. (2013) harvested 167 trees for developing allometric models of above- and below-the-ground biomass of trees; and Ozcelik et al. (2017) used artificial neural network models to predict the above-ground biomass of pine trees, based on data from 164 felled pine trees.

However, these harvesting methods are not only labour intensive, time-consuming (Parresol, 1999), and impractical for protected tree species but can also have caused adverse effects on chemical, biological, and physical properties of soil (Jurgensen et al., 1997, Thiffault et al., 2011). With the growing awareness about protection of the environment, the establishment of forest reserves, and increasing difficulties in harvesting (Barreiro et al., 2016), destructive sampling methods are now being used far less frequently than before.

As the technology advances in every field, more and more techniques and devices, such as such as remote sensing and computer graphic methods, are now available to replace destructive sampling. And these methods have no negative influence on forests. As a kind of remote sensing technology, lidar is being increasingly used for estimating volumes of tree trunks and crowns (Yu et al., 2011; Tao et al., 2015), and above-ground biomass generally (Cao et al., 2018), for describing the three-dimensional structure of forests (Trochta et al., 2017), and the branching structure of trees (Hackenberg et al., 2014), and so on. Luo et al. (2017) combined lidar data and hyperspectral imagery for estimating above-the-ground and below-the-ground forest biomass, and

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Dalponte et al. (2018) combined data from laser scanners and hyperspectral data to predict stem diameters and above-ground biomass.

Some researchers have used photographed trees. For instance, Montes et al. (2000) analysed two photographs each of the same trees from orthogonal views and other information to estimate crown biomass, and Reche et al. (2004) proposed a volumetric approach to reconstructing and rendering trees, using photographs of trees.

Remoting sensing techniques are generally suitable for research on a large scale studying large stands of trees or entire forests. For example, Boudreau et al. (2008) used data from airborne and spaceborne LiDAR to estimate aboveground biomass of forests and they believed that space-based forest inventory is an effective method to estimate aboveground biomass in large spatial scales.

But the date such techniques provide is too coarse-grained and also expensive (Kelbe et al., 2012) for studying single tree. Man et al. (2014) believed hyperspectral and lidar data to be promising for biomass estimation but found it that they also have problematic because it is difficult to classify and attribute individual trees.

However, 3D models for research on biomass have rarely been used with forest in arid and semi-arid region, which are important components of global forests ecosystems. Besides, riparian forests of *P. euphratica,* with their unique growth characteristics, are of great significance to desert oasis ecosystem and to the entire arid and semi-arid ecosystem. In a word, we need to expand and enrich the studies of *P. euphratica* biomass in the riparian forests.

Estimating the volume of *P. euphratica* forests is particularly difficult for two reasons: 1) destructive methods become less applicable in degraded woodland and are also not advisable because the population of *P. euphratica* is already smaller than that of many other species. Hence, using destructive sampling are unsustainable for *P. euphratica*; and 2) results from research on other species such as pines, spruce, beech (Wang et al., 2008) are seldom valid or useful with the riparian *P. euphratica* forest; In fact, many national models for forests biomass are also unsuitable for the riparian forests.

It is against this background that the present work suggests a low-cost framework using a non-destructive approach to estimating the volume of trunks of *P. euphratica* trees. We used the depth sensors in Tango smartphone (Schöps et al., 2015) to develop a fine-grained geometrical 3D reconstruction algorithm for trees with highly variable shapes of trunks.

2. Material and methods

The study was conducted in the riparian forests of the lower reaches of Tarim River in China. This region is one of the most arid regions in the world: the annual precipitations is only 20–50 mm. (Ye et al., 2011). The forests, referred to as the ‘green corridor’, are distributed along the lower reaches of Tarim River between the Taklamakan desert and the Kumtagh desert. Desert riparian forests are rich in biomass (Thevs et al., 2011). The forests in the study region are mainly composed of *P. euphratica*, *Tamarix halostachys caspica, and Haloxylon ammodendron*, and also some herbs such as *Phragmites australis* and *Halimodendron halodendron*. *P. euphratica*, is the keystone species of the riparian forests which are also referred to as Tugai forests (Treshkin, 2001).

2.1. Field measurements

Field data collected in July 2017 in three sections in the lower reaches of Tarim River, namely Yingsu, Laoyingsu and Kumutuge sections (Fig. 1). All the three sections are close to the river and include some *P. euphratica* forests along the river, which play a key role in protecting the ecological environment and reducing the risk of sandstorms to areas.

Trees were sampled from the *P. euphratica* forests. Considering the convenience in scanning 360-degree views, we choose trees that can be easily scanned individually (that is, without any interference from nearby trees). Also included were those range of trunk diameters at breast height (DBH, taken as 1.3 m), those from both favourable and unfavourable spots in terms of growth, and those with both regularly shaped and irregularly shaped trunks.

Before scanning the trunks, we measured the overall tree height (H), trunk height (SH), and diameters at (1) breast height, (2) base of the trunk, (3) top of the trunk. We used a tree height altimeter (Carl-Leiss-Berlin-steglitz Blume vintsge; Harbin Optical Instrument Factory Ltd, Heilongjiang, China) to measure tree height but measured trunk height manually using a 4 m long wooden pole. And we used Tango scanner to scan the tree trunks and to take photos. Many trees with different size of DBH and the frequency distribution of trees are presented in the Table 1. Of the 91 trees sampled, 5 had a DBH between 8 and 10 cm (cm); 30, between 10 and 20 cm; 41, between 20 and 30 cm; 12, between 30 and 40 cm. Of the remaining trees, two trees had a DBH between 40 and 50 cm, and one tree had DBH of 70 cm. The data on tree height and diameters are summarized in Table 2.

In this research, an infrared scanner, which is a built-in feature of a Tango smartphone, and an external Android 3D scanning application (https://matterport.com/) is used for capturing 3D point clouds of the trees with panoramic scanning (360-degree views). The built-in 3D scanner of the smartphone is suitable for scanning objects in a small scale. Using the Tango device, we obtained point clouds of the tree trunks from a distance of 3–5 m from the trunks. The 3D scanner error is about 2.5 cm (as given in the document that accompanies the device). Simultaneously, using mobile scanners has sampling interactivity and the position and views can be changed during scanning. The scanning was taken at the cloudy time so that the performance was less affected by glare.

2.2. Algorithm for trunk volume

All the point clouds were visualized by using a software package, namely MeshLab (http://www.meshlab.net/) and matched with the pictures of trees. Individual trees were visualized by point clouds and abnormal data sets deleted. Superfluous point clouds, such as those of the ground or of the crown, were removed, retaining only the point clouds of the trunks.

We built an algorithm to process the 3D point clouds and to calculate the volume of each trunk. The main idea of this algorithm is to split the point clouds of the trunk vertically into layers or slices and calculate the volume of every layer or slice.

The seven main steps in the algorithm are as follows. 1) In the volume algorithm, a set of the point clouds for a given tree is divided into n slices (typically 100). 2) In every slice, a polygon is defined by the periphery of the plane. 3) In the vertical direction, we find the close points that are clustered close together at the bottom and therefore correspond to the top surface of the slice. 4) A function of polygon area c(r) is developed. 5) According to the area function, we construct the area integral function for calculating the slice volume of the slice. 6) We loop the slice-volume alg1orithms in one trunk dataset and sum them up (Fig. 2). 7) The algorithm of the volume of one trunk is looped until the dataset for all trees are run. Volumes of irregularly shaped trunks are also calculated the same way. In the volume algorithm, a dataset of a trunk is divided into multiple layers, which ensures that the irregular parts of tree trunks can be contained and be calculated to a reasonable accuracy. The formula of the calculating algorithm is as follows:

$$v = \sum_{i=1}^{n} \int_{r}^{r(x)} c(r_i) dr_i \tag{1}$$

where v is the trunk volume, n is the number of slices, and c(r) is the area function of one plate in slice *i*. The pseudocode of the volume algorithm is as follows (Fig. 2).