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Estimation of urban tree canopy cover using random point sampling and remote sensing methods

Ebadat G. Parmehr[a,*], Marco Amati[a], Elizabeth J. Taylor[a], Stephen J. Livesley[b]

[a] Centre for Urban Research, School of Global, Urban and Social Studies RMIT University, Australia
[b] School of Ecosystem and Forest Sciences, Faculty of Science, Burnley Campus, The University of Melbourne, Australia

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ABSTRACT

Trees play an important role in urban areas by improving air quality, mitigating urban heat islands, reducing stormwater runoff and providing biodiversity habitat. Accurate and up-to-date estimation of urban tree canopy cover (UTC) is a basic need for the management of green spaces in cities, providing a metric from which variation can be understood, change monitored and areas prioritised. Random point sampling methods, such as i-Tree canopy, provide a cheap and quick estimation of UTC for a large area. Remote sensing methods using airborne Light Detection And Ranging (LiDAR) and multi-spectral images produce accurate UTC maps, although greater processing time and technical skills are required. In this paper, random point sampling and remote sensing methods are used to estimate UTC in Williamstown, a suburb of Melbourne, Australia. High resolution multi-spectral satellite images fused with LiDAR data with pixel-level accuracy are employed to produce the UTC map. The UTC is also estimated by categorising random points (a) automatically using the LiDAR derived UTC map and (b) manually using Google Maps and i-Tree canopy software. There was a minimum 1% difference between UTC estimated from the map derived from remotely sensed data and only 1000 random points automatically categorised by that same map, indicating the level of error associated with a random sampling approach. The difference between UTC estimated by remote sensing and manually categorised random point sampling varied in range of 4.5% using a confidence level of 95%. As monitoring of urban forest canopy becomes an increasing priority, the uncertainties associated with different UTC estimates should be considered when tracking change or comparing different areas using different methods.

1. Introduction

The Nursery Gardens Industry of Australia has an ambitious target for greening Australian urban areas that will resonate with cities internationally. Their '202020 vision' is to create 20% more green space in urban areas by 2020 (NGIA, 2014). As a part of this process the industry association commissioned a benchmarking study to estimate the amount of urban tree canopy cover (UTC), defined as the ground area (m^2) covered by the crown of a tree, in Australian cities (Jacobs et al., 2014). The benchmarking study used a simple random point sampling method and found a considerable variation in the proportion of canopy cover across 139 Australian local governments in urban and semi-urban environments, reflecting a similarly wide variation in environmental and historic conditions. For example, within the largest city in Australia, Sydney, the estimated UTC of council districts varied between 10% and close to 60% (Jacobs et al., 2014).

The increasing integration of UTC as a serious consideration for decision-makers in Australia is part of a international trend. For example, the American Planning Association has laid out a flowchart of 'Strategic Points of Intervention' including visioning, plan-making, earmarking investment, choosing appropriate planning tools and development for planners to advance urban forestry goals (Kollin and Schwab, 2009). As methods to estimate UTC evolve, it is important for decision makers to assess the performance and suitability of the different methods available. Nielsen et al. (2014) provided a comprehensive review and a qualitative assessment of different canopy inventory methods. King and Locke (2013) compared UTC measurements using three different methods: i-Tree, land cover map and hemispherical photographs. Random and grid points sampling approaches for estimation of UTC are compared by Ucar et al. (2016). Richardson and Moskal (2014) also highlighted uncertainty issues for different methods used in

* Corresponding author at: Level 4, Building 15, RMIT City Campus, 124 La Trobe Street, Melbourne, VIC 3000, Australia.
E-mail address: ebadat.parmehr@rmit.edu.au (E.G. Parmehr).

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Fig. 1. Study area: Williamstown, Australia.

estimating UTC change over time, in which included i-Tree random point sampling, and recommended using LiDAR data to improve accuracy of mapping UTC from remotely sensed images.

Non field-based methods for the estimation of UTC fall into two main categories: random point sampling and remote sensing methods. Random point sampling methods, such as i-Tree canopy, estimate UTC based on limited number of points or plots, while remote sensing methods measure UTC using remotely sensed data. Increasingly available airborne Light Detection And Ranging (LiDAR) and multi-spectral aerial imagery data can be integrated to correctly identify UTC over a large area whilst providing 3D canopy information (O'Neil-Dunne et al., 2014). However, their use is limited by the complex techniques required to accurately produce the UTC map.

In this paper, 'i-Tree canopy' as a random point sampling method and 'fused LiDAR and multi-spectral image' as a remote sensing method are described. Then, the benefits and drawbacks of i-Tree canopy and fused LiDAR and multi-spectral images are discussed in the light of the UTC estimates, errors, uncertainty and processing requirements.

The study area covers Williamstown a suburb within the west of Melbourne, Australia (Fig. 1). Williamstown with total size of 7.35 (km^2) is an established suburb with a mix of residential and industrial areas, as well as, large and established tree canopies. This area comprises 35 Statistical Area Level 1 (SA1s) as defined by the Australian Bureau of Statistics as the smallest spatial units for the release of Census data. SA names SA2134601-SA2134635 were shortened to 1–35 for the sake of simplicity. SA1s have an average population size of 400 people and variable sizes of 0.03–1.18 (km^2), averaging 0.21 (km^2). They are larger than the base unit for Australian standard Census geography, known as mesh blocks, but smaller than suburbs and local government areas. The scale of SA1 boundaries in the choice of canopy scale permits the merging of UTC data with social and economic spatial datasets including the Australian Bureau of Statistics Census.

The remainder of the paper is organised as follows. Section 2 describes random point sampling and remote sensing methods for estimation of UTC in urban areas along with comparison of remote sensing method with random point sampling method, including automatic and manual categorising random points. Then, experimental results measuring UTC using both methods are presented and discussed in Section 3. Conclusions and implications are offered in Section 4.

2. Methods for estimation of tree canopy cover

2.1. Random point sampling

The random point sampling method used in this study to estimate UTC is called 'i-Tree canopy' which was developed by the USDA Forest Service. This method was based on a range of methods in use by cities for urban forest inventory collection since the 1970s (Nowak et al., 1996). It has been used internationally because of its simplicity in use and data requirements. The randomly sampled points are manually categorised as 'tree' and 'non-tree' to estimate the UTC of a predefined area. It uses on-line and readily available aerial and satellite images through Google Maps to identify land cover of the random points. Estimated UTC can be reported in either forms of percent or area, and therefore, the accuracy and precision of UTC can be estimated in either percent or area.

The accuracy of UTC estimated by i-Tree canopy is dependent upon the ability of the operator to correctly interpret the aerial or satellite images and detect the presence or absence of UTC at each sample point. The accuracy of UTC identification decreases where the image quality is poor due to the low resolution of image or shadows (Richardson and Moskal, 2014). In addition, trees can be confused with shrub, or even tall grass, which can lead to an over-estimation of random sample points.

The precision of UTC estimated by i-Tree canopy depends on the number of random sample points. The greater number of sample points leads to a greater precision in the estimated UTC. However, the categorisation of more random sample points increases the time and therefore cost of data collection. A balance between precision and cost is necessary for practical application of the technique.

Although i-Tree canopy user guidelines (http://www.itreetools.org/canopy/) suggest using 500–1000 sample points, the actual number of sample points depends on the precision required in the estimation of UTC. The precision can be measured by the standard error (SE) of estimated UTC. The SE is used as a way of estimating the uncertainty of UTC in i-Tree canopy and decreases if the number of random sample points increases.

In percent UTC, the UTC value is normalised by the size of the predefined area, and therefore, the size of an area does not affect the number of random sample points. In contrast, the size of an area has a direct impact on the number of random sample points in the estimation of area UTC. Therefore, different numbers of random sample points are required to estimate the area UTC of areas with different sizes to maintain a consistent density of random sample points (pts/m^2).

In addition, the number of random sample points directly depends on the UTC value of the area. The SE of n number of tree points and N total number of points can be calculated by $\sqrt{p(1-p)/N}$, where $p = n/N$ (Thompson, 2012). Theoretically estimated SE with varying UTC values for different number of sample points (N) and the relationship between the number of sample points and UTC for different SE values are shown in Fig. 2. In theory, minimum number of sample points to obtain a given SE in UTC estimation can be calculated by $p(1-p)/SE^2$ which is a function of UTC value and SE. Also, confidence interval of UTC estimated for a given confidence level can be calculated by $CI = UTC \pm SE \times CV$. Here, CV is critical value and it is 1.96 for confidence level of 95%.