G Model
UFUG-25425; No. of Pages 9
ARTICLE IN PRESS
Urban Forestry & Urban Greening xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Urban Forestry & Urban Greening
journal homepage: www.elsevier.com/locate/ufug

Mapping of urban roadside trees – A case study in the tree register update process in Helsinki City

Topi Tanhuanpää[a,*], Mikko Vastaranta[a], Ville Kankare[a], Markus Holopainen[a], Juha Hyyppä[b], Hannu Hyyppä[c,d], Petteri Alho[e], Juha Raisio[f]

[a] University of Helsinki, Department of Forest Sciences, Finland
[b] Department of Remote Sensing and Photogrammetry, Finnish Geodetic Institute, Finland
[c] Aalto University, Research Institute of Modelling and Measuring for the Built Environment, Finland
[d] Helsinki Metropolia University of Applied Sciences, Finland
[e] University of Turku, Department of Geography and Geology, Finland
[f] City of Helsinki, Public Works Department, Street and Park Division, Finland

ARTICLE INFO

Keywords:
Individual tree detection
LiDAR
Random Forests
Tree registers
Urban forest

ABSTRACT

This case study describes a method for utilizing leaf-off airborne laser scanning (ALS) data for mapping characteristics of urban trees. ALS data were utilized to detect and update all street trees in the tree inventory of the City of Helsinki, Finland. The inventory consists of roughly 20,000 street trees with mean diameter at breast height (DBH) of 24 cm and mean height of 10.6 m. The large number of trees makes the manual updating process very laborious. The automatic mapping procedure presented in this paper detected 88.8% of all trees in the inventory. Tree height was predicted with root mean square error (RMSE) of 1.27 meters and tree DBH with RMSE of 6.9 cm. The presented method provides a practical and cost–effective tool for the mapping of urban tree characteristics. The cost–efficiency was further enhanced because the used ALS data were originally collected for other urban planning purposes.

Introduction

Tree registers maintained in urban environments

Tree inventories, i.e., tree registers are a common approach for managing urban tree populations. An up-to-date register offers an efficient tool in allocating maintenance operations (watering, pruning, etc.) as well as in taking trees into consideration, for example, when the urban infrastructure is maintained. Although urban trees rarely have value as timber, their maintenance costs may be reduced with the efficient utilization of register data. However, the benefits sought from maintaining a tree register may be lost entirely if the register is not up to date. Updating a tree register manually, i.e., via field measurements, is a laborious and thus costly action. Hence, the utilization of remote sensing data is appealing. This is especially true when remote sensing data are automatically collected for other purposes and are therefore affordable for such use. As in many cities, this is also the situation in the City of Helsinki, Finland where aerial photographs and ALS data are collected for other urban planning purposes, such as mapping of buildings, roads, and other built objects.

The City of Helsinki maintains a register of about 40,000 urban trees, of which about 20,000 are street trees. The other half consists of park trees in the register. Although each tree does not have a definite timber value, as urban trees in general they are of value to, recreation, esthetic, and biodiversity (see, e.g., Rowntree, 1984, 1986; Ode and Fry, 2002; Tyrväinen et al., 2005; Bernath and Roschewitz, 2008). In the City of Helsinki, maintaining a register of the attributes (e.g., tree size, location, and fitness) of individual trees is beneficial for it leads to savings in maintenance actions. According to the City officials in the Street and Park Division of the City of Helsinki, rough estimates for the total planting costs of a street tree vary from 2500 to 5000 Euros depending on the size and quantity of the trees as well as the locations in which they are planted. The majority of the costs arise from road and soil maintenance that must be completed after the old tree trunk and its roots have been removed. These estimates include everything that has to be done in order to get a new tree growing (removal of old trees, planting, road maintenance, and watering of planted trees).

The information gathered for urban tree registers differs from that of traditional forest inventories. As the value of timber is

* Corresponding author. Tel.: +358 443429784.
E-mail addresses: topi.tahuanpaa@gmail.com, topi.tanhuanpaa@helsinki.fi (T. Tanhuanpää).

http://dx.doi.org/10.1016/j.ufug.2014.03.005
1618-8667/

not an issue, the accuracy of the diameter and height observations becomes less important at the individual tree level. However, other variables such as tree vitality, tree location, and identification number become more important as urban aspects are considered (Östberg et al., 2013). Changes in the urban environment are frequent and keeping the tree register current requires regular updating. Because of the changing environment, the validity of a tree register strongly relies on the age of the tree data: the tree data becomes outdated due to tree growth and mortality, maintenance actions, or building of city infrastructure, etc.

Urban street trees

A rough definition for a street tree in the tree register of the City of Helsinki is that the tree has a hard surface on both of its sides. This means that the trees are most often surrounded by concrete and tarmac. The urban growth environment affects the trees' growth (Jim, 1998) and appearance (Schwets and Brown, 2000). Due to various planting and documentation practices pursued during the past decades in the City of Helsinki, accurate knowledge about growing conditions of the roots was not available. For street trees in general, the growing space for roots is usually at least partially restricted (Bühler et al., 2007). In addition to these environmental factors, trees are also pruned at various intensities in order to reshape them or remove hazardous forks. All in all, the growing conditions and treatments of urban trees vary from tree to tree, which affects the appearance and growth of the trees.

Remote sensing of urban trees

The central idea of ALS is that laser pulses are emitted at the measured object and backscattered echoes are recorded and analyzed. When the exact position and orientation of the laser scanner are known, it is possible to form a three-dimensional (3D) point cloud describing the object (Wehr and Lohr, 1999). ALS techniques have been used in various applications in forestry, for example, snow damage detection (Vastaranta et al., 2012), biomass modeling (Kankare et al., 2013), and various biodiversity-related mapping studies (Pesonen et al., 2008; Vehmas et al., 2011).

Two central methods exist for deriving tree and forest characteristics from ALS data. The area based approach (Næsset, 2002) is founded on statistical dependencies between ALS metrics (e.g., relative and absolute heights of laser echoes) and forest variables measured from field plots. ALS metrics are usually derived for a number of grid cells that contain multiple trees. The other widely used method is individual tree detection (ITD) (Hyyppä and Inkinen, 1999). In ITD, individual tree crowns are delineated from ALS point clouds. Thus, ALS-based 3D metrics can be utilized to measure and predict characteristics separately for each tree. When compared to manual field measurements, ALS applications have proven cost–efficient in commercially managed forests (Holopainen and Talvitie, 2006; Uuttera et al., 2006). Advantages in cost efficiency are due to the decreased requirement for costly field measurements.

Although some private companies already use ALS-based urban tree mapping (e.g., Foran Remote Sensing, 2013), very few studies are available on the validity and performance of ITD in the urban environment. In previous studies, the focus was either on the segmentation, i.e., the delineation of individual trees (e.g., Palenichka and Zaremba, 2007) or the prediction of individual tree characteristics. Shrestha and Wynne (2012) used ITD methods in order to estimate a number of characteristics of urban trees. Tree delineation was performed manually, while tree characteristics were modeled through ALS features using linear modeling. Numerous ITD studies in the field of forestry have concerned different applications and the method itself (e.g., Hyyppä et al., 2001; Holmgren and Persson, 2004; Popescu et al., 2004; Koch et al., 2006; Falkowski et al., 2008; Maltamo et al., 2009; Hyyppä et al., 2012). Based on the results of studies thus far, it can be generalized that the ITD method works best when the target forest area has only one storey and the trees are sparsely located. In most cases, urban street trees fulfill both conditions, which make them an interesting target for ITD applications. However, the method should be studied further in the urban environment, where the conditions differ greatly from those of forests (e.g., data quality and tree characteristics).

This study describes an ALS-based updating method for an existing tree register where both tree delineation and the modeling of tree characteristics are executed using automatic procedures. The results are compared with the ones obtained in the forest environment using ITD methods. The characteristics of interest are: diameter at breast height (DBH), tree height, percentage of detected trees, and location accuracy of found trees. The aim was to test and verify the method that was first used in updating the tree register of the City of Helsinki. Although the result was manually modified during the actual updating process to best meet the requirements, in this study we tested the system's performance when no manual adjustments were made. This also shed some light on the accuracy of single-tree detection as well as the prediction of tree-level attributes in the urban environment – a subject dealt with in very few scientific publications. Although mobile laser scanning (MLS) was found to be more accurate in our research group's previous study concerned with the testing of different methods for urban tree detection (Holopainen et al., 2013), the ALS-based locating method also seemed to be adequate for our use in this case study. At this point, accurate MLS measurements would have been too costly for updating the entire tree register. Because it was pointed out in our earlier study that locating the tree-top may not be an ideal way to locate an urban tree, the locating method was further studied. The research questions were specified as follows:

1. What portion of the trees in the register can be found automatically and what is the location accuracy when compared to the original register?
2. What is the overall accuracy of the automatic updating process in terms of diameter and height?

Materials and methods

Study area and tree register

The study area consists of roadside areas in Helsinki on the southern coast of Finland (Fig. 1). The up-to-date tree register consisted of 19,777 street trees around the city. The tree variables used in this study were species and location of each tree. In the register, the trees were divided into nearly 70 different tree species or species groups. However, the vast majority (76%) consisted of four deciduous tree species: lime (*Tilia europaea*) (45%), maple (*Acer platanoides*) (12%), birch (*Betula pendula*) (11%), and elm (*Ulmus glabra*) (8%).

The tree register was used as reference data for the location of individual trees and auxiliary data when determining the species of individual trees. Because DBH values in the register had been produced with models and there was no prior height data, separate field data was collected for modelling and error assessment of both height and DBH.

Field measurements

A sample of 1241 register trees was manually selected and measured for characteristics modeling (Table 1). DBH was measured from every tree, whereas height from every other one. All field data